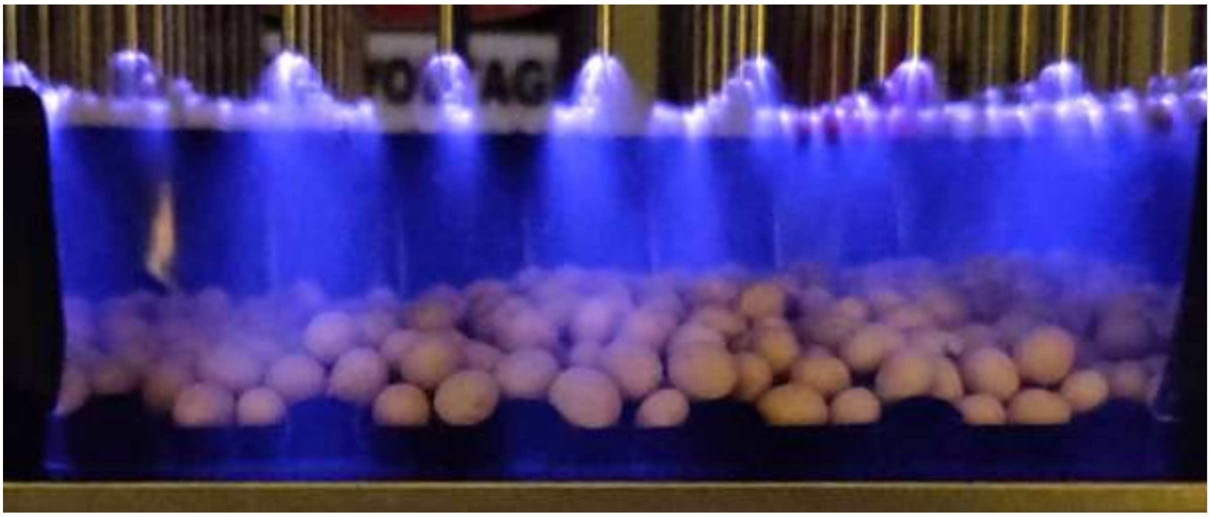
34TH NATIONAL SYMPOSIUM ON PLASMA SCIENCE AND TECHNOLOGY (PLASMA 2019)

34 वीं प्लाज़्मा विज्ञान एवं प्रौद्योगिकी पर राष्ट्रीय संगोष्ठी

(प्लाज़्मा 2019)



Vellore Institute of Technology
(Deemed to be University under section 3 of UGC Act, 1956)

PSSI ESTD 1978

DECEMBER 3-6, 2019
VIT CHENNAI

दिसंबर 3-6, 2019
वीआईटी चेन्नई

VIT®
UNIVERSITY
(Estd. u/s. 3 of UGC Act 1956)

Dr. G. VISWANATHAN
Founder & Chancellor
Former Member of Parliament
Former Minister, Govt. of Tamil Nadu
President, Education Promotion Society for India, New Delhi

Message

I am happy to learn that the Division of Physics in the School of Advanced Sciences, VIT Chennai is organizing the "34th National Symposium on Plasma Science and Technology (PLASMA 2019)" during December 3-6, 2019. I was told that this symposium is organized every year in different parts of the country to promote growth and exchange of information in plasma science and its applications in various sectors. 21st Century technology involves many things with plasma technology starting from fusion energy, plasma television, thin film industries, air purification, agriculture, automobiles, E-textile etc. The main goal of this symposium is to create a platform for the plasma scientific community to express their scientific findings to the country.

Of late, the progress in plasma science and technology is not only contributing to the development of social and economic features but also to the complete development of the country. This PSSI plasma series symposium is establishing a very strong network among academicians, industrialists, scientists, technologists and entrepreneurs throughout the country. I strongly hope that the delegates will use this platform to discuss and deliberate on their research findings in a bid to bring out suitable solutions for the issues that relates to the society.

The fundamental need for research must be that the research findings carried out in the labs should find patronage in the society, which could be done through industries. I am happy to note that this conference is being organised alongwith Plasma Science Society of India (PSSI), Institute for Plasma Research (IPR), ITER India and various other industry partners.

I congratulate the organisers on their efforts in organizing this conference successfully. My best wishes to all the delegates.

I wish the conference all success.

With best wishes

Dr. G. Viswanathan
Founder & Chancellor

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25-11-2019

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MESSAGE FROM VICE CHANCELLOR

I am happy to note that the Division of Physics, School of Advanced Sciences (SAS) at VIT Chennai is organizing the "34th National Symposium on Plasma Science and Technology (PLASMA 2019)" during December 3-6, 2019 alongwith Plasma Science Society of India (PSSI).

Plasma Science and Technology is an extremely important and significant area of research which could lead to technological advances with suitable fundamental understanding of the scientific concepts. It has attained more importance as it has brought together people from different fields of science and engineering who are working in the broad areas of plasma research. VIT always prefers to find applications of the research findings in terms of products alongwith quality publications and I hope this conference will open up frontiers in that direction.

I congratulate the organizers for conducting the conference at VIT Chennai and wish the conference a great success.

May GOD Bless!

Dr. Anand A. Samuel
Vice Chancellor
VIT.

MESSAGE FROM PRO-VICE CHANCELLOR

I am extremely happy to note that the "34th National Symposium on Plasma Science & Technology (PLASMA 2019)" is being organized by the Division of Physics, School of Advanced Sciences, VIT Chennai alongwith Plasma Science Society of India (PSSI) during December 3-6, 2019.

This conference will provide a platform for researchers, academicians and industry personnel from various disciplines to coalesce under one domain of plasma research. The presence of researchers from various places across and outside the country will provide impetus to them to get motivated and build their careers in the fields of fundamental and applied research. As Pro-Vice Chancellor, I extend my hearty welcome to the delegates and congratulate the organizing committee.

I wish the conference a great success!

Dr. V.S. Kanchana Bhaaskaran

Pro-Vice Chancellor
VIT Chennai.

MESSAGE FROM IPR DIRECTOR

प्लाज़्मा अनुसंधान संस्थान
Institute for **Plasma Research**

I am happy to know that the Plasma Science Society of India (PSSI) is organizing its 34th National Symposium on Plasma Science and Technology (PLASMA-2019) in association with Division of Physics in the School of Advanced Sciences, VIT Chennai during 3-6 December, 2019 at VIT Chennai Campus. It is well known that plasma science & technology has made major advances over the past few decades. The worldwide effort towards Controlled Thermonuclear Fusion, which has found a focus in the International Thermonuclear Experimental Reactor (ITER) project, is making good progress. There are major technological contributions being made by ITER-India in this project, with Indian deliverables being amongst the first to reach the project Site. I am happy to know that this year's conference has a session on "ITER-Technology challenges and Indian Support". In parallel with the fusion programme is the ever-growing list of plasma applications in industry, medicine/healthcare, agriculture, textile processing, waste disposal, aerospace technologies, plasma antennas and so on. These are major challenges for the plasma science community in India. Rapid development & deployment of these technologies in India over the next few years requires a focused and broad-based effort similar to that for the fusion programme. I would hope that participation in this Symposium would motivate young researchers from different branches of science and engineering to enter these challenging fields. Lastly, on behalf of IPR, I thank the organizers for their sincere efforts for organizing this symposium and BRNS for its financial support. I extend my best wishes to all the participants and hope that the Symposium will achieve its desired objectives.

(Dr. Shashank Chaturvedi)
Director, Institute for Plasma Research

MESSAGE FROM PSSI PRESIDENT

संदेश

मुझे यह जानकर बहुत खुशी है कि) प्लाज़्मा सोसाइटी आफ इन्डिया“PSSIस्कूल आफ (के साथ मिलकर प्लाज़्मा विज्ञन तथा तनकीकि पर ”एडवांस साईंस के भौतिकि विभाग दिसम्बर 6-3 का आयोजन कर रहे हैं। ये संगोष्ठी (2019-प्लाज़्मा) वीं राष्ट्रीय संगोष्ठी34 के अंतराल में वी.टी.आई., चन्नाई में आयोजित की जा रही है। इस संगोष्ठी में नए खोजकर्ता प्लाज़्मा विज्ञान तथा तकनीकि के क्षेत्र में विद्वान वैज्ञानिकों के साथ चर्चा में भाग लेते है तथा अपनी खोज का प्रदर्शन करते हैं। PSSI इस तरह की संगोष्ठी भारत में भिन्नभिन्न - अनुसंधान संस्था के साथ मविश्वविद्यालयों या विभिन्न िलकर हर वर्ष आयोजित करती हैं। PSSI हर वर्ष रिसर्च स्कोलर का वर्तालाप भी आयोजित करती है। मुझे उम्मीद है कि सभी वैज्ञानिक तथा छात्र मिलकर अपने ज्ञान का आदान प्रदान करेंगे तथा इस संगोष्ठी को सफल बनाएंगे।

शुभ कामनाओं सहित

(डा प्रवीण कुमार .आत्रेय)

अध्यक्ष, प्लाज़्मा सोसाइटी आफ इन्डिया) PSSI(

Foreword

The 34th edition of National Symposium on Plasma Science and Technology (PLASMA2019) is jointly organized by Division of Physics, School of Advanced Science (SAS), VIT Chennai and Plasma Science Society of India (PSSI) during 3-6 December 2019. This symposium series was started in the year 1990 and successfully organized in various national institutes all over the country with the main aim of promoting plasma science and technology within the country. It is getting more importance after India had decided to join in International Thermonuclear Experimental Reactor (ITER) in the year 2005. Looking at the importance of the same, a special session has been dedicated to ITER India to promote and educate their activities from this year.

Plasma of interest ranges over many orders of magnitude in density and temperature from laboratory plasmas, interstellar space plasmas, industrial plasmas and finally inertial confinement fusion plasmas. Plasma science and technology can have significant impact on many disciplines and technologies including those directly linked to the industrial growth. Through this symposium we intend to create and maintain a coherent and coordinated program of research and technological development in plasma science. The progress in science and technology is directly related to the societal, economical and intellectual growth of a country. PSSI symposium series is being organized to make a strong network between academicians, scientists, technologists and entrepreneurs within the country. Plasma science is interdisciplinary in nature and it brings engineers, physicists, chemists, mathematicians, computer scientists in the same platform to exchange their scientific views. Plasma science has tremendous applications in various fields such as thin film industries, agriculture fields, oil and gas sectors other than the nuclear fusion. India is proud to have three fusion reactors, one in SINP Kolkata and two in IPR, Ahmedabad.

PLASMA2019 has attracted more than 350 registrations. The scientific sessions are spread over four days which will comprise of 15 invited talks, 30 oral presentations and around 300 posters. The key note address would be delivered by Dr. A. K. Bhaduri, Director, IGCAR Kalpakkam.

On behalf of organizing committee we express our deep appreciation to all the sponsors including DAE BRNS, CSIR, SERB-DST, Energy Science Society of India (ESSI), IPR and various industry partners for their financial support. We would like to thank Plasma Science Society of India (PSSI) for providing us the opportunity to organize PLASMA 2019 at School of Advanced Sciences (SAS), VIT Chennai. We would also like to express our sincere thanks to all award committee members and session chairs. We would like to thank all the invited speakers for their time and interest in delivering their talk in PLASMA 2019. We

thank proceeding editors and all members of VIT and PSSI who are directly and indirectly involved in organizing the symposium.

At the end we would like to announce that the NAC has selected GNDU Amritsar, Punjab as the host of 2020 PSSI conference. We look forward to see you again at GNDU in 2020. Wishing all of you an enjoyable and peaceful stay here at VIT Chennai and very productive scientific sessions.

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PLASMA – 2019
Detailed Schedule - 03-06 December, 2019

Day - 01 (03-Dec-2019)						
REG	**08:00**	**09:00**	**Registration**			
INAUG	**09:00**	**09:45**	**Inauguration**			
KN-01	**09:45**	**10:30**	**Keynote Address**		**Dr. A. K. Bhaduri, Director, IGCAR**	
TEA-D01	**10:30**	**11:00**	**High Tea**			
D1/OS-01	**11:00**	**13:00**	**Oral Session - 01 : Basic Plasma (BP)**			**Speaker**
S1-I-01	11:00	11:30	Invited - 1	25+5m	**Nonlinear Evolution of Jean's instability: Thermodynamics and Simulations**	**Dr. Avinash Khare (Sikkim University)**
S1-I-02	11:30	12:00	Invited - 2	25+5m	**Ion beam sculpting: wave-plasma cooperation for sustenance in restricted geometry**	**Dr. Sudeep Bhattacharjee (IIT-Kanpur)**
S1-O-01	12:00	12:15	Oral – 1	10+2m	Effect of plasma beta on electromagnetic ETG turbulence induced plasma transport	Mr. Prabhakar Srivastav (IPR)
S1-O-02	12:15	12:30	Oral – 2	10+2m	Kinetic simulation of plasma-wall transition for different plasma and wall properties	Mr. Raju Khanal (Tribhuvan Univ., Kathmandu)
S1-O-03	12:30	12:45	Oral – 3	10+2m	Chirped Axicon-Gaussian laser-driven electron acceleration in vacuum	Dr. Niti Kant (LPU, Jallandhar)
S1-O-04	12:45	13:00	Oral – 4	10+2m	2D-3V PIC-MCC simulation of plasma transport across magnetic filter in ROBIN: Importance of wall effects	Ms. Miral Shah (DAIICT, Gandhinagar)
LNCH-D01	**13:00**	**14:00**				
D1/OS-02	**14:00**	**15:30**	**Oral Session - 02 : ITER Technology - challenges and Indian Support (IT)**			**Speaker**
S2-I-03	14:00	14:30	Invited - 3	25+5m	**ITER Project Overview and India's Contribution**	**Dr. Shishir Deshpande(IPR)**
S2-O-05	14:30	14:45	Oral – 5	10+2m	ITER physics and its challenges	Dr. I Bandyopadhyay (ITER-India)
S2-O-06	14:45	15:00	Oral – 6	10+2m	Technology developments for ITER class NBI and a road map	Mr. Jaydeep Joshi (ITER-India)
S2-O-07	15:00	15:15	Oral – 7	10+2m	Cryostat design and fabrication	Mr. Girish Gupta (ITER-India)
S2-O-08	15:15	15:30	Oral – 8	10+2m	ICRH developments for ITER	Ms. Aparajita Mukherjee (ITER-India)

D1/PS-01	**15:30**	**17:30**				
BYSA	**17:30**	**19:30**	**BUTI Young Scientist Award Presentations**			**Speaker**
BYSA-01	17:30	17:50	BYSA-01	15+5	Creation and Studies of Micro-ion Beams from Intense Electromagnetic Wave Generated Plasmas	Mr. Sanjeev Maurya (IIT-Kanpur)
BYSA-02	17:50	18:10	BYSA-02	15+5	Characteristics of plasmas confined in a dipole magnetic field	Mr. Anuj Ram Baitha (IIT-Kanpur)
BYSA-03	18:10	18:30	BYSA-03	15+5	Exploring Thruster Potential of Compact ECR Plasma Source	Ms. Anshu Verma (IIT-Delhi)
BYSA-04	18:30	18:50	BYSA-04	15+5	Multi-Wavelength Signatures of Build up, Activation and Eruption of a Magnetic Flux Rope from the Solar Atmosphere	Mr. Prabir Mitra (PRL, Udaipur)
BYSA-05	18:50	19:10	BYSA-05	15+5	Excitation of pinned structures in flowing complex plasma	Ms. Garima Arora (IPR)

Day - 02 (04-Dec-2019)						
D2/OS-01	**9:00**	**11:00**	**Oral Session–3: Space, Astrophysical and Ionosphere Plasma (SP)**			**Speaker**
S3-I-04	09:00	09:30	Invited - 4	25+5m	**Data-driven Magnetohydrodynamics (MHD): A novel tool to understand some basic mechanisms of the energy and mass transport in the Sun’s atmosphere**	**A.K. Srivastava (IIT, BHU)**
S3-I-05	09:30	10:00	Invited - 5	25+5m	**Beyond Solitary waves: Nonconventional and multidimensional structures in the Earth's magnetosphere**	**Dr. Suktisama Ghosh (IIGM, Mumbai)**
S3-O-09	10:00	10:15	Oral – 9	10+2m	Particle-in-Cell (PIC) Simulations of Earth’s Magnetosphere and Trapped Particle’s Motions	Dr. Arghya Mukherjee (IISER, Kol)
S3-O-10	10:15	10:30	Oral – 10	10+2m	A velocity shear driven kinetic Alfvén waves instabilities with superthermal electrons	Mr. Krushna Chandra Barik, (IIGM)
S3-O-11	10:30	10:45	Oral – 11	10+2m	Statistical analysis of ground observations of electromagnetic ion cyclotron waves at Maitri	Ms. Aditi Upadhyay (IIGM)
S3-O-12	10:45	11:00	Oral – 12	10+2m	Overtaking of kinetic Alfvén waves in electron-positron-ion plasma	Dr. Nareshpal Singh Saini (GNDU)
TEA-D02	**11:00**	**11:15**	**TEA**			
D2/OS-04	**11:15**	**13:15**	**Oral Session – 4 : Plasma Modelling & Simulation (PM), Laser Plasma (LP)**			**Speaker**
S4-I-06	11:15	11:45	Invited - 6	25+5m	**Acceleration of electrons from a thin foil plasma by tightly focused few-cycle laser beam**	**Dr. Mrityunjay Kundu (IPR)**
S4-I-07	11:45	12:15	Invited - 7	25+5m	**Plasma Simulation Activities**	**Dr. Amita Das (IIT Delhi)**
S4-O-13	12:15	12:30	Oral – 13	10+2m	Minority heating scenarios in low ion temperature plasma	Dr. Asim Chattopadhyay

S4-O-14	12:30	12:45	Oral – 14	10+2m	First evidence of the soliton-type behavior of supersolitary waves in plasma	Dr.Ajay Lotekar (IIGM, Mumbai)
S4-O-15	12:45	13:00	Oral – 15	10+2m	Numerical study of interaction of laser induced counter propagating shock waves	Ms. Kameswari Durvasula, (Univ. of Hyderabad)
S4-O-16	13:00	13:15	Oral – 16	10+2m	Generation of electrostatic mode in a laser plasma interaction	Ms. Ayushi Vashistha (IPR)
LNCH-D02	**13:15**	**14:15**	**LUNCH**			
AWD-GZ	14:15	15:00	Guzdar Award presentation and talk			
AWD-SH	15:00	15:45	Sholapurwala Award presentation and talk			
D2/PS-02	**15:45**	**17:45**	**Poster Session - 02**			
GBM	**18:00**	**19:30**	**PSSI General Body Meeting**			
DIN-D02	**20:00**	**21:30**	**Dinner**			

Day - 03 (05-Dec-2019)						
D3/OS-05	**9:00**	**11:00**	**Oral Session – 5 : Plasma Diagnostics (PD)**			**Speaker**
S5-I-08	09:00	09:30	Invited - 8	25+5m	**Radiation based Diagnostics on Tokamaks in IPR and Application of those for Investigation of Plasma**	**Dr. Malay B. Chowdhuri, (IPR)**
S5-I-09	09:30	10:00	Invited - 9	25+5m	**Microwave Plasma Diagnostics for Fusion Research Machines**	**Dr. Hitesh B. Pandya, IPR**
S5-O-17	10:00	10:15	Oral – 17	10+2m	Simulation of nucleation and growth of yttria nano particles in thermal plasma reactor	Ms. Nirupama Tiwari (BARC)
S5-O-18	10:15	10:30	Oral – 18	10+2m	Impurity Ion Temperature Measurement using Zeeman Influenced Spectral Lines in Aditya-U Tokamak	Ms. Nandini Yadava (Gujarat Uni.)
S5-O-19	10:30	10:45	Oral – 19	10+2m	Initial results of laser heated emissive probe for sol region in Aditya-U Tokamak	Ms. Abha Kanik (VIT, Chennai)
S5-O-20	10:45	11:00	Oral – 20	10+2m	A new collisional radiative model for laser produced Zn plasma using calculated RDW cross-sections	Mr. Shivam Gupta (IIT-R)
TEA-D03	**11:00**	**11:15**				
D3/OS-06	**11:15**	**13:15**	**Oral Session – 6 : Industrial Application (IP), Societal Benefits of Plasma (SP)**			**Speaker**
S6-I-10	11:15	11:45	Invited - 10	25+5m	**Pulsed Power and Plasma Applications for Agriculture and Food processing**	**Dr. Koichi Takaki (Iwate Uni. JP)**
S6-I-11	11:45	12:15	Invited - 11	25+5m	**Non-equilibrium Non-thermal (Cold) Plasma Technologies for Health & Food Applications**	**Dr. Ramprakash (IIT Jodhpur)**
S6-O-21	12:15	12:30	Oral – 21	10+2m	Dirty Waste To Clean Environment And Useful Energy: Air Plasma Gasifier Technology Developed by BARC,	Dr. Srikumar Ghorui (BARC)

S6-O-22	12:30	12:45	Oral – 22	10+2m	Plasma surface engineering of stainless steel for hip implant application	Mr. Ramkrishna Rane (IPR)
S6-O-23	12:45	13:00	Oral – 23	10+2m	Optimization and enrichment of electronic waste to recover valuable metals using plasma arc furnace tech	Mr. A. R. Arivalagan (Politecnico Di Milano)
S6-O-24	13:00	13:15	Oral – 24	10+2m	Understanding gasification process in coke bed air plasma gasifier: 3D CFD simulation study and expt. Observations	Mr. Subhankar Bhandari (BARC)
LNCH-D03	**13:15**	**14:15**				
D3/OS-07	**14:15**	**15:45**	**Oral Session – 7 : Pulse Power Technology (PP) & Nuclear Fusion (NF)**			**Speaker**
S7-I-12	14:15	14:45	Invited - 12	25+5m	**Indigenous development of Multi Gigawatt Pulsed Power Systems for Nuclear and Industrial Applications**	**Dr. Archana Sharma (BARC)**
S7-I-13	14:45	15:15	Invited - 13	25+5m	**Tungsten Compatibility for Spherical Tokamak Reactors: Modeling of Radiation Damage and Fuel Retention**	**Dr. P. N. Maya (IPR)**
S7-O-25	15:15	15:30	Oral – 25	10+2m	Advanced insulators for NNBs: Challenges and involved R&D	Dr. Sejal Shah (ITER-India)
S7-O-26	15:30	15:45	Oral – 26	10+2m	Differential absorption spectrometer for hard x-ray spectrum measurements	Ms. Rakhee Menon (BARC)
D3/PS-03	**15:45**	**17:45**	**Poster Session - 03**			
CULT	**18:00**	**19:30**				
DIN-D03	**20:00**	**21:30**				

Day - 04 (06-Dec-2019)						
D4/OS-08	**9:00**	**11:00**	**Oral Session – 8 : Nuclear Fusion (NF)**			**Speaker**
S8-I-14	9:00	9:30	Invited - 14	25+5m	**Recent Plasma Experiments in SST-1**	**Dr. Daniel Raju (IPR)**
S8-I-15	9:30	10:00	Invited - 15	25+5m	**Investigation of Neutral Particle Dynamics in Aditya and Aditya-U Tokamak Plasmas using Degas2 and Wedge Codes**	**Dr. Ritu Dey (IPR)**
S8-O-27	10:00	10:15	Oral – 27	10+2m	DC and High Frequency Edge Electrode Biasing Experiments in ADITYA-U Tokamak	Mr. Tanmay Macwan (IPR)
S8-O-28	10:15	10:30	Oral – 28	10+2m	Studies On Fusion Relevant Plasma Exposure Behavior Of India Specific Reduced Activation Ferritic Martensitic Steel in CIMPLE-PSI	Dr. Trinayan Sarmah (CPP-IPR)
S8-O-29	10:30	10:45	Oral – 29	10+2m	Joining of SS316l with heat sink material for divertor applications	Dr. K. P. Singh (IPR)
S8-O-30	10:45	11:00	Oral – 30	10+2m	PIC simulation of ion dynamics in an inertial electrostatic confinement fusion device	Mr. Darpan Bhattacharjee (CPP-IPR)
TEA-D04	**11:00**	**11:15**	**TEA**			

D4/PS-04	**11:15**	**13:15**	**Poster Session - 04**
LNCH-D04	**13:15**	**14:15**	**Lunch**
CONCL	**14:15**	**15:45**	**Concluding Session and Prize Distribution**
TEA-D04	**15:45**	**16:00**	**TEA**

ABSTRACT NO.	INVITED TALKS
INV-1	**Nonlinear Evolution Of Jean's Instability: Thermodynamics And Simulations** *Avinash Khare*
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BYSA-03 **Exploring Thruster Potential Of Compact Ecr Plasma Source**

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BYSA-04 **Multi-Wavelength Signatures Of Build Up, Activation And Eruption Of A Magnetic Flux Rope From The Solar Atmosphere**

Prabir Kumar Mitra and Bhuwan Joshi

BYSA-05 **Excitation Of Pinned Structures In Flowing Complex Plasma**

Garima Arora, P. Bandyopadhyay, M. G. Hariprasad and A. Sen*

INVITED TALKS

NONLINEAR EVOLUTION OF JEAN'S INSTABILITY: THERMODYNAMICS AND SIMULATIONS

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Problems related to the formulations of the thermodynamics of gravitating systems are discussed. A new inter particle potential is shown to remove some of these problems i.e., thermal equilibria of these systems exist at all temperatures. Molecular dynamic simulations with new inter-particle potential are performed to study the nonlinear evolution of Jeans instability of the system. The results show the stabilization of the instability due to hard core formation in the nonlinear stage accompanied by first order phase transition, phase coexistence and release of latent heat. Analytical models based on N gravitating hard spheres and Chandrasekhar's theory of polytropes are used to explain the simulation results. Astrophysical significance of the results is discussed.

ION BEAM SCULPTING: WAVE-PLASMA COOPERATION FOR SUSTENANCE IN RESTRICTED GEOMETRY

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With rapid development of basic, applied and inter-disciplinary research, ion beams are becoming an increasingly important research tool. Researchers employ ion beams with energies ranging from a few eV to some MeV for studying ion-matter interactions. There has been significant progress on novel focused ion beam sources and their applications have attracted special attention in recent times. Liquid metal based focused ion beam systems have traditionally addressed areas such as milling, patterning, and high-resolution imaging. However, in order to meet emerging applications, such as processing bio-materials or creation of complex microstructures in micro-fluidic applications, efforts to develop plasma based focused ion beams are utilized, which can be non-toxic, provide higher currents for rapid processing, and do not involve metallic contamination.

Developing plasma sources for focused ion beams is nontrivial and can pose mighty challenges. Often a micro-meter size beam needs to be extracted to maintain a small object size for demagnification, thereby demanding that the plasma source be as small as possible. The situation is exacerbated in case of electromagnetic wave driven plasma sources because of geometrical cutoff limitation, which demands a minimum chamber dimension for wave propagation and subsequent plasma generation. Additionally, the density cutoff limitation is encountered when the plasma frequency becomes larger than the wave frequency. The two limitations are often inextricably intertwined and pose considerable confrontation for wave-particle sustainability.

The talk will begin with a brief discussion of these aspects and demonstrate how they have been obviated in the present research. The remaining part of the lecture will dwell upon recent research results of such a plasma based focused ion beam system developed in the laboratory. It is shown that intense, focused mono-energetic ion beams of different masses are obtained that permits a huge variation of momentum transferred to the substrate, such that size-controlled microstructures with large aspect ratios (line width/depth) can be sculpted on metallic substrates, a feature unrealized in conventional systems. A distinctive phenomenon of nonlinear demagnification is observed for beams, when the plasma electrode aperture size is reduced to below the Debye length. Further reduction of beam size is achieved by employing micro-glass capillaries, where charge dissipation in a hysteresis cycle and self-focusing of beams are observed.

References:

[1] S. K. Maurya, S. Barman, N. Pan and S. Bhattacharjee, Phys. Plasmas, **26**, 063103, (2019).

[2] S. K. Maurya, S. Paul, J. K. Shah, S. Chatterjee, and S. Bhattacharjee, J Appl. Phys., **121**, 123302, (2017).

ITER PROJECT OVERVIEW AND INDIA'S CONTRIBUTION

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Controlled thermonuclear fusion in the laboratory remains a powerful driver in basic and applied plasma research. It offers a potentially attractive solution to power generation due to abundance of fuel, inherent safety and especially since it is environmentally acceptable. Over many years of research, the toroidal plasmas have revealed many facets of stability, control, confinement and transport. The worldwide research has culminated in the dream project called International Thermonuclear Experimental Reactor (ITER). Here the ultimate test of burning plasmas will be carried out in a fusion reactor. ITER is being built in France with 'in-kind' commitments from its seven partners (China, EU, India, Japan, S. Korea, Russia and the US).

ITER-India is a special project within the Institute for Plasma Research, Gandhinagar. The mandate for ITER-India is to deliver India's 'in-kind' commitments to ITER, which are defined by the nine packages: (1) Cryostat, (2) In-wall Shielding, (3) Cryodistribution & Cryolines, (4) Ion Cyclotron Heating RF-power sources (35-65 MHz) for coupling 20 MW, (5) Electron Cyclotron Heating sources for 2 MW at 170 GHz, (6) Diagnostic Neutral Beam, (7) Power Supply Systems for IC, EC and DNB, (8) Component Cooling, Chilled Water and Heat Rejection System, and (9) Diagnostics (with X-Ray, visible and microwave region) with Port Plug. A unique and challenging feature of the ITER project is its splitting into various procurement packages being executed all over the world and the requirement that all these systems integrate well with each other. While this is true for ITER main machine, the system-level challenges add another key feature, in the sense that many systems are significantly large or high capacity in some sense and hence require extensive R&D to mitigate risks. The work-packages of ITER-India include a mix of precision, heavy, R&D intensive and interface intensive systems, under built-to-print and functional systems category. In several systems, components fall under the category of first of its kind or of the largest kind. The uniqueness of specifications lead to a challenging situation – namely that neither the existing labs or potential suppliers have ever done or encountered such scale-up (either in size/volume, capacity, precision etc.) and do not have the R&D infrastructure to match the requirements.

The overview covers some historical highlights, current status and how ITER-India is meeting the challenges of this unique project.

DATA-DRIVEN MAGNETOHYDRODYNAMICS (MHD): A NOVEL TOOL TO UNDERSTAND SOME BASIC MECHANISMS OF THE ENERGY AND MASS TRANSPORT IN THE SUN'S ATMOSPHERE

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The combined interplay of the Sun's complex magnetic field and ionized hot plasma provides a variety of exotic plasma dynamics, including wave processes in its atmosphere at diverse spatio-temporal and spectral scales. Various observatories have been commissioned over the last several decades, on the ground and in space that have contributed to a significantly improved understanding of the energy and mass transport processes in the solar atmosphere. Data-driven Magnetohydrodynamics (MHD) has novel implications in understanding various dynamical plasma processes in the Sun's atmosphere. In this talk, I discuss some energy and mass transport processes (e.g., waves, plasma flows, and magnetic reconnection) and their role in the localized heating and mass cycle of various layers of the solar atmosphere using MHD approximation. I conclude that some of these physical phenomena may also have significant physical implications at the laboratory plasma scales.

BEYOND SOLITARY WAVES --- NONCONVENTIONAL AND MULTIDIMENSIONAL STRUCTURES IN THE EARTH'S MAGNETOSPHERE

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It is well known that the Earth is engulfed within its magnetosphere which is protecting it from the bombardment of the extra terrestrial charged particles and making life possible on the Earth. The study of our magnetosphere is important to understand the Sun-Earth coupling which is manifesting itself by our space weather conditions. Being in a highly technological era, understanding and predictions of space weather is gradually becoming the necessity of our day to day lives. One important aspect of the magnetosphere is its boundary layers which are identified by a sharp variation in their plasma parameters. The available free energy at these discontinuities have turned them into a convenient test bed of nonlinear plasma waves. Satellite observations have revealed localized bipolar or monopolar electric field pulses which are often interpreted by the theory of solitary waves or double layers in one dimension. Present days' in situ measurements with high resolution, space borne instruments have revealed the existence of multidimensional structures in different regions of space. Whereas the previously observed one dimensional localized structures have been successfully modeled by the solitary wave theory, its direct extension to two dimension is found to have its own limitations. The theory of *dromions* may then provide a possible model for such highly localized multidimensional pulses. Dromions are exponentially localized structures in two dimensions which are characterized by time dependent boundary conditions. They appear as a solution of a class of nonlinear partial differential equations. Though the study of the mathematical aspects of dromions is already more than a decade old, its application to space plasma physics has received a scant attention so far. In one of our previous work (*Ghosh etal., 2002 Nonlin. Process. Geophys., 463)*, we have shown that the nonlinear evolution of an electron acoustic wave can lead to a dromion solution. With a chosen set of parameters relevant for the auroral plasma, it was also shown that the shape and size of the analytical solution of the electron acoustic dromion is consistent with the satellite observations. Interestingly, present day MMS observations also revealed bipolar pulses for both parallel and perpendicular electric field which may well be the signature of a two dimensional structures like dromions. Besides the multidimensional localized structures, MMS have also recorded "near unipolar" pulses which appear with an extra wiggle or 'fold' in the otherwise conventional monopolar pulses. Interestingly, our very recent theoretical study has predicted the existence of "folded double layer" for a nonlinear ion acoustic wave propagating obliquely in a magnetized plasma. The morphology of the analytical solution matches with the MMS observations. In short, we may conclude here that, the interpretation of the recent exciting observations by MMS may need theories beyond the conventional solitary waves.

ACCELERATION OF ELECTRONS FROM ATHIN FOIL PLASMA BY TIGHTLY FOCUSED FEW-CYCLE LASER BEAM

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Acceleration of electrons with relativistic energies from a thin foil driven by tightly-focused few-cycle laser beam down to *one* optical-period and beam spot size down to the size of the laser wavelength has been studied using two dimensional electromagnetic particle-in-cell (EMPIC-2D) simulations. In such limits, beam dynamics has been simulated with extreme care using complex analytical signal representation which otherwise manifests artificial acceleration of electrons due to beam singularities. A few advantages of numerical beam propagation over the analytical expression are first discussed. Increasing the pre-plasma scale-length, acceleration of electrons appears in the forward direction while electrons circulate in the plane of polarization for sharp plasma boundary. For weaker intensities laser field is found to be mostly reflected from the skin layer at the sharp target-front resulting lesser energy gain. At increasing relativistic intensities plasma becomes transparent to the laser and more electrons are pulled out, and then pushed back through the plasma forming a circulating electron current. The mechanism of electron heating is under investigation.

PLASMA SIMULATION ACTIVITIES

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Plasma is a complex medium having many interesting attributes. It has an important and extensive role to play in the scientific and technological front and forms the basis for many environment friendly technologies. The complexity of the medium emanates from the fact that it is created by doing violence to matter and its evolution is governed by electromagnetic force fields which are often created by the medium itself. Experiments, theoretical and simulation techniques are adopted to understand the behaviour of this medium. In this talk I will describe about the challenges involved, the required simplifications and diverse simulation approaches that has been adopted in this pursuit.

References:

[1] Plasma medium and its understanding through numerical simulations, Amita Das, Science and Culture, Special issue on Meghnad Saha and the world of plasmas (Nov – Dec 2018) Pg 370.

RADIATION BASED DIAGNOSTICS ON TOKAMAKS IN IPR AND APPLICATION OF THOSE FOR INVESTIGATION OF PLASMA

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Radiation emanated from tokamak plasma is an important tool to diagnose passively without perturbing it. Radiation, especially from X-ray to NIR region can be recorded either in total or spectrally resolved depending on the parameter needed to be obtained. In tokamak, the parameter, such as plasma size and shape, electron temperature T_e, ion temperature T_i, radiation loss P_{rad} and plasma rotation velocity can be estimated through the recording of emitted radiation. Understanding of the particle and impurities transport can be done through the monitoring of the radiation. The plasma visible imaging using high speed camera is used to find out plasma size and its movement. Spectrally resolved visible spectroscopic diagnostics, either using interference filter or by spectrometer can be employed to monitor the fuel ion and impurities inside the plasma for the qualitative and quantitative assessment of the plasma performance. The influx and concentration of the particle and impurities is determined through analysis of absolute intensities of spectral line emission recorded from the tokamaks. Similarly spectroscopy in VUV and X-ray region give information about the plasma core region as these radiations primarily come from the high Te region of the plasma and using these diagnostics plasma temperatures and impurity transport coefficient are estimated for tokamaks in IPR. Similarly, the estimation of Z_{eff} from the measurement of visible continuum emissions and radiation loss using AXUV photodiode detector enables to understand the tokamak plasma properties, such as energy confinement and contamination. In this presentation, diagnostics and their usages for studying the neutral particle behavior, recycling and impurity behavior during Li coating experiment, oxygen and iron impurities transport study and understanding of the radiation losses in Aditya tokamak, will be discussed. This presentation will also cover the visible to VUV spectroscopic measurements on the SST-1 tokamak plasma. The behavior of radial profile of the neutral particle and impurity ion temperatures, impurity ion rotation in the Aditya-U tokamak plasmas will also be presented

MICROWAVE PLASMA DIAGNOSTICS FOR FUSION RESEARCH MACHINES

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Diagnostics are very important to characterize the fusion plasma by measuring plasma parameters such as ' density, distribution function over energy, temperature, their spatial profiles and dynamics. There are mainly two categories of the plasma diagnostics namely; (i) passive methods in which electromagnetic (EM) radiation from microwave to X-ray, emitted by the fusion plasma are monitored to derive the plasma parameters, (ii) active methods EM radiations produced by external sources are used to interact with the fusion plasma to determine the plasma parameters. Brief description about basic principles and characteristics of various diagnostics techniques will be covered in the talk. Among all these, various microwave and millimeter wave fusion plasma diagnostics will be discussed. Further, in case of fusion research machine, there are neutron radiation, high magnetic field and high power RF stray radiation. Difficulties faced in setting up the microwave diagnostic system on the fusion research machine and to determine accurate and reliable measurements of the plasma parameters will also be addressed. The description about techniques to accomplish the plasma parameters measurements in such environment will also discussed.

PULSED POWER AND PLASMA APPLICATIONS FOR AGRICULTURE AND FOOD PROCESSING

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Repetitively operated compact pulsed power generators with a moderate peak power were developed for the applications in several stages of agriculture and food processing. Pulsed high-voltage produces intense high-electric field which can cause some biological effects such as stress response (stimulation) and electroporation. Types of pulsed power that also have biological effects are caused with gas and water discharges which include reactive species such as ROS and RNS [1]. We developed repetitively operated compact pulsed power generators with a moderate peak power for the agricultural applications. The repetitive pulse discharge was used for promoting growth of the vegetables and fruits. The growth rate of the vegetables and sugar content in the strawberry harvested after the cultivation increased by the plasma irradiation to the hydroponic solution [2]. The plasma was irradiated in the drainage water for 10 and 20 minutes each day. The leaf size of the plants increased with plasma treatment time. Number of colony forming units (CFU) of *R. solanacearum* in the liquid fertilizer decreased from 10^7 to 10^2 CFU/mL using the discharge plasma treatment [3]. Seedlings with discharge plasma treatment were relatively healthy; in contrast, all seedlings in the positive control wilted and died from infection of *R. solanacearum* after 12 days. The □s-pulse high-voltage improvement of mushroom yield. The yielding rate of Shiitake mushroom (*L. edodes*) was also improved with the high-voltage stimulation in fruit-body formation phase [4]. The AC high-voltage keeping freshness for a relatively longer period of agricultural [5], and marine products [6]. The electrostatic effects can contribute to remove airborne bacteria and fungi spore from the storage house and container [5]. This removal contributes to reduce the infection risk with fungi and bacteria. Some kinds of fruit and vegetable emit the ethylene gas which accelerate a degradation of other kind fruits and vegetables. The repetitive μs-pulse DBD remediation of air and liquid to inhibit degradation of agricultural products via ethylene removal via oxidization reaction [7]. These applications can contribute a sustainable food supply chain in the world.

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References:
[1] K. Takaki *et al.*, J. Phys. D: Appl. Phys., **52**, 473001, (2019).
[2] J. Takahata *et al.*, Jpn. J. Appl. Phys., **54**, 01AG07, (2015).
[3] T. Okumura *et al.*, Plasma Medicine, **6**, 247, (2017).
[4] K. Takahashi *et al.*, Materials, **11**, 2471, (2018).
[5] S. Koide *et al.*, J. Electrostatics, **71**, 734, (2013).
[6] T. Okumura *et al.*, Jpn. J. Appl. Phys., **55**, 07LG07, (2016).
[7] K. Takahashi *et al.*, Jpn. J. Appl. Phys., **57**, AG04, (2018).

NON-EQUILIBRIUM NON-THERMAL (COLD) PLASMA TECHNOLOGIES FOR HEALTH & FOOD APPLICATIONS

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Atmospheric pressure non-equilibrium non-thermal plasmas, also known as Dielectric Barrier Discharge (DBD) plasmas, have recently found many advanced applications in biology, medicine, food, agriculture, etc. [1]. Such plasmas can efficiently kill bacteria, yeasts, molds and other hazardous microorganisms, including potential bio-terrorism agents, even spores and biofilms, i.e., generally very difficult to inactivate [2]. The most attractive feature of such plasmas is the ability to achieve enhanced gas phase chemistry without the need of elevated gas temperature. In fact, such plasmas exhibit electron energies much higher than that of the ions and the neutral species that remain near to room temperature and the energetic electrons enter into collision with the background gas, causing enhanced level of dissociation, excitation, ionization, etc. Due this fact plasma does not cause any thermal damage to the articles that it comes in contact with and hence one can easily employee such plasmas for bio-decontamination and sterilization of surfaces, medical instruments, water, air, food, even of living tissues without causing their damage and other side effects. Such plasma treatments can be attributed to several synergic mechanisms, including UV radiations, electric field, charged particles, generated radicals and reactive species. However, plasma induced processes are still mostly regarded as an efficient “black box” and hence deeper understanding of these mechanisms and their roles and synergies is absolutely necessary. In this talk a review of Indian efforts in the development of plasma-based VUV/UV Excimer Sources and Cold plasma jets for health and food applications will be presented and strategies will be discussed for multidisciplinary approach to bring out the real fruits of this emerging area of research.

References :

[1] The future for plasma science and technology, Plasma Process Polym. **16,** e1800118 (p-1-29) (2019)
[2] Plasma for Bio-Decontamination, Medicine and Food Security, Machala, Zdenko (et al.) (Eds.), ISBN 978-94-007-2852-3 (2012)
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INDIGENOUS DEVELOPMENT OF MULTI GIGAWATT PULSED POWER SYSTEMS FOR NUCLEAR AND INDUSTRIAL APPLICATIONS

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Intense pulsed power systems are being developed now in a very compact topologies and repetitive mode. Applications of these high power pulsed source are no more limited to R&D activities but also extended towards industrial applications. In this talk journey of BARC's pulsed power program will be illustrated and paradigm shift in the generation of high power microwaves (~1GW), Flash X-rays (~1MeV), Dense plasma focus based Pulsed neutron source (~10^9n/pulse), magnetic field (50T) and controlled shock plasma (100-150MPa) pulses. All these development have been done using mostly off the shelf available components and designed to meet the specified parameters with local fabrications. It gives a comfort of user friendliness, Operation and maintainability with customized solutions. These achievements are attributed to visionary seniors and competent team members who work in synergy with multi disciplinary expertise for delivering the system in a product finish form. My efforts are to take these technologies from lab to the user's site and if any changes are needed it can be addressed as a commitment. Please see the potential of the work and its applicability in individual institute and labs. there is possibility to work in collaboration by in kind contributions also through suitable MoU. This PSSI forum is an apt platform to have this vision of deployment to get fulfilled, thanks to the organizers to include this topic. As "plasma" acitvities initiated the indigenous development work in pulsed power technology for fusion in early 1970 in BARC.

TUNGSTEN COMPATIBILITY FOR SPHERICAL TOKAMAK REACTORS: MODELING OF RADIATION DAMAGE AND FUEL RETENTION

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Spherical Tokamak Reactors (STR) are attractive due to their inherent capabilities viz. disruption avoidance, natural elongation, natural divertor and very high beta capability -- apart from a smaller size, with presumably lower costs [1]. Given the development of new superconducting materials and new divertor concepts, the STRs represent a rapidly developing front [2] and may very well be realized not far in the future. However, the combination of size reduction and aggressively large fusion- power values will lead to extreme wall loading, both in terms of heat and particle fluxes. Several designs of STRs are currently being developed around the world with the scoping studies and available data from currently operating tokamaks as well as other experimental/ dedicated test facilities. Modeling is almost the only available option for projection of scenarios to reactor-like extreme conditions, however comprehensive database and insights from experts around the world [3], need to be used in the modeling to bring realism. In fact, for the STRs, the flux of neutrons as well as heat can be more than an order of magnitude of that for ITER. In this work, we consider tungsten-based plasma-facing materials (PFM) for STRs and examine their compatibility for extreme conditions for two cases namely, (1) to act as a component test facility and (2) as a power plant. The focus of the work is on radiation damage and possible fuel-retention in a few operational scenarios. A scan on machine's key parameters allows a perspective to understand the constraints on PFM. The cases where the poloidal banana width is large enough to allow the alpha particles to be unconfined need to consider concurrent alpha and neutron irradiation. Such situations may result in significant surface modifications [4] with their own consequences. Role of ion-irradiation in experimental simulation of damage will be discussed especially in the context of helium irradiation with pre-damaged materials [5].

[1]. Gi et al., Nucl. Fusion 55 063036 (2015)
[2]. A. Sykes et al., Nucl. Fusion 58 016039 (2018) and references therein
[3]. M. Tillack et al., Nucl. Fusion 53 027003 (2013)
[4]. LaBombard et al., Nucl. Fusion 55 053020 (2015)
[5]. P.N. Maya et al., Nucl. Fusion 59 076034 (2019)

RECENT PLASMA EXPERIMENTS IN SST-1

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After some improvements done for the magnetic null configuration by modifying a few external correction coils of central solenoid, plasma start-up scenarios in Steady-state Superconducting Tokamak (SST-1) [1] have become better. There were two experimental campaigns conducted, one in April and another in September, in which the plasma breakdown and start-up were assisted by the Electron Cyclotron Resonance (ECR) pre-ionization and loop voltage of 5-6 volts produced by the Copper based central solenoid. In the April experimental campaign, plasma currents were driven by Ohmic system for severel 100s of milliseconds followed by the Lower Hybrid Current Drive (LHCD) thereby, enhancing the duration of plasma to about 645ms. In the September campaign, plasma duration of 650millisecod was achieved by Ohmic current drive only. Results from these two campaigns are quite encouraging for future plasma experiments with the enhanced pulse duration (beyond 1 second), using the combination of both Ohmic and LHCD systems. Major focus of the experiments would be on the plasma start-up optimization, along with the operation of Ohmic and LH current drive and superconducting poloidal field coil. The operational limitations and issues during plasma experiments would also be addressed in this paper in detail.

References:

[1] “Present Status of the SST-1 project”, Y. C. Saxena and SST-1 team, Nuclear Fusion 40 (2000) 1069

INVESTIGATION OF NEUTRAL PARTICLE DYNAMICS IN ADITYA AND ADITYA-U TOKAMAK PLASMAS USING DEGAS2 AND UEDGE CODES

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The fuel neutrals present in the confined plasma of a tokamak are known to play several important roles in overall performance of the discharge. There exists different sources of neutral entering into the plasma during a discharge, such as: gas-puffs/SMBI/pallet injection, mainly for maintaining the plasma density and the neutral recycling from the limiter/divertor/vessel wall. These neutrals enter in the plasma as a molecule and interact with plasma particles and decide the global plasma parameters. The temporal and spatial variation of electron density and temperature profiles affect the neutral particle penetration inside the plasma. The penetrated neutrals in turn change the radial profiles of temperature and density. Due to the several limitations in measurements of neutrals inside the plasma, simulations are required for thorough understanding of the processes involved in molecular dissociation, atomic ionization/recombination etc. The study of neutral penetration in ADITYA and ADITYA-U tokamak plasmas is carried out in detail using DEGAS2 code. The DEGAS2 is basically a neutral particle transport code, which is implemented for the first time for ADITYA tokamak with limiter geometry and the concentration of neutral particles is estimated [1]. Furthermore, the penetration of neutral particle from edge to core region of plasma is investigated for different discharges of ADITYA tokamak by modelling the experimental $H_{\square}$ spectral line profile and radial profile of H_α emissivity [2,3]. The simulated result elucidate that the neutral molecules penetrate quite far inside the limiter radius. In an another study, the particle confinement time is calculated for ADITYA tokamak plasmas by estimating the recycled neutrals through the modeling of experimental H_α emissivity profile [4]. From the radial profile of particle confinement time, it is found that nature of particle transport in core as well as edge region in ADITYA tokamak is anomalous in nature. An attempt is also made to examine the neutral penetration and subsequent changes in the temperature and density profiles due to gas-puffs, the DEGAS2 code is coupled with UEDGE, which is a two dimensional edge-plasma fluid transport code. The estimated change in the plasma density is found to be in good agreement with that of the measured values [5].

References:

[1] Dey R. et al, "Investigation of neutral particle dynamics in Aditya tokamak plasma with DEGAS2 code", Nucl. Fusion, 57 086003 (2017).

[2] Dey R. et al, “Investigation of atomic and molecular processes in H_α emission through modelling of measured H_α emissivity profile using DEGAS2 in ADITYA tokamak”, Nucl. Fusion, 59 076005 (2019).
[3] Dey R. et al, “Modeling of H_α emission from ADITYA tokamak plasmas”, Atoms, 7 95 (2019).
[4] Dey R. et al, “Estimation of radial profile of particle confinement time from H_α emissivity profile in Aditya tokamak and inferrence of its particle transport ”, Under Revision, Nucl. Fusion (2019).
[5] Dey R. et al, “Studies of edge plasma parameters along with the neutrals of ADITYA-U tokamak using combined UEDGE-DEGAS2 code”, submitted to Nucl. Fusion, (2019).

ORAL PRESENTATIONS

EFFECT OF PLASMA BETA ON ELECTROMAGNETIC ETG TURBULENCE INDUCED PLASMA TRANSPORT

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Plasma transport across the confining magnetic field continues to bother fusion fraternity; consequently, numerous efforts made in investigations on its experimental, theoretical and computational understanding. Till now, the problem concerning ion scales greatly resolved but contribution of electron scale towards plasma loss still remains unresolved. The reason may be the inability of carrying out direct measurements in fusion devices because of the extremely small scale length of instability and prevalent violent conditions [1]. Recent success on unambiguous demonstration of excitation of Electron Temperature Gradient (ETG) turbulence in Large Volume Plasma Device has motivated us to investigate ETG induced turbulent transport [2]. We investigated convective particle transport and compared contribution from electrostatic and electromagnetic components with theoretical estimates. It was observed that induced particle transport is directed radially inward [3]. Surprisingly, we found the existence of finite and non- zero EM flux against predicted zero for slab ETG model despite having magnitude significantly small compared to ES counterpart [4]. We carried out investigations for plasma beta effect on particle and energy transport by varying plasma beta between 0.01- 0.2. Suitable diagnostics are developed for simultaneous measurement of temperature, potential and density fluctuations. Detailed results on contribution of phase angle modification to particle and energy transport will be presented in the conference.

References:

[1] P. C. Liewer, J. M. McChesney, S. J. Zweben, and R. W. Gould, Phys. Fluids **29**, 309 (1986).

[2] S. K. Mattoo, S. K. Singh, L. M. Awasthi, R. Singh, and P. K. Kaw, Phys. Rev. Lett. **108**, 255007 (2012).

[3] P. Srivastav, R. Singh, L. M. Awasthi, A. K. Sanyasi, P. K. Srivastava, R. Sugandhi, R. Singh, and P. K. Kaw, Phys. Plasmas **24**, 112115 (2017).

[4] P. Srivastav, R. Singh, L. M. Awasthi, A. K. Sanyasi, P. K. Srivastava, R. Sugandhi, and R.Singh, Plasma Phys. Control. Fusion **61**, 055010 (2019).

KINETIC SIMULATION OF PLASMA-WALL TRANSITION FOR DIFFERENT PLASMA AND WALL PROPERTIES

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The plasma sheath, formed in the immediate vicinity of a material wall facing plasma, plays an important role in determining overall plasma properties as well as particles and energies reaching the wall. The kinetic trajectory simulation (KTS) model, which we have developed, will be introduced and results obtained for different plasma and wall properties will be presented. In the KTS model the ion kinetic equations are solved for given ion distribution functions at the injection and the potential profile is iterated towards the final time-independent self-consistent state. On the other hand, the electron densities are obtained analytically considering Boltzmann distribution and cut-off by the negative wall. The analysis of magnetized plasma sheath characteristics with two species of positive ions reveals that the presence of second ion affects the velocity distribution functions of both ion species. Special focus will also be given to the presheath-sheath coupling scheme for the magnetized plasma sheath. The energy of ions reaching the material wall and sheath thickness can be controlled by applied magnetic field and its orientation.

CHIRPED AXICON-GAUSSIAN LASER-DRIVEN ELECTRON ACCELERATION IN VACUUM

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Electron energy enhancement by a frequency chirped radially polarized (RP) axicon-Gaussian laser pulse in vacuum in the presence of wiggler magnetic field is analyzed. A strong longitudinal electric field is produced by axicon laser which is mainly responsible for direct electron acceleration in vacuum. Interaction time between laser and electron has been increased on account of linear frequency chirp, however, the applied magnetic wiggler field helps in improving the strength of ponderomotive force in order to keep the electron traversing in the accelerating phase up to longer distances. It is noticed that an electron with initial energy of few MeV, accelerates up to GeV energy with optimized laser and magnetic field parameters.

References :

[1] S. Tokita, S. Inoue, S. Masuno, M. Hashida and S. Sakabe, *Appl. Phys. Lett.* **95** 111911 (2009).
[2] V. Malka, J. Faure, Y. A. Gauduel, E. Lefebvre, A. Rousse, K. T. Phuoc, *Nature Phyics* **4** 447 (2008)

2D-3V PIC-MCC SIMULATION OF PLASMA TRANSPORT ACROSS MAGNETIC FILTER IN ROBIN: IMPORTANCE OF WALL EFFECTS

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Plasma transport across the magnetic filter in negative ion sources is complex to understand due to different drifts and instabilities [1]. We have developed a 2D-3v Particle-in-Cell Monte Carlo Collisions (PIC-MCC) code with periodic boundary conditions and simple hydrogen chemistry [2][3] for comparison with experimental results from ROBIN (RF oriented beam source in India) [4]. Simulation results showed some discrepancies with the experimental results, which is due to closed diamagnetic current due to presence of periodic boundary condition. Our code has been further extended to a more realistic model with wall physics to understand the plasma diffusion across the magnetic field. In this work we present a comprehensive comparison between the results from the two models (periodic vs. non-periodic). The comparative studies have been performed under realistic conditions similar to ROBIN. A more realistic with detailed negative hydrogen ion chemistry is under development.

References:

[1] S. Kolev, G. J. M. Hagelaar, and J. P. Boeuf, "Particle-in-cell with Monte Carlo collision modeling of the electron and negative hydrogen ion transport across a localized transverse magnetic field," *Phys. Plasmas*, vol. 16, no. 042318, pp. 1–9, 2009.

[2] B. Chaudhury, M. Shah, U. Parekh, H. Gandhi, and P. Desai, "Hybrid Parallelization of Particle in Cell Monte Carlo Collision (PIC-MCC) algorithm for simulation of Low temperature Plasmas," in *Second workshop on software challenges to exascale computing*, 2018.

[3] H. Shah, S. Kamaria, R. Markandeya, M. Shah, and B. Chaudhury, "A Novel Implementation of 2D3V Particle-In-Cell (PIC) Algorithm for Kepler GPU Architecture," in *Proceedings of 24th International conference High Performance Computing, Data and Analytics (HIPC 2017)*, 2017, pp. 1–10.

[4] K. Pandya *et al.*, "First results from negative ion beam extraction in ROBIN in surface mode," *AIP Conf. Proc.*, vol. 1869, p. 030009, 2017.

TECHNOLOGY DEVELOPMENTS FOR ITER CLASS NEUTRAL BEAM SYSTEMS AND A ROAD MAP FOR THE INDIGENIZATION

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Neutral beam systems for ITER class fusion machine consist of components which involves large number non-conventional manufacturing technologies and each of them have to be developed to meet the system requirements. While realization of the components for ITER, some of the technologies are already being exercised at global level and have been developed for the first time ever, however, at the works of foreign manufacturers. These manufacturing technologies includes (1) precision machining to the accuracy of few tens of microns (2) Deep drilling of ~1.8m with the drift control of 0.5mm (3) similar and dissimilar material welding technologies conforming to the highest quality class for water to vacuum junction with full penetration technique and 100% volumetric examinations (4) Brazing technologies over large areas (5) Copper electrodeposition (6) Ceramic to metal transitions for high voltage applications. The paper shall present the overview of development of technologies, challenges faced, their resolutions, qualification aspects and learning. Further, in order to establish a self-reliance in developing several such technologies in the application areas of fusion technologies, continued efforts are being made with a systematic process developments and prototyping. These includes, precision machining, high energy beam welding, laser based additive manufacturing technologies, copper electro deposition, additive manufacturing, cladding technologies and friction stir channel processing. Many of them have already been demonstrated as a proof of principle and qualification has been performed through destructive examination, non-destructive examination, metallurgical characterizations and functional tests as applicable. The paper shall present these developments followed by a road map for developing such non-conventional manufacturing technologies within the domestic frame with the aim of reducing the dependency to the foreign suppliers and enable the manufacturing of these complex components completely indigenously.

CRYOSTAT DESIGN AND FABRICATION EXPERIENCES

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Cryostat is a large stainless-steel vacuum vessel which provides vacuum environment to ITER Machine. The cryostat is ~29 meters in diameter and ~29 meters in height having thickness varies from 25 mm to 200 mm. Cryostat also provides support to complete tokamak machine and takes all machine loads during normal and accidental events. ITER machine has massive weight resting on cryostat pedestal ring and transfer huge loads during machine operations. To meet these requirements, Cryostat has been designed for various operational conditions.Cryostat has many interfaces with stringent tolerance requirements and different thickness of material at various location. Due to large size of Cryostat, it has three stages of fabrication. In first stage the components are being fabricated at India having size restriction of 9mx9mx19m. In second stage these components are being assembled at site workshop to form four main sections and in third stage these sections will be assembled in pit to make complete Cryostat. The requirement of stringent tolerances, handling heavy weights, welding of various thickness and many stages of fabrication make the work one of its kind and challenging.This Paper covers the details of design evaluation of Cryostat, fabrication challenges and learning.

PARTICLE-IN-CELL (PIC) SIMULATIONS OF EARTH'S MAGNETOSPHERE AND TRAPPED PARTICLE'S MOTIONS

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The Earth surface is constantly bombarded by the solar wind and the Earth's magnetosphere is the region dominated by its dipolar magnetic field which forms an obstacle in the path of the solar wind, causing it to be diverted around the Earth. The dynamics of such kind of systems are essentially governed by the Magnetohydrodynamics (MHD) equations [1]. MHD neglects single particle aspects and treats the wind and the ambient medium as conducting fluids characterized by macroscopic parameters viz. density, velocity, magnetic field and temperature. But the high energetic charged particles present in the solar wind essentially get trapped in the Earth's magnetosphere and exhibit fascinating events under certain conditions. For example, formation of Van Allen radiation belts, dazzling aurora lights, substorms, etc.

Due to very low particle density, single/test particle motion "under background fields" is adequate and reasonable approximation to reveal the dynamics of these particles near the magnetosphere. By using the particle module available in the PLUTO code [2] an earlier study on the "modeling of far-out star-planet systems" [3] has been revisited to extract the dynamics of the particles near the Earth's magnetosphere. This model has been benchmarked by tracking the orbits of the particles and comparing them with the existing theoretical results. Our model has been further extended to study the acceleration processes and injection near the magnetotail and aurora region [4].

References:

[1] Models of Star-Planet Magnetic Interaction. In: Deeg H., Belmonte J. (eds) Handbook of Exoplanets. Springer, Cham, (2017).
[2] A Particle Module for the PLUTO Code. I. An Implementation of the MHD–PIC Equations, The Astrophysical Journal, **859**:13 (2018).
[3] Modeling Star–Planet Interactions in Far-out Planetary and Exoplanetary Systems, The Astrophysical Journal, **877**:80 (2019).
[4] Particle Acceleration in the Magnetotail and Aurora, Space Sci Rev, **173**:49 (2012).

A VELOCITY SHEAR DRIVEN KINETIC ALFVÉN WAVES INSTABILITIES WITH SUPERTHERMAL ELECTRONS

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The generation of kinetic Alfvén waves (KAWs) by velocity shear through a theoretical three component plasma model comprising of background Maxwellian ions, κ-electrons and drifting Maxwellian beam ion are presented. The ion beam is streaming along the ambient magnetic field, whereas, velocity shear is perpendicular to it. The role of velocity shear and κ-electrons in the generation of resonant instability of KAWs is examined. The effect of other plasma parameters such as number density, propagation angle, species temperature, plasma beta (thermal pressure/magnetic pressure) is analysed. The results of the study are compared with the Maxwellian electrons case. It is found that the non-thermal electron impedes the growth of KAWs and also narrows down the wave unstable region, whereas, the Maxwellian electron facilitates the growth and enhances the wave unstable region. A relatively high number density and velocity shear are required to excite the KAWs with non-thermal electrons as compared to the Maxwellian electrons. The model can generate a frequency of ≈18 mHz that may be helpful in understanding the characteristics of ultralow-frequency waves (1mHz-30Hz) observed in the auroral/polar cusp region of Earth's magnetosphere.

STATISTICAL ANALYSIS OF GROUND OBSERVATIONS OF ELECTROMAGNETIC ION CYCLOTRON WAVES AT MAITRI

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The EMIC waves are the discrete emissions of the plasma waves generated in inner magnetosphere which are known to be excited by the temperature anisotropy of the ions of energy range 1-100 keV. EMIC waves are usually excited in the equatorial plane ($\pm 11^{\circ}$) of the magnetosphere where the spatial gradient of magnetic field is lower. They interact with the radiation belt electrons through the Doppler shifted cyclotron resonance and scatter them into the atmospheric loss cone. They influence the dynamics of the energetic particles of the inner magnetosphere. These waves travel along magnetic field lines to its footprint in the high latitude ionosphere. Their signatures can be recorded in both satellite and ground observations. These are observed as the Pc1 geomagnetic pulsations on ground and the magnetic fluctuations remain in the frequency range of 0.1-5 Hz. In present study we have used Induction Coil Magnetometer (ICM) observations recorded at Indian Antarctic station Maitri (Geographic coordinates: 70.7° S, 11.8° E; Geomagnetic coordinates: 63.1° S, 53.6° E) during 2011-2017.We are presenting a statistical study of ground observation of EMIC waves covering 7 years of data, divided in quiet and disturbed days. The data spans both ascending and descending phase of the solar cycle 24, which has witnessed extremely low activity. Based on the duration and power of the individual EMIC wave in the spectrogram we identified days and total duration of EMIC wave occurrence. The occurrence of EMIC wave is noted in different frequency regimes between 0.12 - 2 Hz. All EMIC wave events separated on the basis of solar flux (i.e., low, moderate, high) and their seasonal, local time dependence, and durations have been examined. Overall the EMIC waves are observed on 1263 days (3166.5 hours, 5.58% of total duration) out of 2364 days for which data was available. A significant contribution of EMIC wave occurrence comes from the descending phase (3.71%) as compared to ascending phase (1.87%) of the solar cycle, which suggests nearly a two-fold increase in their occurrence. The duration percentage of EMIC waves on magnetically disturbed days is approximately equal (1.06 times) to that on quiet days. The ground observation of EMIC waves shows a clear seasonal dependence during moderate-high solar flux with peak around winter (March-October). In local time, peak occurrence of EMIC waves is seen between11.7 - 20.7 LT. The longer duration (240 - 1000 minutes) EMIC wave events are dominated on quiet days (20.9%) as compared to disturbed days (14.1%). The solar wind parameters were used to understand the descending phase dependence.

OVERTAKING OF KINETIC ALFVÉN WAVES IN ELECTRON-POSITRON-ION PLASMA

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Over the past many years the variety of nonlinear structures, Alfven waves and the magnetoacoustic waves (slow and fast) are the basic wave modes in the magneto-hydrodynamic (MHD) systems in which Alfvén waves are the low frequency waves (below the ion cyclotron frequency) which play a central role in many laboratory, cosmic as well as fusion plasmas where the plasma β is typically much smaller than the electron to ion mass ratio. The observational data from the Freja and the FAST satellites [1] have revealed a clear signature of solitary Alfvénic structures [2]. Kinetic Alfven waves arise when the perpendicular wavelength of ordinary Alfven wave is comparable to the ion Larmor radius. The propagation and interaction of multi-solitons are important phenomena in plasma physics. They interact elastically and owing to this reason, the amplitudes of solitons do not change; however each soliton gets a phase shift. In the present work, we have investigated the propagation of ion acoustic kinetic Alfven waves in a low β plasma. In this regard, Korteweg de Vries equation is derived and discussed using the plasma parameters that are typically found in solar corona. The interaction of fast IAKAWs is explored by using the Hirota bilinear formalism [3], which admits multi-soliton solutions. It is pertinent to mention here that this solution describes two solitons travelling in the same direction and the soliton interaction takes place when the faster solitary wave overtakes the slower solitary wave. It is further noted that the amplitude of the respective solitary waves remain unchanged after the interaction, however, they do experience a phase shift. This study may also be helpful in understanding various non-linear coherent structures in space and astrophysical plasma environments.

References:

[1] J. S. Makela et al, Observations of mesoscale auroral plasma cavity crossings with the Freja satellite, Geophys. Res. Lett. **103**, 9391 (1998).
[2] M. Singh et al., Kinetic Alfvén solitary waves in a plasma with two-temperature superthermal electron populations: the case of Saturn’s magnetosphere , MNRAS, 486 (4), 5504 (2019)
[3] K. Singh et al, Effect of polarization force on head-on collision between multi-solitons in dusty plasma, Phys. Plasmas 25, 033705, (2018)

FIRST EVIDENCE OF THE SOLITON-TYPE BEHAVIOR OF SUPERSOLITARY WAVES IN PLASMA

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Supersolitary waves (SSWs) are a new class of solitary waves in plasmas, which are characterized by having extra wiggles on both sides of its associated bipolar electric field structure. In the past, many researchers have studied their existence in different plasma constituents. However, whether they follow the soliton-type properties or not is yet to examine. We performed a fluid simulation of the head-on collision of supersolitary wave (SSW) with a regular solitary wave (RSW) in a plasma consisting of cold fluid ions and two-temperature electrons having kappa distributions. We have set up the fluid simulation to evolve both ion acoustic (IA) SSW and IA RSW self-consistently. Our simulation shows that the generated SSW maintain its shape while propagating at a constant speed. Furthermore, the simulation demonstrates that the head-on collision of SSW with RSW does not affect their original characteristics revealing its soliton-type behavior. This is the first simulation to confirm the soliton-type behavior of the SSWs in plasma.

NUMERICAL STUDY OF INTERACTION OF LASER INDUCED COUNTER PROPAGATING SHOCK WAVES

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The hydrodynamics of two interacting counter propagating shock waves generated from ambient air plasmas is numerically studied using FLASH two-dimensional radiation hydrodynamic (2D-RHD) code and compared with the experimental results. For generating plasmas, two laser beams were line-focused at a separation of 4 mm and the plasmas so produced were allowed to expand in the opposite directions. Experimentally, the two shock waves were generated using second harmonic (532 nm) of a Nd:YAG laser beam of pulse duration 10 ns with unequal energies of 50 (S1) and 100 mJ (S2) (1:2 ratio of the energy sources), respectively. The formation and interaction of two plasma plumes and shock waves was studied from the initial laser interaction times to over a longer durations of up to 30 µs. The plasma dynamics and the subsequent shock wave expansion were validated with the experimental results show a good agreement. The simulated results predicted that the shock waves generated from the two plasma sources started interacting with each other from time duration of 500 ns leading to the formation of a stagnation layer at the interaction zone of the two shock wave. A high-pressure jump of 4 MPa is formed at the stagnation layer at 650 ns whose pressure is higher than that of the individual pressures [1] occurred at the two sources S1 (1.4 MPa) and S2 (1.9 MPa). A similar trend is also observed in the density at the stagnation layer with a maximum density of 3.5×10^{-3} gm/cm^3 at the time of 650 ns. Later on

after 1 μs, the density jump at the stagnation layer decreases and a drag in the density jump occurs towards the low energy plasma source S1. Since, the energy of the plasma source created with S1 (50 mJ) is small in comparison with S2 (100 mJ), the hydrodynamic expansion is favored towards the plasma outer region of the S1 which is in the direction opposite to laser beam propagation (-Z direction of S1) and along the propagation of S2. This hydrodynamic expansion of the plasma is called as the jet let. Since the area of plasma outer region (POR) [2, 3] of S1 is small compared to that of S2, the enhanced plasma jet penetrates into plasma outer region POR of S1 along –Z direction which is clearly from the experiments as well as from the simulations. The radius of this formed jet let is observed to increase with time. The high density colliding plasma plumes are very useful to understand the design of inertial confinement fusion (Hohlrums) [4], X-ray laser research, generation of higher ion temperature [5] and charge particle acceleration using Thomson scattering in conjunction with proton radiography etc. to name a few.

References:

[1]. Raizer, Y.B.Z.d.a.Y.P., *Physics of Shock Waves and HighTemperature Hydrodynamic Phenomena*. 2012: (Dover Publications.

[2]. Numerical investigation of nanosecond laser induced plasma and shock wave dynamics from air using 2D hydrodynamic code. Physics of Plasmas, p. 083110.(2017)

[3]. Role of laser absorption and equation-of-state models on ns laser induced ablative plasma and shockwave dynamics in ambient air: Numerical and experimental investigations. Physics of Plasmas, p. 072108.(2019)

[4]. Review of indirect-drive ignition design options for the National Ignition Facility. Physics of Plasmas, p. 2164-2170.(1999)

[5]. Laser-driven accelerators by colliding pulses injection: A review of simulation and experimental results. Physics of Plasmas, p. 056703.(2009)

GENERATION OF ELECTROSTATIC MODE IN A LASER PLASMA INTERACTION

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The interaction of laser with plasma is known to be highly non-linear and give rise to several drifts and instabilities. In our 2-D Particle - In - Cell (PIC) simulation study using OSIRIS4.0, we have mainly concentrated on role of EXB drift in coupling laser energy into plasma and into ion species in particular. We show that non-relativistic pulsed CO2 lasers (λ = 10μm) in the presence of ambient magnetic field have been able to couple its energy into over-dense plasma which is otherwise not possible according to the presently known absorption mechanisms. EXB drift creates a charge separation in the system which leads to coupling of laser energy into plasma via generation of electrostatic modes in the system. In this way, we have observed ions dominated mechanism for laser energy coupling which would be discussed in detail.

References:

[1] Kruer et.al, Phys. Fluids 28:430(1985).
[2] A. Kumar et al,Plasma Phys.Control. Fusion, vol. 61, 2019

SIMULATION OF NUCLEATION AND GROWTH OF YTTRIA NANO PARTICLES IN THERMAL PLASMA REACTOR

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Simulation of particle nucleation and growth has been carried out for yttria with argon as the carrier gas in a thermal plasma reactor. The set of General Dynamic Equation (GDE)) (one equation for each particle size) governing the particle number conservation for different processes like collisions among different particles, monomer evaporation and particle transport have been solved following the approach of Girshick et.al[1]. A simulation code under this formalism is developed in Fortran 90. Considering the largest particle present in the system may be of micrometer size (~ 10^6 atoms/molecules), GDE forms a set of around 10^6 equations. For a tractable solution, we have used discrete section model of Girshick for simulating particle nucleation and growth. The particle size spectrum is divided into sections. Within a section particle number density is assumed to be constant. Smaller particles up to a chosen particle size are treated individually. Total number of monomers in a given section is defined as a new variable in terms of which equations are written. Only one equation per section is sufficient to describe the particle dynamics under this consideration. Equations in time domain are solved numerically using Runge Kutta-4 method. To compute values of various summations appearing in the particle dynamic equations, eleven-interval Gaussian quadrature method has been used. Parameters like saturation ratio, critical cluster size, mass mean diameter, mean particle size, particle size distribution are computed with the developed code. Simulation is done for a range of cooling rate (from 5000 K/S to 5,00,000 K/S) and pressure (0.1 atm,1 and 10atm). It has been observed that for a fixed pressure, as cooling rate increases super saturation ratio increases and critical cluster size decreases. Mass mean diameter and mean particle size of the particle decreases with increasing cooling rate. For a fixed cooling rate, super saturation ratio is observed to be high at low pressure(~0.1 atm) and low at atmospheric pressure (1 atm). Reduction of mean particle size and mass mean diameter have been investigated as a function of pressure.

References:

[1] Homogeneous Nucleation of Particles from the Vapor Phase in Thermal Plasma Synthesis Plasma Chemistry and Plasma Processing, vol 9, No. 3, 1989

IMPURITY ION TEMPERATURE MEASUREMENT USING ZEEMAN INFLUENCED SPECTRAL LINES IN ADITYA-U TOKAMAK

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Measurement of the impurity ion temperature at the plasma edge is important to understand the various phenomena happening in the edge. In edge transport study, impurity ion temperature is involved in the force balance equation through the forces due to ion temperature gradient and friction arises due its parallel flow along the magnetic field. However, in many cases, ion temperature has been usually considered as some factors of electron temperature instead of the value from measurement. The edge ion temperature can be obtained using Doppler broadened spectral lines from the low-Z impurities, such as carbon and oxygen present even in the present day's tokamak having all metal walls. However, the shapes of the spectral lines from these ions are affected by tokamak high magnetic field via Zeeman Effect, which causes the erroneous temperature measurement done using Doppler broadening technique. In Aditya-U tokamak, oxygen and carbon spectral lines having wavelengths at 650.0 nm and 658.2 nm respectively has been routinely monitored with a high resolution multi-track spectroscopic system. By measuring temperature with Doppler broadened spectral line without considering Zeeman Effect, sometimes it comes out to be higher than the ionization potential of these ions. As for example, ion temperature comes out to be more than 30 eV for C^+ ion. A proper analysis technique has been developed to remove the inaccuracy present in temperature measurement. The estimated temperature becomes ~ 12 eV after Zeeman Effect taken into account. In this work details on the estimation of carbon and oxygen ion temperatures at the plasma edge in Aditya-U tokamak are presented and analyzed with other plasma parameters, plasma edge electron density and temperature.

INITIAL RESULTS OF LASER HEATED EMISSIVE PROBE FOR SOL REGION IN ADITYA – U TOKAMAK.

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Langmuir probes have been used widely for estimation of plasma parameters indirectly from its measured V-I characteristics. However, due to error probabilities in recording Langmuir probe V-I under certain circumstances, conventional emissive probes (CEP) are more popular for direct measurement of plasma potential. Laser Heated Emissive Probe (LHEP) has several

advantages over CEP, especially in tokamaks where the frequent vacuum breaks are not at all desirable to change the burnt filaments of CEP. A unique design of the LHEP for ADITYA-U tokamak overcoming many constraints of the complicated geometries and limitations of a big device like tokamak have been designed and installed. Radially movable Graphite probe tips of 6 mm diameter were kept in SOL region of ADITYA-U tokamak and biased at 1 kHz frequency, thereby having optimum measurements in one plasma shot of ~200 ms. Results were recorded with and without heating probe tips. In this paper we present the results of the response of LHEP probe tips when biased in cold condition and when heated with CW CO_2 laser at 10.6 µm having a maximum power of 55 watt powers, at different laser powers. Direct measurements of radial profiles of plasma potential in the edge plasma region of ADITYA-U tokamak, which will give the radial electric fields in the edge region is recorded and reported here.

References:

[1] A comparative study of sheath potential profile measurements with laser-heated and current-heated emissive probes, Review of Scientific Instruments **87**, (2016)

[2] Emissive probes, J P Sheehan and N Hershkowitz, Plasma Sources Sci. Technol. **20** (2011)

[3] Overview of operation and experiments in the ADITYA-U tokamak, R.L. Tanna et al (2019) Nucl. Fusion **59** 112006

[4] A set-up for a biased electrode experiment in ADITYA Tokamak, Pravesh Dhyani et. al. Meas. Sci. Technol. **25** (2014)

A NEW COLLISIONAL RADIATIVE MODEL FOR LASER PRODUCED Zn PLASMA USING CALCULATED RDW CROSS-SECTIONS

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Recently spectral measurements of neutral Zn emission lines from an ultrafast laser produced plasma in the pressure range of 0.05 to 10 Torr were reported [1]. The plasma parameters viz. electron temperature (T_e) and electron density (n_e) were obtained from the measured optical emission spectra using simple local thermodynamic equilibrium (LTE) model. It would be therefore interesting and worth developing a detailed collisional radiative (CR) model to obtain the reliable plasma parameters from their spectra. From laser produced zinc plasma (LPZP) emission measurements of Smijesh et al. [1], we develop a detailed CR model. In such plasma, the electron impact excitation of Zn is a dominant process and for the modeling purposes, the excitation cross sections for the various fine structure transitions involved among ground state and excited states are required which we obtained using fully relativistic distorted wave (RDW) approximation theory [2]. We consider 30 fine structure levels along with the ground state of Zn and Zn^+. The model incorporates various population transfer kinetic processes among fine structure levels such as electron impact excitation, ionization, and radiative decay along with their reverse processes e.g. electron impact de-excitation and three body recombination [3]. The n_e and T_e of LPZP are evaluated and published [4].

References:
[1] N. Smijesh and R. Philip, J. Appl. Phys., **114**, 093301, (2013).
[2] T. Das, L. Sharma, R. Srivastava, and A. D. Stauffer, Phys. Rev. A, **86**, 022710, (2012).
[3] S. Gupta, R. K. Gangwar and R. Srivastava, Spectrochimica Acta Part B, **149**, 203, (2018).
[4] S. Gupta, R. K. Gangwar and R. Srivastava, Plasma Sources Science and Technology, **28**, 095009, (2019)

DIRTY WASTE TO CLEAN ENVIRONMENT AND USEFUL ENERGY: AIR PLASMA GASIFIER TECHNOLOGY DEVELOPED BY BARC, MUMBAI

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The H-OH-Ar plasma system has been modeled considering a total of 18 species (Ar, Ar^+, Ar^{++},Ar^{+++},O_2,O_2^+,O_2, O, O^-, O^+, O^{++}, O^{+++}, H_2, H,H^+, H_2O, OH, e) generated through 14 non-equilibrium Saha equations. Associated rate constants have been evaluated taking reaction energy, energy level, and degeneracy data from literature. Thermodynamic properties of the plasma containing these species have been estimated in terms of partition functions, which in turn depend on their energy levels and degeneracy. The energy of the v^{th} vibrational level of a diatomic molecule is computed from vibrational constants of the respective molecules. The energy of the J^{th} rotational energy levels are computed from the rotational and vibrational constants of concerned species. Debye-Hückel correction that accounts for additional effects due to electrostatic interactions among charged particles becomes significant only above 10 atm. Since the maximum pressure considered in this case is 5 atm, the effect is not accounted in deriving the two temperature Saha equations through minimization of Gibb's free energy. Lowering of the ionization potential caused by the same effect has further reduced influence, and not considered. The partition function of any monatomic species has been calculated as the product of its translational and internal partition functions. For molecules, the internal partition function has been estimated as the product of its vibrational, rotational and electronic partition functions. Necessary energy level and degeneracy data for all relevant species have been compiled from latest literature.The dissociation energies of ortho- and para-H_2 differ by 118.48 cm^{-1}. Combining all contributions, the ionization energy of ortho-H_2, is accounted as 124357.238 cm^{-1}. The dissociation energy of H_2 is derived as 35999.583 cm^{-1}. The three vibrational modes of water, namely, the symmetric stretch (3656.7, 5160), the asymmetric stretch (3755.8, 5360) and the bending mode (1594.8, 2290) have been considered. The vibrational frequencies in cm^{-1} and the characteristic temperature in K for each mode are shown in the parentheses. The vibrational partition function is given by the product of vibrational functions for each of these frequencies. Similarly, the rotational partition function for water has been calculated as the product of rotational functions for each mode. Symmetry number that indicates the distinct number of ways by which a molecule can be brought into identical configurations by rotations has been accounted and taken as 2 for water molecule. Required rotational temperatures have been estimated from basic principle using respective moment of inertia. The dissociation energy (D_o) of water (to form a hydrogen atom and a hydroxyl radical from water in its ground state) is accounted from recent literature as 41145.94 cm^{-1}. The characteristic rotational temperature of OH is not readily available in literature. It has been estimated from basic principle as 16.8K. The equilibrium structure and fundamental vibrational frequency of the diatomic species OH has been accounted as 3707.1cm^{-1}. Variation in species densities and thermodynamic properties of the plasma have been obtained for temperatures up to 40,000K and Argon-steam ratio (mass) up to 0.4, covering most of the situations of practical interest.

PLASMA SURFACE ENGINEERING OF STAINLESS STEEL FOR HIP IMPLANT APPLICATION

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The austenitic stainless steel SS316L (SS) is widely used in various biomedical applications e.g. orthopaedic implants, bone scaffold, stent applications etc. The major problem of SS is that, it suffers from poor wear and corrosion resistance. Additionally, the release of toxic metal ions such as Ni, Cr etc. in the body can create allergy to patients. Plasma based duplex surface engineering (Plasma nitriding followed by Ti/TiN multilayer coating) has been performed to improve the adhesion, wear resistance and bio properties like cell viability for Hip implant application. Thick Ti/TiN multilayers (thickness ~6.5 □m) coating was done on plasma nitrided stainless steel. The tribological properties of multi-layered Ti/TiN coating (8 layers) on SS316L (SSML) were compared with Ti/TiN coating on plasma nitrided SS316L samples (SSPNML). The samples were characterised by X-Ray Diffractometer (XRD), Field Emission Scanning Electron Microscopy (FESEM) and Transmission Electron Microscopy (TEM). The hardness, scratch, wear and cytotoxicity tests were also carried out by Nano-indentation, micro-scratch, sliding wear resistance and in vitro cytotoxicity evaluation. It was found that Nano-hardness, micro-scratch resistance and sliding wear resistance of the SSPNML samples in simulated body fluid (SBF) were much better than those of the SSML and SS samples. Further attempt has been made to measure the cyclic fatigue behavior, generally experienced by a normal hip-joint during walking, for SS, SSPNML femoral hip joint head prototype samples under repetitive loading conditions against ultra-high molecular weight polyethylene (UHMWPE) cup. Results of hip simulation and the corresponding FESEM images of femoral hip joint head ball, UHMWPE cup clearly signify that the SSPNML ball are more resistance to cyclic fatigue up to 1 million cycle as compared to SS ball.

References:

[1] K. Shukla, R. Rane, J. Alphonsa, P. Maity , S. Mukherjee, Structural, mechanical and corrosion resistance properties of Ti/TiN bilayers deposited by magnetron sputtering on AISI 316L, Surface and Coatings Technology, 324, 167 (2017).

[2] Aniruddha Samanta, Himel Chakraborty, Manjima Bhattacharya, Jiten Ghosh, Monjoy Sreemany , Sandip Bysakh, Ramkrishna Rane, Alphonsa Joseph, Ghanshyam Jhala, Subroto Mukherjee, Mitun Das, Anoop Mukhopadhyay Nanotribological response of a plasma nitrided bio-steel, Journal of the Mechanical Behavior of Biomedical Materials ,65, 584 (2017)

OPTIMIZATION AND ENRICHMENT OF ELECTRONIC WASTE TO RECOVER VALUABLE METALS USING PLASMA ARC FURNACE TECHNOLOGY

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Electronic waste (E-waste) recovery plays a vital role in a country’s economy and proper handling of E-waste shows the nations interest towards waste management and sustainability. The increasing trend of E-waste along with economy and technology makes the developed and technologically advanced nations to be the highest in per-capita E-waste generation [1]. The hazards of improper treatment of E-waste are very severe as it contains heavy metals and brominated flame retardant (BFR) coated plastics which gives out harmful dioxins and furans on improper incineration [2]. The necessity of a circular economy and urban mining is rising due to the decreasing trend of natural resources. The growing population and high materialistic needs of the people has forced us to choose an alternative resource, one of the routes is by extracting valuable metals from E-waste. Hence in this paper we will be discussing about the optimization and enrichment of E-waste for the recovery of valuable metals including precious metals like Au, Ag, Pd, Pt from Printed Circuit Board (PCB) waste of computers and mobile phones through Plasma Arc Furnace Technology in Nitrogen and Oxygen environment. The recovery has been estimated for different size fractions of the powdered PCBs. A tubular plasma arc furnace is used for high temperature pyrolysis of E-waste, also at such high temperature, of more than 850*C harmful gases such as dioxins and furans are unstable and other gases are also analyzed. The characterization of E-waste is done before and after the thermal treatment using XRD, SEM, XRF and ICP-MS analysis.

Keywords: E-waste, Thermal Plasma arc technology, precious metals recovery, urban mining

References:

[1] The Global E-waste Monitor – 2017, United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Vienna

[2] Chemical hazards associated with treatment of waste electrical and electronic equipment; Waste Management 31 (2011) 45-558

UNDERSTANDING GASIFICATION PROCESS IN COKE BED AIR PLASMA GASIFIER: 3D CFD SIMULATION STUDY AND EXPERIMENTAL OBSERVATIONS

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Management of solid waste is considered to be the most challenging issue in both developed as well as developing country in present scenario. Air plasma gasification process is regarded as the most advanced and innovative technology to process all types of wastes including municipal, industrial, medical and radioactive waste. Because of the availability of electrons, ions, radicals and highly concentrated thermal energy air plasma technology offers superior thermo chemical environment for solid waste gasification. The design and process calculation of all the equipments of coke bed based plasma gasifier facility is reported. A comprehensive 3D Computational Fluid Dynamic (CFD) analysis of the coke bed based air plasma gasification system has been done. The experimental investigation on a coke bed based air-plasma gasifier unit, secondary combustion chamber, off-gas processing units developed at BARC has been presented. Conversion efficiency as high as 99 % is achieved for variety type of solid waste including MSW, cellulosic waste, used resins. The composition of the flue gas from stack has been measured and reported. It was successfully demonstrated that coke based air plasma gasification is a in an advanced, cost effective and environmental friendly solid waste treatment technology which can be used as alternative to conventional waste processing technology.

References:

[1] Fabry F, Rehmet C, Rohani V, Fulcher L (2013) Waste gasification by thermal plasma: a review. Waste Biomass Valor 4:421

[2] U. Arena, Process and technological aspects of municipal solid waste gasification. A review Waste management, 32 (2012)

ADVANCED INSULATORS FOR NNBs: CHALLENGES AND INVOLVED R&D

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Indian Negative Neutral Beam (NNB) programs like Indian Test facility, Twin source, ROBIN involves systematic R&D to reach the final mandate of ITER Diagnostic Neutral Beam (DNB) operation. Insulators are integral part of NNB injector systems because several

of its subsystems need high voltage insulation. Considering operating environment, HV application, structural integrity, radiation and vacuum compatibility etc., precise grade insulators are selected. After the selection of the material, several prototype experiments are performed to ensure the operational performance of the insulating material. DNB HV bushing design is validated by 50 kV prototype bushing. 0.5 m ceramic ring was manufactured by cold isostatic pressing at Kyocera, Japan. Brazing of kovar sleeves at both the ends were done by active titanium brazing. This ring was tested for its electrical performance up to 70 kV applied voltage and vacuum compatibility up to 10^{-6} mbar. Radiation dependent electrical and structural performance of ceramic was studied for neutron and ion beam irradiation. The material showed excellent electrical, vacuum and radiation compatibility. Due to non-radiative environment of Indian Test Facility (INTF), the bushing is designed with porcelain insulation. To fit all the feedlines in singe insulator, its diameter of porcelain ring was kept ~0.8 m which was the critical manufacturing challenge. To decide porcelain grade, two small rings of C120 with diameter ~0.4 m was provided by supplier. Electrical and structural compatibility was ensured on these rings. Followed by these testing, manufacturing of large diameter ring was initiated. As the thickness requirement was 60 mm with steps at both end, the most critical part was drying as several failures encountered during this stage of fabrication. After these failures, fabrication process was established with precise drying and machining methods. 0.8 m diameter ring with steps was successfully developed for the first time indigenously in close collaboration with BHEL, Bangalore. The ring was tested up to 120 kV (20% higher than operating voltage) without any electrical breakdown. The integrity of the ring was measured across the thickness using Ultrasonic test (UT). No noticeable crake or void was measured. Another important development was 0.5 m FRP ring for Twin Source experiment. It showed an excellent electrical performance for 100 kV applied voltage. IR >1T-ohm at 5 kV. Further, its electrical performance with time also retained which shows its durability for required insulation performance. Presentation would describe design requirements of insulators, approach adopted, involved R&D, advanced technology involvement, issues encountered, their mitigation and final outcome.

DC AND HIGH FREQUENCY EDGE ELECTRODE BIASING EXPERIMENTS IN ADITYA-U TOKAMAK

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DC edge electrode biasing experiments have been widely carried out in various tokamak [1,2,3] to induce an external electric field inside the tokamak. It ultimately leads to modification of particle transport leading to improvement in plasma confinement. Taylor et al. demonstrated this by achieving H-mode in CCT tokamak [1] using DC electrode bias. Recently, DC edge electrode biasing has been used to mitigate disruptions via control MHD modes in ADITYA tokamak [4] and active control of mode rotation in HBT-EP tokamak [5]. Here, for the first time, we introduce the effect of high frequency edge electrode biasing in ADITYA-U tokamak. A capacitor based high frequency power supply (30 mF, 450 V), capable of operation up to 20 kHz, is developed for high frequency edge electrode biasing. The effect of both, DC and high frequency edge electrode biasing on the electrostatic and magnetic fluctuations in the edge region will be reported. The edge fluctuations in potential, density and temperature are measured using three radial array of Langmuir probes providing radial, poloidal and toroidal variations. The magnetic fluctuations are measured using Mirnov coils. The effect of edge electrode biasing on confinement properties in ADITYA-U tokamak will also be reported in this paper.

References:

[1] H-mode behavior induced by cross-field currents in a tokamak, *Phys. Rev. Lett.*, **63**, p. 2365, (1989)
[2] Radial current in a tokamak caused by a biased electrode, *Nucl. Fusion*, **32**, p. 271, (1992)
[3] Modification of edge current profile and improved confinement induced by biased electrode in the very low qa (VLQ) discharges of SINP – tokamak, *Nucl. Fusion*, **47**, p. 331, (2007)
[4] A novel approach for mitigating disruptions using biased electrode in Aditya tokamak, *Nucl. Fusion*, **54**, p. 083023, (2014)
[5] Mode rotation control in a tokamak with a feedback-driven biased electrode, *Rev. Sci. Instrum.* **90**, p. 023503 (2019)

STUDIES ON FUSION RELEVANT PLASMA EXPOSURE BEHAVIOR OF INDIA SPECIFIC REDUCED ACTIVATION FERRITIC MARTENSITIC STEEL IN CIMPLE-PSI

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In recent years, bare Reduced Activation Ferritic Martensitic (RAFM) steel has been proposed as a plasma-facing material for future tokamaks such as DEMO, due to a number of advantages, including their better neutron irradiation resistance, superior hydrogen retention characteristics, and also because they will be cheaper and easier to work with compared to tungsten. It is therefore important to understand their irradiation behavior under fusion relevant exposure conditions. Different variants of RAFM such as EUROFER, CLF-1 or

F82H have been studied under exposure of low temperature deuterium or helium plasma, in various linear plasma devices, including PSI-2, PISCES and PILOT-PSI facilities. In this presentation, we report first investigation of the effect of long fluence helium plasma exposure on the India specific RAFM (IN-RAFM), with the variation of ion-flux by almost an order (~$3\times10^{22-23}$ $m^{-2}s^{-1}$) and target temperatures in between 316-830 K, in the CIMPLE-PSI device. CIMPLE-PSI is a tokamak divertor simulator device that can reproduce both heat-flux (10 MW/m^2) and ion-flux (10^{24} $m^{-2}s^{-1}$) at ITER relevant extreme limit, for fusion relevant plasma surface interaction research [1]. The exposure resulted in drastic modification of the top exposed surface of the samples, with morphologies ranging between nanometer-sized vertical needles to foam-like spongy surfaces and thick hollow fibers, the exact type of which was determined primarily by the temperature of the plasma exposed steel target. Measurements by Energy Dispersive X-ray Spectroscopy (EDS) and Rutherford Backscattering Spectroscopy (RBS) confirmed surface enrichment of the exposed samples with high-Z elements because iron and chromium were preferentially sputtered out by the helium and other impurity ions. However, the surface lateral in-homogeneities produced under high ion-flux and temperature exposure conditions critically influenced the shape of the RBS spectrum, which necessitated a new way of interpretation of the measured data. Through optical emission spectroscopic observations, we confirmed that the sputtering yield of the steel reduces with exposure time, because of the W enrichment and also due to the formation of the porous microstructures on the exposed steel surface. It was also concluded that diffusion of helium into the sub-surface areas and their agglomeration into helium bubbles were the precursors for the formation of the surface microstructures at relatively high target temperature.

References:

[1] Design, development and recent experiments of the CIMPLE-PSI device, Nucl. Fusion, **59**, p 112008 (2019).

JOINING OF SS316L WITH HEAT SINK MATERIAL FOR DIVERTOR APPLICATION

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Divertor Plasma Facing Component (PFC) of ITER-like component has a multilayered structure made of various materials such as tungsten, copper, CuCrZr and SS316LN materials etc. Joining of dissimilar materials is problematic as having a different coefficient of thermal expansion between two materials. Vacuum brazing is a reliable technique for the joining of dissimilar materials such as SS316L with CuCrZr materials which provides a clean and sound joint [1-2]. High-temperature vacuum brazing of SS316L with CuCrZr has been performed using BNi-2 material at 1040°C for 5 mins and vacuum cooled. The brazed joint has been characterized by Non-destructive testing (NDT) - Ultrasonic testing (UT), Microstructural examination, micro hardness and shear measurement. The brazed joint of SS316L-BNi-2-CuCrZr sample has been undergone 500 nos. of the thermal cyclic test at 450°C using

Gleeble 3800 system. Shear measurement exhibits a sound joint with 118 MPa. The experimental detail and results of the characterization will be presented in the paper.

Keywords: PFC, NDT-UT, Vacuum brazing

References:

[1] N. Litunovsky, E. Alekseenko, A. Makhankov, I. Mazul, Development of the armoring technique for ITER Divertor Dome, Fusion Eng. Des. **86** (2011) 1749–1752.

[2] S.S. Khirwadkar et.al, Fabrication and characterization of tungsten and graphite based PFC for divertor target elements of ITER like tokamak application, Fusion Eng. Des. **86** (2011) 1736–1740.

POSTER PRESENTATIONS

THERMAL-HYDRAULIC ANALYSIS OF STEAM GENERATORS (SG) FOR POWER EXTRACTION FROM FUTURE FUSION REACTORS

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This paper presents the thermal-hydraulic simulation of steam generators (SG) for extracting the power from tokamak based fusion reactors. Three different coolants seem to have been considered currently by the fusion blanket community: - Water, Helium and Lead lithium-eutectic (PbLi). Transfer of heat from the primary coolant to secondary coolant is the most important operation for this concept of fusion reactors to drive the power turbine and to generate electricity. Nuclear fission technology is already established, some key ideas have been taken from this technology to design SG for nuclear fusion. Gen-IV fission reactors would be gas-cooled reactors which will be using helium gas as a coolant. Based on the comparison study, shell and tube and printed circuit heat exchangers (PCHE) have been identified as the potential candidates. Steam generator design for the He-coolant concept has been discussed in this study. Thermal-hydraulic analysis has been performed using ANSYS CFX. Attempt is made to improve the scientific and engineering information by compiling work that has carried out as well as utilization of information from present day reactors (fusion and fission).

EXPERIMENTAL AND COMPUTATIONAL STUDIES ON THE FORMATION OF DEFECT CLUSTERS IN GOLD IRRADIATED TUNGSTEN FOIL

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Tungsten is considered as a promising candidate for plasma facing material in nuclear fusion reactors due to its low fuel retention, high melting point and low erosion yield. The radiation damage in tungsten, while subjected to a harsh environment of fusion energy (neutrons and alpha particles) which may significantly enhance the fuel retention in it [1]. Since the reactor-like conditions such as the energy, magnetic field gradients, the concomitant flux of H-isotopes, impurities and neutrons etc cannot be realized in lab experiments, there is a need for careful extrapolation of the fission neutrons and surrogate ion-irradiation experiments to the tokamak environment. This requires the evaluation of defects from a vast data base of different ion mass, energy, flux, fluence and irradiation temperature and their correlation to H-isotope trapping. It is believed that for a

similar dpa heavy-ion irradiation in a wide energy range (150 keV to 20 MeV) tend to produce defects similar to that of neutrons at high temperature [2]. However, the primary-knock-on atom spectrum created by neutrons and heavy ions are significantly different and this will lead to different defect structures [3]. In this work we present the difference in the PKA spectrum and the defect structures due to neutrons and 80 MeV gold ion irradiated tungsten samples using experimental and computational techniques. The irradiation experiments were carried out in recrystallized tungsten foil samples for a fluence of 1.3×10^{14} ions/cm^2 at room temperature. The range of Au ions in the foil was ~4.5 µm and the corresponding dpa was 0.22. The meso-scale defects in the samples (~nm) investigated using transmission electron microscopy and positron annihilation spectroscopy showed the formation of dense vacancy and interstitial clusters in the samples. The defect cluster size varied between 2 nm to 15 nm and the cluster density was up to 1.3×10^{12} cm^{-2}. Simulations have shown that 80 MeV Au- irradiation produces PKA spectrum far beyond (up to 50 MeV) the neutron PKA range (up to 300 keV) energy. Molecular dynamics simulations show that beyond a threshold energy (> 150 keV) the individual cascades splits into multiple ones that are spatially and temporally interacting leads to the formation of small yet dense defect clusters. The defect evolution in the irradiated sample is explained using a phenomenological model of competitive capture of mobile defects in the samples. The difference in the defect evolution in the neutron and ion-irradiation experiments will also discussed.

References:

[1] R.G. Abernethy, Mater. Sci. Technol. 33, 388399, (2017).
[2] K. Nordlund et al., Nat. Commun. 9, 1084, (2018).
[3] P.N. Maya et al., Nuclear Fusion, 56, (2019).

PREPARATION OF PURE AND MODIFIED LI_2TIO_3 CERAMICS PEBBLES AND ITS CRUSH STRENGTH & ACTIVATION ENERGY CALCULATION FOR BREEDER BLANKET APPLICATION

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Pure Li_2TiO_3 (LTO) Ceramics pebbles and LTO modified by Mg were prepared by chemical method of sol. gel. Technique [1]. Pebble shape of prepared ceramics was obtained by speherodization of gel followed by calcinations. Proper calcinations temperature was determined by differential thermal analysis (DTA). Phase determination was completed by help of X ray diffreactometer (XRD). Crush strength of pebbles was carried out by ASAM D695 compression machine. Crush strength of Li_2TiO_3 pebbles was found as 36.67N in the case of 1.0% Mg doping. Higher crush strength due to Mg doping was observed, crush strength in pure LTO was reported earlier as 18 N. Activation energy calculation of prepared LTO was done by using Arrhenius equation and validation was done by a computer programming by Java [2]. Activation energy of Mg modified sample was found as 1.038eV/mole while in the pure LTO activation energy was 3.063 eV/mole.

EFFECT OF COLD PLASMA ON SEED QUALITY OF CROP PLANTS - A REVIEW

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In universe matter exists in four states solid, liquid, gas and plasma. Plasma can be created by heating a gas or subjecting it to a strong electromagnetic field. Plasma occur naturally in form of sun, solar wind, lightening and can also be created artificially through discharge tubes and welding arcs. Plasma exists in two forms cold and hot plasma. Different physical methods has revolutionized current research in the field of agricultural science. Plasma treatment can be considered as the next physical source. Which offer a broad range of interesting seed application for enhancing seed quality and its maintenances.Seeds can be treated with plasma by bombarding or by coating. Plasma treatment changes the wetting properties and water imbibition of seeds, stimulates seed germination, reduces the number of seed borne pathogens attached to the seeds, enhances various enzyme activities and antioxidant activities in seeds, accelerates seed reserves utilization, increase chlorophyll contents, improves photosynthetic capacity and finally results in higher plant growth and yield [1]. It is also used as a germination retardant by creating hydrophobic condition in seed to avoid flood condition. Keeping the all above facts in mind, selected seed treatment technologies with their improvement and significance will be discussed in this review.

References:

[1] Filatova, I., V. Azharonok, M. Kadyrov, V. Beljavsky, A. Gvozdov, A. Shik, A. Antonuk (2011). The effect of plasma treatment of seeds of some grain and legumes on their sowing quality and productivity. International Conference on Plasma Physics and Applications, 1–4, Iasi, Romania.

DEPENDENCE OF THE ION ENERGY ON THE GROUP VELOCITY OF THE INCIDENT LASER PULSE PROPAGATING THROUGH A DENSE PLASMA FOIL IN THE RADIATION PRESSURE DOMINANT REGIME

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The laser acceleration of charged particles is conceived to be one of the main applications of various high power laser facilities around the world. One can generate very strong electric fields in the plasma by using ultra-short electromagnetic (EM) pulses provided by these laser facilities. It gives a path for tabletop future accelerators providing high energy charged particle beams [1-3]. The effect of group velocity of the incident laser pulse plays an important role in laser driven charged particle acceleration. This effect significantly alters the radiation pressure acceleration (RPA) and the maximum energy gained by the ions as well [4].This paper presents our analytical and numerical results which clearly show the effect of the incident laser pulse group velocity on the maximum energy acquired by the ions. We derive expressions for the ion energy and momentum and give numerical results exhibiting their dependence on the group velocity of the laser pulse propagating through a thin dense plasma foil.

References:

[1] E Esarey, C B Schroeder and W P Leemans, Rev. Mod. Phys. **81**, p 1229, (2009)
[2] A Maachi, M Borghesi and M Passoni, Rev. Mod. Phys. **85**, p 751, (2013)
[3] G Mourou, T Tajima and S V Bulanov, Rev. Mod. Phys. **78**, p 309, (2006)
[4] S S Bulanov, E Esarey, C B Schroeder, S V Bualnov, T Zh Esirkepov, M Kando, F Pegoraro and W P Leemans., Phys. Plasmas **23**, 056703, (2016)

INTEGRATION OF PROPRIETARY SOFTWARE USING OPEN SOURCE TOOL IN ICRH DAC SYSTEM

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Ion Cyclotron Resonance Heating (ICRH) for high power RF experiments has been conceptualized for Tokamak. Data Acquisition and Control system (DAC) for ICRH system has been commissioned with new concept of low cost design in the 3 amplifier stages of RF generator up to 200kW of RF power. DAC electronics hardware includes 32-analog input channels, 32-digital input channels, 16-digital output channels and 16-analog output channels for the measurement and control of the system parameters. Experimental Physics and Industrial Control Systems (EPICS) based open software platform is chosen for this purpose due to its wide popularity in the big physics projects community eco-system. The salient feature of this Implementation is a modular design concept that facilitates low cost, intelligent and reconfiguration integration of DAC hardware with different open source and proprietary software. The instrumentation hardware used for this modular design is Programmable Logic Controller (PLC) for the control and monitoring. Control System Studio (CSS) is used to develop the application for user interface that can easily glue with EPICS variable. NI DAQ card has been used for data archival in two different ways, one with hardwired trigger from PLC channels and another using software trigger event with EPICS variable. CALab is used to trigger data acquisition event using EPICS variable in order to synchronize data monitoring with data acquisition. Procured USB based DAQ module having capability of acquire data at 10 kHz rate. Data visualization and plotting is developed using LabVIEW which uses separated calibration module for acquired row data. Spline interpolation method is used for calibration of nonlinear range of data for acquired signals. This paper describes the integration scheme and control structure of proprietary system access using EPICS open source environment.

GENERATING RF PULSES OF DIFFERENT DUTY CYCLES AND AMPLITUDES WITH RISE AND DECAY FOR ICRH OPERATION

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There are different methods developed for producing pre-ionization and second harmonic heating of plasma using fast wave antenna that is an established technique for ion cyclotron heating of tokamak plasma [1]. In order to use same ICRH system for pre-ionization as well as heating, one needs to do few modifications in the control system. There is a requirement of having different amplitude pulse to share ICRH RF power for various experimental conditions. It is also having facility of adjustable rise and decay in pulse development using software. In this paper we explain the necessary modifications made in the previously developed VME based real time operating and control system to cater experiment requirements. The control system software is based upon single digital pulse operation for the RF source. It is planned to integrate multiple analog pulses with different duty cycle in master digital pulse for data acquisition and control system for ICRH system to be used for operation of RF Generator. The task of RF ICRH DAC is to control and acquisition of all ICRH system operation with all control loops. For pre ionization startup as well as heating experiments using multiple RF Power of different power level and duration with help of RF attenuator. The existing control system software is based upon the pulse operation of RF source using digital pulse generated by VME control system. Recently we modified the software to generate multiple analog pulses with different duty cycles with rise and decay in master digital pulse for data acquisition and control system.

References:

[1] Engineering design report (EDR) of ICRH-SST1, SST-2.03-050199-RF Group

THEORETICAL INVESTIGATION OF INTENSE HIGH FREQUENCY RADIATIONS AS A RESULT OF INTENSE RELATIVISTIC LASER PLASMA INTERACTION IN THE RADIATION PRESSURE DOMINANT REGIME

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In the radiation pressure dominant regime (RPD) when an intense laser pulse interacts with a dense counter-propagating relativistic plasma mirror then the reflected pulse is compressed in the longitudinal direction, becomes more intense, and consists high harmonics. Its frequency is upshifted by a factor of quadruple of the square of the Lorentz factor of the plasma mirror due to double Doppler effect [1-2]. In this paper we present our analytical and numerical results of the enhanced frequency and brightness of the reflected laser pulse. The reflected frequency lies in the X-ray or gamma-ray range. This phenomenon is important tool for developing the sources of coherent radiation [2].

References:

[1] T Zh Esirkepov, S V Bulanov, A G Zidkov, A S Pirozhkov, and M Kando, Eur. Phys. J. D **55**, p 457-463, (2009)
[2] S V Bulanov, T Zh Esirkepov, M Kando, A S Pirozhkov, and N N Rosanov, Phys. Usp. **56**, p 429-464, (2013)

DEVELOPMENT OF 7KV, 6A SOLID STATE HVDC SWITCH WITH SERIES CONNECTED IGBTS

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Various high power RF amplifiers are being used in the High Power ICRH Systems Division of IPR. The high power tubes e.g. Triodes, Tetrodes used in these amplifiers, need various HVDC power supplies. These supplies need to have features like low ripple, good regulation and fast switch off protection in case of internal arc fault in the Triodes or Tetrodes. Consequently, DC voltage needs to be removed within few microseconds for protection of the tube. In case of arc fault, the conventional power supplies are short circuited with a very fast switch known as crowbar switch. Though adequate and reliable, this method puts enormous stress on the power supply and can cause considerable disturbance in the input power lines. With development of the solid state devices such short circuiting of conventional supplies can be avoided. A suitable solid-state device based switch can be used in series to open circuit the arc fault. For such an application, the 7kV, 6A series switch with adequate isolation is fabricated and tested. This poster presents selection of IGBTs, static and dynamic voltage snubber details, jitter among various devices, switch performance and application. Further, isolation level requirements of various circuits and components are analyzed.

RECENT PLASMA EXPERIMENTS IN SST-1

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Improvement on magnetic null configuration in Steady-state Superconducting Tokamak (SST-1) [1] by modifying a few external correction coils of central solenoid has led to better plasma startup. Recent experiments have been conducted using the pre-ionization by Electron Cyclotron Resonance (ECR) and central solenoid to produce loop voltage of 5-6 volts. Experiments with only Ohmic system as well as the Ohmic plus the Lower Hybrid Wave (LHW) have helped in enhancing the plasma duration of about 650ms. Experiments are ongoing with the objective of enhancing the plasma pulse duration beyond 1 second, and to focus various Physics and technological aspects associated to the plasma startup as well as radio frequency (RF) current drive. This paper would discuss the operational experiences along with various limitations and issues in detail.

References:

[1] "Present Status of the SST-1 project", Y. C. Saxena and SST-1 team, Nuclear Fusion 40 (2000) 1069

DEVELOPMENT AND INTEGRATION OF GLASS AND PLASTIC FOC LINK FOR DIGITAL PULSE SIGNAL TRANSMISSION

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ICRH system is distributed at RF lab and SST hall that are 200meters apart. Synchronisation with RF Pulse is required for the acquisition, control and monitoring of different sub-system placed at SST-1 Hall i.e. VME system, Camera, Yokogawa recorder, density measurement, Diagnostic circuit and CRO. Glass and Plastic Fiber optics cable link has been developed for Digital synchronisation trigger pulse i.e. TTL pulse of variable signal from RF lab to the shield room and RF bay area of SST-1 Hall. Developed link is made to transmit and receive Digital TTL signal either in pulse or in continuous mode from SST-1 shield room or RF Lab. Required signal processing is done at termination end as per the interface requirement i.e. inversion of TTL signal, conversion of signal from Glass FOC to plastic FOC or vice versa, light optical signals to compatible voltage signal, Digital ORing of signals etc.In this paper, full system link design concept, interfacing and integration results, component and hardware details would be presented.

IMPACT OF NITROGEN GAS ON EDGE AND SOL PLASMA TURBULENCE

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Edge and Scrape-off Layer (SOL) plasma are highly turbulent in the presence of interchange instability. This instability can be modified in the presence of impurity gases like Neon, Argon, Nitrogen, etc. The main purpose of these gas feeds is to reduce heat loads on the limiter plates and also to provide radiative improved confinement, and disruption mitigation in tokamak. Earlier, impact of Neon gas has been studied [1]. Here we have analyzed the effect of Nitrogen gas as an impurity in the Edge and SOL regions. We have derived a set of model equations for the description of the interchange plasma turbulence in the presence of the Nitrogen gas. The gas is ionized by the electron impact ionization and the ionized gas subsequently radiates energy during radiative cooling processes with the plasma electrons. The model equations have been solved using a numerical code where all input parameters are related to Aditya tokamak. Dynamics of Nitrogen molecular and atomic ions have been simulated and it is found that atomic ions penetrate much deeper into the plasma due to the presence of inward propagating pulse generated by interchange turbulence. Molecular ions mainly form in the last closed flux surface region and dissociate before propagating further inside in the Edge. The radial profile of electron density, electron temperature, molecular and atomic ions has been presented from the numerical data. The reduction of radial outward particle flux in the presence of Nitrogen gas has been observed mainly due to the increase of radial electric field shear. It is found that the Nitrogen gas shifts poloidal wave numbers towards lower values that indicate the reduction of the interchange plasma turbulence at longer wavelengths.

References:

[1] Dynamics of Neon Ions after Neon Gas Seeding into Tokamak Plasma, N. Bisai et al 2019 Nucl. Fusion in press *https://doi.org/10.1088/1741-4326/ab3d31*.

MODIFICATION & UP-GRADATION IN EXISTING ICRH INTERLOCK PROTECTION SYSTEM AS 30KV-130A RHVPS INTEGRATED FOR HPA4 STAGE RF-AMPLIFIER

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ICRH-DAC (Data Acquisition and Control) controls and monitors the RF power to the dummy load /Aditya / SST-1 tokamak[1] for conditioning, heating, pre-ionization and current drive experiments. RF generator has four stages of high power tube based amplifiers namely HPA1, HPA2, HPA3 and HPA4. For higher power commissioning work i.e. raising RF power from HPA4, RHVPS (Regulated High Voltage power supplies) is integrated. Normal operation and system protection of RF Amplifier & associated Power supply relies only on the hardware reliability of the control signals. RHVPS integration leads to modification and up-gradation in existing interlock protection system as RHVPS is placed around 200 meters away from ICRH control room. Glass fiber based critical signals i.e. Fault, Trip, and Emergency Shutdown are integrated in the existing system [2]. Fault signal i.e. DI from RHVPS is integrated with Interlock card. Screen TRIP signal is integrated with newly developed protection card, output of this card is logically AND with existing Interlock signals. Over current signal from Crowbar panel is logically AND with other critical signal. This signal is further logically AND with other three critical signals like reflected power limit signal, HV from crowbar and Screen grid Trip Protections. As soon as any fault occurs in any power supply of the system or in RF tube, interlock card i.e. ORing of the critical signals sense it and generate this control signal. This Logically Anded with RF trigger pulse from VME as its another input which immediately stop the pulse to signal generator hence no RF signal applied from the signal generator to LPA. High voltages of all the stages are also stoped with this Latched Interlock pulse for further protection of the tubes. Control signals are successfully implemented for online monitor and control in the VME Processor as well with Hardware interlock protection circuit. Active testing of Actual RHVPS operation has been done by applying High Voltage upto 25KV with HPA4 tube. This paper would discuss functionality, performance and test results of in-house developed interlock circuit, FOC link, delay optimization etc.

References:

[1] D. Bora et al Cyclotron resonance heating systems for SST-1, Nuclear Fusion: Volume 46 Number 3 March 2006.
[2] Manoj Singh et al Design, Development, Integration and Testing of Glass fibre optic based control signal for remote operation of RHVPS.Reference: IPR/TR-344/2015.

DEVELOPMENT OF -4KV, 1A HIGH VOLTAGE DC POWER SUPPLY FOR SST-1 CURRENT START UP EXPERIMENT

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Recently, a DC power supply of rating -4kV, 1A with features like voltage variability, automation, low ripple, good regulation, over-voltage ,and current protection has been developed for providing electric field between two parallel plates those are located in SST-1 vessel. The supply will be used to push plasma radially to the plasma centre for current start-up experiments. This power supply can selectively be operated in the CW or pulse mode.
The power supply is made in conventional type topology and consists of a three-phase power controller, step-up transformer, bridge rectifier followed by a capacitor bank. The over-voltage and over current protection enable this power supply to switch off and pulse blocking in case of a fault.The HVDC Power Supply has been designed, developed and tested successfully on dummy load for more than -4 kV, 1A with fault simulation conditions. This power supply is developed and ready to use for actual load.The poster presents the topology used, circuit details, selection of components, various protections and test results.

PLASMA INDUCED NITROGEN DOPED BIMETALLIC PHOSPHIDE FOR EFFICIENT ELECTROCATALYSIS

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Electrochemical water splitting has become a crucial tool for green energy technology. Transition metal (Ni, Co, Fe etc.) based phosphide materials are gradually gaining ground as cost effective as well as easy to synthesize earth abundant electrocatalysts [1,2]. Nitrogen doped rGO hybridized with transition metal phosphides could be beneficial for efficient electrocatalysis [3]. In this work, N_2 plasma treatment has been efficiently employed to synthesize N doped rGO based nickel iron phosphide (N-rGO/NiFeP). Plasma based doping could be an efficient eco-friendly alternative to the high temperature treatment or chemical reaction [4]. Here, nitrogen has been doped in rGO by varying the irradiation time 3, 5 and 8 minutes with controlled power at 100W while maintaining the pressure at 0.3mbar. The structural, morphological and chemical characterizations of the plasma treated samples are performed with XRD, FESEM, TEM and Raman spectroscopy. The as prepared samples have been investigated for electrochemically driven water splitting. Moreover, Ar and N_2 plasma can be applied as an effective surface energy technology to prepare heteroatom doped efficient low cost electrocatalysts in future.

References:
[1]. Sugar Blowing-Induced Porous Cobalt Phosphide/Nitrogen- Doped Carbon Nanostructures with Enhanced Electrochemical Oxidation Performance toward Water and Other Small Molecules, Small, 13, 1700796, (2017).
[2]. Porous Cobalt-based Thin Film as a Bifunctional Catalyst for Hydrogen Generation and Oxygen Generation, Adv Mater, 27, 3175, (2015).
[3]. N-doped reduced graphene oxide supported mixed Ni2P-CoP realize efficient overall electrolysis, Electrochimica Acta, 282, 626, (2018).
[4]. Plasma-induced nanoporous metal oxides with nitrogen doping for high-performance electrocatalysis, Nanotechnology, 28, 242501, (2017).

ION BERNSTEIN MODE INSTABILITY IN PRESENCE OF ION CYCLOTRON TURBULENCE ASSOCIATED WITH PARTICLE HEATING.

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A particle distribution function for non-uniform plasma is considered with inclusion of density gradient parameter. The ion-cyclotron turbulence is considered to be present in the system and the fluctuating parts of this quasi-steady plasma state corresponding to this turbulence is evaluated on the basis of weak turbulence theory. In this quasi-steady state of plasma we consider Ion-Bernstein mode wave as perturbation to the system. Nonlinear interaction of Ion-Bernstein mode with turbulence field is considered and the various fluctuating parts of linear and non-linear parts of distribution functions are evaluated by using Vlasov-Poisson system of equations [2,3]. We have analysed the non-linear dispersion relation of Ion-Bernstein mode and investigated the conditions [1] for mode conversion while propagating through non-uniform media.

References:
[1] Mohammad Javad Kalaee , and Yuto Katoh. Study of a condition for mode conversion from purely perpendicular electrostatic waves to electromagnetic waves. Phys. Plasmas 23,072119(2016).
[2] P.N.Deka and A. Borgohain . On unstable electromagnetic radiation through nonlinear wave- particle interactions in presence of Drift wave turbulence. J. Plasma Phys (2012).
[3] A.Borgohain and P.N.Deka. Electrostatic instability in magnetically confined inhomogeneous plasma driven by nonlinear force. Phys. Letters A, Volume 378,Issue 10, 2014.

SPECIES IDENTIFICATION, TEMPERATURE AND DENSITY MEASUREMENT IN THE HOH ARGON PLASMA USING EMISSION SPECTROSCOPY

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Optical emission spectroscopy is an important diagnostic technique for species identification. This paper presents observed OH band, H_α, H_β, H_γ lines along with atomic lines of Argon in the plasma jet emanated from HOH argon dc arc plasma torch. It is observed that formation of OH band along the axial direction starts after few mm distance from the nozzle exit. Initially its intensity increases with axial distance and reaches a maximum at some location then starts decreasing. Using Stark broadening of H_β line, the electron number density has been measured while plasma temperature is measured using Boltzman plot technique. Rotational temperature has been estimated by matching experimental OH band and simulated OH band at different temperature using LIFBASE software. Electron number density and excitation temperature measured at nozzle exit is 1.8 X 10 ^{23} /m^3 are 8000 K respectively. Variation in electron density and temperature are presented with axial distance. It is found that electron temperature is higher than ion temperature. Observed central dip in the H_α line profile that gives indication of deviation from thermal equilibrium.

RESPONSE OF CARBON AND TUNGSTEN SURFACES TO HYDROGEN PLASMA AT DIFFERENT ORIENTATION OF MAGNETIC FIELD

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For analyzing plasma wall interaction in all plasma applications and diverter of fusion device in bounded region, it is mandatory to understand the interactions between energetic bulk plasma with material surface. The ion reflection coefficient, absorption coefficient, total charge density etc have been studied using Kinetic Trajectory Simulation model at different orientation of applied magnetic field for Carbon and Tungsten based surfaces or wall. It has been observed that the ion reflection coefficient and ion absorption coefficient of incident particles do not depend on the orientation of magnetic field i.e., they were constant for different angles. But the density of ions, total charge density, and Thomas Fermi energy was greatly influences by the angle variation.

C-R MODEL FOR AR-CO_2 MIXTURE PLASMA USING RELIABLE FINE STRUCTURE CROSS SECTIONS

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The carbon dioxide (CO_2) gas plasma are very interesting due to its application in numerous fields such as plasma polymerization, etching, deposition, etc. In order to achieve efficient processing in a specific application, it is important to understand the discharge-kinetics by employing the appropriate diagnostic approach. The inert gas optical emission spectroscopy approach is very suitable for diagnostic of these plasmas. It can provide information about electron temperature and density which are key parameters to monitor in any plasma mediated processing. In this light the Ar is the most preferred choice due to its relatively lower cost. Moreover the addition of Ar gas in CO_2 plasmas also assist in maintaining the discharge at relatively lower power. It is mainly due to the fact that the ionization energy of Ar is lower than the CO_2 molecules. However, in order to extract plasma parameters, the OES measurements need to be coupled with a suitable collisional radiative (CR) model. Using our calculated relativistic cross-sections, we developed a fine structure resolved CR model for Ar atom. In the present study, we applied our CR model to study the discharge-kinetics of Ar/CO_2 mixture plasma. The OES measurements are taken from a recent study reported by Martinez *et al.* [1]. They reported the OES measurements of Ar/CO_2 (20-80%) gas mixture plasma. In the present work, we have modified our pure Ar inert gas CR model and applied it to study the measurements reported by Martinez *et al.* [1]. Previously, we have also extended our model to other inert gas mixture plasmas [2, 3]. The further modeling results along with discussion shall be presented during the conference.

OBSERVATION OF DUST ACOUSTIC SHOCKS AND STABLE DUST STRUCTURES IN MODERATELY COUPLED DUSTY PLASMA

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Linear and nonlinear dust acoustic waves are studied experimentally in a homogeneous unmagnetised dusty plasma [1-4]. Linear dust acoustic wave is excited by applying a variable duty cycle dc voltage through a wire shaped grid. In this regime, the phase velocity of the wave increases due to ion - dust streaming and wave suffers damping with increasing dust density. The formation of shocks [5] was observed when two insulating slits having dimensions (6 cm X 2.5 cm X 0.05 cm) are inserted in front of the grid. A pulsed dc voltage of 60 volts with 500 ms ON time and 1000 ms OFF time was applied into the grid to excite dust acoustic shocks. The self-steepening of nonlinear dust acoustic waves into a saw tooth type wave with sharp gradient in dust density was observed. This is very similar to the numerical solutions [6] of the fully nonlinear fluid equations for a nondispersive dust acoustic wave. The variation of shock amplitude and width from the slit position also studied.

References:
[1] N. N. Rao, P. K. Shukla, and M. Y. Yu, Planet. Space Sci. 38, 543, 1990
[2] A. Barkan, N. D’Angelo, and R. L. Merlino, Phys. Plasmas, 2, 3563, 1995
[3] J. Pramanik, B.M.Veeresha, G.Prasad, A.Sen and P.K.Kaw, Phys. Lett. A 312, 84-90, 2003
[4] P.Bandyopadhyay, G.Prasad, A.Sen and P.K.Kaw, Phys. Lett. A 368, 491-494, 2007
[5] J.Heinrich, S.H Kim and R.L.Merlino, Phys Rev Lett, 103, 115002, 2009
[6] P.K.Shukla and B.Eliasson, Phys. Rev E, 86, 046402, 2012

EXCITATION OF ELECTRON CYCLOTRON RESONANCE AND ITS HARMONICS IN MICROWAVE GENERATED, LOW PRESSURE PLASMAS

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Multicusp (MC) magnetic confinement of plasma play an important role in microwave generated low pressure plasma providing high degree of ionization for various plasma-assisted applications [1]. It serves the dual purpose - helps in plasma generation through electron cyclotron resonance (ECR) heating and at the same time helps in plasma confinement through magnetic mirror effect. In spite of various works in MC bounded plasma [2, 3], limited reports are available on study of effect of input frequency (*f*) in the microwave regime over a wide range (6 - 11 GHz), on the resulting plasma. The present work aims to study such effect thereby demonstrating plasma heating by self-excited ECR and its harmonics.The experimental set-up consists of a microwave source comprising of a function generator followed by a travelling wave tube amplifier (TWTA)(IFI GT186-300, 6 - 18 GHz). The microwaves are guided to a cylindrical vacuum chamber (VC, diameter 20 cm) via a flexible waveguide. A cylindrical MC (diameter 8.2 cm), is placed co-axially within VC. Argon, in the pressure range of 0.2 – 1.2 mTorr, is used as the test gas. For diagnostics, a Langmuir probe (LP) and an electric field probe (EP) connected to a spectrum analyzer (E4408B, 9 kHz - 26 GHz) are employed. Interesting features are observed in the radial profile of plasma electron temperature (T_e (r)) when the input microwave frequency, f = 6 GHz. It reflects wide range of resonance heating suggesting simultaneous existence of ECR and its harmonics ($\square = n\square_c$ where n = 2,3). At the same time, the spectrum of wave emission from such plasma shows sharp peaks at 6 GHz ($\square_c$), 12 GHz ($2\square\square_c$) and 18 GHz ($3\square\square_c$) with a narrow bandwidth - indicative of electron cyclotron emission (ECE). The line spectra of ECE is in contrast to previous ECE reports where it shows a wide spectrum [3]. The later emission is observed while resonantly heating the preformed plasma by injecting high frequencies [4] whereas in our case, ECE is emitting by the self-excited plasmas generated by the high frequencies. Calculations suggest that gradient of magnetic field at the resonance positions plays an important role in exciting the harmonics of ECR.

References:
[1] Yu A Lebedev, Plasma Sources Sci. Technol. 24, p 053001 (2015).
[2] H. Amemiya and M. Maeda, Rev. Sci. Instrum. 67, p 769 (1996);
[3] M. E. Austin, M. W. Brookman, W. L. Rowan, S. Danani, E. W. Bryerton, and P. Dougherty, Rev. Sci. Instrum. 87, p 11E111 (2016)
[4] G. Arnoux, S. Alberti, L. Porte, E. Nelson-Melby, J-P Hogge and TCV Team, Plasma Phys. Control. Fusion 47, p 295 (2005).

IMPLEMENTATION OF AN IMPROVED HALO MODEL WITH SELF-CONSISTENT POWER BALANCE IN TSC

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Accurate modeling of major disruption (MD) and vertical displacement events (VDE) in ITER is necessary to determine the halo current amplitude during these events and hence the electromagnetic loads on the machine components. Predictive simulations for MD and VDE events in ITER have been carried out using TSC and DINA codes [1-2]. However, in these simulations, the halo current amplitude depends critically on the choice of the halo parameters, namely the temperature and width of the halo region. Due to lack of credible experimental data of these two parameters and also no sound physics based model so far, these parameters were chosen rather ad-hoc as inputs to these codes to best match experimental data in the earlier simulations [3]. To have a more self-consistent model of the halo width, an improved halo model is being implemented in TSC that takes into account the full power balance, including the Ohmic heating through the halo current, the conductive losses along the open field lines, and losses through line radiation due to impurities [4]. Such a model was included in a simplified way in the DINA code [5] assuming SOL-like transport. Details of this model implemented in TSC and simulations of halo current evolution during major disruptions of Alcator C-Mod discharges using this model will be presented in this paper.

References:
[1] I. Bandyopadhyay et al., IAEA FEC 2010, IT/P-16.
[2] S. Miyamoto et al., Nucl. Fusion 54 (2014) 083002.
[3] Bandyopadhyay I. et al., 2016 IAEA Fusion Energy Conf. (Kyoto, Japan, 17–22 October 2016) TH/P1-19.
[4] D. Kiramov et al., 43rd EPS Conference on Plasma Physics (2016), P4.071.
[5] V. Lukash et al., 2016 IAEA Fusion Energy Conf. (Kyoto, Japan, 17–22 October 2016) TH/P1-16.

EVOLUTION OF SERIES OF ELECTRON ACOUSTIC SOLITARY WAVE PULSES IN PLASMA

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The generation of series of electron-acoustic solitary wave (EASW) pulses in three-species plasma is investigated by using the one-dimensional fluid simulations. We consider an unmagnetized collisionless plasma consisting of cold electrons, hot electrons, and ions. The Gaussian perturbations in the equilibrium electron and ion densities are used to excite the waves. This simulation demonstrates the generation of a series of EASW pulses in three-species plasma through the breaking of the wave. We investigate the role of the ponderomotive force in the process of the wave breaking. We observed the variation of the maximum ponderomotive force acting spatially on the leading and trailing edge of the hump in the cold and hot electron and ion fluid densities. It is seen that the maximum imbalance in the magnitude of the ponderomotive force acting on both sides of hot electron density hump occurs at the time of wave breaking. This reveals that the imbalanced ponderomotive force acting on the hot electron fluid is responsible for the breaking of the electron acoustic wave in plasma [1].

References:

[1] Amar Kakad and Bharati Kakad, Generation of series of electron acoustic solitary wave pulses in plasma, Accepted manuscript in Physics of Plasmas (September 2019).

THE EFFECT OF ION TEMPERATURE ON THE FORMATION AND DYNAMICS OF ELECTROSTATIC SOLITARY WAVES IN PLASMAS

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We perform the fluid simulations to examine the effect of ion temperature on the formation and dynamics of solitary waves in an unmagnetized two-component plasma consisting of ions and electrons. Based on the fluid theories, some of the previous studies have reported that the plasma with the electron temperature greater than the ion temperature (i.e. $T_e > T_i$) supports ion acoustic solitary waves (IASWs), whereas the plasma with $T_e << T_i$ supports electron acoustic waves (EASWs). We have performed the simulation for a wide range of ion temperatures (with fixed electron temperature) to examine the criteria of temperature and thermal velocities in the generation EASWs and IASWs in plasmas. Our simulation shows that the plasma with $T_i > T_e$ possesses two wave modes depending on the ratio of electron to ion thermal velocity. When the ratio of electron to ion thermal velocity, $R=V_{the}/V_{thi} > 1$, the system supports the generation of IASWs, whereas for $R < 1$ it supports the generation of EASWs. The analysis of characteristics like amplitude, width, and phase speed of these solitary waves implies that the EASWs have a negative potential, whereas the IASWs has

positive potential. The transition from IASWs to EASWs occurs when the phase speed of the solitary wave exceeds the limiting value of $\sqrt{3}V_{the}$. This study presents the detail investigation of the evolution of EASWs and IASWs generated in plasmas having $T_i > T_e$ that will have implications in modeling such waves in space and laboratory plasmas [1].

References:

[1] Amar Kakad, Bharati Kakad, Ajay Lotekar, and G. S. Lakhina, Role of ion thermal velocity in the formation and dynamics of electrostatic solitary waves in plasmas, Physics of Plasmas 26, 042112 (2019).

INFLUENCE OF DUST CHARGE GRADIENT AND POLARIZATION FORCES ON JEANS INSTABILITY IN STRONGLY COUPLED PLASMA

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We have investigated the combined effects of dust charge gradient (DCG) force (due to charge variations) and polarization force (due to inhomogeneity in the number densities of electrons/ions) on the dust acoustic wave (DAW) and linear Jeans instability in unmagnetized, collisionless, strongly coupled dusty plasma (SCDP). The electron and ion fluids are assumed to be thermal and weakly coupled which are characterized by the Boltzmann relation. The dynamics of strongly coupled gravitating dusty fluid is characterized by the generalized hydrodynamic (GH) fluid model which is modified due to the combined effects DCG and polarization forces. The modified dispersion characteristics of low frequency DAW mode, compressional viscoelastic mode and linear Jeans instability are examined using the linear perturbation method. In the kinetic regime, the DCG and polarization force dependent DAW mode is independent of strong coupling effects in the gravitating SCDP. The fundamental Jeans instability and critical Jeans wavenumber are suppressed due to the DCG force, polarization force and strong coupling effects, hence play significant role in the dust cloud collapse of dense astrophysical matters. The numerical calculations have been performed to study the effects of considered parameters on the growth rate of unstable Jeans modes.

References:

[1] R. P. Prajapati and S. Bhakta, Phys. Lett. A **379**, 2723 (2015).
[2] A. G. Khrapak and S. A. Khrapak, Phys. Plasmas **25**, 034503 (2018).

NON RESONANT INSTABILITY OF KINETIC ALFVÉN WAVES BY ION BEAM AND VELOCITY SHEAR

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The non-resonant instability of kinetic Alfvén waves (KAWs) due to ion beam and velocity shear along with the non-thermal electrons is discussed. The theoretical model consists of cold background ions and the source of free energy, i.e., the hot beam ions, both having Maxwellian distribution and hot electrons having non-thermal distribution. For the parameters considered, the velocity shear can excite the KAWs as a purely growing mode, whereas, the ion beam alone cannot excite the waves. The ion beam and velocity shear act as a dual source and can excite the KAWs but this time the wave is not a purely growing mode. It is found that the non-thermal electron restricts the wave propagation close to 90^0, whereas, the Maxwellian electron allows the wave to propagate away from perpendicular propagation. The effect of other plasma parameters such as number density, species temperature etc. on the excitation of KAWs is studied. The above model can produce a wave growth rate of ≈ 132.5 mHz in KAWs. The value of parallel wave number $\lambda_{\|} \sim$ (25-628)$\times 10^3$ km and perpendicular wave number $\lambda_{\perp} \sim$(125-628) km obtained from our numeric may be relevant in understanding the observed characteristics of ULF waves in the Earth's magnetosphere.

ROLE OF LOW ENERGY INERT GASEOUS ION BEAM IMPLANTATION ON OPTICAL PROPERTIES OF METALLIC THIN FILMS

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The interest of scientific community has gone to look at the behavior of metallic thin films (MTF) by realizing their potential applications in various fields such as optical sensors, mirror coatings for spacecraft, optical filters and in photonic devices [1]. In addition to pure metallic thin films, the behavior of MTF under the implantation of various inert as well as reactive ion or radical species has opened new areas of research to investigate the modified surface properties. Optical properties of irradiated MTF have already been investigated under the implantation of very high energy (30 -160 keV) proton, gamma ray, alpha particle, and argon ions [2]. However, there has been lack of research on low energy implantation of MTF [3]. Therefore, it would be interesting to explore the modified optical properties of MTF under low energy inert gaseous ion beam implantation. In the research carried out so far on the optical properties of Al, Au, Ag and Cu metallic thin films implanted with various low energy (0.5 keV) Ar ion fluences, several exciting features have been observed in their reflection and transmission spectra. Reflectivity of all metallic thin films exhibits a decreasing trend with the increasing dose of argon ions, while some peaks are observed in their transmission spectra at a particular wavelength. Transmission corresponding to the peaks increases with the increase in argon ion fluence and it can help to look at the application of MTF as filters to pass specific wavelength through MTF. Another distinguishing feature is the dependence of optical properties on the material being used for metallic films, fluence and energy of implanted foreign ions. Since the optical constants play a crucial role in determining the optical properties of the medium, the Pseudo – Brewster angle technique is employed to obtain the optical constants (real and imaginary part of the refractive index) for both pristine as well as irradiated MTF. Similar investigation of optical properties of all MTF will be carried out under the implantation of low energy (0.5 keV) Kr inert gaseous ion beams with varying fluence. Apart from this, both the real and imaginary part of the refractive index will be computed by using pseudo – Brewster angle and the experimental results of both optical properties and optical constants with theoretical justification will be presented in the conference.

References:

[1] Ilaria Di Sarcina, M L Grilli et al., Applied optics., **53**, p 314-320, (2014)
[2] Q Wei, H Liu et al., Thin solid films., **519** , p 5046-5049, (2011)
[3] S Zuccon, E Napolitani et al., Optical material express., **5**, p 176-187, (2014)

FLUID SIMULATION OF ASYMMETRIC ELECTRON ACOUSTIC DOUBLE LAYERS OBSERVED IN THE EARTH'S INNER MAGNETOSPHERE

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The Van Allen Probes have recorded an interesting observation of symmetric and asymmetric bipolar electric field structures on November 13, 2012 in the Earth's inner magnetosphere. Conventionally, the symmetric bipolar pulses are interpreted as electron phase-space holes and its associated dynamics is well understood. These asymmetric structures are interpreted as electron acoustic double layers (EADLs). Even though they are interpreted as EADLs, their generation mechanism and physical properties are not well understood yet. We have simulated the EADLs observed on November 13, 2012, by Van Allen Probe-B. In order to understand their formation and evolution, we have performed the fluid simulation. We have found that the localized depletion and enhancement in the electron populations in the Earth’s magnetosphere act as a perturbation to excite the symmetric bipolar electron acoustic solitary waves, which later evolve into the EADLs. The ponderomotive force is found to be the main driver behind transformation of the solitary wave to EADLs via formation of the electron-acoustic shocks.

CHARACTERIZATION OF POTENTIAL FLUCTUATIONS IN ATMOSPHERIC PRESSURE PLASMA JETS

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Non-equilibrium atmospheric pressure micro-plasmas are termed as "cold" plasmas. They have widely different electron (T_e ~0.5 eV) and ion temperatures (T_i ~0.025 eV). These plasmas are becoming popular because of wide variety of applications in several fields such as surface functionalization, biology, medicine, environmental and cell or tumor treatments. Flux of reactive species and strength of electric field impinging into cell, wound or tumor are the key parameters of these applications. A minor fluctuation in potential and electric field may affect these processes because of transport and heating of active species. Therefore, it is important to investigate fluctuations in the plasma jet. Our present work is aimed at characterizing the fluctuations in atmospheric pressure plasma jet (APPJ). The plasma is ignited inside a glass capillary tube by applying a high voltage and charge particles emerge out from the capillary in the ambient air as a fine plasma jet of length ~10 mm and diameter ~ 0.8 mm. A two-pin probe having diameter of 0.18 mm and length of 1 mm each, has been employed to measure the potential at two nearby local points in the jet. The separation between the two pins is 0.260 mm, therefore it is straightforward to calculate the electric field between the two pins of the probe at any radial, angular or axial position in the plasma jet. The dynamic behavior of plasma jet and possible instabilities have been analyzed by employing the classical tools such as Fast Fourier transform (FFT), Wigner distribution, time frequency analysis (TFA) and time cross correlation analysis. Time shift between the electric signals captured at two spatial location inside the jet can be studied with cross correlation function and dependence of this time shift on the gas flow rate could be utilized to reflect the laminar to turbulent transition [1]. Wigner distribution and TFA method can be used to see time evolution of frequencies by locating the fluctuation both in frequency and time [2]. Effect of applied voltage amplitude, gas flow rate and working gas mixture ratio on the frequency spectrum has been studied. Symmetry and uniformity of electric field along axial and azimuthal direction has been verified with FFT method. Consequences of high frequencies of applied signals on fluctuation characteristics are under investigation.

References:

[1] X. Tu, B. G. Cheron, J. H. Yan, and K. F. Cen, Plasma Sources Sci. Technol. **16** 803 (2007)
[2] X. Tu, B. G. Cheron, J. H. Yan, L. Yu, and K. F. Cen Phys. Plasmas **15** 053504 (2008)

INTERACTION OF ELECTRON ACOUSTIC NONLINEAR STRUCTURES IN A PLASMA WITH GENERALIZED (R,Q) DISTRIBUTION

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Over the last few decades, studies on the nonlinear propagation of electron acoustic waves (EAWs) have received a great deal of attention. Electron acoustic waves are high frequency electrostatic waves and can be generated in a plasma which contains two populations of electrons (cold and hot) with stationary background of ions [1]. The thermal pressure of the hot electrons is a source of the restoring force and cold electrons provide inertia. Numerous investigations have been reported to study electron acoustic solitary waves and shocks in different kinds of plasmas. A limited number of investigations have been reported to study head on collision of electron acoustic solitons in nonrelativistic or weakly relativistic plasmas. The significance of considering the relativistic dynamics of electrons arises due to the fact that the effect of relativistic streaming electrons on the large electric field observed in the polar cusp regions of the pulsar magnetosphere can make the cold electron species to achieve relativistic velocities [2]. A theoretical investigation is carried out to study head-on collision among electron acoustic solitary waves (EASWs) with collisionless, homogenous and unmagnitized relativistic plasma comprising inertial cold electrons, hot electrons obeying (r, q) distribution and immobile ions. By employing the extended Poincarè-Lighthill-Kou (PLK) method, two sided KdV equations are derived. The Hirota direct method is used to obtain multi-soliton solutions for each KdV equation[3]. Plasma parameters, typically found in Saturn's magnetosphere and the Earth's auroral region, where two populations of electrons exist, are considered for numerical analysis. It has been found that the flatness parameter (r), tail parameter (q) and other plasma parameters affect significantly the propagation properties of nonlinear electron acoustic solitary waves (EASWs).

References:

[1] P. K. Shukla, L. Stenflo, and M. Hellberg, *Physical Review E* , **66,** 2000.
[2] N. S. Saini, and Kuldeep Singh, *Physics of Plasmas* , **23,** 103701(1-10) 2018.
[3] Kuldeep Singh, Papihra Sethi and N. S. Saini, *Physics of Plasmas*, **25,** 033705 (1-11), 2018.

HEAD ON COLLISION OF LOW FREQUENCY SHOCK WAVES IN A QUANTUM PLASMA

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The micron sized dust particles are present in most of the space and astrophysical plasma environments as well as in laboratory plasmas. Dusty plasmas are universal in various parts of our cosmic environment, such as in the planetary ring system of Saturn, in Jupiter's moon and in the dust rings of the Martian moon and etc. The dust grains may be positively or negatively charged due to various charging mechanisms. The charging of dust grains relies on the various properties of the dust grains as well as on the surrounding plasma medium. The collection of electrons and ions by dust grains is not only dependent on the electron and ion densities but also shape dependent. The charging of massive dust particles happens due to the sticking of electrons and ions to the grains surface. The electrons are lighter than ions and have a higher mobility which leads to negative charging of the dust particles at equilibrium. These highly charged dust grains give rise to different kinds of wave modes in dusty plasmas; dust-ion acoustic mode (DIA) is one of such modes. DIA waves can propagate in cosmic plasma environments, in the dusty plasma of Earth’s mesosphere and contribute to the low–frequency noise in the F-ring of Saturn. The quantum effects in plasmas become significant, when the associated de Broglie wavelength of the particles is comparable to the inter-particle distance. In present investigation, we have analyzed the interaction of dust ion-acoustic (DIA) shock waves in quantum plasma whose constituents are electrons and ions showing quantum behavior and negatively charged dust grains. The ions (quantum nature) and dust grains are assumed to be mobile and inertialess electrons are considered to be quantum. Using an extended Poincare-Lighthill-Kuo perturbation method, two sided Burgers equations for shock waves are derived. The analytical phase shifts of DIA shock waves after collision have been deduced. The impacts of physical parameters such as the quantum diffraction parameter for electrons and ions, kinematic viscosity which arises due to dust charge variation, the unperturbed dust to ion density ratio, and temperature ratio on the phase shifts occurred during the head-on collision between DIA shock waves are analyzed. The results of present investigation may be useful in the understanding of fundamental plasma phenomenon in a dusty plasma environment containing inertialess quantum electrons, inertial ions and dust particulates.

References:

[1] R. Kohli and N. S. Saini, Phys. Plasmas **24**, 63701 (2017)
[2] P. Chatterjee, M. Ghorui and R. Choudhury, Pramana – J. Phys., **80**, 3, p 519–531 (2013)

DESIGN OF POST INSULATOR FOR ELECTRO-MECHANICAL REQUIREMENT OF BEAM SOURCE TO CHARACTERIZE IN INDIAN TEST FACILITY (INTF)

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Beam Source consists of ion source and accelerator system, shall be installed in a 180 m^3 UHV vessel for the plasma production and negative ion acceleration in Indian Test Facility (INTF). Beam Source is mechanically supported on the electrically grounded Vessel. During operation, the source will be lifted to operating voltage of -100kV. Electrical isolation between Beam Source and Vacuum vessel is provided by ceramic isolators, named Post Insulator. Post Insulators are attached with metallic flanges and connected with vacuum vessel and Beam Source on either ends. It is necessary to validate electrical and mechanical performance of post insulator in operating conditions prior to its assembly.The objective of this paper is to present the design and analysis of Post Insulators, with respect to its functional and operational requirements. Design calculations are done for finalize the size and configuration of the post insulators, and subsequently Finite Element Analysis method has been adopted to verify the design with respect to its different load combinations imposed by the dead weight of beam source, reaction forces from the transverse and rotational movements of beam source and other accidental load scenarios. Additionally, seismic analysis was also performed to verify the design considering the Ahmedabad zone seismic spectrum. Electrostatic analysis of post insulator is carried out for 100 kV isolation for various configurations of stress shields to simulate possible electric stress on different location of post insulator. Based on the analysis result with optimum electric stresses, the design of post insulator is finalized. This paper would give details of post insulator design criteria, analytical assessment, final design and its validation for structural, electrical and vacuum compatibility.

INVESTIGATION OF DISINFECTANT PROPERTIES OF PLASMA ACTIVATED WATER (PAW)

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In the last two decades, cold atmospheric plasma (CAP) has gained significant attention in the field of medicine and agriculture. CAP has high electron temperature compared to ions and neutrals. Cold atmospheric plasma interacts with water and forms stable (long-live) reactive oxygen and nitrogen species (RONS) which remain in the water. Due to the presence of these species water becomes active therefore commonly known as Plasma Activated Water (PAW) [1-2]. Researchers have reported two configurations to generate PAW. In the first one, plasma discharge immersed inside the water [3] whereas in the second configuration plasma discharge remains close to the water surface [1]. In the present work, we have used dielectric barrier discharge (DBD) co-axial torch to generate plasma close to the water surface. These RONS present in the PAW play a major role in killing of pathogens and therefore has potential to use it in the field of food and agriculture, surface and instrument disinfectant [2-3]. In the present work we have successfully identified and measured the presence of RONS in PAW. NO_2^- ions concentration are detected using strip test, and measured using colorimetric method. Similarly, NO_3^- ions concentration is detected using colorimetric test, and measured using UV technique. Ozone concentration is determine using indigo colorimetric test. Test Strip and colorimetric method also implemented for the detection of Hydrogen peroxide (H_2O_2) in PAW, but it is beyond detection limit due to the fact H_2O_2 reacts with NO_2^- ions to give NO_3^- ions, and also that the plasma generated is in glow discharge region [1]. Generated PAW is acidic in nature with pH in the range of 2.5 to 3.5 due to the presence of NO_3^- and NO_2^- (Nitric and Nitrous acid) species. The oxidation reduction potential (ORP) of PAW was measured and it falls in the range of 550 – 650 mV.

In the present work, we have mainly emphasized on the disinfectant study of Pseudomonas aeruginosa (P. Aeruginosa) using PAW as a disinfectant. About 6 log reduction in Colony Forming Unit (CFU) is observed in PAW (ORP 600+ mV) compared to control (Bacterial strain in Phosphate Buffer solution, PBS). Further, the results have shown that with the increase in ORP value of PAW, its disinfectant ability increases.

References:

[1] Achieving reactive species specificity within plasma-activated water through selective generation using air spark and glow discharges, Plasma Process Polym., (2017)
[2] Effect of plasma activated water on the postharvest quality of button mushrooms, Agaricus bisporus, Food Chem., p 436-444, (2016)
[3] Inactivation of Bacillus subtilis Spores in Water by a Direct-Current, Cold Atmospheric-Pressure Air Plasma Microjet, Plasma Process Polym., p 157-164, (2012)

DESIGN, TESTING, INSTALLATION AND COMMISSIONING OF LOW VOLTAGE ELECTRICAL POWER DISTRIBUTION

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The recently constructed Auxiliary Building and New Lab Building requires electrical power for the HVAC, lighting and experimental loads. To provide the electrical power to HVAC and lighting of both the buildings and experimental loads, a low voltage electrical distribution system has been designed. , The 11 kV is stepped down to the voltage levels of the load (415/230V) by means of distribution transformers, which are installed in the transformer bays outside the Auxiliary building and new lab building. The Electrical Panels located inside the buildings receive power from the secondary of Distribution Transformers and distributes power to the end loads. This paper summarises the installation and commissioning tests performed on the electrical distribution system.

References:
[1] IS 8623: Specification for Low-Voltage Switchgear and control gear assemblies
[2] Electrical Installation Guide by Schneider Electric

CHARACTERIZATION OF PARALLEL-PLATE DIELECTRIC BARRIER DISCHARGE WITH SINGLE AND DOUBLE DIELECTRIC-INSULATED ELECTRODES

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The dielectric barrier discharge (DBD) is a popular & scalable plasma source for the production of atmospheric-pressure glow discharge using various electrode geometries for industrial applications. Parallel-plate electrodes are the basic configuration and employed often in laboratories for testing. In DBD, plasma-facing surface of electrode is masked with thin dielectric sheet or sometimes coated with a thin insulating layer in order to prevent glow-to-arc transition. In this paper, we have characterized the glow discharge properties when the dielectric layer is pasted only on one electrode as compared to both. In our experiments, glow discharge is ignited in helium gas at atmospheric pressure when a sinusoidal voltage is applied between pair of circular electrodes. It was observed that the discharge operates in filamentary mode when the dielectric layer is pasted only on powered electrode. It is transformed to diffuse mode when both the electrodes are insulated. The recorded current waveform show many peaks indicating the presence of filamentary discharge with one dielectric. We have simulated the vacuum electric field between the electrodes to clarify the observation. A comparison of other electrical properties such as current density, power density, applied frequency, voltage etc is presented.

References:
[1] J.R. Roth, ‘Industrial Plasma Engineering,’ Bristol, U.K.: IOP, **1**, Principles, (1995).
[2] A. K. Srivastava and G. Prasad, J. Electrostatics, **72**, p. 140-146 (2014).
[3] A. K. Srivastava, Materials Today: Proceedings, **18**, p. 1033-38 (2019).
[4] A. V. Pipa and R. Brandenburg, Atoms, **7**, 14, p.1-18 (2019).

DEVELOPMENT OF ARC DETECTION SYSTEM FOR RF SOURCE AND MICROWAVE COMPONENTS

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ITER-India, IPR has developed a dedicated test facility for testing of MW level RF source and associated components [1] [2]. The test facility includes MW level RF source, high power dummy load, transmission line components including mis-match lines comprising of stub and phase shifter, Data acquisition & control system, auxiliary power supplies, high

voltage power supply (HVPS), AC power distribution network, active water & air cooling etc. The same facility will be used in future for testing of RF sources related to ITER deliverables.The RF vacuum tubes of the RF source must be protected against faults like over current, overvoltage and overloads which may occur during operation. Arcing is one of the major faults in the cavity of the source and the transmission line components during high power RF operation, which can cause a severe damage to the system. Arc at output of RF source causes excessive VSWR condition, which can damage the vacuum tube permanently, if action is not taken immediately. To protect the vacuum tube and other critical components, RF drive and HVPS needs to be switched off within 10µs, once arcing is detected. Therefore, a reliable arc detection system is essential to safeguard the system and to continue a reliable operation. An indigenous development of arc detector is initiated by ITER-India, IPR. To detect light during arc fault condition, a view port is used in cavity and transmission line and the arc light is transmitted to detection circuit using fiber optic cable. Detection circuit uses photo transistor to detect the light and generate latched fault signal to turn off the RF drive as well as associated HVPS. Arc detection circuit is tested successfully with response time of <10µs, which is acceptable for protection purpose of the RF source and associated components. Such methodology of arc detection and protection can be used in any high power RF and microwave system. In this paper, a detailed design of developed Arc Detection System along with its test results will be discussed.

References:

[1] Aparajita mukherjee et al., Status of R&D activity for ITER ICRF power source system, Fusion Engineering and Design 96–97 (2015) 542–546

[2] Rajesh trivedi et al., Outcome of R&D program for ITER ICRF Power Source System, Preprint, FEC-2018.

STUDY OF RAYLEIGH- TAYLOR INSTABILITY IN STRONGLY COUPLED MAGNETIZED PLASMA WITH FLR CORRECTION

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In the present work, the effect of Finite larmor radius (FLR) corrections is studied on Rayleigh-Taylor (R-T) instability propagating in a strongly coupled, magnetized plasma medium. We have use the (GHD) generalized hydrodynamic model to derive the analytical dispersion relation. The dispersion relation is modified due to the presence of magnetic field and FLR effects.. Then the dispersion relation is also discussed in weakly coupled (hydrodynamic) and strongly coupled (kinetic) limits. Numerical calculations are discussed and it is examined that the FLR effect suppresses the growth rate of R-T instability. The Rayleigh-Taylor (R-T) instability has been recently investigated in strongly coupled plasma looking to its importance in Inertial Confinement Fusion reactions and in dense stellar systems.

ENERGETIC PLASMA ION BEAM PRODUCED RIPPLE PATTERNS FOR SERS BASED DETECTION OF COMPLEX MOLECULES

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Noble metal nanoparticle based Surface Enhanced Raman Scattering (SERS) spectroscopy is a promising technique for the detection of molecules at very low concentration [1]. This technique can be used for developing low concentration detection technologies for various complex molecules like glucose, blood, pesticides, etc. In this technique, metal nanoparticles arrays grown on energetic plasma ion beam produced ripple patterns produce large electromagnetic filed enhancement between the nanoparticles that leads to higher SERS signal. In the present work, ripple patterns are formed on Si substrate by Argon ion sputtering and silver nanoparticles are grown on the patterned Si substrate using electron beam evaporator. Molecules (glucose, blood and pesticides) with various diluted concentration are deposited on the prepared Si substrate with nanoparticle arrays and Raman spectra has been taken. It has been observed that molecules on nanoparticle arrays gives better SERS signal enhancement compared to that of Molecules on plane Si and plane Si with randomly ordered nanoparticles. The analysis shows glucose having concentration as low as $5x10^{-5}$g/ml can be detected using silver nanoparticle arrays grown on Si substrate with ion beam produced ripple patterns [2]. The analysis with pure blood samples shows that glucose peaks with other characteristic peaks of glucose are clearly visible with enhanced intensity for blood samples deposited on Si substrate with silver nanoparticles. The technique has been successfully used for the detection of pesticides under diluted concentration.

References:

[1] N. Jeffrey, W. Anker, Paige Hall, Olga Lyandres, Nilam C. Shah, Jing Zao, Richard P. Van Duyne, Nat. Mater. 7 (2008) 442.
[2] Sooraj K P, Mukesh Ranjan, Rekha Rao, Subroto Mukherjee, Applied Surface Science 447 (2018) 576-581

PRE COMMISSIONING TESTS OF DRY TYPE TRANSFORMER

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The distribution system at IPR involves various voltage levels. All high power electrical loads are supplied from a 132 kV switchyard through five power transformer and associated 11 kV and 22 kV feeders . Further distribution for various low power loads is done at 415 V and 230 V. Various experimental facilities are housed in the New laboratory building. To cater to the Low voltage experimental loads in this building a cast resin transformer was procured. This paper summarises the pre-commissioning tests on the transformer. The purpose of commissioning tests on transformer is to validate transformer's performance.

These tests also establish that the erection of the transformer is correct and all the connections / cables have been installed in accordance with the approved erection drawings and diagrams. . This paper discusses the procedures and testing results of the transformer.

References:

[1] Power Transformers Principles and Applications – John J. Winders, Jr
[2] NFPA70B – 2006, Recommended Practice for Electrical Equipment Maintenance.
[3] IEEE 902-1998 – Guide for Maintenance, Operation and Safety of Industrial and commercial Power System.

ESTIMATION OF PLASMA PARAMETERS USING NEURAL NETWORK FOR LARGE VOLUME PLASMA DEVICE

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Langmuir probe [1-2] is widely used for localized measurement of plasma parameters in an experimental plasma device. Conventionally, I/V characteristic curve obtained from the sweeping of Langmuir probe is exponential in nature and depends on electron temperature. Usually, the derivation of electron temperature require fitting procedures, which are time-consuming in an experimental campaign, where a large number of I/V characteristics are to be analyzed. In LVPD [1], introduction of a large electron energy filter has divided plasma into three distinct plasma regions having strikingly different plasma characteristics [3, 4]. I/V curves obtained in these regions require different polynomial fittings for obtaining an accurate estimation of electron temperature. Manual iterations are thus required which are cumbersome and time-consuming. In this background, we found that the referred neural network fitting techniques [5-9] used across various plasma machines provide comparatively accurate fitting for highly non-linear I/V curves obtained in LVPD. This paper discusses the requirement, tools, and techniques, developed software for processing Langmuir probe data and finally a comparison of plasma parameters obtained with NN with conventional fitting procedures.

References:

[1] The theory of collectors in Gaseous Discharges, H.M. Mott smith and I. Langmuir, Phys. Review, 28, 1926.
[2] Understanding Langmuir probe current-voltage characteristic, R.L. Merlino, Am. J. Phys., 75 (12), 2007.
[3] A large volume plasma device, S K Mattoo et al, Rev. Sc. Instrum. 72 (10), 3864-3872 (2001).
[4] Performance of large electron energy filter in large volume plasma device, S K Singh, et al, Rev. Sc. Instrum. 85 (3), 33507-17 20014.
[5] Fast curve fitting using neural network, C M Bishop, C. M. Roach, Rev. Sc. Instrum, 63, 4450 (1992).

[6] Neural network and their applications, C.M. Bishop, Rev. Sc. Instrum, 65 1803 (1994).
[7] Automatic fast fitting of single Langmuir probe characteristics on RFX, M. Bagatin et. al., Rev. Sc. Instrum., 68, 365(1997).
[8] Application of neural network for the measurement of electronic temperature in Nuclear Fusion experiments, Neural comput & Applic, 10, 351-356 (2002).
[9] Analysis of Langmuir probe data by artificial neural network, Filip Rafaj, Bachelor thesis, 2016.

INVESTIGATION OF ELECTRO-THERMAL CHARACTERISTICS OF A NOVEL LOW PRESSURE NON-TRANSFERRED DC PLASMA torch

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The electro-thermal characteristics of a novel dc plasma torch have been investigated under low pressure conditions. Such plasma torches are an essential component of the very low pressure plasma spraying coating technique, which has recently evoked lot of interest among researchers and coating experts due to its rapid rates and coating stability. This technique is quickly transforming as state-of-the-art. The investigations have been performed at a chamber pressure of ~ 30 mbar; however, torch vacuum compatibility has been checked up to a pressure of 10^{-6} mbar. The experiments were performed with a total nitrogen gas flow rate of 50 – 110 slpm. The total gas flow rate was divided into two components in 3:1 ratio, the former being the primary plasma forming gas and latter being the secondary shroud gas which acts as a cold boundary layer and provides wall stability for the torch components but does takes part in plasma formation downstream [2]. Significant changes in various plasma parameters have been observed in this study. A comparative analysis of the device with atmospheric operation shows that, when operated under low pressure conditions, the operational range extends from 20 A to 500 A without any considerable degradation in anode life time [1]. For an anode exit diameter of 17 mm, the plasma plume length is observed to be of ~ 1.0 – 1.5 m. The saddle point of the I-V curve varies for different gas flow rates. It is also observed that that the arc voltage is strongly influenced by gas flow rate and increases significantly with increase in gas flow rate at higher currents. The efficiency of the plasma torch is observed to be very good ~ 75 – 80 % for all conditions.

References:

[1] Prediction of operational characteristics of a dc non-transferred arc plasma torch using similarity criteria, European Physical Journal D, 71: 247 (2017)
[2] Influence of the Shroud Gas Injection Configuration on the Characteristics of a DC Non-transferred Arc Plasma Torch, Plasma Chemistry and Plasma Processing, 38:759–770 (2018)

SHEATH AS A MITIGATION SCHEME IN COMMUNICATION BLACKOUT

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Communication blackout refers to the scenario when a spacecraft or module loses all of its communication with the Earth while reentering the Earth's atmosphere at hypersonic speed. The blackout occurs due to the envelope of ionized air (plasma) around the spacecraft, created by the heat from the compression of the atmosphere. During the blackout, the radio waves used for communication between ground stations and satellites are attenuated and/or reflected by the plasma layer. The population of electrons near the antenna is the main reason behind this blackout. The plasma layer usually has an electron number density of 10^{17} to 10^{20} m^{-3}. If the frequency at which the electrons oscillate is greater than the frequency of radio wave transmission, it results in a reflection of the radio waves. The plasma frequency is directly proportional to the square root of the electron density of the plasma layer. Therefore, reducing electron density will certainly help in bringing down the plasma frequency. Eventually, it will help to reduce the blackout period. There are electrostatic and magnetized mitigation schemes, which provide a possibility for communication during radio blackouts. The present study has attempted to explore the possibility of such mitigation schemes. The results suggest that magnetized mitigation schemes have more control over electron dynamics and capable of more power optimization. Exact environmental factors have been incorporated in the modeling to provide optimized parameters for different configurations of mitigation.

References:

[1] Hartunian, R. A., Stewart, G. E., Fergason, S. D., Curtiss, T. J., and Seibold, R. W., "Cause and Mitigations Radio Frequency (RF) Blackout During re-entry of Reusable Launch Vehicles," ATR 2007(5309)-1, AEROSPACE CORPORATION, 2007, ATR-2007(5309)-1.

[2] Scalabrin, L. C., *Numerical Simulation of Weakly Ionized Hypersonic Flow Over Re-entry Capsules*, 2007, Ph.D. thesis, Department of Aerospace Engineering, University of Michigan.

[3] Bilen, S. G. and Gilchrist, B. E., "Transient Plasma Sheath Model for Thin Conductors Excited by Negative High Voltages with Application to Electrodynamic Tethers," *IEEE Transactions on Plasma Science*, Vol. **28**, No. 6, Dec 2000, pp. 2058–2074.

[4] Kim, M., Keidar, M., and Boyd, I. D., "Analysis of an Electromagnetic Mitigation Scheme for Reentry Telemetry through Plasma," *Journal of Spacecraft and Rockets*, Vol. **45**, No. 6, 2008, pp. 1223–1229.

CENTRALIZED DATA LOGGING SYSTEM FOR LARGE VOLUME PLASMA DEVICE

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Large volume Plasma Device (LVPD) is dedicated for carrying out investigations relevant to magnetospheric and fusion plasmas [1]. In LVPD, experiments are carried out using in-house developed LabVIEW based data acquisition and control system [2-3]. The design of the data handling system [4] is based on hybrid architecture employing MDS+ based data archival and Syslog based data logging along with local storage at I&C systems. Recently, a high end Xenon based HP 380L server on RHEL 7.2 has been procured, configured and prototyping has been carrying out. A generic data logger module based on syslog interface has been developed [5]. This data logging software extension for LVPD is under progress for currently operational software modules. A new data handling system based on Queue based message handler design pattern has been developed. The paper discusses the centralized data handling hardware, configuration, data logging software, analysis, results and lesson learned.

References:

[1] Large Volume Plasma Device, S. K. Mattoo et. al., Rev. Sci. Instrum., 72, 3864 (2001).
[2] Process Automation System for Integration and Operation of Large Volume Plasma Device, R. Sugandhi et al, Fus Eng Des, 112, 804-813 (2017)
[3] State of art data acquisition system for large volume plasma device, R Sugandhi et al, Proc.10th APFA conf., Institute for Plasma Research, India, 14-18 Dec 2015.
[4] Data Handling System at Large Volume Plasma Device, R. Sugandhi, et. al, 32nd National Symp. on Plasma Science and Tech., Gandhinagar, 7-10 Nov 2017
[5] Investigation of LabVIEW and Syslog Interface using In-house Developed Generic Logging Software, G. Kaur, R. Sugandhi et al, Proc. 2nd Int. Conf. on Innovations in Power and Advanced Computing Technologies, Vellore, 22-23 Mar 2019.

DEVELOPMENT OF FDTD MODEL FOR PLASMA ANTENNA DESIGN

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Plasma antenna is a separate class of RF antenna which uses ionized gas as the conducting element. The resurgence of interest in plasma antenna is due to its low radar cross-section characteristic which makes it a perfect tool for defense communication. The present work is aimed to investigate the distinctive features of the plasma antenna sustained by a surface wave. A 30 cm long plasma column [1] acting as a plasma antenna has been simulated by using frequency-dependent forward difference time domain (FDTD) method in Cartesian geometry. This technique has been extensively used to study the electromagnetic wave behavior generated due to the interaction of an electromagnetic wave and plasma wave [2]. Important profiles of antenna element such as current, potential, conductivity, etc. have been studied by varying operating parameters (working pressure, drive frequency, length of plasma column, etc.). Numerical results indicate that, the characteristics of plasma antenna significantly depends upon plasma parameters namely plasma frequency and collision frequency. The investigation is conceptualized to improve the available plasma antenna designs.

References:

[1] R. Kumar, and D. Bora, J. Appl. Phys. 107, (2010).
[2] T. Naito, S. Yamaura, Y. Fukuma, and O. Sakai, Plasma Phys, 23, 093504 (2016)

3D ELECTROSTATIC ANALYSIS FOR HIGH VOLTAGE APPLICATIONS BY FINITE ELEMENT METHOD

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In this work we have carried out a detail 3-dimensional electrostatic analysis for a high voltage multiplier being developed at Institute for Plasma Research for accelerator and other fusion research applications. This Symmetrical Voltage Multiplier (SVM), which multiplies the voltage in two stages, is a complex geometry with many components such as ceramic capacitors, nylon insulating supports, brass connecting discs, separators etc. all assembled closely in a cylindrical fiberglass encloser that is pressurized with dry nitrogen gas to avoid arcing. A detailed 3-dimensional finite element model is developed using *Comsol Multiphysics* [1] to analyze and investigate the possible arcing locations and then to find the appropriate remedies [2]. These results are presented in this paper.

References :

[1] http://www.comsol.com/
[2] High Voltage Engineering Fundamental by E.Kuffel

REMOTE OPERATION AND STATUS MONITORING OF AIR COMPRESSOR SYSTEM

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Smooth and reliable operation of pneumatic services is always mandatory for the round – the-clock operating system. At IPR, 1.3 kW at 4.5 K helium refrigerator/liquefier (HRL) cryogenics system, which is in the operational stage since 2003, and it is in use to cool down the magnets of Steady State Super-conducting Tokamak (SST-1). The HRL system consists several sub-systems mainly, Cold-Box, Purifier, SCMS, LN2 Valve-Box, LN2 Booster System, Helium Compressors, Helium Recovery Compressors, Oil Removal System, High-pressure (HP) and Medium pressure (MP) tanks for helium gas inventory and Nitrogen inventory System, etc. Operation, control, and observation of these systems done by PLC and SCADA. There are two nos. of ELGI make air-compressors are used to provide pressurised air to operate process control valves and other process equipment. This pneumatic utilities have also been used by SST-1 intra-divisions for their sub-systems. A PLC-based automation and control system has been indigenously developed along with its program logic, SCADA GUI for remote operation, observation fault diagnostic to minimize human intervention for the Air-compressor. This paper describes all efforts done towards automation of pneumatics utilities.

CONTROL OF RADIAL GRADIENT SCALE LENGTH OF ELECTRON TEMPERATURE IN A DOUBLE PLASMA DEVICE

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A double plasma device (DPD) has been configured for controlling plasma parameters, especially electron temperature in the target region by selective electrostatic filtering of source plasma. The filtering was realized by properly biasing a metallic grid placed between source and target chambers. Argon plasma produced in the grounded source chamber using a multi filamentary plasma source at pressure of 3 x 10^{-4}mbar. The role of floating grid, biased grid, variation in effective grid transparency by varying Debye sheath etc. in controlling the plasma parameters were investigated. A reduction in electron temperature was observed by varying the grid bias from -25 V to 0V and increase in electron temperature observed beyond grid bias of 0V. Effective electron cooling observed with 45% transparent grid whereas electron heating was seen with 75% transparent grid and the temperature has risen from 4.8 eV to 7.3 eV. A detailed analysis on the control of electron temperature is made by changing the effective grid thickness considering Debye sheath into account. Besides controlling electron temperature, a control over plasma potential and plasma density is also realized in the target region where plasma potential has changed from -5 V to +25 V and density from 1.16 x 10^{15} to 8.52 x 10^{15} m^{-3} respectively, for the similar range of applied grid bias. The filtering effect of biased grid can be clearly observed from the estimation of EEDF, which shows the suppression of energetic electrons during the cooling and rise of energetic tail during the localized heating. The mechanism of electron temperature control has been further applied to a cassette of concentric segmented multiple grids by separately charging it to demonstrate a control over radial gradients. We could demonstrate a

control on radial gradient of electron temperature with scale length less than 10 cm in unmagnetized plasma of DPD.

References:

[1] R. J. Taylor, K. R. MacKenzie, and H. Ikezi, Review of Scientific Instruments 43, 1675 (1972);

[2] Kohgi Kato, Satoru Iizuka, and Noriyoshi Sato, Applied Physics Letters 65, 816 (1994).

[3] K. H. Bai, J. I. Hong, S. J. You, and H. Y. Chang, Phys. Plasmas 8, 4246 (2001).

[4] S. K. Singh, P. K. Srivastava, L. M. Awasthi, S. K. Mattoo, Rev. Sci. Instrum. 85, 033507 (2014).

INTOUCH WONDERWARE SCADA SOFTWARE UPGRADATION FOR THE SST-1 CRYOGENIC SYSTEM

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The SST-1 Cryogenic system has been widely spreader in terms of handling many auxiliary sub-systems, which include integrated flow distribution system (IFDCS), current feeder system (CFS), LN2 management system and 80 K booster system. These subsystems operate in round-the-clock basis and it is mandatory to provide safe and reliable solution in terms of continuous data archive for the control and monitoring of the system. Supervisory Control and Data Acquisition (SCADA) software sitting at the heart of SST-1 cryogenic control systems and it is one of the simplest and the most cost-effective ways to help and unify operation. The essential DAQ platform works on Wonderware InTouch SCADA software version 9.5 has been upgraded from our old SCADA along with its runtime as well as development licenses. This upgraded new SCADA software is with a long history for helping optimize engineering efficiencies. Greater operational context coupled with an enhanced user interface, mobility and integration capabilities; is now helping in operation with more timely, integrated and actionable to help fast-track decision making and optimize various parameters. Upgrading to the latest SCADA version ensures us continue to leverage our best-in-class technologies and innovations based on evolving industry trends and market drivers. This paper describes the selection, installation and activation techniques and migration of existing applications in safe and reliable way.

DESIGN AND DEVELOPMENT OF ALARM ANNUNCIATION SYSTEM FOR SST-1 CRYOGENICS

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The Cryogenics sub-systems of Steady State Superconducting Tokamak (SST-1) are 1.3kW Helium Refrigerator/Liquefier plant, Liquid Nitrogen (LN2) distribution system, Integrated flow distribution system (IFDCS), Current feeder system (CFS) and 80K Booster system. These cryogenics sub- systems have their own control system consist of Programmable logic controller (PLC) and Supervisory Control and Data Acquisition (SCADA).It is essential to have centralized alarm annunciation system for immediate attention of operator in case of abnormal process parameters behavior and emergency situation exists in any cryogenics sub-systems. Alarm annunciation application designed and developed in Wonderware SCADA. Control area network established among all cryogenics sub-system's control nodes [1]. OPClink gateway and FSGateway are configured for establishing communication between Alarm annunciation application and SCADA applications running on different cryogenics sub-systems control nodes. The main critical process parameters of all sub-systems are addressed and defined in Alarm annunciation SCADA application. This application runs at back end and alerts the operator by audible sound and blinking graphics in case of abnormal events. The Alarm annunciation application performed satisfactory in recent SST-1 plasma experiment campaign. The features of developed applications are presented in this paper.

References:

[1] Implementation of Time Synchronized Cryogenics Control System Network Architecture for SST-1, Fusion Engineering and Design 112(2016) 747-751.

EFFECTS OF ION DRAG FORCE AND DUST CHARGE GRADIENT FORCE ON THE COULOMB FISSIONING OF UNMAGNETIZED DUSTY PLASMA

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The combined effects of ion drag force, dust charge gradient (DCG) force, polarization force and ion-neutral collision force are studied on the low frequency dust acoustic wave (DAW) and pinching instability in unmagnetized weakly coupled dusty plasma. The thermal electrons satisfy the Boltzmann relation while dynamics of inertialess ions are modified owing to dissipation effects of ion-neutral collisions. The effects of ion drag force, DCG force due to variation in charge and polarization force due to inhomogeneity in the medium are taken into account in the dynamics of unmagnetized weakly coupled dust particles. The presence of ion

drag force causes fragmentation of dust cloud into two parts which is known as Coulomb fissioning. The modified dispersion characteristics of DAW and pinching instability are derived using the plane wave solutions. The numerical studies have been performed to show the effects of ion drag and DCG forces which are important for the low charges in the dusty plasma. The laboratory as well as astrophysical applications in dust cloud fragmentations have been examined.

References:

[1] A. G. Khrapak and S. A. Khrapak, Phys. Plasmas **25**, 034503 (2018).

ROLE OF TEMPERATURE FLUCTUATIONS ON ETG INDUCED PARTICLE FLUX MEASUREMENT IN LVPD

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Langmuir probes are widely used for estimating plasma parameters both in tokamaks and basic plasma devices [1-3]. Generally, contributions from temperature fluctuations are ignored while calculating the plasma density. In LVPD, ETG induced particle flux is measured from the correlated density and potential fluctuations by neglecting the temperature fluctuations [4-6]. As observed level of temperature fluctuations is high (10-30%) in ETG dominated region of LVPD, hence their contribution cannot be totally ruled out [3]. We revisited the ETG induced particle flux measurement by including the contribution of temperature fluctuations. For this, a specially designed probe array is used capable of providing simultaneous measurement of mean plasma parameters and estimation of fluctuation induced plasma transport. Results on modified density fluctuations and implication on particle loss will be presented in the conference.

References:

[1] Z. Chen, Y. Sun, Z. Wang, Z. Yang, Y. Ding, and G. Zhuang, Plasma Sci. Technol. **14**, 1041 (2012).

[2] R. Balbín, C. Hidalgo, M. A. Pedrosa, I. García- Cortés, and J. Vega, Rev. Sci Instrum. 63, 4605 (1992).

[3] S. K. Mattoo, S. K. Singh, L. M. Awasthi, R. Singh, and P. K. Kaw, Phys. Rev. Lett. **108**, 255007 (2012).

[4] P. Srivastav, R. Singh, L. M. Awasthi, A. K. Sanyasi, P. K. Srivastava, R. Sugandhi, R. Singh, and P. K. Kaw, Phys. Plasmas **24**, 112115 (2017).

[5] P. Srivastav, R. Singh, L. M. Awasthi, A. K. Sanyasi, P. K. Srivastava, R. Sugandhi, and R.Singh, Plasma Phys. Control. Fusion **61**, 055010 (2019).

[6] P. Srivastav, R. Singh, L. M. Awasthi, A. K. Sanyasi, P. K. Srivastava, R. Sugandhi, and R.Singh, Phys. Plasmas **26**, 052303 (2019).

PLASMA SPRAY DEPOSITION OF CHROMIUM OXIDE COATINGS ON SS 316 L FOR WEAR RESISTANCE APPLICATIONS

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Plasma spray deposition is a well-established technique for thick ceramic coatings on various substrates to shield them from corrosion and wear. Owing to its high hardness and high melting point, chromium oxide finds wide application as wear resistant and thermal barrier coatings [1]. Wear resistance of chromium oxide has been widely studied. Particles injected into the plasma jet undergo rapid melting and get accelerated. These molten droplets moving at high velocities (higher than 100 m/s) and at a temperature higher than the melting point [2] strike the surface of the substrate and flatten to form an adherent coating in one single step. However, the plasma process requires optimization for desired coating thickness and adhesion strength for any required application. The present study offers comprehensive investigation on plasma process parameters for the development of chromium oxide coatings on SS 316L substrate. Dense adherent coatings of chromium oxide could be deposited on SS 316L with an intermediate bond coat of NiCrAlY to enhance the adhesion properties.

References:

[1] A. Cellarda, V. Garniera, G. Fantozzia, G. Baret, P. Fort, Wear resistance of chromium oxide nanostructured coatings, Ceramics International 35 (2009) 913–916
[2] Vandana Chaturvedi, P.V. Ananthapadmanabhan, Y. Chakravarthy, S. Bhandari, NirupamaTiwari, A. Pragatheeswaran, A.K. Das, Thermal plasma spheroidization of aluminum oxide and characterization of the spheroidized alumina powder, Ceramics International 40 (2014) 8273–8279

DEVELOPMENT OF THE NEAR-INFRARED SPECTROSCOPIC SYSTEM FOR ADITYA-U TOKAMAK AND INITIAL RESULTS

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A new spectroscopic system detecting spectral emission in the near infrared (800 - 1700 nm) region of EM spectra is planned to be installed on the Aditya-U tokamak. The measurements will provide information that can be used for machine protection, plasma control and performance evaluation. The hydrogenic series is a sensitive diagnostic in the plasma region having large ne and lower Te, such as diverter region. Here, the three-body recombination rate is highly sensitive to Te and ne, and the Br9/Paα intensity ratio can be used as a possible Te sensitive diagnostic. As NIR signal is contaminated by thermal emission from PFC's, plasma bremsstrahlung emission and recombination emission. Signal estimation are thus necessary to demonstrate to finalize the collection optics of the NIR spectroscopic system. We have developed code in SCILAB for signal estimation of a few prominent lines of hydrogen in the NIR region which correspond to the Paschen and Brackett series as well as for the background Bremsstrahlung radiation. This signal enables us to set up the optics along the maximum signal chord. Initial experiments for the NIR emission in the edge region of Aditya-U as well as other laboratory experiments are also reported.

References:

[1] V.A. Soukhanovskii et al, Near-infrared spectroscopy for divertor plasma diagnosis and control in DIII-D tokamak Rev. Sci. Instrum., 85, 11E418, (2014)

[2] V.A. Soukhanovskii et al, Near-infrared spectroscopy for burning plasma diagnostic applications Rev. Sci. Instrum., 79, 10F539, (2008)

FIELD EMISSION PROPERTIES OF ATOMICALLY HETEROGENEOUS METALLIC NANOSTRUCTURES CREATED BY MICROWAVE PLASMA GENERATED LOW EERGY ION BEAMS

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Metal surfaces when exposed to moderately high ion fluxes of inert gases having low energies lead to significant surface structuring. Plasma based ion beam surface patterning is attributed to surface atoms removal and rearranging as self organized nanopatterns with incorporation of inert gas ions inducing heterogeneity of the substrate's surface in the atomic level. The self-organized patterns are usually conical in shape with radius of curvature in the sub-nanometer regime. These patterning can be explained as an interplay of ion sputtering and surface diffusion (towards the peak of conics), which cause increase in surface porosity and surface emission area[1].It would be of interest to investigate the field emission properties of such homogeneously distributed atomically heterogeneous nanopatterns. Field Emission is a quantum mechanical process having vast technological applications in field-emission displays, electron microscopes, vacuum nanoelectronics etc. Fowler Nordheim equations provide approximate geometry independent theoretical description of field emission from bulk material. Thus, there is a requirement for new, geometry and adatom based [2] investigation which are not presently addressed by the existing Fowler-Nordheim theory. Hence it is crucial to investigate both the theoretical and experimental interrelations of surface geometry, work function, field emission parameters [3] of low energy ion beam irradiated metallic surface for better understanding of the present research results. In the research carried out so far, appropriate inert gas ions of optimized energies (~2-2.5 keV) and flux (~10^{19} $m^{-2}s^{-1}$,obtained from a microwave plasma based ion source) is utilized to create atomically heterogeneous and self-organized conical submicron structures (or nanostructures) on copper substrates. Higher ion beam fluence tends to produce

uniformity in nanostructures with well defined hillocks. Surface characterization has been carried out using AFM, SEM, KPFM and EDAX, providing estimation of their shapes, roughness, the percentage of implanted ions and their modified work function variation. Investigations conducted on copper substrates with varying fluences reveal nanopatterns are confined to surface layers (~nm). Field emission experiment with varying voltage to get field emission current is carried out using the modified samples. Fowler Nordheim equations have been applied to calculate field enhancement factor and show their variance with varying ion species keepingthe material of the substrate constant. The results of metallic substrate surface modification for different type of ion species with varying fluence along with their field emission experimental results will be presented in the conference.

References:

[1] Irem Tanyeli, Laurent Marot et al, Scientific Reports, 5 9779, p 1-9 (2015)
[2] A. Kyritsakis and J.P. Xanthakis Proc. R. Soc.A 471 20140811,p1-10(2014)
[3] Dogyun Hwangbo,S.Kajita et al, IEEE Transactions on Plasma Science 45 8,p 2080-2086(2017)

PREVENTIVE MAINTENANCE ACTIVITIES OF SST-1 CRYOGENIC SYSTEM AT IPR

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SST-1 Cryogenics system has wide spread in terms of various sub-systems, which include main helium cryo plant with capacity of 1.3 kW at 4.5 K, liquid nitrogen distribution system, integrated flow distribution and control (IFDC) system, 80 K thermal shields system, 80 K valve-boxes and current feeders systems. IPR also provides pneumatics utilities to intra-SST-1 Tokamak divisions. Being one of the critical sub-system of SST-1 Tokamak, in order to ensure smooth and reliable operation of cryogenic system, needs mandatory preventive routine maintenance schedule as per protocols[1][2]. In this paper, we will report experience and lesson learnt during the preventive maintenance activities of SST-1 cryogenics system.

References:-

[1] TANK J., Preventive Maintenance Experience for 1 kW Class Helium Liquefier/Refrigerator System at IPR, ICEC23- ICMC 2010, Poland
[2] G. MAHESURIYA., Operational and Troubleshooting Experiences in the SST-1 Cryogenic System, Advances in Cryogenics Engineering, June 2013, Vol-1573-59B, and pp. 1645-1651.

PERFORMANCE VALIDATION OF VACUUM INSULATED CRYO FLEXIBLE HOSES

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Low transfer loss of cryogenic fluids play very important role in cryogenic engineering. Specially, cryo fluids Viz. liquid nitrogen and liquid helium, the vacuum insulated flexible cryo hoses are very popular. These cryo compatible vacuum insulated flexible hoses are very reliable and easy to layout in a specific route, while transferring the cryo fluids from storage Dewar to miscellaneous applications or sub-systems. At IPR cryogenic facility, procurement of various sizes of vacuum insulated flexible hose has been done for transferring the cryogens to various applications. It is necessary to do the performance validation of the hoses before connecting to the systems. For this, we have dedicated testing and performance validation procedure in our quality checks plan, which includes vacuum check at room temperature, thermal cycle test at 77 K (liquid nitrogen conditions)[1], physical observation on frosting on the outer jacket, and finally helium leak testing at its operational service conditions[2]. In this paper, we summarize the procedure of various performance validation tests and its technical results.

References:

[1] Srikanth G.L.N et al., "Integrated Liquid Nitrogen Distribution Network for the cooling of SST-1 80K thermal shields system" 13th IIR International Conference on Cryogenics, April 2014

[2] Rajiv Sharma et al., "Repairing and welding Experience of LN2cryogenic Transfer Line of 80 K Distribution System of SST-1" Indian Welding Journal Volume 50 No. 1, January 2017

BEHAVIOR OF DIFFERENT REACTIVE SPECIES OF ATMOSPHERIC PRESSURE PLASMA JETS IN PRESENCE OF STRONG MAGNETIC FIELD

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Atmospheric pressure plasma jets (APPJ) are non-equilibrium plasmas which have different electron (~0.5 eV) and ion temperatures (0.025 eV). As it is formed in the atmosphere many reactive species are present in the plasmas along with the working gas which is helium in our case. The APPJ is created by dielectric barrier discharge method inside a capillary tube. In our work, two types of electrode configuration have been used to create the plasma. One configuration is ring to ring electrode which requires comparatively high voltage to ignite the plasma, and is called low frequency high voltage system (LFHV) and another configuration is needle to ring electrode in which we can ignite the plasma in lower voltages as the frequency

is quite high and it is called high frequency low voltage system (HFLV). The reactive species present in the plasma jet can be determined by the optical emission spectroscopy. The prominent lines which can be observed by the spectrometer are atomic He I lines (587.6 ($3d^3D \rightarrow 2p^3P^0$), 667.8 ($3d^1D \rightarrow 2p^1P^0$), 706.5 ($3s^3s^1 \rightarrow 2p^3P^0$), 728.1 ($3s^1S^0 \rightarrow 2p^1P^0$) nm), second positive system (SPS) of nitrogen with the vibrational transition 0-0 with band head at 337.1 nm and other vibrational transitions in SPS are 1-0 (315.9 nm), 0-1 (357.7 nm) and 0-2 (380.4 nm). The first negative system (FNS) of nitrogen ion can be observed at 391.4 nm and atomic oxygen line at 777.3 nm ($3p^5P \rightarrow 3s^5S^0$). Besides, weak intensity of hydrogen Balmer lines H_α (656.3 nm), H_β (486.1 nm) and OH band also can be observed at 308 nm. Application of transverse and parallel magnetic field along the direction of the jet will affect the plasma parameters (electron density and temperature). The positive and negative reactive species will respond differently. The plasma jet is not a continuous jet, it consists of plasma bullets which are created in every pulse of the applied voltage and travels along the jet with a very high speed (~ 10^6cm/s) [1]. These plasma bullets gain their maximum velocity when the intensity of nitrogen ionic line is maximum. Effect of magnetic field on these nitrogen ions will affect the plasma bullet dynamics. Magnetic field will also affect the electron density and temperature inside the plasma jet. The electron temperature and electron density are measured by the Boltzmann plot and Stark broadening methods respectively [2].

References:

[1] A. Shashurin, and M. Keidar, Phys. Plasmas 22, 122002 (2015).
[2] Z. S. Chang, G. J. Zhang, X. J. Shao, and Z. H. Zhang, Phys. Plasmas 19, 073513 (2012).

PARTICLE-IN-CELL MODELING OF PLASMA INTERACTION ON COLLECTOR SURFACE

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The plasma interaction with plasma facing materials has wide range of applications such as in fusion devices, plasma diodes, surface modification of materials, sputtering and many more. A one-dimensional (*1d*) electrostatic Particle-in-Cell (PIC) model has been developed and presented for bounded plasma system (single-emitter plasma diode) to investigate the interaction of plasma on the collector surface. It is assumed that the electrons and ions have cut-off Maxwellian velocity distributions at the injecting side. In addition, the plasma is assumed to be collisionless. It is found that the ion and electron concentrations decrease toward the collector surface. The ions are accelerated towards the negative biased surface whereas the electrons are repelled from it. However, those electrons having high thermal mobility can reach the collector surface. The sharp monotonic decrease of electrostatic potential near emitter and collector regions implies the formation of plasma sheath with collector sheath thickness larger than that of emitter. It is found that the electron and ion densities are dominant near the emitter and collector surfaces, respectively. In addition, the particle reflection coefficient decreases for both molybdenum (Mo) and tungsten (W)

surfaces with the increase in impact energy of ion, however, the reflection coefficient for W-surface is higher than that of Mo-surface by about 34.43% in magnitude. The obtained results are found to be in reasonable agreement with previous similar works.

LASER CLUSTER INTERACTION IN STRONG EXTERNAL MAGNETIC FIELD

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Laser interaction with atomic clusters leads to the production of high energy electrons, ions and x-rays which may be useful for future generation of particle and photon accelerators. However, the effect of laser magnetic field is often neglected in the theory and simulation of laser-cluster interaction since laser magnetic field is very weak by a factor of inverse light speed as compared to the laser electric field. We find that, even in the non-relativistic regime of laser intensities ($\leq 7.5 \times 10^{17}$ W/cm^2), the peak magnetic field strength can be substantial ($\sim$ 3.33 kilo Tesla) and this magnetic field alters the electron dynamics and energy absorption by electrons in the short-pulse regime of laser cluster interaction. In addition to the inherent laser magnetic field we apply external magnetic field in different orientations w.r.t. to the former and study the dynamics of cluster electrons and consequent laser energy absorption.

References:

[1] M. Kundu and D. Bauer, Phys. Rev. Lett. 96, 123401 (2006).
[2] SS Mahalik, M Kundu - Phys. Rev. A 97, 063406 (2018)

CHARACTERIZATION OF PLASMA TURBULENCE IN A MIRROR LEAKED PLASMA OF LVPD

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Magnetic mirror configuration is commonly adapted method for efficiently confining plasmas in cylindrical plasma systems. Not only laboratory plasmas but the dynamics of plasmas surrounding earth's magnetosphere is also governed by the strong magnetic mirror action at its poles. The bulk plasma embedded by population of energetic electrons travel along the magnetic field line gradients and suffers namely, 1) reflection from the mirror points at poles, 2) scattering; which introduces strong anisotropy, and 3) a part of it leaks through the magnetic mirror into the earth's atmosphere and contributes in the excitation and de-excitation of neutral particles and aurora formation. In general, these are strongly influenced by electromagnetic wave activities, especially of whistlers.In LVPD,

we produced similar experimental scenario, where plasma produced in low magnetic field is allowed to interact with high magnetic field region through a magnetic mirror of ratio, $R_m \sim 25$. Investigations suggest that in the transition region, a part of the plasma is leaked through the mirror while remaining one suffers strong reflection. The mirror leaked plasma is characterized for electron energy distribution function and excitation of small scale turbulence spread across electrostatic and electromagnetic regimes. The mirror leaked plasma is extensively studied by varying the strength of loss cone. The outcome from this study carries direct relevance to magnetospheric plasma and charge particle precipitation into the earth's magnetosphere. Detailed results on this will be presented in the conference.

References:

[1] A. K. Sanyasi, L. M. Awasthi, P. K. Srivastava *et al.*, Phy. Plasmas **24**, 102118 (2017).
[2] S. K. Singh, P. K. Srivastava, L. M. Awasthi *et al.*, Rev. Sci. Instrum. 85, 033507 (2014).

EXPERIMENTAL & CFD SIMULATION STUDY OF ATMOSPHERIC PLASMA SPARY COATINGS OF RARE EARTH PHOSPHATES

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Rare earth phosphates are considered as potential protective surface coating material for corrosion and high temperature application. By virtue of some distinctive properties like environmental durability, chemical inertness and high melting point rare earth materials have become popular surface coating material. Present paper focuses on the development of atmospheric plasma spray coating on various substrates namely SS and graphite. A comprehensive 3D simulation study has been done to understand atmospheric plasma spray coating process using rare earth material as powder material. The optimized plasma spray coating process parameter has been obtained by performing rigorous experimental as well as CFD simulation study. Very good agreement has been found between CFD simulation results and experimental observations. Plasma sprayed coating was investigated using scanning electron microscope and EDAX. Thermal cycling test of the coated coupons have been done. Results reveal that good quality surface coating can be developed using atmospheric plasma spray process.

References:

[1] P. Fauchais, Understanding plasma spraying, J. Phys. D: Appl. Phys. 37, 2004, 86–108
[2] Ramachandran K and Nishiyama H 2002 Three-dimensional effects of carrier gas and particle injection on the thermo-fluid fields of plasma jets J.Phys. D: Appl.Phys. 35,307.

LARGE AREA WAVEGUIDE BASED NON-THERMAL PLASMA DEVICE FOR RADIOACTIVE DECONTAMINATION: OVERCOMING DESIGN COMPLICATIONS

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Continuous demand for non-conventional, non-polluting energy sources has caused a surge in nuclear industry. However, its rapid expansion brings the question of nuclear waste management. Conventional methods of wet-chemical, mechanical machining, high pressure gas phase decontamination process generate a lot of secondary waste and they do pose a threat of accidental exposure to personnel. Researchers worldwide are looking for alternative waste management systems involving plasma and laser. Non-thermal plasma especially has the potential to become the alternative in radioactive decontamination [1]. However, low surface area of such plasma generation devices almost always are the bottleneck for practical application in nuclear industry [1]. Due to overcome this limitation, a novel large area open ended stepped rectangular waveguide based plasma generation system is modeled to generate atmospheric pressure non-thermal plasma for this purpose. Considering practical applications, plasma treatment area needs to be significantly large for scaling up the decontamination process and reduction in operational time. We have presently designed a plasma cavity consisting of stepped rectangular waveguide system (2.45 GHz) with open end dimensions of 86mm(a)×10mm(b). Designing such a large area an open ended rectangular waveguide has its own complications. Firstly, all higher order modes will propagate in addition to fundamental modes in the cavity, which will cause mode-interference resulting in microwave dispersion where fundamental and higher order modes will propagate with different group velocity within the cavity. Secondly, 'impedance matching' in such case will be challenging unlike co-axial geometry and we needed to introduce step discontinuity inside the waveguide to match the input impedance of the co-axial power cable to minimize the reflection of power [2, 3]. Step discontinuity complications especially of wave transitions are addressed in the design by placing stub tuner so that proper transition of TEM waves to TE or TM waves is achieved.The paper will discuss in detail about all the design challenges and how one can overcome them while designing a large area atmospheric pressure non-thermal plasma device.

References:

[1] Feasibility of using non-thermal microwave plasma for nuclear waste management: A detailed study backed by plasma spectroscopy, Environmental Technology & Innovation, Elsevier 12 (2018) 219–229.

[2] Moisan M and Zakrzewski J 1991 Plasma sources based on the propagation of electromagnetic surface waves *J. Phys. D:Appl. Phys.* 24 1025.

[3] Chen X 1989 Modelling of a radio-frequency plasma torch including a self-consistent electromagnetic field formulation *J. Phys. D: Appl. Phys.* 22 361–3.

CREATION AND STUDIES OF MICRO-ION BEAMS FROM INTENSE ELECTROMAGNETIC WAVE GENERATED PLASMAS

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Ion beams based on plasma ion sources find many emerging applications in science and technology. These beams, particularly from nobel gaseous plasmas, can be non-toxic and provide rapid processing of materials [1]. The applications span over several areas such as micro-nano pattering, rapid fabrication of semiconductors, modification of surface properties, including studies of optical and field emission properties of created nano-structures [1,2]. A microwave plasma based multi-element focused ion beam system has been developed [2] in our laboratory, which has significant advantages over conventional FIB systems and can provide variable projectile masses by employing different gaseous plasma ions and higher beam currents. Microstructures (such as gratings, a group of letters, array of spots etc.) of high aspect ratio (~100-1000) are created employing 26 keV Ar, Kr and Ne ion beams [2]. A theoretical model is developed to calculate the impact of the beam to the target sample by defining a new parameter called "current normalized force" which is total momentum transferred per unit time and normalized with the beam current. Capillary guiding of the plasma ion beams has demonstrated the self focusing of the beam which can be employed to reduce the source size (plasma electrode aperture) for the reduction of beam size for a constant demagnification of the electrostatic lens [3]. Observed hysteresis in beam current with ion energy is used to calculate the dissipated charge from the beam using the hysteresis area. The effect of plasma and beam parameters on focal dimensions has been investigated, and a unique feature of enhanced nonlinear demagnification is observed when the plasma electrode aperture is reduced to below the Debye length [4].

References :

[1] L. D. Menard and J. M. Ramsey, Nano Lett. **11**, 512 (2011).
[2] S. K. Maurya, S. Paul, J. K. Shah, S. Chatterjee, and S. Bhattacharjee, J. Appl. Phys. **121**,123302 (2017).
[3] S. K. Maurya, S. Barman and S. Bhattacharjee, J. Phys. D: Appl. Phys. **52**, 055205 (2019).
[4] S. K. Maurya, S. Barman, N. Pan, and S. Bhattacharjee, Phys. Plasmas **26**, 063103 (2019).

CHARACTERISTICS OF PLASMAS CONFINED IN A DIPOLE MAGNETIC FIELD

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There has been a long quest to understand charged particle behaviour and underlying complex processes in a plasma confined in a dipole magnetic field. For an understanding of the properties of such plasmas, keeping in view easier plasma accessibility and steady state operation, a compact table-top experiment employing microwaves of 2.45 GHz has been developed [1], by employing a single water cooled cylindrical permanent magnet (NdFeB). The plasma is generated by electron cyclotron resonance (ECR) heating.Visual observations (in terms of digital images) of the plasma shows alternate bright and relatively less bright regions with resemblance to trapped charged particles in the earth's radiation belts [2]. The brightest region alongside the magnet is the ECR region. Planar Langmuir and emissive probes are employed to determine the plasma parameters [1, 3] such as electron temperature (T_e), ion density (N_i), space potential (V_s), ion saturation current (I_{is}) including plasma beta (β). The magnetic dipole field is mapped in all space using a Hall effect probe. T_e is found to lie in the range of 2 -13 eV while the maximum plasma density (N_+) is of the order of 10^{17} m^{-3}. It is found that the density peak occurs away from the magnet. V_s and I_{is} is more or less uniform in the central region (r ~ 6.5 – 7 cm), which also indicates the better confinement of plasma in this region. A maximum β for the present experimental system is ~ 2%. Assuming azimuthal symmetry a mathematical model for particle diffusion has been developed by considering the fluid equation of motion [4], continuity equation [4], Fick's law [4] along with magnetostatic fields and gradients in the plasma potential. The equations are written in spherical polar coordinates (r, θ and φ), to address the dipole variation of the magnetic field. A numerical solution obtained using the Runge-Kutta (RK4) method for the radial and angular components of the diffusion equation, yields the plasma density profiles, which are compared with those obtained experimentally and found to agree reasonably well. The code uses the experimentally obtained T_e and V_s as input. The experimental and calculated results from the model, as a function of radial distance, neutral pressure and polar angle will be presented in the conference.

References:

[1] A. R. Baitha, A. Kumar and S. Bhattacharjee, Rev. Sci. Instrum., **89,** p 023503-6 (2018).
[2] A. C. Boxer *et al*. Nature Phys., **6**, p 207 – 212, (2010).
[3] S. Bhattacharjee and H. Amemiya Rev. Sci. Instrum., **70,** p 3332-37 (1999).
[4] F.F.Chen, Introduction to Plasma Physics and Controlled Fusion, second edition **1** Ch. 5 (Springer, Berlin) (1983).

KP EQUATION OF DUST ION ACOUSTIC WAVE IN MULTICOMPONENT PLASMAS

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A number of observations have confirmed the presence of superthermal particle in most of the astrophysical, space and laboratory environments. The most common distribution function employed to illustrate the superthermal particles in the generalized Lorentzian or the Kappa function. This distribution is observed to provide the best fit for the superthermal particles. As Dust is also omnipresent in different environments, so it is interesting to analyse the nonlinear excitations in a multicomponent plasma in presence of charged dust particulates. In the present investigation we have studied the characteristics of two dimensional small amplitude dust-ion-acoustic wave in Vasyliunas-Cairns (VC) distributed plasma. The KP equation has been derived using reductive perturbation technique. From the solution of KP equation, we have studied the characteristics of small amplitude dust ion acoustic structures. We have also investigated the stability of the solitary wave solutions of KP equation. It is remarked that all different physical parameters have great influence on the characteristics of solitary wave. The findings of this investigation may be useful in understanding the nonlinear structure in space dusty plasma like Saturn's magnetosphere.

References:

[1] Kadomstev, W.S., Petviashvili, V., Soviet Physics **15**, 539 (1970).
[2] Vasyliunas, V.M., J. Geophys. Res.**73**, 2839 (1968).
[3] N.S. Saini , Nimardeep Kaur, T.S. Gill, Adv. Space Research, **55**, 2873 (2015).

STUDY OF RAYLEIGH- TAYLOR INSTABILITY IN STRONGLY COUPLED MAGNETIZED PLASMA WITH FLR CORRECTION

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In the present work, the effect of Finite larmor radius (FLR) corrections is studied on Rayleigh-Taylor (R-T) instability propagating in a strongly coupled, magnetized plasma medium. We have use the (GHD) generalized hydrodynamic model to derive the analytical dispersion relation. The dispersion relation is modified due to the presence of magnetic field and FLR effects.. Then the dispersion relation is also discussed in weakly coupled (hydrodynamic) and strongly coupled (kinetic) limits. Numerical calculations are discussed and it is examined that the FLR effect suppresses the growth rate of R-T instability. The Rayleigh-Taylor (R-T) instability has been recently investigated in strongly coupled plasma looking to its importance in Inertial Confinement Fusion reactions and in dense stellar systems.

OBSERVATIONS OF ELECTROMAGNETIC ION CYCLOTRON WAVES IN THE LUNAR WAKE

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We present an observation of electromagnetic activity by ARTEMIS P1 and ARTEMIS P2 satellites. The wave characteristics such as wave normal angle, ellipticity, polarization etc. are delineated. Our analysis shows that the wave propagates below 35^0 angle to the ambient magnetic field and the wave activity is below the proton gyro-frequency ($\Omega_H +$). These properties suggest that Electromagnetic Ion Cyclotron (EMIC) waves are present in the lunar wake and outside of it. These waves play major role for the pitch angle scattering of the relativistic particles from ring current. The cross-correlation between the different magnetic components of the wave magnetic field for individual spacecraft is high. We have performed power and phase cross-correlations between two spacecraft measurements to validate spatial and temporal extent of EMIC waves in the lunar wake. These intense waves are almost observed simultaneously by the spacecrafts ARTEMIS P1 & P2 which is indicative of spatial broadening of EMIC waves. Thus, the EMIC wave may play the important role in the dynamics of the lunar wake.

VARIATIONAL MOMENT METHOD FOR SOLVING GRAD-SHAFRANOV EQUATION IN AXISYMMETRIC TOKAMAK PLASMAS WITH UP-DOWN ASYMMETRY

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A variational moment method was developed to solve Grad-Shafranov Equation for Axisymmetric Tokamak Plasmas by Lang L. Lao et al [1,2]. In this method, to find the flux surfaces the Cartesian coordinates R and Z in a poloidal section are expanded in a Fourier series in terms of poloidal angle. Then the corresponding action is minimized with respect to Fourier components to obtain coupled second-order differential equations in them, which are then solved for fixed boundary using Shooting Method. In this poster, we present the details of the theory, a new implementation of the code in Python and its extension for up-down asymmetric cases.

DESIGN OF A MULTICHANNEL CDTE BASED FAST ELECTRON BREMSSTRAHLUNG DETECTION SYSTEM FOR ADITYA-U LHCD DISCHARGES

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In ADITYA-U & SST-1 Tokamaks, a single channel CdTe detector is being used to measure fast electron bremsstrahlung emission (FEB) in the energy range of 20-200 KeV. Single channel FEB system only provides the information of line integrated measurement of FEB from a single line of sight. To study the power deposition profile of lower hybrid current drive in ADITYA-U tokamak, a multichannel FEB detection system is designed [1]. In order to optimize the designed parameter and performance of the system, a synthetic FEB diagnostic has been utilized [2]. The designed 9 channels system consist of CdTe detector array integrated with PR-16 preamplifier, fast shaping amplifier and a fast digitizer of 10 MHz. The FEB (Hard X-rays) emission from the 9 different chords will registered with temporal resolution of 5-10 ms depending upon the slowing down time scale of the electrons in the said energy range for ADITYA-U tokamak plasma parameters. In order to filter out low energy photons, 1 mm thick Al foil will placed in front of the HXR camera system [3]. Stray hard X rays resulting from thick target bremsstrahlung emission and photons scattered from tokamak surrounding structure will be shielded with 80 mm thick lead sheets.

References:

[1]Y Peysson, *et.al*, Tomography of fast electron bremsstrahlung emission during lower hybrid current drive on TORE SUPRA, RSI, **70**, p 3987, (1999).
[2] Santosh P. Pandya, *et.al.*, **2018**, *Phys. Scr.*, **93**, 115601
[3] John E Liptac Jr, *et.al* , Lower hybrid modeling and experiments on Alcator C-Mod by, MIT Thesis, (May-2006).

ELECTROMAGNETIC WAVE INTERACTION WITH PLASMAS CONFINED BY A DIPOLE MAGNET

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Existence of variety of wave phenomena in the geospace environment has interested researchers due to its constructive interplay with plasma resulting in applications like radio communication, space physics and basic research. Detailed study on wave dynamics in plasma is an active area of research as it gives an intuition about the wave plasma interaction in local domain both instantaneously and with temporal evolution. But its proper inspection is difficult in space and thus laboratory plasma can be used as a tool to address the fundamental physics issues. In this work we will model the interaction of a perpendicularly launched wave with a plasma slab where the magnetic field is oriented perpendicularly [1] to the direction of propagation. We will then extend the work to investigate oblique propagation of waves with the external magnetic field where the angle between the wave vector and the magnetic field will be varied to mimic the situation that happens in a dipole plasma at different polar angles. The Maxwell's equations will be solved by considering the dielectric permittivity [1-2] of the magnetized plasma with suitable boundary conditions. The main aim of the work would be to investigate power balance [2-3] which will tell us about the temporal evolution of the electron energy [3] and steady state temperature.

References:

[1] I Dey and S Bhattacharjee, Phys. Plasmas **18**, 022101 (2011)
[2] D Hemmers, M David, H Kempkens and J Uhlenbusch, J. Phys. D: Appl. Phys. **31,** 2155-2164 (1998)
[3] G J M Hagelaar, K Makasheva, L Garrigues and J P Boeuf, J. Phys. D: Appl. Phys. **42** (2009) 194019

ACCELERATION OF ELECTRONS FROM A THIN FOIL PLASMA BY TIGHTLY FOCUSED FEW-CYCLE LASER BEAM

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Acceleration of electrons with relativistic energies from a thin foil driven by tightly-focused few-cycle laser beam down to *one* optical-period and beam spot size down to the size of the laser wavelength has been studied using two dimensional electromagnetic particle-in-cell (EMPIC-2D) simulations. In such limits, beam dynamics has been simulated with extreme care using complex analytical signal representation which otherwise manifests artificial acceleration of electrons due to beam singularities. A few advantages of numerical beam propagation over the analytical expression are first discussed. Increasing the pre-plasma scale-length, acceleration of electrons appears in the forward direction while electrons circulate in the plane of polarization for sharp plasma boundary. For weaker intensities laser field is found to be mostly reflected from the skin layer at the sharp target-front resulting lesser energy gain. At increasing relativistic intensities plasma becomes transparent to the laser and more electrons are pulled out, and then pushed back through the plasma forming a circulating electron current. The mechanism of electron heating is under investigation

DEVELOPMENT AND CHARACTERIZATION OF ATMOSPHERIC PRESSURE RF PLASMA JET

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There has been a growing interest in the development of atmospheric pressure cold plasma devices, specifically Atmospheric Pressure Cold Plasma Jets (APCPJs), for clinical purposes [1, 2]. As APCPJ produces a blend of Reactive Oxygen and Nitrogen Species (RONS) therefore it can be used as a tool for the treatment of biological species [1]. Although several studies have been carried out to characterize the plasma jets, there is still a need to control the jet parameters for optimizing their performance. In the current study, a high voltage (~2 kV_{p-p}), 13.56 MHz, RF APCPJ is developed using a customized, series resonance circuit. A non-intrusive method is also proposed using V-I probe measurement for determination of global plasma parameters i.e. electron density (n_e) and electron temperature (T_e) which are the key parameters for the controlled production of RONS in atmospheric plasmas. To avoid the reflections at load side, voltage and current profiles were recorded before the matching network to ensure matching of plasma load impedance [3]. This was fulfilled by imposing the zero phase shift condition between the voltage and current probes. This technique was also used to compute the *complex* impedance of the plasma load and power dissipation under different operating conditions. Experiments were performed using helium and argon gases at different RF power (1-40 W) and gas flow rates (1-10 lpm). Preliminary calculations provide an estimate of n_e and T_e to be 10^{18} m^{-3} and 0.1 eV respectively for helium gas at 10 W RF power and gas flow rate of 6 lpm. A detailed description of the device and experimental results will be presented in the conference.

References:

[1] Atmospheric-pressure plasma sources for biomedical applications, *Plasma Sources Science and Technology*, **21**(4), p.043001, (2012)
[2] Atmospheric pressure plasma jets: an overview of devices and new directions, *Plasma Sources Science and Technology*, **24**(6), p.064001, (2015)
[3] Principles of plasma discharges and materials processing, *John Wiley & Sons*, (2005)

INDIGENEOUS DEVELOPMNET OF MULTIPORT LOOP TYPE CO-AXIAL DIRECTIONAL COUPLER

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ITER-India, IPR is responsible for delivery of 8 + 1(prototype) RF sources to ITER project [1]. Each RF source will be built of two RF amplifier chains combined at end stage. Each source will provide output power of 2.5MW/CW at VSWR 2:1. Total 20MW of RF power will be delivered to ITER plasma in frequency range of 36-60MHz [2]. The RF amplifier chain is built up in three stages high power amplifier HPA1, HPA2 and HPA3. To measure the forward and reflected RF power at the output of each stage of amplifier, co-axial directional coupler is connected as a part of transmission line components. In these directional couplers, pick up loops are mounted on the outer conductor. These pick up loops are coupled with the propagating RF wave in the transmission line through both capacitive (with E-field) and inductive coupling (with B-field). The distance and area of the loop decides the capacitive coupling while the orientation of the loop with respect to wave propagation direction decides the inductive coupling of loop. Thus the magnitude of power coupling is dependent on the capacitive coupling while the directivity of the signal coupled with loop is dependent on the inductive coupling. Usually one directional contains two ports one for forward signal while other for reflected power signal. For multiple measurements requirement there will be need of splitters and which will add loss and uncertainty error in the measurement. Increasing the number of ports in a directional coupler can provide multiple measurement signals without adding uncertainty error, but at the same time it may deteriorate return loss/ insertion loss response & isolation of directional coupler. ITER-India, IPR has indigenously developed, multiport directional coupler which is providing two forward and two reverse signals i.e. containing four measurement loops. This paper discusses the detailed design of loop type directional coupler and ways to improve directivity of directional coupler. At the same time indigenously development of multiport directional coupler is presented with detail simulation and analysis, without disturbing return loss/ insertion loss response & isolation of directional coupler.

References:

[1] Aparajita mukherjee et al., Status of R&D activity for ITER ICRF power source system, Fusion Engineering and Design 96–97 (2015) 542–546
[2] Rajesh trivedi et al., Outcome of R&D program for ITER ICRF Power Source System, Preprint, FEC-2018

INDIGENOUS DEVELOPMENT OF FINGER CONTACT FOR RF COMPONENTS IN MHZ FREQUENCY RANGE

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ITER India, IPR has to deliver 9 RF sources including one prototype RF source to ITER project. The indigenous development of different RF components like cavity, switch, direction coupler, stub, phase shifter, gas barrier etc. has been undertaken as part of development program to become self –dependent in high power RF components technology.
In these RF components, a critical sub-component is finger contact, which is developed indigenously by ITER-India, IPR to overcome monopoly of the foreign supplier. Finger contact is used in sliding parts of amplifier matching circuit and transmission line components for maintaining electrical contact during mechanical movement. The selection of material for contact finger is based on electrical conductivity and spring action properties of material. Beryllium copper brush 25 material is being used because it achieves the highest strength and hardness available among all copper alloys after age hardening. It exhibits excellent bendability. After forming in the fully age hardened condition, the above material provides a unique combination of very high strength with high conductivity and high fatigue strength limit. As per different requirement in the different RF components, ITER-India, IPR have developed two types of finger contact, i.e. one with 0.15 mm and other with 0.2 mm thickness. The manufacturing methodology, RF current carrying capacity and mechanical strength analysis of the finger contacts will be discussed in this paper.

THE A-PARTICLE AND HEAVY ION PICKUP AND ACCELERATION BY THE KINETIC ALFVEN WAVES

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Satellite observations show that in the fast solar wind, the α-particles and heavy ions are faster than most of the proton population. The high speed of these particles can be explained with the help kinetic Alfven waves (KAWs) [1,2]. The KAWs are known for strong wave particle interaction which are formed when the characteristic wavelength perpendicular to the background magnetic field becomes comparable to the ion gyroradius. Unlike the Alfven waves, the KAWs have a finite electric field parallel to the background magnetic field. It is this parallel electric field that traps the α-particles and heavy ions. So, in this investigation we derived the expression for the dispersion relation of the KAWs. It is found that when the velocity of the solar wind becomes equal to the local Alfven velocity, the low frequency KAWs are excited. In this situation, the α-particles and heavy ions are picked up by the wave and impart them the velocity greater than the solar wind. In the parametric analysis, we

studied the effect of magnetic field, proton number density, mass of the heavy ions and various other parameters on the efficiency of the pickup and acceleration. This study may be very useful to explain the high speeds of α-particles and heavy ions in the solar environment.

References :

[1] Song Liting and Xiao Chijie, Science in China, **45**, p 385-393, (2002).
[2] Xing Li, Quanming Lu and Bo Li, Astrophys. Journal., **661**, p L105-L108, (2007).

OPTIMIZED ELECTRON BEAMS FROM INHOMOGENEOUS PLASMA DENSITY PROFILE IN LASER WAKEFIELD ACCELERATION

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Electron beam quality in bubble regime of the Laser Wake Field Acceleration (LWFA) can be optimized even for a given laser and plasma parameter set by varying the plasma density ramp. This is experimentally possible for changing the pre-pulse parameters. In this study, we have simulated LWFA in bubble regime by taking exponentially rising plasma density profile similar to the experimental gas jet density profile. We have varied the plasma scale-length of the ramp part and optimized it to observe injected electron bunch quality. The 2D-PIC Simulations performed using the particle-in-cell (PIC) code EPOCH have been carried out for a laser pulse (wavelength=800nm, pulse duration=30fs, Intensity=5.5×10^{19} W/cm^{2,} spot diameter=9 microns) interacting with a plasma having initial exponential ramp followed by uniform density. The ramp density exponentially increases from a low value (0.0001 n_c) to maximum 1x 10^{25}/m^3 within 100 micrometre of longitudinal distance and remains constant after that for a length of 900 micrometre. By varying the density scale-length in the ramp, we could achieve the maximum electron energy 250 MeV (an enhancement of ~ 10 %) with less divergence and better energy spread. Further, an ion channel was introduced to control the transverse oscillations of electrons leading to different properties of accelerated electron bunch. The simulation results will be discussed in the light of their experimental possibilities. Numerical experiments of exponential plasma density ramp, and ion channel with such realistic density ramp have not been reported in literature.

ESTABLISHING MANUFACTURING FEASIBILITY OF ITER CRYOSTAT THROUGH MOCK-UPS

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Cryostat is a large stainless steel vessel providing vacuum environment to ITER Machine components. It houses and supports critical components like the vacuum vessel & superconducting magnets and also envelops the entire basic systems of the ITER Tokamak machine. It weighs ~ 3500 t and measures up to ~29 meters in diameter and ~29 meters in height. For the entire vessel, material of construction is Dual marked SS304/304L and thickness varies from 25 to 200 mm. It is a single wall cylindrical construction, reinforced by horizontal and vertical ribs. The Design, manufacturing and inspection of the cryostat is being carried out as per ASME Section VIII Division 2, supplementary requirement of ITER Vacuum Handbook with a stringent tolerance requirements proposed by ITER Organization.
The cryostat is made up of Austenitic stainless steel material which is fully weldable material, tough due to low thermal conductivity and high co-officiant of thermal expansion result from welding causes greater distortions in assembly which is getting enhanced when there is less mass available in component due to number of cutouts. In a view of these conditions and stringent tolerances proposed as a ITER requirements it was decided to perform to the scale mock-up for Base section and Lower Cylinder and Top Lid sector to simulate the 1) welding Configuration: thickness and Accessibility 2) Welding Processes and Sequence 3) Dimensional Tolerance requirement 4) Non-Destructive examinations.
In current work, the detail plan and process followed for Base section, Lower Cylinder and Top Lid Mock-ups and its execution is described in detailed along with achieved results and learnings. As a part of implementation cryostat base section and Lower cylinder manufacturing is completed at site, whereas upper cylinder and Top Lid manufacturing is in advance stage.

PROPERTIES OF PLASMOID INSTABILITY IN DOUBLE TEARING MODE

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Magnetic reconnection and tearing mode instability, both have been studied extensively in resistive MHD regime. Similar to single tearing mode, study of double tearing mode(DTM) has also been reported analytically and numerically in different geometries. Recent work on DTM shows the reconnection rate is proportional to positive exponent of Lundquist number [1], unlike Sweet-Parker model where reconnection rate is proportional to inverse(positive)

power of Lundquist number (resistivity). Recently, study of these DTM at high Lundquist number in Hall MHD regime [2-4] suggests the reconnection rate is also proportional to negetive (positive) exponent of Lundquist number (resistivity). Using a recently developed 2D compressible MHD solver, we will reproduce the result of these DTM studies in resistive MHD and extend this by including "Hall term" in resistive MHD equations. Detail of this work will be presented.

References:

[1] M. J. Nemati et. al., The Astrophys. J. 821:128 (4pp), (2016).
[2] Z. W. Ma et. al., Phys. Plasmas 22, p 062104 (2015).
[3] L. N. Wu et. al., Phys. Lett. A 377, p 2372, (2013).
[4] C. L. Zhang et. al., Phys. Plasmas 16, p 122113 (2009).

DUST ACOUSTIC ROUGE WAVES IN A COMETARY PLASMA ENVIRONMENT

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Nanometer and micrometer sized dust is present in almost all astrophysical and laboratory plasma environments. They not only alters the plasma spectrum, also give rise to various modes of electrostatic waves and vibrations. In this paper we study the properties of Dust Acoustic Rouge Wave(DARW)s in a cometary environment with positively and negatively charged dust components, hydrogen ions, solar electrons and cometary electrons. The lighter components are assumed to follow non – Maxwellian Kappa distribution. The solutions are found using reductive perturbation method, by deriving the Nonlinear Schrodinger Equation (NLSE).

References:

[1] Ion-acoustic rouge waves in multi-ion plasmas, M. Hassan et al, *Commun. Theor. Phys.* **71** 1017 (2019)
[2] Solitary waves in a plasma with oppositely charged dust(heavier, pair-ions) and kappa modeled lighter ions and electrons, Sijo Sebastian *et al*, *Phys. Scr.* **90** 035601(2015)
[3] Electrostatic solitary structures in non-thermal plasmas, R.A. Cairns *et al*, *Geophys. Res. Lett.* **22** 2709 (1995)
[4] Modulational instability and localized excitations of dust-ion acoustic waves, I. Kourakis *et al*, Phys. Plasmas **10** 3459 (2003)

ANALYTICAL & SIMULATION COMPARISON OF WAKEFIELD GENERATION IN PLASMA

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When an intense laser beam propagates through the plasma, strong wakefields are generated in both longitudinal and transverse direction which can be used for acceleration of charged particles [1,2,3]. The strength of generated wakefields depends on the power and repetition rate of the laser and its pulse profile [3,4]. The present study deals with the comparison and verification of both analytical and simulation results of laser-plasma interaction. The analytical formulation of the study is based on Maxwell's equations, Lorentz force, continuity, and Poisson equations. Variational as well as perturbation techniques are used for studying the wakefield generation in plasma [3,6]. Through mathematical formulation, we have found that the strength of the wakefield generated depends upon the pulse profile and power of the laser. Analytical results obtained were compared with the particle in cell simulation results.

References:

[1] T. Tajima and J.M. Dawson, Phys. Rev. Lett. 43(4) 267 (1979)
[2] P. Chen et al., Phys. Rev. Lett. 54(7) 693 (1985).
[3] P. Jha, A. Saroch and R. Mishra, Laser and Particle Beams 31,629–637 (2013).
[4] P. Sprangle et al., Phys. Rev. E 63(5) 056405 (2001)
[5] T. Katsouleas et al., Part. Accel. 22, 81 (1987)
[6] A. Sävertet al.,Phys. Rev. Lett. 115(5) 055002 (2015)

SOLITARY WAVES IN A COMETARY PLASMA WITH DUST, IONS AND ELECTRONS

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Plasmas are macroscopically neutral states of matter, containing free electrons and ionized atoms. Presence of any micron-sized species, called dust, could make the behaviour of plasmas significantly different. The altered equilibrium density by the dust could lead to various interesting phenomena in them. Such dusty plasmas are common in many astrophysical and laboratory environments [1-4]. In order to understand the morphology of coma, solitary waves in plasma have to be analysed [5]. Due to the presence of high energy particles in cometary tail and also due to tremendous decrease in number of collisions in such low temperature environments, cometary plasma deviate from the customary Maxwellian distribution. A non-Maxwellian distribution, called Kappa distribution, was described by

Vasyliunas, to cope with such situations[6]. It fitted well with many astrophysical environments. In addition to solar wind protons, solar wind electrons, H^+ and O^+, the coma of Halley contains H_2^+, He^+, He^{2+}, C^+, OH^+, H_2O^+, CO^+, H_3O^+ and S^+ [7]. In the present work, we study the existence of solitary waves in a many component plasma: negatively and positively charged dust, H^+ ions , solar electrons and cometary electrons. The effect of spectral indices, charge density and charge number of dust, on the amplitude of solitary waves is investigated. The influence of heavier dust addition is also examined. In addition, the range of values of N_i (ion number density) and T_i (ion temperature) for which compressive and rarefactive solitons exists is also studied.

References:

[1] Trajectories of charged dust grains in the cometary environment, Horanyi, M. and Mendis, D. *The Astrophysical Journal*, **294** 357 (1985)
[2] A survey of dusty plasma physics, Shukla P K, *Phys. Plasmas* **8** 1791 (2001)
[3] Introduction to dusty plasma physics, Shukla P K and Mamun A A 2002
[4] Solitary potentials in cometary dusty plasmas, Mamun A A and Shukla P K, *Geophys.Res.Lett.* **29** 1870 (2002)
[5] Morphological analysis of the tail structures of comet P/Halley 1910 II, Voelzke M R and Izaguirre L S, *Planet.Space Sci.* **65** 104 (2012)
[6] Solitary waves in a plasma with oppositely charged dust(heavier, pair-ions) and kappa modeled lighter ions and electrons, Sijo Sebastian *et al*, *Phys. Scr.* **90** 035601(2015)
[7] Ion composition and dynamics at comet Halley, Balsiger H et al, *Nature* **321** 330 (1986)

INVESTIGATIONS ON HYDROGEN PLASMA IN LARGE VOLUME PLASMA SYSTEM

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Hydrogen plasmas offer a wide variety of applications due to the presence of multiple species *viz.*; H, H_2, H^+, H_2^+, H_3^+, H^- etc. Some notable applications are ion beam (H^+, H^-) production for fusion plasma heating and plasma processing [1-3] of semiconductors. Both of these applications require the production of uniform and dense plasma over a large area which, in case of plasma processing, enables Si wafers of 12-18 inches to be treated uniformly resulting in reduced manufacturing time. On the other hand, a thermonuclear fusion reactor like ITER [4] requires a large area high energy H^- beam to generate neutral beam for diagnostics and heating of fusion plasma. IIT Delhi has a large volume plasma system that has been able to produce very high density ($n \sim 10^{11}$ cm^{-3}), large volume (1 m dia. × ≈ 1 m high) uniform Ar plasmas at moderate powers of a few hundred Watts using compact ECR (Electron Cyclotron Resonance) [5, 6]. The existing system and the aforementioned applications of large-area hydrogen plasmas provided the motivation to study its behavior in the existing experimental large volume plasma chamber at different pressures and input powers. Initial experiments have been conducted in the large volume system using Hydrogen gas at low power (400W) and low pressure (2.0mTorr) using only a single CEPS attached to the top dome. Radial measurements were taken using two cylindrical Langmuir probes placed at two axial planes at z = 37.5 cm & 60.0 cm from the CEPS source mouth. A monotonically decreasing plasma profile is obtained with density (n) of ~ 4.5×10^{10} cm^{-3} at the center of the chamber and ~ $1.5x10^{10}$ cm^{-3} at r = 30 cm, along with average electron temperature (T_e) around 1 eV. This low-temperature plasma is favorable for volumetric production of H^- ions which are further useful in neutral beam injection for fusion plasma heating. Also, the low energy plasma is advantageous in damage-free plasma processing of Si wafers. Further experiments with high power (> 1 kW) are planned in the future. Complete chamber assembly and the results of the conducted experiments will be presented in detail.

References:

[1] Fantz, U., Franzen, *et al*, Review of Scientific Instruments, 79(2), 02A511, 2008
[2], Muramatsu, M., and A. Kitagawa , Review of Scientific Instruments 83(2), 02B909, 2012.
[3] Wang, F, *et al*, ACS applied materials & interfaces, 6(17), p.015098, 2014.
[4] Ikeda, K, ,Nuclear Fusion,50(1), p014002, 2009
[5] Ganguli, A., *et al* Plasma Sources Sci. Technol. 25(2), p.025026, 2016.
[6] Tarey, R. D. *et al* , Plasma Sources Sci Technol. 26(1), p.015009,2016.

WELDING IMPROVEMENTS FOR CRYOSTAT FABRICATION: EXPERIENCE AND LEARNINGS SO FAR

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Cryostat is a large Austenitic stainless steel vessel providing vacuum environment to ITER Machine components and supports critical components like the vacuum vessel & superconducting magnets and also envelops interfacings systems of the ITER Tokamak machine [1]. It weighs ~ 3500 t and measures up to ~30 meters in diameter and ~30 meters in height. It is made up of a dual mark 304/304L single wall cylindrical construction, reinforced by toroidal and vertical ribs. In addition to the Crysotat Design code ASME Section VIII Div. 2[2], ITER vacuum handbook also applies for the Design, fabrication and inspection of the cryostat segments. Due to large number of interfacing components, the Cryostat consists of number of cutouts and large number of penetration resulting in number of subassemblies. It is also made Massive amount of welding deposition is required to join these subassemblies to fabricate the segment.Fabrication of Cryostat involves stringent tolerance requirements, similar and dissimilar weld joints including higher thickness weld joints in every position, welding accessibility to the welding machine and welding operator, ITER Vacuum requirements [3]. To achieve these requirements, several improvements were done from the currently followed practices. One of the important key factors for the manufacturing of welded components is to design weld edge preparation which facilitates the welder/welding operator to produce sound welds. Current work details out the improvement done for the various weld joints from 5mm thickness weld joint (Lip seal weld joints) to

290mm Top Lid Flange. All improvements are validated through various welding Mockups followed by volumetric examinations. This poster also discusses the successful Implementation of the improvements and learnings in the actual manufacturing at Factory and Site.

References:

[1] A. Bhardwaj, "Overview and status of ITER Cryostat manufacturing" *Fusion Eng. Des.*, 2016
[2] ASME Section VIII Div. 2
[3] ITER Vacuum Handbook and its appendices

MAGNETIC FIELD AND 3D ION TRAJECTORY CALCULATION FOR SST NBI BENDING MAGNET

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Neutral Beam injection (NBI) is a very well established and efficient technique for heating and current drive of magnetically confined tokamak plasma. The objective of Steady state Superconducting Tokamak (SST) NBI system is to raise plasma ion temperature to 1 keV by injecting Neutral hydrogen beams of energy 30 - 55 keV. Production of NB is a complex process. First hydrogen plasma is produced in vacuum chamber called plasma box. The plasma consists of three species of positive hydrogen ions e.g. H1+ (full energy component), H2+ (half energy component) and H3+ (one-third energy component) which are separated from the plasma box and accelerated to the desired energy by set of electrodes consists of shaped apertures maintained at differential voltages called ion extractor grids. These accelerated positive hydrogen ions get neutralized after passing through a hydrogen gas cell called neutralizer by a process called charge exchange. The neutralization efficiency is not 100% as it depends on beam energy, e.g., in our case it is 70% for positive hydrogen ion beam of energy of 55 keV. The un-neutralized ions are separated and deflected by Bending Magnet placed just after neutralizer. These deflected un-neutralized ions get dumped on a system called ion dump. The ions which are neutralized forms an accelerated neutral beam which enters into tokamak plasma and deposit their kinetic energy among the background tokamak plasma ions and electrons as a result plasma heating takes place. The bending magnet plays a vital role for production in neutral beam. For our SST NBI a bending magnet is designed with maximum magnetic field of 1.7 kG, fabricated and installed inside NBI vacuum vessel. During beam operation we must know the trajectory of the above mentioned three hydrogen ion species so that all these ions get deposited into proper locations on ion dump without damaging other beam line components. This paper shall present both 3D ion trajectory plot and magnetic field calculation done using 3D OPERA computer program. This work would help us to pre-set bending magnet parameters, e.g., current density required to generate required magnetic field for given beam energy and 3D ion trajectory originated from the gap between the pole pieces and identification of safe incidence location above bending magnet.

EXPLORING THRUSTER POTENTIAL OF COMPACT ECR PLASMA SOURCE

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The performance of a plasma thruster is assessed for efficient propulsion by analysing the unique characteristics of plasma produced by a Compact ECR Plasma Source (CEPS). For this purpose CEPS [1] was attached coaxially to two different sizes of expansion chamber, namely Small Volume Plasma System (SVPS, ID = 15 cm, Length = 37 cm) and Medium Volume Plasma System (MVPS, ID = 48.2 cm, Length = 75 cm). Argon plasma produced by CEPS at 2.45 GHz, cw, microwave frequencies was characterized using a cylindrical Langmuir Probe (LP) along the axis over a wide range of pressure. In the first study where the CEPS was attached to the SVPS, only the downstream plasma in the SVPS could be evaluated for its thruster properties since *no measurements could be performed within the harsh plasma environment of the CEPS* and so that plasma properties within the CEPS were unknown at the time. Within the SVPS, typical bulk and warm electron density, $n \approx 10^{11}$ cm^{-3} and $n_w \approx 10^8$ cm^{-3} respectively were measured at 0.5 mTorr and 500 W of microwave power. A unique feature was the *n/B = const*, scaling observed along the axis over a wide range of argon pressure. Bulk and warm electron temperatures ($T_e \approx 2.5$ eV and $T_w \approx 50$-60 eV) were uniform along the axis with the plasma potential dropping gently from $V_p \approx 27$ V to 18 V along the axis. Steady state equation of motion for ion was solved to calculate the ion flow velocity to evaluate the thrust produced by the system. Estimates yield peak thrusts of ∼2.5 mN (at 0.5 mTorr) and 7.5 mN (at 0.05 mTorr), for moderately low microwave powers of ∼500 W [2]. The MVPS experiments were conducted to accommodate low-pressure operation for reducing friction. Apart from other differences with the SVPS, a major difference is that the MVPS plasma *does not obey* the *n/B = const*. scaling seen in the SVPS. A completely new LP was designed and fabricated to withstand the plasma within CEPS, for assessing if the CEPS can provide significant thrust *on its own*. Inside the CEPS, at ≈ 0.5 mTorr and 600W, high plasma densities (≈ 10^{12} cm^{-3}) and high bulk electron temperatures (15-20 eV) were observed. Apart from this, the most unique feature of the CEPS plasma is the presence of *very high plasma potentials that are dropped sharply within a short distance by about ≈ 65 V, inside the CEPS itself* [3]. The latter drop can accelerate ions efficiently and the computed thrust *due to the CEPS alone* was found to be ≈ 38 mN. The latter values are *very high in comparison to existing thrusters like the helicon thrusters* (≈ few mN). This suggests that it might be possible to develop the CEPS into an efficient standalone thruster.

References:

[1] Ganguli A and Tarey R D 2006 Permanent Magnet Compact Electron Cyclotron Resonance Plasma Generator Indian Patent # 301583, Patentee: IIT Delhi
[2] Ganguli A et. al. Plasma Sources Sci. Technol. **28**, 035014, (2019)
[3] Verma A et. al. Plasma Res. Express **1**, 035012, (2019)

QUALITATIVE ANALYSIS OF MATERIALS USING LASER INDUCED BREAKDOWN SPECTROSCOPY

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Laser Induced Breakdown Spectroscopy (LIBS) utilizes the atomic emission of radiations from the laser produced plasma of materials. The plasma is formed by laser ablation, the ionization and evaporation of atoms and molecules on the surface by high-power laser pulses of nanosecond time scale. The LIBS technique has become a very popular analytical method in view of some of its unique features such as applicability to any type of sample, practically no sample preparation, remote sensing capability and speed of analysis [1]. Laser Induced Breakdown Spectroscopy was one among the two pay loads of the Pragyan rover of the prestigious Chandrayan-2 mission. This technique is highly sensitive for qualitative analysis of concentrations of few parts per million. The technique has great applications in space exploration, deep ocean analysis, pollution monitoring, detection of adulterants and polar ice research. In the present work, the LIBS analysis of an Indian five rupee coin was done using Q-switched Nd: YAG laser pulses of wavelength 1064 nm. The presence of the cupronickel (Cu-Ni) alloy was qualitatively identified by analyzing the characteristic emission spectra.

References:

[1] Laser Induced Breakdown Spectroscopy (LIBS), Part I: Review of basic diagnostics and plasma particle interactions: Still challenging issues within the analytical plasma community, Focal Point, Accepted manuscript (30 September 2010).

PRODUCTION OF ARC PLASMA AND ITS CHARACTERIZATION FOR DIFFERENT MATERIALS OF THE ELECTRODES

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Plasma is produced by arc discharge between two electrodes made of brass, copper, and iron and is characterized by using movable single and double Langmuir probe. A movable Langmuir single probe system has a reference point since it is biased with reference to one of the electrodes of the arc plasma producing system. In double probe method, each probe is biased with respect to one another. The two probes in a vertical plane are biased with a potential and allowed to move through the arc plasma. The plasma density obtained is in the order of 10^{17} m^{-3} suggesting that the arc is appropriate for the study and treatment of surfaces as well as for treatment of water. Variation in parameters of the arc plasma and its characterization for different materials of the electrodes are studied.

MODELING ELECTRONEGATIVE PLASMAS WITH Q NON-EXTENSIVE DISTRIBUTION OF ELECTRONS

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In many plasma sources, the distribution of electron density is found to be deviated from their well- known Boltzmann distribution. Therefore, non-extensive statistics [1,2] is adopted to analyze such systems. The investigation of change in the behaviour of plasma parameters due to the presence of negative ions in such systems becomes essential since it will reveal advanced applications of electronegative plasmas in many fields like surface-plasma interaction, plasma-based surface treatments [3], and more. In the present study, we have investigated the sheath formation mechanism for electronegative plasmas where behaviour of positive ions, negative ions, and electrons are described by their fluid approach, Boltzmann distribution, and q-non-extensive distribution, respectively. The impact of both positive and negative ions' temperature on the sheath formation mechanism is analyzed in detail since the temperature of the ions plays a crucial role in many plasma-based material processing experiments; change in temperature results in abrupt modifications in surface properties. Also, the impact of density ratio of negative ions to electrons i.e. electronegativity on the sheath formed is entertained herewith.

References:

[1] Tsallis C 1988 Possible generalization of Boltzmann-Gibbs statistics *J. Stat. Phys.* **52** 479–87

[2] Borgohain D R and Saharia K 2018 Behavior of collisional sheath in electronegative plasma with q- nonextensive electron distribution *Phys. Plasmas* **25** 32122

[3] Singh O, Malik H K, Dahiya R P and Kumar P 2016 Influence of negative bias voltage on structural and mechanical properties of nanocrystalline TiNx thin films treated in hot cathode arc discharge plasma system *Ceram. Int.* **42** 18019–24

EFFECT OF COLLISION ON ELECTRONEGATIVE MAGNETIZED PLASMA SHEATH

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The effect of collision on electronegative magnetized plasma sheath has been investigated by using three-fluid model. The electronegative plasma consists of singly charged positive hydrogen ions (H^+), negative oxygen ions (O^-) and electrons. The electron and negative ions are considered to obey Boltzmann distribution and the normalized fluid equations are solved numerically for given boundary conditions to analyze potential profile, ion density profile, ion velocity profile, kinetic energy profile, electron density profile and negative ion density profile. It is found that the collision frequency has significant effect on the sheath properties. The electrostatic potential monotonically increases towards the wall and its magnitude at the wall increases from 38 to 47 for the increasing of collision frequency from 0.00 to 0.03. The ion velocity decreases at the sheath edge and increases towards the wall and its magnitude at the wall increases from 8 to 9 for the increase in collisional frequency from 0.00 to 0.03. The obtained results are compared with previous works and found to be in qualitative agreement. The study of electronegative magnetized plasma sheath has useful applications in surface modification of materials, sterilization of equipments, etching, sputtering, thin film deposition and many more.

MAGNETOGRAVITATIONAL STABILITY OF HALL PLASMA WITH FLR CORRECTIONS ANDTHERMAL CONDUCTIVITY FLOWING THROUGH POROUS MEDIUM

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The problem of flow through porous medium of a hydro-magnetic system in context with astrophysical system is carried out. The porosity, viscosity, electrical and thermal conductivity and finite Larmor radius (FLR) corrections along with MHD equations are considered for the problem. The condition of instability of self-gravitational plasma is investigated in the presence of Hall current. The medium is to be assumed to be acted by a uniform magnetic field. The genera dispersion relation is obtained from linearized perturbation equations of the problem using normal mode analysis method. The general dispersion relation is discussed for transverse wave propagation to the magnetic field. In the transverse mode of propagation the effect of porosity on Jeans criterion is observed in the presence of magnetic field and FLR, however it reduces the stabilizing effect of both the

parameters. The effect of Hall current is not appeared in Jeans criterion of the system. The condition of stability of the system is also discussed with help of Routh Hurwitz's criterion.

EFFECT OF MAGNETIC FIELD ON ELECTRONEGATIVE PLASMA-WALL TRANSITION

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The present work is concerned with the electronegative magnetized plasma sheath properties via fluid approach, which consists of helium ions (He+), negative oxygen (O^-) and electrons. It is assumed that electrons and negative ions are in thermal equilibrium and obey Boltzmann distribution whereas ions follow the momentum transport equation. The compiled set of fluid equations has been solved for the given boundary conditions. It is found that the magnitude of electrostatic potential monotonically increases towards the wall, which is consistent with Debye shielding. The particle densities decrease towards the wall whereas decreasing rate of negative ions much faster than that of ions and electrons. The magnitude of velocity of ions at the wall gets increased from 5 km/s to 38 km/s when the magnetic field increases from 50 to 150 mT. In order to shield the effect of wall potential the space charge density increases towards the wall and its peak nature shift towards the sheath entrance indicate.

WAKEFIELD GENERATION IN MAGNETIZED PLASMA

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In this study we report the effect of magnetic fields on the axial and longitudinal wakefields generated due to the laser plasma interaction in the mildly relativistic regime of the laser intensity. Laser-plasma interaction is affected by the presence of external magnetic fields [1-3]. Numerical study of the wakefields has been performed considering the propagation of a linearly polarized laser pulse through plasma which is uniformly magnetized. The external magnetic fields have been applied along the propagation directionas well as perpendicular to the polarization of the laser pulse. An enhancement in the axial wakefields generated can be used for accelerating the charged particles to high energy range in the plasma based accelerators. Perturbative technique is used to calculate the electric and magnetic fields generated within and behind the laser pulse. Further, using VSim particle-in-cell simulation codes, the analytical study have been validated.

References:
[1] Brodin G. and Lundberg J., Phys. Rev. E, 57 (1998) 7041
[2] Hur M. S., Gupta D. N. and Suk H., Phys. Lett. A, 372 (2008) 2684.
[3] Ren C. and Mori W. B., Phys. Plasmas, 11 (2004) 1978.

EFFECT OF MAGNETIC FIELD AND ITS OBLIQUENESS ON PLASMA SHEATH CHARACTERISTICS HAVING TWO SPECIES OF POSITIVE IONS

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The present work is concerned with magnetized plasma-wall interaction process in which the plasma consists of two species of singly charged positive ions (helium and argon) and electrons. It is assumed that the electrons obey the Boltzmann distribution. Both the ions have same degree of ionization but different masses. The normalized set of fluid are solved for given boundary conditions. It is found that the variation of magnitudes of magnetic field and its obliqueness have significant effect on plasma sheath properties. The normalized electrostatic potential is minimum at the sheath entrance and then monotonically increases towards the wall. As the magnetic field increases from 0.082 T to 0.411 T, the magnitude of wall potential gets increased from 34 to 73. The magnetic field and its obliqueness have no significant effect on density profile of heavier ion species; however the lighter ions are significantly affected. The velocity fluctuations of lighter ions is more than that of heavier ions and the velocities at the wall increase from 6 to 8 and 2.8 to 3.6 when the obliqueness of magnetic field increase from 10^0 to 30^0, respectively.

MULTI-WAVELENGTH SIGNATURES OF BUILD UP, ACTIVATION AND ERUPTION OF A MAGNETIC FLUX ROPE FROM THE SOLAR ATMOSPHERE

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Magnetic flux ropes (MFRs) are sets of magnetic field lines that are twisted around a common central axis usually more than once [1]. MFRs can store huge amount of non-potential magnetic energy in them and therefore play important role in the solar eruptions. The generation mechanism of MFRs is, however, less understood. Several statistical studies (i.e., [2]) have established that large solar flares are generally accompanied by small-scale pre-flare activities. Depending on the location of the pre-flare activities compared to the location of the main flare, they are classified in three groups: co-spatial, adjacent and remote

[3]. Although the occurrence of co-spatial and adjacent pre-flare brightenings, are frequent and their role toward the main flare is well understood, cases of remote pre-flare brightenings are very rare. We present a unique event where a flux rope was built up and activated in response of magnetic flux cancellation along the polarity inversion line (PIL) and its triggering was caused by a remote region of pre-flare brightening. The active region associated with the eruptive flare consisted with a leading negative polarity sunspots and a bipolar trailing sunspot, associated with striking moving and rotational motions. Non-linear force free field (NLFFF) extrapolation results indicate presence of a flux rope along the PIL in the trailing sunspot which was observed in the form of a hot channel associated with a filament. An elongated phase of flux enhancement and a subsequent period of flux cancellation from the flaring region prior to the onset of the flare, led to build up and activation of the flux rope. The remote pre-flare brightening region was associated with a set of randomly oriented field lines. Our analysis suggests occurrence of strong, localized regions of photospheric current of opposite polarities at the remote region where the initial reconnection took place. Triggering of the eruption was caused by a slipping type reconnection between the remote region and one leg of the flux rope. The eruption of the flux rope led to formation of a fast, halo coronal mass ejection which caused one of the largest geo-magnetic storms in the last decade. Further, magnetic energy from the active region increased by a subtle amount during pre-flare enhancement and decreased during the impulsive phase which is expected.

References:

[1] Coronal prominence structure and dynamics: A magnetic flux rope interpretation, Gibson, S. E., & Fan, Y. 2006, Journal of Geophysical Research (Space Physics), 111, A12103.
[2] Soft X-Ray Pre-Flare Emission Studied in Yohkoh-SXT Images, Fárník, F., & Savy, S. K. 1998, SoPh, 183, 339
[3] Spatial Relations between Preflares and Flares, Fárník, F., Hudson, H., & Watanabe, T. 1996, SoPh, 165, 169.

UNDERSTANDING THE ROLE OF THICKNESS OF PLASMA IN THE PROPAGATION OF ELECTROMAGNETIC WAVES IN COLLISIONAL PLASMA USING COMPUTER SIMULATION TECHNOLOGY

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Plasma with its property of quasi-neutrality can selectively change the mode of propagation of electromagnetic (EM) waves in it. The present work discusses the propagation of EM waves of 8-12 GHz in a cold un-magnetized collisional plasma using CST, Microwave studio which is commercially available software. The microwave power is radiated through a horn antenna which is designed for a constant gain throughout the operating frequency range. For the presented 3-D simulation 'the plasma' is considered as cold plasma and is treated as Drude Dispersion material whose properties are governed by two plasma parameters namely Plasma frequency (ω_p) and collisional frequency (υ_c). The thickness of the plasma plays an important role in propagation of EM waves through it. The work studies the relation between the wavelength of the incident microwaves and its propagation in the plasma. The present works describes the optimum thickness of plasma for maximum attenuation of the incident microwaves. The studies are carried out at the far field of the antenna.

Keywords: Electromagnetic wave Propagation, Drude model, Computer simulation technology, plasma parameters.

STUDY OF IMPURITY BEHAVIOR IN SST-1 TOKOMAK PLASMA USING VISIBLE SPECTROSCOPY

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Spectroscopy is a non-invasive important tool in probing plasma behaviour as it gives information about nature and quantity of impurity. Tokomak plasma has the combination of low, such as oxygen and carbon and medium Z, like chromium and iron, impurities depending on the plasma wall material. Impurity plays a crucial role in the plasma current evolution and temperature as it decides the plasma resistivity. It also gives us information about energy loss by radiation. The spectroscopic studies of radiated emission from hydrogen and impurities present in the tokomak plasma gives information on various plasma parameters, such as ion temperature, Zeff and their variation with operating conditions.

In SST-1 tokomak, a low resolution survey spectrometer is used to record typical spectrum in the plasma current flat top region representing various species for qualitative and quantitative analysis of composition of Plasma. 7 channel fiberscope system, where light is transported using optical fibres of 1 mm core diameter and NA 0.22, wavelength selected by an Interference filter with 1 nm band width, and detected by photomultiplier tube is regularly used to monitor the emissions from fuel gas (Hydrogen) and low Z (C, O, He) species from the plasma. Visible Continuum signal from Line free region at 523.4 nm with $\Delta\lambda$= 1nm, is also monitored with good temporal resolution to Infer Z_{eff} of Plasma. We will present the results from various SST-1 Plasma discharges describing the variation in impurities and Z_{eff} value with plasma parameters and discuss the correlation between impurities and plasma properties with different operating conditions. Electron density and Temperature estimation using He line intensity ratio during LHCD breakdown experiment will also be discussed.

ROLE OF FINITE EXTENT OF LASER PULSE IN OVERDENSE PLASMA

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In laser plasma system, interaction of high power laser with solid target results in ionising the target and formation of REB(Relativistic Electron Beam). Many studies have reported that plasma generates return current in response to incoming forward current consisting of REB in such way that they compensate each other [1] . Among these, analytical studies have been initializing system in equilibrium and most simulation studies are done with infinite laser pulse interaction with overdense plasma. But in experimental scenarios, system is in inequilibrium state as intense laser will interact with solid dense plasma in very violent and non-linear fashion. Transverse finite extent of pulse also opens up a possibility of magnetic field generation at the long scales in the bulk plasma[2]. In this presentation we will show the role of return current in inhibiting REB and in generating long scale magnetic field. Role of plasma impedance will also be discussed.

References:

[1] Anomalous Resistivity Resulting from MeV-Electron Transport in Overdense Plasma, Y Sentoku et. al. Phys. Rev. Lett. 90, 155001, (2003)
[2] Evidence of new finite beam plasma instability for magnetic field generation, arXiv:1712.03099v1

DEVELOPMENT OF STEERABLE ECRH LAUNCHER FOR ADITYA-U AND SST-1

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Electron Cyclotron Resonance Heating (ECRH) can be used for various experiments on the tokamak. It is primarily used for pre-ionization, heating, current drive and Neo-classical tearing Mode (NTM) suppression [1, 2]. The high power microwave beam generated by Gyrotron can be used for NTM suppression by steering it in the poloidal direction by ECRH launcher [3]. This steering is done in real time. The new ECRH launcher is under development for Aditya-U and SST-1 tokamak. This launcher is capable of steering the ECRH beam up to ±10º in poloidal direction in 100 ms. The poloidal movement of the launcher will be controlled by a closed loop system. The toroidal steering of the beam for maximum ±20º is also possible on shot-to-shot basis. This poster explains the design of

mechanisms for the mirror movement and thermal and structural considerations in design of the launcher. The high power microwave (~500 kW) beam incidents on the mirrors and it has MW level of transient heat fluxes, which is absorbed by thermal mass of the mirror [4]. Thermal simulations have been done to predict the temperature rise in the mirror for single pulse as well as multi pulse operation. Performance of two different mirror materials SS304 and Oxygen Free High Conductivity Copper (OFHC) have been studied and compared. The bulk mean temperature rise and cool down time have been evaluated for both the materials using finite element simulations.

References:

[1] V. Erchmann, "Steady state ECRH for next step superconducting fusion devices," Fusion Engineering and Design,Vol 84, Issues 2–6, June 2009
[2] D. Bora, K. Sathyanarayana, B.K.Shukla et. al. "Cyclotron Resonance Heating systems for SST-1," Nuclear Fusion 46 (2006) S72 - S84
[3] R. J. La Haye, "Neoclassical tearing modes and their control," Physics of Plasmas Vol 13, 2006
[4] Braj Kishore Shukla, Paresh J. Patel, Jatin Patel, Rajan Babu et al "42-GHz/500-kW Electron Cyclotron Resonance," IEEE transactions on plasma science, vol. 43, no. 1 p 485-488

IMPACT OF NITROGEN GAS ON EDGE AND SOL PLASMA TURBULENCE

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Edge and Scrape-off Layer (SOL) plasma are highly turbulent in the presence of interchange instability. This instability can be modified in the presence of impurity gases like Neon, Argon, Nitrogen, etc. The main purpose of these gas feeds is to reduce heat loads on the limiter plates and also to provide radiative improved confinement, and disruption mitigation in tokamak. Earlier, impact of Neon gas has been studied [1]. Here we have analyzed the effect of Nitrogen gas as an impurity in the Edge and SOL regions. We have derived a set of model equations for the description of the interchange plasma turbulence in the presence of the Nitrogen gas. The gas is ionized by the electron impact ionization and the ionized gas subsequently radiates energy during radiative cooling processes with the plasma electrons. The model equations have been solved using a numerical code where all input parameters are related to Aditya tokamak. Dynamics of Nitrogen molecular and atomic ions have been simulated and it is found that atomic ions penetrate much deeper into the plasma due to the presence of inward propagating pulse generated by interchange turbulence. Molecular ions mainly form in the last closed flux surface region and dissociate before propagating further inside in the Edge. The radial profile of electron density, electron temperature, molecular and atomic ions has been presented from the numerical data. The reduction of radial outward particle flux in the presence of Nitrogen gas has been observed mainly due to the increase of

radial electric field shear. It is found that the Nitrogen gas shifts poloidal wave numbers towards lower values that indicate the reduction of the interchange plasma turbulence at longer wavelengths.

References:

[1] Dynamics of Neon Ions after Neon Gas Seeding into Tokamak Plasma, N. Bisai et al 2019 Nucl. Fusion in press *https://doi.org/10.1088/1741-4326/ab3d31*.

ANALYSIS OF SPECTRAL EMISSIONS IN VUV (110 - 300 NM) FROM IMPURITIES IN SST-1 TOKAMAK PLASMA

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Impurities in the tokamak plasma mostly provide emissions in the X-ray to vacuum ultraviolet (VUV) regions of electromagnetic spectrum as the core electron temperature is ~ keV in the present day's tokamak. Then, VUV spectroscopy has been used extensively to study the impurity in the plasma core to understand there transport into the core from the plasma edge, which interacts with plasma facing components, sources of impurities. The spectral lines in the VUV wavelength range of 110 to 300 nm is reach in information as it has many radiative transitions from Be, Li, and He-like ions of impurities. As for example, spectral lines at 229.6, 154.8 and 227.1 nm are from Be (C^{2+}), Li (C^{3+}), and He (C^{4+}) -like carbon ions. In SST-1 tokamak spectral lines in this wavelength have been regularly monitored using a normal incidence spectrometer. The VUV spectroscopic system consists of a 1 m Czerny - Turner type spectrometer and an X-ray sensitive CCD camera having 1340x400 pixels. The spectrometer is equipped with the MgF_2 coated grating having 1200 lines/mm blazed at 150 nm enabling the reciprocal linear dispersion of 8.3Å/mm. The wavelength coverage is 215 Å around a pre-selected VUV wavelength. The diagnostic is integrated with SST-1 tokamak in vacuum and is evacuated using turbo molecular pump based vacuum pumping system. The VUV spectrum is recorded at pre-selected wavelength with a temporal resolution of 10-20 ms depending upon exposure time of the CCD. In this study, spectral lines have been analyzed through their identification and VUV survey spectrum is presented for the typical SST-1 plasma. The temporal evolution and statistical behaviour of the various spectral lines are also investigated with respect to various machine and plasma parameters.

PLASMA NITRIDING AND CARBURIZING OF TUNGSTEN AND ITS ALLOY FOR FORMATION OF TUNGSTEN NITRIDE

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In a fusion reactor helium is the result of thermonuclear reaction. As the diverter material is mainly made of tungsten material, it has been observed that during the thermonuclear reaction, interaction between plasma containing helium and pure tungsten takes place. This leads to formation of nanostructures called tungsten "fuzz" which are highly brittle and can lead to increased sputtering of tungsten as well as contamination of the plasma by tungsten particles consequently. In this regard reducing the formation of tungsten fuzz formation has to be addressed. In order to solve this problem it is required to carry out some modification of tungsten material. This can be done by incorporating nitrogen as reported by many researchers [1-2]. Tungsten carbide material is usually very hard in nature and therefore it is widely used for manufacturing of cutting tool tips for high - quantity and high - precision machining. Tungsten carbide is also being used in nuclear reactor as a neutron reflector [3]. Since, Tungsten carbide tips are expensive; a coating of tungsten carbide on high speed steels can be used as a cheap alternative.In this study, efforts have been done for producing tungsten nitride and tungsten carbide using plasma nitriding and carburizing processes. They were treated at 950 ^{o}C for 5 and 10 hours. Plasma nitrided and carburized tungsten samples were then characterized for surface hardness, layer thickness, surface roughness and the phases formed during the processes. It was found that there was an increase in surface hardness after these treatments. However, it was found that the thicknesses of the modified layers were different in these processes mainly due to the different diffusion coefficients of nitrogen and carbon in tungsten material.

References:

[1] Interaction of nitrogen plasmas with tungsten K. Schmida , A. Manhard, Ch. Linsmeier, A. Wiltner, T. Schwarz-Selinger, W. Jacob, S. M and Nucl. Fusion 50 (2010) 025006 (8pp)
[2] Nitrogen retention mechanisms in tokamaks with beryllium and tungsten plasma-facing surfaces PHYSSCR-103382.R1
[3] Tungsten Carbide compact primary shielding for Small Medium Reactor, M.A.N. Giménez, E.M. Lopasso, Annals of Nuclear Energy 116 (2018) 210–223

EDGE BIASING ON THE EDGE AND SCRAPE-OFF LAYER TOKAMAK PLASMA TURBULENCE

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Edge biasing in tokamak edge region is an important topic as it can control particle recycling, exhausts, confinement time, and reduction of heat loads on the limiter plates. Here, in this work, we have investigated some of the above effects theoretically and also numerically. Electron conservation, quasineutrality, and electron energy equations have been solved, where biasing in the edge region is provided by material plates. Interchange plasma turbulence has been used for the description of the equations [1,2]. Positive, negative, and AC biasing have been investigated. In each case, the poloidal length of the biasing probe has been changed and the impact of this biasing length has been analyzed. It is found that radial profile becomes more peaked for lower poloidal biasing length, but when the length increases more than 35 ion gyroradius then the radial profiles do not vary with the length. The radial electric field and its shear are also modified by the length. Normally, the shorter length gives more shear rate at the probe position but in the edge region the situation becomes different, details will be reported. Turbulent decorrelation rate and radial electric field shear are found almost the same order of magnitude for different type of biasing. AC biasing becomes less effective than negative biasing.

References:

[1] N Bisai, Amita Das, Shishir Deshpande, *et al.*, Phys. Plasmas, **11**, 4018 (2004)
[2] Ph. Ghendrih, Y. Sarazin , G. Attuel, *et al.*, Nucl. Fusion **43**, 1013–1022 (2003)

BUILDING MANAGEMENT CONTROL SYSTEM FOR NEW LABORATORY BUILDING HVAC PLANT AT IPR

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The Building management system for new laboratory building of IPR is consist of nine number of Direct Digital Control panels (DDC). DDC panels are incorporating programmable logic controllers (PLC), I/O expansion modules, Communication modules and end terminal connections. Field process instruments such as pressure transmitters, temperature transmitters and level switches are connected to analog input and digital input modules of PLCs. Final control elements such as heaters, variable frequency drives (VFD) of motors and three way diverting valves are connected to analog output and digital output modules of PLCs. Main control station is located in new auxiliary building at IPR. The Control station is installed with Supervisory control and data acquisition system (SCADA) of Vijeo Citect. The communication is established

between the central SCADA system and nine DDC panels using Modbus TCP/IP communication. The graphical user interfaces (GUI) are developed in SCADA system for real time monitoring and controlling the HVAC parameters. The historical and real time trends are developed for analysis purpose. The alarm logs for critical system parameters and event logs generations are programmed in SCADA. The installation and commissioning tasks of these nine DDC panels and Main control station are presented in this paper.

PLASMA CHARACTERISATION IN A SPHERICALLY CONVERGENT ION SOURCE

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Different types of compact plasma sources are designed for utilizing its effects in specific fields such as fusion, material studies, propulsion studies, and other potential applications. Sources that can produce fusion by a discharge plasma requires a high density of ions. The Spherically Convergent Ion Source (SCIS) is one of such plasma source that can confine ions isotropically by the principle of Inertial Electrostatic Confinement Fusion (IECF) [1]. This principle was first proposed by P. Farnsworth [2] and experimentally verified in early 70's by Hirsch in a device called Fusor [3]. The main concept of this device is to accelerate lighter ions such as H^+, D^+, T^+ in a negative potential well wherein the inertia of recirculating ions electrostatically confines the plasma [4]. Although, the device was designed for energy production but, due to the low Q value (low fusion output), the consequent fusion output products (neutrons, protons etc.) were used for different near term applications in the field of defence, security, medicine, oil fields etc. In this paper, we present a parametric study on the plasma produced inside the SCIS device. The plasma discharges namely, the hot cathode and the cold cathode plasma were produced by introducing deuterium gas in the SCIS chamber. Electrostatic probes such as single Langmuir probe and double Langmuir probe were used for analyzing the current-voltage (I-V) characteristic graphs of both the type of plasma. The plasma parameters such as plasma potential (V_p), electron temperature (T_e), plasma density (n_i) and Debye length (λ_D) were measured to specify the behaviour of the plasma ions that assimilate to produce fusion inside the device. The study also includes the measurement of potential profile and ion density profile inside the chamber during the High Voltage (HV) discharge. The details are discussed in the paper.

References:

[1] Ryan Meyer, Inertial Electrostatic Confinement: Theoretical and Experimental Studies on Spherical Devices, PhD Thesis, Graduate School at the University of Missouri-Columbia, 2007
[2] P. Farnsworth, Electric discharge device for producing interactions between nuclei, U.S. Patent 3, 258, 402, (June 28, 1966).
[3] Robert L. Hirsch, Inertial-Electrostatic Confinement of ionized fusion gases, J. Appl.

Phys. 38, 4522, (1967).
[4] N. Buzarbaruah, N.J. Dutta, D. Borgohain, S.R. Mohanty, H. Bailung, Study on discharge Plasma In a cylindrical inertial electrostatic confinement fusion device, Physics Letters A, 381 2391 – 2396 (2017).

PULSED FUSION GRADE PLASMA INDUCED STRUCTURAL PHASE TRANSFORMATION IN SS USING A PLASMA FOCUS DEVICE

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Stainless steel (SS) has been widely used for various components in nuclear power industries due to its outstanding mechanical and physical properties. It is therefore important to study its behaviour under extreme conditions (high heat load, exposure to intense and energetic radiations etc) produced in current as well as future fusion reactors e.g. International Thermonuclear Experimental Reactor (ITER) and Demonstration power station (DEMO). Fusion like conditions is produced in plasma focus device for a few tens of ns time [1]. Being a copious source of radiations including ions, electrons, X-rays, and neutrons as well as simple in operation makes plasma focus device suitable for study of materials behaviour under conditions similar to that of produced in fusion reactors [2]. Four different samples (each 2 mm thick × 10 mm dia.) of SS, polished and exposed to single and multiple plasma focus discharges (5 and 10) using a medium energy plasma focus device, MEPF-12. MEPF-12 device was operated using 4 mbar of deuterium gas filling pressure at operation energy of 11.5 kJ (40 μF, 24 kV). In each PF discharge, the sample was exposed to deuterium ion and neutron fluence of $\sim 10^{14}$ ions/cm^2 and $\sim 10^6$ neutrons/cm^2, respectively. The exposed samples have been characterized for analysis of their surface modifications specifically surface morphologies and change in crystalline structure of sample using various characterization techniques. The post irradiation XRD analysis of the SS sample exposed to single as well as to multiple PF discharges confirmed structural phase transformation from initial mixed ferrite (α)-austenite (γ) phase [BCC-FCC] to single austenite phase (FCC). This could be possibly due to sufficient rise in sample surface temperature required for structural phase transformation in single shot exposure to intense deuterium ions and/or due to sufficient concentration of deuterium atoms implanted into the SS sample. The surface profilometry analysis revealed that high surface roughness (R_a) has been introduced in the sample due to irradiation. The SEM image revealed the erosion due to sputtering, melting and evaporation of surface layer. Results of comprehensive analysis of all the exposed samples along with virgin samples shall be presented.

References:

[1] Formation of a high-density deuterium plasma focus, Phys. Fluids 8(2), p 366-377, (1965).
[2] Surface modifications of fusion reactor relevant materials on exposure to fusion grade plasma in plasma focus device, Applied Surface Science 355, p 989-998, (2015).

NUMERICAL STUDIES FOR BATH COOLED HEAT EXCHANGERS IN SUB-COOLED LN2 FOR THE CRYOGENIC GASEOUS HELIUM

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Cryogenic gaseous Helium is emerging as a promising coolant for the various High-Temperature Superconductor application such as power cables, transmission lines as well as cables for tokamak magnets. Helium gas can be cooled to ~ 65 K through heat exchangers using sub cooled LN2. The thermo-hydraulic analysis towards the design of tube type heat exchangers is numerically investigated to study the effect of various flow parameters. The different configurations of tube type heat exchangers are considered and studies to evaluate their suitability for cryogenic gaseous Helium. It will be further optimized with their experimental performance in Sub-cooled setup.

Keywords: HTS, Heat Exchangers, CFD, Cryogenics, Subcooling

References:

[1] BOOK OF CRYOGENIC SYSTEMS by R. barron
[2] https://www.ansys.com/ Website of Ansys

RETRO-FITMENT OF EUROTHERM PC3000 PLC OF PURIFIER FOR 1.3 kW AT 4.5 K HELIUM REFRIGERATOR CUM LIQUEFIER FOR SST-1

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The Helium refrigerator cum liquefier plant of 1.3 kW at 4.5 K supplies 50-60 g/s forced flow two- phase Helium at 4.5 K or 300 g/s forced flow supercritical Helium (SHe) at 4.5 K to superconducting magnet (SCMS) of SST-1 and Liquid Helium (LHe) for vapor cooled current leads for plasma experiments [1]. The Helium plant of SST-1 has four sub-systems namely compressor station, oil removal system, purifier and cold-box [2]. The purifier has a dual 80K charcoal adsorber bed with a 300-80 K Liquid Nitrogen (LN2) pre-cool heat exchanger with process instrumentation. The purifier is used to remove impurities (N2, O2, H2O, Hydrocarbons (CxHy)) from Helium gas. Each sub- system is controlled by dedicated PLC and communicates to master cold-box PLC. The purifier system has Eurotherm PC3000 PLC, which is obsoleted. The spares and technical support were not provided by OEM now. Hence, retro-fitment of the old PC3000 PLC system with a new Eurotherm Programmable Automation Controller (PAC) T2750 is executed. The purifier PLC has control logics written in Sequential Function Chart (SFC) language, as per IEC 61131

programming standard, 61 Input / Output (I/O) channels and 5 Proportional-Integral-Derivative (PID) control loops. All SFC logics, process I/O and communication interface are kept the same in a newly developed program for the PAC T2750 system. The JBus serial communication between purifier and ColdBox is kept the same for command/status message and alarm log-sheet print. All modes of purifier such as on-line adsorption, pre-commissioning, E700 heat exchanger warm-up, bed warm-up, evacuation, purging, purifier cold standby / warm standby, etc. have been implemented correctly as per existing logics and checked with actual purifier process. A new SCADA application is in-house developed for the operation of the purifier system and easy troubleshooting. The operation of the newly installed PAC T2750 system in purifier is successful for a recent one month-long SST-1 campaign. This paper will discuss the architecture of existing Helium plant, methodologies adopted in retro-fitment of old Eurotherm PC3000 PLC, features of new PAC T2750 system, implementation challenges, development of new SCADA application and lessons learned during project execution.

References:

[1] P. Panchal et al., Cryogenic Process Optimization for Simultaneous Cool Down of the TF and PF Superconducting coils of SST-1 Tokamak, IOP Conf. Series: Materials Science and Engineering 502 (2019) 012106

[2] C. Dhard et al, Commissioning and Operational Experience with 1 kW Class Helium Refrigerator / Liquefier for SST-1, AIP Conference Proceedings 710, 160 (2004)

TEST RESULTS OF INDIGENOUS PROTOTYPE 2 STREAM (HE/HE) PLATE-FIN HEAT EXCHANGER OF HE PLANT

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A 2-stream (He/He) vacuum-brazed Al-plate-fin heat exchanger (PFHE) has been designed and manufactured indigenously at IPR. This is a prototype (about $1/4^{th}$ of full scale) of the 2-stream PFHE required for the IPR's indigenous helium plant of cooling power 1 kW at 4.5 K. This has serrated fins of thickness 0.2 mm and density ~709 fins/m. Serrated fins have been considered as this gives higher heat transfer [1]. Of course, this type of fin gives higher pressure drop, but, the design have been carefully done so that this is low enough for the helium plant. This is designed to cool the hot helium stream by the cold helium stream in the counter-flow configuration. The nominal operating temperature is between 310 K to 90 K and pressure is between 1.2 to 14 Bara. This heat exchanger's performance has been tested in the same temperature range but the pressure for both streams was ~14 Bara. Aspentech software is used to find the performance of this PFHE at tested conditions and compared with the performances from tests. This paper will give details of these.

References:

[1] Kays WM, London AL. 1984 Compact heat exchangers. In: McGraw-Hill series in mechanical engineering. *New York: McGraw-Hill Book Co*.J.

APPLICATIONS OF TRANSMISSION ELECTRON MICROSCOPY IN PLASMA PROCESSING

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A transmission electron microscope (TEM) is an advanced microscopy tool which finds major applications in materials science and engineering. TEM uses a highly energetic and monochromatic beam of electrons to pass through a carefully prepared ultra-thin (<200 nm thick) material samples for the microscopic analysis. The advantages of TEM can be summarized as: 1) High resolution imaging, 2) Elemental analysis & 3) ability to provide crystallographic information of even nano-features of materials. Both cold and hot plasmas find numerous applications in modifying physical and chemical properties of materials. Typical plasma processes include thin film deposition, inducing physical and chemical changes on the surfaces, enhancing the efficiency of diffusion based hardening processes, development of multi-layered coatings, synthesis of nano-materials etc. TEM can contribute to great extent in developing the scientific understanding of these processing methods. In the present work, it is discussed on the utilization of TEM for analysing thin films such as TiN, and multi-layered coatings required for the development of CZTS solar cells. Elemental identification and elemental mapping of different layers is also presented. It is also elaborated on the importance and criticality of preparing cross-sectional samples, particularly glass substrate samples. Size & shape analysis, elemental identification, and crystallographic study of nano-particles – synthesized using various methods like thermal plasma arc system etc. – are also deliberated.

IDENTIFICATION OF DRIFT WAVES IN IMPED

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Laboratory plasma inherits non-uniformities due to its finite size. In magnetic field environment these non-uniformities drives various instabilities. Density gradient driven drift waves are commonly observed instabilities in magnetized laboratory plasma. In this work, theoretical and experimental study of drift waves, is presented. Systematic identification of drift waves is performed in IMPED and using the unique control feature of device, control over excitation of drift waves is shown. Corresponding theoretical models are discussed to explain the experimental data.

References:
[1] Bose, Sayak, P. K. Chattopadhyay, J. Ghosh, S. Sengupta, Y. C. Saxena, R. Pal, Manjit Kaur, P. K. Chattopadhyay, J. Ghosh, and Y. C. Saxena. 2015. "Inverse Mirror Plasma Experimental Device - A New Magnetized Linear Plasma Device with Wide Operating Range, J. Plasma Physics (2015), vol. 81, 345810203
[2] Chen, Francis F. Introduction to plasma physics and controlled fusion. Vol. 1. New York: Plenum press, 1984. Harvard

PROBLEM OF PHASE JUMP AND METHODS FOR REMOVAL OF IT FROM THE DENSITY SIGNAL

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An Interferometer is widely used for the line averaged density measurement of the fusion plasma. A 140 GHz heterodyne system[1] has been used at Aditya and SST Tokamak for line averaged plasma density measurement. It measures the phase based on the time difference between two zero-cross points. Due to sharp density gradient or sudden change in plasma column movement can cause the refraction of the signal and phase jump occurs. It causes a very large phase shift in the signal and hence in density also.The density signal gets affected after that for the whole period of the time. So, to recover the density information in post-processing of the IF signals, two methods have been used. (A) Phase jump correction program (B)By downsampling the IF signals. In phase jump correction,a faulty zero cross points are replaced by its previous non-faulty points.While in another method after applying the downsampling and filter a phase has been reconstructed by an ARCTAN[2] and unwrapping. Both the methods are applied to the phase jump signal and phase jump can be removed. But in the case where the phase jump is not very sharp in that case, the total phase jump can not be recovered. A second method is also used to find out phase from IF signals. The advantages and drawbacks of these methods will be discussed in detail.

References:
[1] Interferometer User and Operation Manual, ELVA-1, Millimetre Wave Division, St.Petersburg, Russia.
[2] One-Dimensional Phase Unwrapping Problem By Dr. Munther Gdeisat and Dr. Francis Lilley

DEVELOPMENT AND TESTING OF ELECTRICAL INSULATION FOR ADDITIONAL TURNS OF TR#4 COILS OF SST-1

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The requirement of better magnetic null is the prime requirement for the plasma initiation in SST-1. From simulation it was found that adding four more turn with the present single turn TR#4 coils will cater this requirement. In order to verify the improvement of magnetic null, four turns dummy copper cable installed and charged up to 300A and magnetic field measured inside vacuum vessel. After these measurements, it was found that an additional four turns in TR 4#T and TR4#B enhances the magnetic null evolution during Ohmic coil charging. Since Ohmic coil operates at high voltage, hence the inter-turn and ground insulation requirement is very stringent. Commercially available insulation resin and hardener mixed in fixed ratio used to shock FRP tapes to serve this requirement. A dummy copper conductor sample is used to prepare a sample with this insulation resin and FRP tapes and cured at room temperature (RT). This sample was tested it up to 22 kV [1]. Similar insulation system applied for the actual copper conductor used for additional turns of TR#4 coil winding. Installed and insulated TR#4 coils have been repeatedly operated up to 7 kA for last two experimental campaigns. This presentation illustrates the detailed scheme, process of insulation and testing results. The test results of the coil after insulation is also included in this presentation.

References:

[1] Megger - Guide to Insulation Testing. (www.instrumart.com/assets/Megger-Guide-to-Insulation-Testing.pdf)

DATA ANALYSIS OF QUENCH EVENTS OF SST-1 TF COILS USING MATLAB

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Superconducting (SC) magnet system of SST-1 consists of sixteen Toroidal Field (TF) coils. These magnets have been routinely charged to produce toroidal magnetic field up to 1.6 Tesla at major radius of SST-1 with operating current of 5 kA DC current for plasma experiments. TF coils quench detection system [1] is built to detect coils quench due to normal and off normal events in SST-1. During SST-1 plasma experiments, it was realized to have a software tool to quickly analyze and plot voltages and temperatures profiles of quench events if any in TF coils. A Matlab based software utility has been developed to quickly analyze the temperature and voltage data of quench events. This software plots quench TF coil voltage

and corresponding temperature sensors data in multiple axis from the selected data files acquired in the existing DAQ system of magnets. This software plots each individual double pancake (DP) voltage taps data as well as difference between two DP voltage taps. This poster describes flow diagram of Matlab based programme, important features, analysis and plotting performance of these GUI based software utility.

References:

[1] Design and implementation of Quench detection instrumentation for TF magnet system of SST-1, Fusion Engineering and Design 89 (2014) 623–627

DEVELOPMENT OF SIGNAL CONDITIONING ELECTRONICS FOR PROTOTYPE MAGNET CRYOSTAT TEST

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The magnet system division at IPR has been working on the installation and testing of prototype magnet cryostat. This prototype magnet cryostat consists of 80 K thermal shield as well as vacuum chamber integrated with it to achieve temperature around 80 K within this chamber. The monitoring of temperature, pressure, vacuum and LN_2 mass flow rate measurements of various sub-sections of this cryostat are important parameters of this cryostat during evacuation and cool-down experiments. Signal conditioning electronics cards have been developed to cater the need of various cryogenic compatible temperature sensors, venturi meters and pressure transmitters to be installed on cryostat 80 K bubble panel as well as on inlet and outlet headers. Its design carry all the necessary measures to counter various EMI/RFI interference and measure low amplitude signal in high common mode electromagnetic voltage pickup environment. Minor modifications in the existing signal conditioning cards [1] can serve for signal conditioning of PT-100 sensors for temperature measurements. The card uses inbuilt constant current module for excitation of PT-100 sensors. Modifications and testing were carried out in signal conditioning cards to cater the need for PT-100 sensors. This poster gives the overview of the modified signal conditioning electronics hardware and testing of integrated signal conditioning electronics with PT-100 sensors.

References:

[1] K. Doshi et al., “Precision signal conditioning electronics for cryogenic temperature and magnetic field measurements in SST-1,” IEEE Trans. Plasma Science, vol. 40, no. 3, pp. 641–645, Mar. 2012.

MECHANICAL DESIGN OF 24 KA BUSBAR SYSTEM FOR LLMHD EXPERIMENT

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An engineering design, analysis, and fabrication drawings/3D CAD model of a 24 kA bus bar system between MTDD lab and LLMHD lab has been completed by MESD on a job request from the IPR Fusion Blanket Division. This bus bar system is required to connect Electromagnet for LLMHD experiment in LLMHD lab to the 30 V 30 kA regulated DC power supply in MTDD lab, separated by a 12 meter wide road/open space between the two labs. The paper will present the engineering design, force estimation between bus bar paths, engineering analysis using FEA, 3D CAD models of copper bus bar layouts, bus bar configuration, joints, their support structures inside the two lab spaces and also through the road/open space, insulator design, interface related issues and future works.

ABSOLUTE CALIBRATION OF TE COOLED IR ENHANCED SILICON AVALANCHE PHOTODIODE DETECTOR WITH AN INTEGRATION SPHERE

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Avalanche photodiodes (APD) are widely used for detecting low level light signals from visible to near IR region and are used in light scattering experiments e.g. Thomson scattering for the detection of scattered photons. A test bench experiment was performed to calibrate and characterize the APD with its signal conditioning electronics for quantifying the number of photons it can detect at a given gain. Using a pulsed optical source, integrating sphere and appropriate collection and coupling optics, the APD is characterized for different junction temperatures. The number of photons falling on the APD is estimated using a calibrated power meter. The calculated value of number of photons and the experimentally measured values for the no of photoelectrons from the APD are compared and found to be in agreement within acceptable range of errors.

STRESS ANALYSIS OF CRYOGENIC PIPING LAYOUT OF EXPERIMENTAL SET-UP FOR 3- STREAM PLATE-FIN HEAT EXCHANGER

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The indigenous IPR helium refrigerator/liquefier (HRL) plant being developed at Gandhinagar, Gujarat, for tokamak application, has Vacuum-brazed Al-plate-fin heat exchangers. These are some of the most important components of the cold box of the HRL. These Heat Exchangers will be used at cryogenic temperature and are generally made of aluminum alloy (Al3003/Al5052) considering high thermal conductivity, good machinability and good mechanical strength at low temperature. A 3-stream plate-fin heat exchanger (HE), to be used for HRL plant, has been designed and manufactured indigenously. This is a vacuum-brazed counter-flow type with serrated fins of fin density ~700fins/m. The performance test of this 3-stream heat exchanger has been done at cryogenic temperature. The piping design and layout has been done carefully to take care the operating pressure and thermal stresses [1,2]. The piping layout has been analyzed using CAESAR II software for stress analysis for both room temperature and 80 K operational situations. The details of these will be presented in this paper.

Keywords: Piping analysis, Cryogenic temperature, heat exchanger

References:

[1] Process plant layout and piping design, Bausbacher,ED and Hunt,Roger,PTR Prentice Hall 1993 .
[2] Piping and pipeline calculation manual construction, design fabrication and examination,Ellenberger,J.Phillip,publish by Elsevier2010.

STUDY OF TRANSMUTATION, GAS PRODUCTION AND DISPLACEMENT DAMAGE IN PLASMA FACING MATERIALS FOR FUSION APPLICATIONS

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Tungsten due to its high melting temperature of 3422 ^{0}C, high thermal conductivity of 1.75 W. cm^{-1}. k^{-1} and high threshold energy of 216 eV for deuterium sputtering is a prime candidate material to be used in plasma facing components in ITER and other upcoming fusion reactors. Neutrons created during the fusion of D-T plasma cause transmutation, gas production and displacement damage in tungsten and adversely affect its strength and lifetime of tungsten. In the present work, transmutation, gas production and displacement damage have been studied for all the stable isotopes of tungsten for neutron irradiation of up to 15 MeV energy. Nuclear reaction cross section for transmutation, and gas production and energy differential cross section of PKA species from all the open reaction channels have been calculated with TALYS-1.8 code [1]. Nuclear models in TALYS-1.8 code have been selected based on the comparison of calculated reaction cross section and energy spectrum of outgoing particles with the existing experimental data from EXFOR data library [2]. Damage matrices which are required to calculate the displacement damage cross section have been calculated with NRT and Arc-dpa method [3]. Constant parameters of arc-dpa have been derived with the result of molecular dynamics (MD) simulation of damage cascade carried out with LAMMPS code [4]. MD simulations of displacement damage have been carried out for the native PKA in tungsten at up to 200 KeV damage energies. Gas production and displacement cross section have been calculated at up to 15 MeV neutron energy and used to calculate the dpa and GPA in tungsten for ITER and EU Demo neutron spectrum [5]. Values of GPA comes out to be 14.2 appm/FPY (helium production) and 56.8 appm/FPY (Hydrogen production) for ITER neutron spectrum and 37.3 appm/FPY (helium production) and 56.8 appm/FPY (Hydrogen production) for European demo neutron spectrum respectively at the first wall. Similarly, dpa values come out to be 3.3 dpa/FPY and 8.6 dpa/FPY for the ITER and EU demo neutron spectrum at first wall. A similar assessment of transmutation, GPA and dpa is also carried out for iron and chromium.

[1] A. J. Koning et al *Nuclear Data Sheets*, vol. 113, pp 2841-2934, 2012
[2] EXFOR IAEA data library, https://www-nds.iaea.org/exfor/
[3] Kai Nordlund et al, *Nature communication*, DOI: 10.1038/s41467-018-03415-5.
[4] S.J. Plimpton, *J. Comput. Phys.* 117 (1995) 1-19
[5] Gilbert et al, *Nucl. Fusion* 51 13 (2011)

TESTING AND SET UP OF 2.45 GHZ ECR ION SOURCE ON 300 KV HIGH VOLTAGE DECK

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A 300 kV high voltage deck has been indigenously developed and set up at IPR. It is developed to inject the deuterium beam in to acceleration system of 14-MeV neutron generator as well as low energy (up to 300 keV) deuterium ion beam irradiation facility. A permanent magnet based 2.45 GHZ ECR ion source along with ion extraction system is installed on the HV deck for producing the deuterium beam. The 350 kV, 15 kVA DC Isolation transformer is used to provide the power on HV deck. This paper described design of the 300 kV high voltage deck system, installation setup and latest results of the ion beam extraction.

EFFECT OF CZTS THICKNESS ON SOLAR CELL PERFORMANCE USING TITANIUM NITRIDE AS BACK CONTACT LAYER PREPARED BY MAGNETRON SPUTTERING

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Cu_2ZnSnS_4 (CZTS) based multilayer thin film solar cell with structure SLG/Mo/CZTS/CdS/ZnO/ZnO:Al is studied in detailed for its performance by many researchers [1]. The problems of MoS_2 formation at Mo/CZTS interface and its effect on device performance is also being reported and studied [2]. Effect of thickness of CZTS absorber layer on device performance, is also studied theoretically and experimentally as well [3-5]. However the effect of CZTS thickness on MoS_2 formation is not been explored while studying the effect of CZTS thickness on device performance. It is necessary to study the effect of CZTS thickness using a back contact layer which is not affected during sulfurization process. Titanium Nitride (TiN) is one of the alternative layer proposed for back contact of CZTS based thin film solar cell [6]. In this study we have prepared the CZTS based thin film solar cell using structure SLG/TiN/CZTS/CdS/ZnO/ZnO:Al to avoid MoS_2 formation. Thickness of CZTS layer is varied from 600 nm to 1400 nm. Thickness variation affects the structural and phase formation properties of the CZTS layer which as diagnosed using SEM, XRD techniques. After preparation of device, illuminated & dark I-V measurements are done to characterize the performance of the device. Thickness of 1000 nm is found more suitable for a better efficiency.

References:

[1] Tang Jiao Huang1, Xuesong Yin, Guojun Qi and Hao Gong, CZTS-based materials and interfaces and their effects on the performance of thin film solar cells, Phys. Status Solidi RRL 8, No. 9, 735–762 (2014).

[2] Hongtao Cui, Xiaolei Liu, Xiaojing Hao, Fangyang Liu, Ning Song, Wei Li, Chang Yan, Gavin Conibeer, Martin Green, Improvement of Mo/Cu2ZnSnS4 interface for Cu2ZnSnS4 (CZTS) thin film solar cell application, Mater. Res. Soc. Symp. Proc. Vol. 1638 (2014).

[3] Yi Ren, Jonathan J. S. Scragg, Christopher Frisk, Jes K. Larsen, Shu-Yi Li and Charlotte Platzer- Bj€orkman, Influence of the Cu2ZnSnS4 absorber thickness on thin film solar cells, Phys. Status Solidi A, 1–8 (2015).

[4] H. Heriche, Z. Rouabah, S. Benabbes and L. Selmani, Thickness optimization of various layers of CZTS solar cell, Journal of New Technology and Materials, Vol. 04, N°01 (2014)27-30.

[5] Christopher Frisk, Yi Ren, Shuyi Li, Charlotte Platzer-Björkman, CZTS Solar Cell Device Simulations with Varying Absorber Thickness, *2015 IEEE 42nd Photovoltaic Specialist Conference (PVSC).*

[6] Souhaib Oueslati, Guy Brammertz, Marie Buffière, Hossam ElAnzeery, Denis Mangin,Ounsi ElDaif, Oualid Touaya, Christine Köble, Marc Meuris and Jef Poortmans, Study of alternative back contacts for thin film Cu2ZnSnSe4-based solar cells, J. Phys. D: Appl. Phys. 48 (2015) 035103 (9pp)

EFFECT OF SULFURIZATION TIME ON CZTS THIN FILM FOR SOLAR CELL APPLICATIONS

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Cu_2ZnSnS_4 (CZTS) thin film is a promising material for next generation thin film solar cell as an absorber layer due to its opto-electric properties and earth abundant nontoxic constituent [1]. Sulfurization process of Cu/Zn/Sn precursor thin film to form CZTS layer can be done using different techniques where the materials such as SnS powder and H_2S gas are used in the presence or absence of sulfur containing atmosphere at various temperature and time [2,3]. It is reported by many researchers that one of the main criteria for obtaining high efficiency of solar cell is to have a void free and homogeneous CZTS thin film [4,5,6]. Since, sulfurization process is one of the steps during formation of CZTS layer, it is necessary to explore the effect of sulfurization parameters on properties of CZTS layer systematically for further improvement. In this study, CZTS based thin film solar cell is developed in the following configuration: SLG/Mo/CZTS/CdS/i-ZnO/ZnO:Al. CZTS layer is synthesized on Mo coated soda lime glass by sulfurization of co-sputtered Cu/Zn/Sn. Sulfurization was done at 550℃ with different holding time (like 30 min, 60 min, … , 180 min) for optimization. The formation of CZTS phase was confirmed by XRD and EDX. CZTS surface morphology and cross section of fabricated solar cell were analyzed by SEM. The solar cell fabricated with the CZTS thin film sulfurized for 120 min shows the best conversion efficiency of 3.8% with an open circuit voltage of 540mV, short-circuit current density of 12.9 mA/cm^2 and fill factor of 50%.

References:

1. Cu_2ZnSnS_4 solar cells prepared with sulfurized dc-sputtered stacked metallic precursors, Thin Solid Films 519, 7382–7385, (2010)
2. Fabrication of Cu_2ZnSnS_4 film by sulfurization of Cu/ZnSn/Cu precursor layers in sulfur atmosphere for solar cell, Solar Energy materials & Solar Cells 95, 3216-3221, (2011)
3. Effect of pre-annealing on the phase formation and efficiency of CZTS solar cell prepared by sulfurization of Zn/(Cu,Sn) precursor with H2S gas, Solar Energy 136, 499–504, (2016)
4. Effect of a pre-annealing treatment (PAT) on $Cu_2ZnSn(S,Se)_4$ thin films prepared by rapid thermal processing (RTP) selenization, Solar Energy materials & Solar Cells 143,218-225, (2015)
5. Growth of void free Cu_2ZnSnS_4 (CZTS) thin films by sulfurization of stacked metallic precursor films, Vacuum 104, 57-60, (2014)
6. Effect of post-annealing atmosphere on grain size and surface morphological properties of pulsed lased deposited CZTS thin film, Ceramics International 40, 15097-15103, (2014)

DEVELOPMENT OF TOKAMAK MODELS FOR EXHIBITS

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Institute for Plasma Research, IPR is actively involved in to generating awareness about plasma, tokamak and plasma applications for schools, colleges and at different science exhibitions under outreach program. For this purpose many physical models and posters have been prepared. Generally it is found that a small tokamak model of size 150mm (for ease of handling) is essential to explain the tokamak functions and role of the major sub system used in building the Tokamak machine. The model is designed and fabricated toincorporate the major sub sytems required in a tokamak. The model is designed to include dismantling and assembly featured built in.As explained, the tokamak model is based on the concept of removable and assembled sections. It has 12 sub-systems. Model comprises of 33 pieces, with three sections. The lower base plate and upper baseplate are in a single piece. The two PF coils are in one piece, vacuum vessel sector, plasma sectors are three pieces each. Toroidal Field (TF) coils, support pillars, vacuum vessel window are 6 in number, Vacuum pumps are 3 in nos. The upper Poloidal Field (PF) coil and lower Poloidal Field coils are made in one piece. Central Solenoid is made as a single piece. The method of fabrication chosen is rapid prototyping. Different versions of model is designed to add more features in upgraded version. The material used in fabricating the model is Acrylonitrile Butadiene Styrene (ABS), ABS plastic is used for the version1 and version 2, while Polylactic Acid, PLA is chosen for the version 3. Each following version, is improvised than the earlier version based on time required for the assembly and disassembly. The tokamak version3 has been finalized for mass production for do it yourself, DIY tokamak model kit. In this paper design and fabrication of the Tokamak model is discussed and the feedback received from the students, teachers and participant is highlighted.

PIPING LAYOUT AND FLEXIBILITY ANALYSIS OF THE CLOSED LOOP INDIGENOUS HELIUM COMPRESSOR

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The indigenous helium refrigerator/liquefier (HRL) plant being developed at IPR will use an indigenous helium compressor. This compressor is being developed by modification of an open loop air compressor. This is an oil-injected screw air compressor originally operating as an open-loop. To make it helium compressor, it is necessary to make it closed loop with necessary instrumentation and valves and oil removal system elements. This needs to be done carefully to take care different operating pressures and temperature conditions. Looking at these different situations a piping layout has been made and which has been operated and found working satisfactory. The operational pressure at different location in the layout ranges

from 0.2 to 16 bar and temperature range varies from 5 to 55 ^{0}C. Appropriate safety valves also have been added. The flexibility analysis of this layout has been done using CAESAR pipe software. The details of these will be presented in this paper.

BUILDING MANAGEMENT CONTROL SYSTEM FOR NEW LABORATORY BUILDING HVAC PLANT AT IPR

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The Building management system for new laboratory building of IPR is consist of nine number of Direct Digital Control panels (DDC). DDC panels are incorporating programmable logic controllers (PLC), I/O expansion modules, Communication modules and end terminal connections. Field process instruments such as pressure transmitters, temperature transmitters and level switches are connected to analog input and digital input modules of PLCs. Final control elements such as heaters, variable frequency drives (VFD) of motors and three way diverting valves are connected to analog output and digital output modules of PLCs. Main control station is located in new auxiliary building at IPR. The Control station is installed with Supervisory control and data acquisition system (SCADA) of Vijeo Citect. The communication is established between the central SCADA system and nine DDC panels using Modbus TCP/IP communication. The graphical user interfaces (GUI) are developed in SCADA system for real time monitoring and controlling the HVAC parameters. The historical and real time trends are developed for analysis purpose. The alarm logs for critical system parameters and event logs generations are programmed in SCADA. The installation and commissioning tasks of these nine DDC panels and Main control station are presented in this paper.

DEVELOPMENT OF GRAPHICAL USER INTERFACE USING LABVIEW FOR MACHINE VISION ACQUISITION IN SST-1

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Optical imaging diagnostics is installed on SST-1 tokamak to measure various plasma parameters like plasma shape, size, movement [1] etc. Since very high magnetic field exist in tokamak, the cameras cannot be mounted directly on the machine. Images are transported through wound image fiber bundle and coupled with CCD camera placed outside the machine. Presently two imaging systems are installed on SST-1. One is aligned to view plasma tangentially to see the poloidal cross section of the plasma and other one is aligned for wide angle viewing of plasma. All these systems need to operate remotely and data is acquired in sync with plasma discharges. The LabVIEW based graphical user interface (GUI) is developed for trigger based synchronized image / video acquisition and data storage

purpose. The high frame rate camera (~ 5000 fps) and low frame rate camera (~ 30 fps) is installed around the SST-1 machine and image is acquired during the campaign. The GUI is also integrated with main plasma timing system for information exchange like shot number and status.

References:

[1] Observation of plasma shift in SST-1 using optical imaging diagnostics, Manoj kumar et al., Journal of Physics: conference series 823 012056 (2017)

UNDERSTANDING OF PARTICLE TRANSPORT USING ESTIMATED τ_p PROFILE OF ADITYA TOKAMAK PLASMA

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Particle transport which is one of the significant research area in the magnetically confined fusion research area is less understood compared to energy transport as the complexity involved in the experimental estimation of particle source term. The studies of particle transport through the analysis of the confinement times are mostly done with the global particle confinement time, which is estimated using the equation τ_p=N/Φ, where N is the total particle content inside the plasma and Φ is the total particle outflux from the plasma. In the present work, the particle transport on ADITYA tokamak was studied by using the radial profiles of particle confinement time of ADITYA tokamak plasmas. The radial profile of particle confinement time is estimated using the experimental spatial profile of H_α brightness in combination with the DEGAS2 code [1]. It is found that the τ_p values are varied from 65.0 to 1.5 ms from the plasma core to edge. The values of diffusion coefficient (D) at plasma core and edge are estimated using τ_p and values are 0.2 and 3 m^2/s, respectively. Later, these values were compared with the D calculated using Bohm diffusion and neo-classical transport. It is found that the estimated D is almost two orders lower in magnitude than the Bohm diffusion in the core region whereas it is almost having similar order in the plasma edge. However, the estimated D values at the plasma core and edge regions are quite larger than those calculated using neo-classical transport. This indicates the anomalous nature of particle transport in ADITYA tokamak.

References:

[1] Goto M. et al Particle source and edge confinement study based on spectroscopic diagnosis in the LHD, Plasma Phys. Control. Fusion, 58 084001 (2016).

WAVELET SPECTRAL AND CORRELATION ANALYSIS OF AN IMPURITY EMISSION FROM THE ADITYA-U TOKAMAK EDGE

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Impurity transport and control is one of the key areas of importance for optimized operation of the magnetically confined fusion plasma devices. Impurities comes from the plasma facing components due to plasma-wall interaction or is deliberately puffed for the alteration of the plasma properties, and gets transported from edge to core region of a tokamak via neo-classical and anomalous transport mechanism. As a consequence, the accumulation of impurities in the core region, their direct contribution to the Z_{eff} and higher emissivity can significantly influence the overall plasma confinement and RF heating efficiency. Therefore, understanding of impurity transport behavior under different operating regimes and its dependency on the plasma parameters controlling their transport is required. This study explores the correlation present between the fluctuations observed in the spectral line emission from (O II, C II and C III) impurities ions, the poloidal magnetic field, electron density, electron temperature in the edge region of ADITYA-U tokamak. Important information regarding the nature of anomalous transport of the impurity ions in the edge region is obtained.

STUDY OF MICROINSTABILITIES IN A MULTISPECIES VLASOV-PLASMA USING KINETIC SIMULATION

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The finite amplitude collective plasma perturbation essentially involve exchange of energy between particles and wave. The kinetic simulations of collective plasma in the phase space are the most effective way of analyzing this essentially nonlinear process of wave particle interaction. A perturbation of hot electron species nonresonantly excite an ion perturbation that in turn trap the electrons and modify the process of growth of the ion acoustic mode. This process is analyzed by means of an electrostatic kinetic Vlasov simulation procedure by applying a modified flux balance method. The multiple time scales are resolved in the simulation procedures and the microinstabilities present in the system are identified using a spectral analysis.

DESIGN AND IMPLEMENTATION OF PHASE SHIFTED RESONANT CONVERTER POWER SUPPLY FOR PLASMA TORCH

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The switch mode technique has brought several changes in design of equipment and power supplies in various applications. In plasma applications there is requirement of different type of power supplies. The focus of our work is in plasma torches. MOSFET/IGBT based power supplies are in continuous demand with various specifications. Most of the transformers are wound with Litz type wires to reduce inductance and capacitance effect. For high current applications, generally strip type conductors are preferred. However with the strip type conductors winding, the capacitance increases substantially. This will result in substantial losses while operating switch mode power supply in hard switching mode. We have designed amorphous core based switch mode power supply with a switching frequency of 20 KHz.
Amorphous core UU6597 from M/S Usha Amorphous, New Delhi is procured. The UU core is of 188/97/170. The core area is 62.83cm^2 and A_L value of 1.5µH/turn^2. Numerical calculation was made using the standard analytical equation and the number of primary and secondary turns were determined by optimizing core and conductor loss. Transformer primary was wound with copper foil of 0.3mm thickness and of 100mm width. The primary number of turns is 16 and secondary turns 8. The two primaries are connected in series. There were 6 secondary in each leg and all of them are connected individually to 100 amps switching diode MMF2X100J120D. The transformer is connected in center tap mode in secondary side. Two modules of IGBTs of Semikron make (SKM200GB12T4) were connected in full bridge configuration. The IGBTs were driven by SKPER32R driver card of Semikron. UC3875 IC is used to generate phase shifted PWM (PSPWM) signals along with CD4050 IC used as buffer. These phase signal have been fed to SKPER32R driver card to drive IGBT. The fault signals coming out of SKPER32R from each IGBT are then fed to IC CD4072 to suppress PWM signals in the event of short circuit. Dual input inductors of 560µH each were mounted on positive and negative rail of the bus bar. Each module was energized by feeding 3 phase power through EMI filter and ac inductor. The rectified voltage from the bridge with filtering was feed to IGBT full bridge. The output DC voltage and current were measured. The input current to the switching transformer is measured using CT. A set of series connected capacitors were used to provide phase required for Zero voltage switching and to satisfy minimum current required for ZVS. The output DC voltage increases with increasing the series capacitance. Later we have operated power supply with plasma torch. The arc current was increase by increasing the phase shift. The results of the performance of plasma torch with PSPWM are presented.

References:

[1] Unitriode application note U-136A.

VISIBLE IMAGING OF THE TOKAMAK PLASMA

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A tangential optical imaging system has been installed on the SST-1 tokamak. This system is used to measure the various plasma parameters like plasma shape, size, movement etc. The measurement of these parameters is very important from the machine operation point of view and to study plasma wall interaction. As the visible light includes both the line emission from the neutral atoms and continuum bremsstrahlung emission which originates in the core of the plasma. Hence, this is a useful tool to study and analyze the plasma profile. This system consists of wound imaging fiber, relay lenses, camera and accessories. As the camera cannot be directly mounted to the viewport of the tokamak due to strong magnetic field, the wound image fiber is mounted on the tangential viewport of the tokamak, on which a suitable lens is mounted. On the other end, a relay lens is used to transfer the image from the fiber to the camera focal plane. The camera is externally triggered, which acquires the plasma images during the operation at an interval of 30 miliseconds. The camera uses GigE interface for the acquisition as well as to transfer the images from the camera to the computer. Post processing of the images are done in order to predict the spatial and temporal distribution of the plasma. In this presentation results obtained during recently concluded experimental campaign will be presented.

References:

[1] S. Zweben, R. Maqueda, D. Stotler, V.J. Mastrocola, et al. 'High-speed imaging of edge turbulence in NSTX' Nucl. Fusion, 44 (1) (2004), pp. 134-153

[2] N. Nishino, K. Takahashi, H. Kawazome, S. Yamamoto, et al. 'High-speed 2-D image measurement for plasma-wall interaction studies' J. Nucl. Mater., 337–339 (2005), pp. 1073-1076

[3] Ales Havranek, Vladimir Weinzettl, David Fridrich, Jordan Cavalier, 'Michael Komm Fusion Engineering and Design,' Volume 123, (2017), pp. 857-860

NON-THERMAL ATMOSPHERIC PRESSURE PLASMA TORCH POWER SOURCE DEVELOPMENT FOR DENIM JEANS COLOUR FADING

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Denim jeans colour fading is the very polluting job in the field of textile industries. In the conventional process of the denim jeans colour fading, industries used the hand scraping, rock, sand, acid wash and other chemical abrading substances. The non-thermal atmospheric pressure plasma torch is the very eco-friendly process to denim jeans colour

fading by the plasma etching process. The non-thermal atmospheric pressure plasma torch is driven by a very compact high voltage alternating power supply. The power of the plasma torch is analyzed and also tested with various other parameters like voltage and gas flow for its optimal condition. The denim jeans material is used for the experiment purpose because it's widely used in the textile industries. The non-thermal atmospheric pressure plasma torch device is equipped with the XYZ translator instrument. This XYZ translator guided by the computer added design software.

FEASIBILITY STUDY OF CAPACITOR BANK BASED POWER SUPPLY FOR TOROIDAL FIELD COIL OF SMALL SCALE SPHERICAL TOKAMAK AT IPR

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Spherical Tokamak (ST) is being actively pursued worldwide for economical and practical advantages of fusion power. They are attractive because of low aspect ratio, relatively small size, effective utilization of magnetic field, high beta & high boot strap fraction [1, 2]. A small scale ST is being proposed using available infrastructure, utilizing technologies & expertise gained from our tokamak experiments. Toroidal Field Coils, Ohmic Coils, Poloidal Field Coils and Correction Coils are electromagnetic Coils which would be the part of Spherical Tokamak including the Vacuum Vessel. As per the preliminary design, Toroidal Field Coils would generate toroidal magnetic field of 0.1 T (at 12 kA for ~50 milliseconds). In order to generate current of 12 kA for 50 milliseconds in Toroidal Field Coils, Capacitor bank based power supply topologies are explored. The feasibility study and preliminary design of Toroidal Field Power Supply system of 12 kA for 50 milliseconds duration of flat-top & 10 milliseconds ramp up has been completed. This paper describes the feasible topologies for Capacitor Bank based Power Supplies for generating constant current of 12 kA in Toroidal Field Coil System. It also covers the design aspects, electrical circuit simulation and analysis of Toroidal Field Power Supply using PSIM.

References:

[1] Features of spherical torus plasmas, Nucl. Fusion 26 (1986) 769
[2] Compact fusion energy based on the spherical tokamak, Nucl. Fusion 58 (2018) 16039

STUDIES ON ELECTRON ENERGY GROUPS IN A HOT CATHODE DISHCHARGE IN PRESENCE OF A MAGNETIC FILTER

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Plasma confinement has been of interest to researchers from long ago. Many researchers like James et al.[1], Leung et al.[2], have been on a quest to confine the plasma and study its properties. The hot cathode discharge setup at CPP-IPR is a multicusp device with two magnetic cages, consisting of two chambers: the source and the target, designed to produce and confine plasma[3,4]. Even though the device has a simple assembly, low cost operation, and low power, it has been used by many to carry out various interesting and useful studies.
Formation of distinct electron groups has been observed in low-temperature plasma and is found to be similar to that of the solar wind, which has three groups: Core, Strahl, and Halo[5]. Experimentally, different groups of electrons have also been observed in helicon plasma[6] as well as in magnetron sputtering plasma[7] and also in dc glow discharges in the cathode region[5]. In this present study, we aim to distinguish these groups in this hot cathode discharge setup in presence of a magnetic filter. For the experiment, we have produced plasma in the source region and then allowed to difuse to the target region across a magnetic filter. The plasma parameters such as Plasma Density (n_i), Debye Length (λ_D), Plasma Temperature (T_e), and Electron Energy Distribution Function (EEDF) are analyzed together with the study distinguishing electrons of different energy groups.

References:

1. James Sinnis and George Schmidt, The Phys. Of Fluids, vol. 6, no. 6, p. 841, 1962.
2. K.N Leung, T. K. Samec and A. Lamm, Phys. Letters, Vol. 51A, no. 8, p. 490, 1975.
3. K.N. Leung, Noah Hershkowitz and K. R. Mackenzie, The Phys. Of Fluids, Vol. 19, No. 7, p. 1045, 1975.
4. Alfred Y. Wong, *Introduction to Experimental Plasma Physics*, Vol. 1, Spring, 1977
5. V. Kolobov, V. Godyak, *Electron Kinetics in low-temperature plasmas*, Phys. Plasmas **26**, 060601 (2019); doi: 10.1063/1.5093199
6. B B Sahu et. al 2014 Plasma Sources Sci. Technol. 23 065050.
7. T. E. Sheridan, M. J. Goeckner, and J. Goree, Journal of Vacuum Science & Technology A **9**, 688 (1991)

STUDIES ON PHOTOCATALYTIC AND ANTIBACTERIAL PROPERTIES OF PLASMA SYNTHESIZED TUNGSTEN-OXIDE NANOMATERIALS

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Tungsten-oxide (WO_3) nanomaterials are characterized with relatively smaller band gap energy (2.4-2.8 eV) that renders photocatalytic behavior under visible light illumination. Pure WO_3 with exotic, porous, morphology [1], or as composites while mixed with other nanomaterials [2], may be used for photocatalytic degradation of harmful dyes in wastewater. However, the absence of a high throughput nano-synthesis technique is often the bottleneck for successful utilization of nanomaterials for actual applications [1]. In the recent past, using a thermal plasma torch assisted simple experimental system, we have demonstrated rapid synthesis of WO_3 nanomaterials up to few hundred grams per hour. In this reactor configuration, an expanded argon plasma beam is produced with collimated, frozen structure inside a vacuum chamber that interacts with a remotely placed solid tungsten target in presence of oxygen, which leads to production of tungsten-oxide nanoparticles through oxidation of the bulk metal and subsequent sublimation of the oxide. This paper will report studies on the photocatalytic and antibacterial properties of the synthesized nanomaterials. Nanocomposites were prepared by mixing the nano metal-oxide with some carbon nanomaterials including graphitic carbon nitride (g-C_3N_4) and graphene-oxide. The photocatalytic dye degradation properties were explored on Rhodamine-B solution. In spite of low specific surface area, stoichiometric WO_3 composites showed better photo-catalytic degradation behavior compared to $WO_{2.92}$, may be because of better crystallinity of the material. The nanocomposite: WO_3/ g-C_3N_4, degraded standard solution of Rhodamine-B up to 78% in just fifteen minutes, which was very impressive. In this paper, we will also report on the antibacterial properties of the synthesized nanomaterial that may lead to multi-functionality during treatment of wastewater.

References:

[1] Gram-scale synthesis of ultrathin tungsten oxide nanowires and their aspect ratio-Dependent photocatalytic activity, Adv. Funct. Mater. **24**, p 6029-6037, (2014).
[2] Functionalization of tungsten oxide into MWCNT and its application for sunlight-induced degradation of rhodamine B, J. Colloid Interface Sci. **362**, p 337-344, (2011).

MAGNETOSPHERIC ELECTRIC FIELD FROM GROUND-OBSERVED LOW LATITUDE VLF CHORUS EMISSIONS DURING MAGNETIC STORM

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An attempt has been made to estimate magnetospheric equatorial electric field (E) in the vicinity of chorus source during magnetic storm period from the VLF chorus emission observed at our low latitude ground stations Jammu (L = 1.17) and Gulmarg (L = 1.28). The special feature of VLF chorus emissions observed at Jammu and Gulmarg is the regularities of the chorus spectra development by the gradual increase of upper boundary frequency (UBF) of the chorus emission during the first initial phase of observation. The method of estimating E from the observed regularities of the chorus spectra development by the gradual increase of UBF of the chorus emissions has been outlined. UBF-method based on the measurement of the upper boundary frequency of the ground-observed VLF chorus is used for the estimation of L-value of the chorus source of the reported VLF chorus, which is found to be about 4 (**L~4**). The estimated magnetospheric equatorial electric field E from the VLF chorus emission observed at Jammu and Gulmarg during magnetic storm period is 0.89 mVm^{-1}, which is in agreement with the results reported by the earlier workers. The importance of an electric field study has been indicated.

References:

[1] Sazhin, S.S., Magnetospheric chorus emissions: a review. Planet. Space Sci., 1992, 40, 681-693.

[2] Smirnova, N. A.,Fine structure of the ground-observed VLF chorus as an indicator of the wave particle interaction processes in the magnetosphric plasma. Planet. Space Sci., 1984, 32, 425-438

NUMERICAL SOLVER FOR COLLISION-LESS PLASMAS : DEVELOPMENT AND APPLICATIONS OF A 1D2V VLASOV MODEL

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Gridded Vlasov methods which solve directly the coupled Vlasov-Poisson equation on a grid of phase space has proven to be an efficient method to study non-linear wave-particle interaction phenomenon associated with several laboratory and astrophysical plasmas [1,2]. For example energetic particles produced in fusion experiments, solar wind and magneto spheric plasmas etc. Earlier formation and dynamics of 1D electrostatic phase space vortices has been studied, at electron as well as ion scale and in collision-less plasmas as well as in the collisional environment, using in-house developed 1D-1V Vlasov - Poisson solver (VPPM

2.0)[3] . VPPM 2.0 is a Eulerian solver based on Piecewise Parabolic Method (PPM) [4] and Cheng - Knorr[5] time spilling scheme with periodic boundary conditions. Now in order to address more realistic problems related to laboratory and space plasmas, VPPM 2.0 demands an upgrade to 1D-2V.

In the following we will address benchmarking of 1D-2V VPPM 2.0 and the problem of kinetic non-linear interaction phenomenon using 1D-2V VPPM 2.0 with various perturbative methods. The details of the work will be presented.

References:

[1] F. Filbet a, E. Sonnendrücker, Computer Phy Communications 150 (2003) 247–266
[2] V. Saini, S. K. Pandey, P. Trivedi, and R. Ganesh, Phys. Plasmas 25, 092107 (2018).
[3] P. Trivedi, PhD Thesis, HBNI, Institute for Plasma Research (2019).
[4] P. Colella and P. R. Woodward, J. Comput. Phys. 54, 174 (1984).
[5] C. Z. Cheng and G. Knorr, J. Comput. Phys. 22, 330 (1976).

CHARACTERIZATION OF HELICON PLASMA PRODUCED BY OXYGEN/ARGON GAS COMBINATION

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A helicon plasma source (HeliPS) operated with 13.56 MHz RF power supply has been designed, developed and successfully used to produce helicon plasma in different gases in CPP-IPR [1]. In the experiment reported here, helicon plasma is produced in Argon/Oxygen gas combination to study the characteristics of such plasmas both in source and expansion chambers and to understand the influence on negative ion production. In the source chamber, plasma parameters such as plasma density, electron temperature are measured by varying different experimental parameters such as RF power, gas mixing percentage, etc. to study the discharge mode transitions [2,3]. In the expansion chamber, a magnetic cage reduces loss of plasma to the chamber wall. Plasma density, electron temperature, positive ion saturation current, electron energy density function (EEDF) [4,5] have also been measured in the expansion chamber. Utilizing the effective temperature and effective mass, negative ion density measurements in the expansion chamber has been performed and comparison of data made between pure Oxygen and Argon/Oxygen gas combination.

References:

[1] N. Sharma, M. Chakraborty, N. K. Neog, M. Bandyopadhyay, Fusion Engineering and Design 117 (2017) 30–38
[2] N. Sharma, M. Chakraborty, N. K. Neog, M. Bandyopadhyay, Review of Scientific Instruments **89**, 083508 (2018); doi: 10.1063/1.5030624
[3] Young Wook Lee, Hye Lan Lee, and T. H. Chung, J. Appl. Phys. 109, 113302 (2011)

[4] D. C. Seo, T. H. Chung, H. J. Yoon, and G. H. Kim, Journal of Applied Physics **89**, 4218 (2001); doi: 10.1063/1.1354633
[5] M. Shindo, R. Ichiki, S. Yoshimura, Y. Kawai, The Solid Film 390 (2001) 222-227

ROLE OF IONS IN A TOROIDAL ELECTRON PLASMAS: A PARTICLE-IN-CELL STUDY

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Cylindrically trapped pure electron plasma is prone to long time confinement. This non-neutral plasma species is studied theoretically/computationally and experimentally, to explore the fundamental ideas (as for example: isomorphism between 2D inviscid Euler fluids, ion resonance instability). In several pure electron plasma experiments, ions from background molecules by energetic electrons, lead to ion resonance instability.IPR has pioneered experiments in toroidal pure electron plasmas[1,2]. Recently, tight aspect ratio toroidal device[3] at IPR has achieved longtime confinement of pure electron plasma. Confinement is achieved by loading the electrons along the magnetic field and trapping the same by applying negative voltage at the "end plugs"[3]. Toroidal bouncing may result in ionization. In the present study, a Particle-in-Cell (PIC) simulation study of the collisionless, cold, pure electron plasma with the focus on the role of ions, has been performed in a similar parametric space as toroidally experimental device[4], but, with one difference. Whereas the experimental device has discontinuity in the toroidal direction with electric field endplugs resulting in a high frequency toroidal bounce motion of electrons, in our simulation the device is toroidally axi-symmetric and bounce motion is neglected. A 3D PIC code PEC3PIC[5] used for this study.Ion driven dynamics of cold electron cloud in a toroidal magnetic trap is investigated using a 3D PIC code PEC3PIC[5]. Major focus of the study are (i) 3D nonlinear evolution of electron and ion clouds (ii) effect of toroidicity induces mode coupling of electron and ion clouds and (iii) possibility of ion induced instabilities. Some of the numerical optimization studies will also be discussed.

References:

[1] P. Zaveri et al. Phys. Rev. Lett. 68, p 3295-3298 (1992)
[2] S. Khirwadkar et al. Phys. Rev. Lett. 71, 4334 (1993)
[3] L. Lachhvani et al. Phys. Plasmas 24, 102132 (2017)
[4] R. Ganesh and S. Pahari, in Frontiers in Turbulence and Coherent Structures, Vol. 6, p. 471
[5] S. Khamaru, M. Sengupta and R. Ganesh, Manuscript Under Review (2019)

DESIGN AND DEVELOPMENT STUDY OF A CRYOCOOLER BASED CRYOSORPTION PUMP

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In magnetically confined high-temperature plasmas, cryopumping is essential for removing the large throughput of hydrogen and helium gases [1]. For large scale application, it is necessary to standardize the pumping characteristic of the sorbent coated cryo pumping element. In this context, a cryocooler based cryopumping setup is designed and developed at the Institute for plasma research (IPR) to characterize the sorbent coated cryopanels. Design and development of a GM cycle cryocooler based cryopump is carried out at the IPR. The pumping element and associated cryogenic components are designed following standard heat load calculation. The total heat load on the cryopanel without any gas throughput is estimated to be < 3 W. With the application of gases it is calculated to be ~ 4 W for a maximum throughput of 10 Pa.m^3/s. the minimum temperature achieved at the cryopanel surface is ~ 10 K. Activated coconut shell charcoal of higher BET surface area (~ 1300 m^2/gm) and adhesive of thermal conductivity ~ 1.0 W/m.K are used as the sorbent and the bonding agent, respectively. The coconut shell charcoal is characterized in the adsorption test facility at IPR [2]. The pumping performance is studied following recommended AVS procedures [3]. Pumping study for various gases such as Hydrogen, Helium, Nitrogen, Argon and Xenon are performed. The pump achieves a lowest vacuum of the order of 10^{-6} Pa in no gas load condition. The pump has been uninterruptedly operated (in N_2 gas environment) for > 25 hours without degrading its performance. The specific pumping speed of the cryopanel is ~ 3.0 l/s/cm^2 for N_2 gas. A close similarity between the theoretical calculation and experimental results is obtained. Details of the cryopump design and experimental results will be presented.

References:

[1] C. Day, D. Murdoch, R. Pearce, The vacuum systems of ITER, Vacuum. 83 (2008) 773–778.

[2] J. Mishra, J. Agarwal, S. Kasthurirengan, S. Mukherjee, P. Nayak, P. Panchal, R. Gangradey, Adsorption characteristic study of activated carbons down to 4.5 k, Mater. Today Proc. 5 (2018) 3425–3431.

[3] M.H. Hablanian, Recommended procedure for measuring pumping speeds, J. Vac. Sci. Technol. A Vacuum, Surfaces, Film. 5 (1987) 2552–2557.

CHARACTERIZATION OF BLACK BODY TARGET MATERIALS FOR CALIBRATION OF MICHELSON INTERFEROMETER DIAGNOSTIC

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At SST-1 tokamak in IPR, Michelson interferometer diagnostic has been installed to measure the plasma electron temperature profile and its evolution. This is done by acquiring the spectrum of the electron cyclotron emission (ECE) in the spectral range 70–500 GHz. The diagnostic needs to be calibrated before measurements and this is done in two phases. The first phase of the calibration process is done in-lab using ambient source at room temperature and cold source at 77 K. The second phase of the calibration is done from tokamak hall considering the losses of all the waveguides and transmission line components [1]. A high temperature source is required for second phase of calibration to improve the poor signal level and reduce the averaging time. The entire calibration process is done with Hot / Cold technique and three blackbody sources at three different temperatures are required. It is essential to characterize multiple black body target materials and identify suitable materials for developing the required sources for calibration. Also, due to limited availability of high temperature target materials, a new source is developed which is expected to exhibit black body properties at high temperature. Characterization of the target materials has been done by measuring their monostatic transmission and reflection. To gain knowledge on the scattered power by the targets, characterization by measuring the reflectivity at various specular angles has been performed. This paper presents the results of the characterization of the different blackbody target materials, development of a new high temperature source and a comparative study has been carried out.

References:

[1] Schmuck, S. et al. Electron cyclotron emission measurements on JET: Michelson interferometer, new absolute calibration, and determination of electron temperature. Rev. Sci. Instrum. 83, (2012).
[2] Space qualified Tessellating TeraHertz RAMs for the 50 to 1000 GHz Region and beyond.http://www.terahertz.co.uk/index.php?option=com_content&view=article&id=145&Itemid=448.

MODE SPECTRA ANALYSIS OF A DC COULOMB CRYSTAL

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We report the mode spectra analysis of a Coulomb crystal in DC glow discharge plasmas. The experiments are performed in Dusty Plasma Experimental Device (DPEx) [1], in which a DC glow discharge Argon plasma is produce in between the circular anode and tray shaped grounded cathode. Mono-dispersive MF particles of diameter 10.66 µm are introduced in the plasma to create a large sized 2D dusty plasma crystal [2]. In the plasma environment, the dust particles get negatively charged due to high mobility of electrons and levitate in the cathode sheath by the balance of gravitational and sheath electric forces. The laser illuminated dust particle coordinates as a function of time are recorded using high speed and high resolution CCD camera. The coordinates of each particle are then extracted over the time using IDL based particle tracking code. Fourier spectra analysis is used to estimate the longitudinal as well as transverse modes over the range of discharge parameters. The results and the methodology will be discussed in the conference.

References:

[1] S. Jaiswal, P. Bandyopadhyay, and A. Sen, Rev. Sci. Instum **86**, 113503 (2015).
[2] M G Hariprasad, P. Bandyopadhyay, G Arora, and A. Sen, Phys. Plasmas **25**, 123704 (2018).

DESIGN, FABRICATION, INSTALATION AND TESTING OF Nb_3Sn SUPERCUNDUCTOR BASED SOLENOID COIL

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Nb_3Sn superconducting strands are required for high magnetic field (>8 T) generation. Optimization of heat treatment [1] is essential for the superconductivity of this strand. Nb_3Sn strands are required to be heat treated at 650°C under vacuum. The heat treatment cycle runs continuously about 22 days. A solenoid coil has been design to produce the magnetic field around 1 T at its center. This solenoid is layer wound type and fabricated using Nb_3Sn strands of diameter 0.82 mm.The inner and outer diameter of solenoid coils are 96 mm and 122 mm respectively. The height of this solenoid is 68 mm with total no. of turns about one thousand. The operating current of this solenoid is about 180 A at 4.2 K. The heat treatment was carried out at 650°C under vacuum. The metallurgical and superconductivity tests of heat treated Nb_3Sn strands taken out from both ends of coils carried out. Support structure and end terminals connected with this solenoid to withstand thermal and electromagnetic loads and current charging. This solenoid is integrated with self-field facility to test at 4.2 K. The testing of this solenoid coil is in progress. The design, fabrication and test results of this solenoid will be elaborated in this presentation.

References:

[1] Heat treatment and Metallurgical characterization of Nb3Sn/Cu KODA strands, IPR/TR-470/2018

CHARACTERIZATION OF A LARGE SIZE COULOMB CRYSTAL IN DC GLOW DISCHARGE PLASMAS

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In the present investigation, we report the characterization of a large size DC coulomb crystal produced in a versatile dusty plasma experimental setup. Its geometry and design principle has been attracted a great deal by previously developed DPEX device at IPR [1]. However, its principle purpose is solely differs from DPEX device. Studies like voids generation in DC crystal, Phase coexistence, phase transition, fluctuation rectification, effect of spatial inhomogeneity of dust density on its dynamics etc. where dust crystal size plays significant role and therefore, a system for large size DC coulomb crystal is highly preferred. To perform various experiments with large size 2D Coulomb crystal, a L-shaped tabletop dusty plasma experimental setup with asymmetric electrode configuration is recently built up at IPR. A glow discharge plasma is produced by applying a DC voltage in between the anode and cathode in the background of Ar gas. Various plasma parameters such as plasma density, electron temperature, plasma and floating potentials, electron energy distribution function etc. along the axial and radial directions are then measured using single and double Langmuir probes, emissive probe and spectroscopic techniques over a range of discharge conditions. Mono-dispersive MF particles of diameter 10.66 µm are introduced in the plasma to create a dusty plasma. As soon as dust particles are exposed to plasma they get negatively charged due to high mobility of electrons and the two counteracting gravitational and sheath electric forces settle particles in a plane parallel to cathode and confined with suitable axial and radial confinement. The laser illuminated dust particle coordinates as a function of time is recorded using high speed and high resolution CCD camera. The consecutive images of dust crystal are then used to estimate the basic crystal parameters such as inter particles distance, dust temperature, pair correlation function, dust density, Delaney triangulation, dust charge etc.. The results from initial experiments on the large dust crystal will be discussed in the conference.

References:

[1] S. Jaiswal, P. Bandyopadhyay, and A. Sen, Rev. Sci. Instum **86**, 113503 (2015).
[2] M G Hariprasad, P. Bandyopadhyay, G Arora, and A. Sen, Phys. Plasmas **25**, 123704 (2018).

FIRST ORDER SOLID-LIQUID PHASE TRANSITION IN COMPLEX PLASMAS

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We report the first order phase transition in a strongly coupled two-dimensional DC discharge complex (dusty) plasma. Experiments are carried out in Dusty Plasma Experimental (DPEx) Device in which complex plasma is produced by using mono-dispersive MF particles in the background of a DC glow discharge Argon plasma [1]. An explosive full melting of the dusty plasma crystal is observed with a negligible decrease in neutral gas pressure (0.1 Pa). The dust temperature dramatically increased to approximately 50 eV from 2 eV and the Coulomb coupling parameter changed to approximately 7 from 220. Structural analysis of two-dimensional crystal and liquid is carried out through a number of analysis like pair correlation function, Voronoi diagram and Delaunay triangulation. The melting process is accompanied by fluctuations that are most likely due to wake effects arising from the flow of plasma ions leading to unstable mode excitations and concomitant heating of the crystal.

References:

[1] M. G. Hariprasad, P. Bandyopadhyay, G. Arora, and A. Sen, Phys. Plasmas, 25, 123704 (2018).

CONCEPTUAL DESIGN OF DATA ACQUISITION AND CONTROL SYSTEM OF LARGE SCALE CRYOGENICS PLANT SYSTEM

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To develop helium plant of 200W cooling capacity at 4.5 K, the cryogenics components test facility is going to build at IPR, which accomplish with main components compressors, oil removal system and cold box to produce cold helium. Cryogenics plant test facility will be used to test the cryogenics components, compressor closed loop operation, different types of plate-fin heat exchangers and helium purifiers. Hence, such cryogenic test facility needs measurement of large number of sensors (temperature, pressure, flow, speed, vibration, level etc…) for diagnostic and controls of valves to operate in the controlled environment. The facility will be used for development and analysis of cryogenics process algorithm. This paper will describe the conceptual design, architecture and process logic of the control system. The system is optimized with different type of PLCs, based on the cost and functionality required for operation and control. Main control system will be developed with

Siemens PLC for its rugged operation. Pressure and temperature sensors, which are required for control operation of liquefier will be measured with this PLC. Temperature sensor which are not used for control purpose and only used for diagnostics will be acquired with temperature scanner module. Only data acquisition sensor having 4-20mA output will be acquired in the 8 channels Data acquisition boards with Modbus interface. Modular approach is chosen to build the system. The Control system of Compressor station has been developed as first module of Large Scale Cryogenics Plant system with open loop control system. It will be put in the close loop control mode after analysis of the compressor operation. Modular approach is selected for easy step wise integration. Each data acquisition module will be integrated with Modbus interface to the central system. In totality around 62 nos. of Analog inputs, 26 nos. of Analog output, 70 nos. of Digital Input and 100 nos. of Digital output channels are estimated for plant control system. Open source software is selected for software development. Plant data will be stored in the data base for post analysis. The concept have been developed for full plant system including controlled operation, data logging, storage, display, process, access for automated operation.

EXCITATION OF PINNED STRUCTURES IN FLOWING COMPLEX PLASMA

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We report experimental observations on the excitation of pinned solitary structures in a flowing complex plasma. The experiments are performed in π- shaped Dusty Plasma Experimental (DPEx) [1] device where a DC glow discharge Ar plasma is created in between a disc shaped anode and a long tray shaped cathode. A dusty plasma is then formed using poly-dispersive kaoline particles. A floating copper wire mounted radially on the cathode creates a sheath around it in the plasma environment and acts as a charged object for the flowing dusty plasma fluid. The flow of dust cloud is initiated by lowering the potential of the charged object from ground potential and the flow speed is controlled precisely by connecting the wire from grounded potential to various intermediate potentials including floating potential. It is found that for particular discharge conditions and critical velocities of the fluid flow, high amplitude non-linear standing structures get excited. The amplitude, width and number of the excited structures are studied for different flow velocities of the dust cloud. It is noticed that with the increase in the flow velocity, the amplitude of the stationary structures increases whereas the number increases from one, two to many. These solutions are distinct from previously observed non-stationary precursor solitons [2] and constitute a new class of driven nonlinear structures. The experimental observations are compared with special solutions of a model forced-Korteweg de Vries (f-KdV) equation and found to be in good qualitative agreement. The potential applications of such excitations in the context of solar wind interaction with planets and satellite interaction with ionospheric plasmas are discussed.

References:

[1] S. Jaiswal, P. Bandyopadhyay, and A. Sen, Rev. Sci. Instrum. **86** (2015) 113503.

[2] S. Jaiswal, P. Bandyopadhyay, and A. Sen, Phys. Rev. E **93** (2016) 041201(R).

LOW-TEMPERATURE PLASMA NITROCARBURIZING OF AUSTENITIC STAINLESS STEELS TO IMPROVE SURFACE HARDNESS

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Low-temperature plasmas are applied largely to develop functional surface coatings and to cause surface modifications that improve surface mechanical properties such as hardness, wear resistance and fatigue resistance of austenitic stainless steels which otherwise have poor wear properties due to low hardness. One such plasma based surface hardening process is plasma nitriding in which DC/pulsed-DC discharge of N_2-H_2/N_2-Ar/N_2-Ar-H_2 gas-mixtures are employed. Plasma nitriding processes were usually carried out at 380^oC-450^oC, for 5h-10h during which nitrogen diffuses from the plasma to the substrate being treated forming a hard case of nitrogen-rich expanded austenite (γ_N) phase on the surface and down to 10-15 µm deep from the surface [1-3]. Improvement of the surface hardness and the case-depth depends upon the gas-mixture composition wherein H_2 and Ar influence the nitrogen transport from the discharge to the substrate. H_2 and Ar help in breaking the passive Cr_2O_3 layer on stainless steels by sputtering allowing nitrogen to penetrate and also increase the formation of $NH^{\cdot}$ and N_2^+ which are major nitrogen transporting species in the discharge. Case-depths in austenitic stainless steels can further be improved by low-temperature plasma nitrocarburizing process in which small amounts (1%-5%) of CH_4/C_2H_2 are added to the N_2-H_2/N_2-Ar/N_2-Ar-H_2 gas-mixtures as a hard carbon-rich (expanded austenite, γ_C) layer forms below the hard nitrogen-rich layer extending the hard case forming a dual-layered structure.
In the present work, AISI 304 and AISI 304L austenitic stainless steels samples were plasma nitrocarburized at 400^oC and 5 mbar for 5 h with discharges of N_2-H_2-C_2H_2, N_2-Ar-C_2H_2 and N_2-Ar-H_2-C_2H_2 keeping constant N_2 (50%) and C_2H_2 (2%) partial pressures to compare between the effects of H_2 and Ar in nitrogen and carbon transport from the discharge and the resulting improvements in surface hardness, corrosion resistance and case-depth. Surface hardness and corrosion resistance for the samples were found to improve significantly after the plasma nitrocarburizing treatments and greater improvements were observed in samples that were treated with N_2-H_2-C_2H_2 plasma. AISI 304 samples showed higher improvements than AISI 304L samples. Case-depths were observed to have the dual-layered structure and were found to be highest in the samples treated with N_2-Ar-H_2-C_2H_2 plasma and least depths were observed in samples treated with N_2-H_2-C_2H_2 plasma.

References:

[1] J. Alphonsa, B. A. Padsala, B.J. Chauhan, G. Jhala, P.A. Rayjada, N. Chauhan, S.N. Soman, P.M. Raole, Plasma nitriding on welded joints of AISI 304 stainless steel, Surface and Coatings Technology, 228, Supplement 1, p S306-S311 (2013)

[2] B. Larisch, U. Brusky, H.-J. Spies, Plasma nitriding of stainless steels at low temperatures, Surface and Coatings Technology, 116–119, p. 205 (1999)
[3] M. Naeem, J. Iqbal, M. Abrar, Kamal H. Khan, J.C. Díaz-Guillén, C.M. Lopez-Badillo, M. Shafiq, M. Zaka-ul-Islam, M. Zakaullah, The effect of argon admixing on nitriding of plain carbon steel in N_2 and N_2-H_2 plasma, Surface and Coatings Technology, 350, p 48 (2018)

THE STUDY OF THE EFFECT OF COMPRESSIVE LOAD ON CRITICAL CURRENT OF HIGH TEMPERATURE SUPERCONDUCTING TAPES

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The high temperature superconducting tapes are of extensive interest for the generation of high magnetic fields within limited space due to comparatively high operating temperature and rampant rise in helium cost. Second generation (2-G) high current HTS tapes of several tens of meters are now commercially available for various practical applications. The suitability of these tapes is required to be tested for particular operating conditions of HTS based magnets. In this work, an attempt has been made to evaluate the electromechanical properties of commercially available HTS tapes. Previously, these tapes have tested under the different tensile cyclic load [1,2] at 77 K. These tapes are also subjected to compressive loads while used for multi-turn solenoid coil and twisted cable fabrication. The intended compressive loads in the range of 1-15 ton will be applied to study its effect on the critical current and n-value of these tapes at 77K operating temperature. In this presentation, the studies on the effect of different compressive loads on electrical properties of commercially available HTS tapes at 77 K will be elaborated.

References:

[1] Effects of room-temperature tensile fatigue on critical current and n-value of IBAD–MOCVD YBa2Cu3O7−x /Hastelloy coated conductor, Samuel Rogers, Wan Kan Chan, Justin Schwartz; Samuel Rogers et al 2016 Supercond. Sci. Technol. 29 085013.
[2] Electromechanical Investigation of 2G HTS Twisted Stacked-Tape Cable Conductors, L. Chiesa, N. C. Allen, and M. Takayasu, IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 24, NO. 3, JUNE 2014.

SHEET MODEL OF UPPER-HYBRID OSCILLATION IN AN INHOMOGENEOUS COLD PLASMA IN PRESENCE OF INHOMOGENEOUS MAGNETIC FIELD

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The space-time evolution of upper-hybrid oscillations in an inhomogeneous cold plasma in the presence of an inhomogeneous external magnetic field is studied using a 1-1/2 D sheet code based on Dawson Sheet Model [1]. In the absence of an external magnetic field, finite plasma inhomogeneity results in wave breaking via phase mixing [1,2,3]. Oscillations/waves also break if the external magnetic field is inhomogeneous even if the background is homogeneous [4]. But it is possible to avoid the breaking of upper-hybrid oscillation in the presence of inhomogeneity in both external magnetic field and background ion plasma density [5]. These theoretical predictions are verified by performing numerical simulations.

References:

[1] J. M. Dawson, Phys. Rev. 113, 383–387 (1959).
[2] E. Infeld, G. Rowlands, Phys. Rev. Lett. **62**, p 2269 (1989).
[3] Mithun Karmakar, Chandan Maity, Nikhil Chakrabarti and Sudip Sengupta, Physics of Plasmas **25**, p 022102 (2018)
[4] C. Maity, N. Chakrabarti, and S. Sengupta, Phys. Rev. E 86, 1–6 (2012).
[5] Anwesa Sarkar, Chandan Maity and Nikhil Chakrabarti, Physics of Plasmas **20**, p 052301 (2013)

PRELIMINARY DESIGN AND ANALYSIS OF FLYWHEEL SYSTEM FOR PULSED ALTERNATOR

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Flywheel driven Pulsed alternators are used for the short pulse high energy need applications like rail guns and central solenoid coils of Tokamak etc. The main components of pulsed alternator are: Flywheel, AC Servomotor with VFD, Bearings, Shaft, Alternator, AC-DC Converters, Transformer and electronic Switches. Flywheel is basically a device to store kinetic energy. Kinetic Energy is stored in the flywheel over long durations to the speeds of 6000-12,000 RPM driven by low power Servomotor. Flywheel’s main characteristic compared to other systems is its capability to take and release energy in very short periods of time, for which flywheels have traditionally been used in compressors, press and strike machinery. Flywheels are being made out of composite materials, resulting in a substantial increase in energy density storage capability due to higher speeds of operation. This energy is

superior to that of batteries which have a slow loading and unloading cycle due to their inherent chemical process, as well as a short life if the interchange time decreases.
The flywheel's shaft is connected to a load (i.e.) alternator to produce electricity. The output of pulsed alternator would be conditioned to meet pulse load requirements. Anticipated application loads are Central Solenoid of Small Scale Spherical Tokamak, Linear Induction Motors etc.This paper would presents Preliminary design and analysis of flywheel system.

References:

1. Jose L.Perez-Aparicio and Lluis Ripoll, Exact, integrated and complete solutions for composite flywheels, Composite Structures 93 (2011) 1404-1415.
2. D.H. Curtiss,P.P. Mongeau, R.L. Puterbaugh, Advanced Composite Flywheel Structural Design for a pulsed Disk Alternator, Kaman Electromagnetics Corporation, Hudson,MA. IEEE Transactions on magnetics, VOL.31,No.1,January,1995.

REMOTE HANDLING OF VFD USING LABVIEW AND MODBUS PROTOCOL NON-CONVENTIONAL ANTENNA EXPERIMENTS

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Experimental setup of non-conventional antenna demands remote control and monitoring of motor which is driven by the VFD (Variable Frequency Drive). The local control of this drive needs one to remember hex codes for the parameters to be controlled which is not only cumbersome but also requires extra human intervention during the experiment execution
A remote control application over serial link has been developed for control and monitoring of motor. The VFD supports serial communication protocol Modbus-RTU for varying parameters like frequency, torque, ON/OFF etc. The NI LabVIEW based application GUI (graphical user interface) is developed to change the various parameters of the VFD. The LabVIEW application is developed into a run time and hence does not require LabVIEW license during execution This paper will present details of Modbus serial communication with the device and challenges that we overcome in development of this application.

References:

[1] www.ni.com.
[2] Amtech VT240S (VFD) user manuals

USE OF ACOUSTIC TRAP AS NANO POWDER COLLECTION MECHANISM: AN INVESTIGATION

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Nano sized powder of various materials is in great demand due to its varied potential applications such as: Catalysts, Solid Rocket Fuel, Synthetic Bone, Conducting Paste, Magnetic Tapes & Fluid, Targeted Drug Delivery, Metallic Paint, Sintering Aids, and Transparent Polymers. With increasing demand in each of these fields, the necessity for an efficient technique for Nano Powder generation is inevitable. One of the effective methods to produce Nano Powder in large quantities is to evaporate the feed raw material by Transferred Arc plasma process and subsequent collection of the nucleated and grown Nanopowder. The collection zone plays a vital role in the quality (smaller particle size and narrower size range) of the product. The conventional collection method of such powders employs techniques such as cyclone separators and powder sintered filters. But recent literature [1-2] suggests a possible better efficient system in collecting the Nanopowders. The work here reports on using Ultrasonic Transducers to generate standing waves and thereby creating an Acoustic Trap. This trap has the potential to hold Nano-sized powder without any interaction with the surrounding structure. Collection efficiency (quantity of collected Nano Powder/quantity of Nanopowder produced) is expected to increase using this method. Detailed analyses of the Potential Energy map and Acoustic Radiation Force across the sound domain have been estimated and will be presented. The results suggest that the condensed Nano Powder can be effectively trapped and collected using the Ultra Sonic transducer array.

References:

1. A. Marzo, M. Caleap and B.W. Drinkwater "Acoustic Virtual Vortices with Tunable Orbital Angular Momentum for Trapping of Mie Particles", *Phys.Rev.Lett.*, **120** (2018) 044301
2. M.A.B. Andrade, A.L. Bernassau and J.C. Adamowski, "Acoustic levitation of a large solid sphere", *Applied Phys. Lett.*, **109** (2016) 044101

AUTOMATION OF GRAPHITE BASED PLASMA TORCH USING MICROCONTROLLER

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Plasma pyrolysis system is used for the safe disposal of plastic and paper waste. Plasma Pyrolysis system consists of plasma torch which is made up of graphite electrode in which one electrode works as anode while two electrodes works as cathode. Initially with a predefined gap an arc is maintained between anode and cathode. As the arc continues an erosion of electrodes take place. In this situation to sustain arc, the gap

between electrodes has to be maintained automatically. For this purpose a logic circuitry has to be developed which sense the arc parameters and automatically adjust the electrode position. Logic circuitry using 8 bit microcontroller AVR v7 is used for automation and control of plasma torch.

DATA ACQUISITION AND CONTROL SYSTEM FOR INITIAL TOROIDAL MAGNETIZED PLASMA EXPERIMENTS

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To study the effect of parallel electric field in the toroidal plasma, an experiment has been designed and carried out in toroidal machine, having major radius of ~30cm, and minor radius of ~10.5cm. The toroidal magnetic field is formed using 8-toroidal coils and is powered by capacitor bank (0.16F, 200V). Plasma of ~8ms duration is formed using ECR breakdown technique with 2.45 GHz, 500W magnetron. The Ohmic coil is placed in the bore of the machine which is discharged with capacitor bank to produce loop voltage in the device. In order to obtain plasma discharge, the capacitor banks and power supplies need to be operated and controlled in time synchronous manner. To achieve these objectives, the data acquisition and control system is developed on PXI platform using LabView. The control system generates voltage references for power supplies and provides timing control for on/off operation. The data acquisition and control system is used to conduct experiments, acquire basic initial plasma diagnostics data and archive it in file system. A basic data plotting and analysis utility is also developed. Initial experiments were carried out successfully with the developed data acquisition and control system.

PRELIMINARY DESIGN OF OHMIC SYSTEM FOR SMALL SCALE SPHERICAL TOKAMAK

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Spherical Tokamaks (ST) are being explored worldwide for economical and practical aspects of fusion power. They are attractive because of low aspect ratio, relatively small size, effective utilization of magnetic field, high beta & high boot strap fraction [1, 2]. A small scale ST is being designed at IPR as a first step with the available infrastructure and utilizing technologies & expertise gained from our tokamak experiments. Ohmic system for small scale ST is being designed to assist plasma breakdown and current ramp up. Because of the very small space available at inboard side, it is technically challenging to develop ohmic system for ST. This paper describes the physics, electrical, mechanical design of ohmic

system. The magnetic null simulation of ST using ANSYS Maxwell is reported besides the heating and cooling analysis of the ohmic transformer.

References:

[1] Features of spherical torus plasmas, Nucl. Fusion, **26**, p 769, (1986)
[2] Compact fusion energy based on the spherical tokamak, Nucl. Fusion, **58**, p 16039, (2018)

GENERATION OF SHEAR FLOW IN A FLOWING DUSTY PLASMA

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We report the generation of shear flow in a flowing dusty plasma experiment. The experiments are performed in Dusty Plasma Experimental (DPEx) device in which the glow discharge plasma is produced by applying a DC voltage in between a circular anode and a grounded tray cathode in the background of Argon gas [1]. Firstly, the laminar flow in the dust fluid is initiated along the axis of the cathode using single gas injection technique [2]. In this set of experiments, the dust particles are found to flow without creating any velocity shear in the dust fluid. To generate a velocity shear in the direction perpendicular to the flow, an obstacle is kept on the cathode tray, which partially hinders the flow of dust particles. The dust particles, which are located far from the obstacle flow with higher velocity whereas the particles, which are located near the obstacle flow with slower velocity resulting a strong shear in the interface. To tune the shear velocity in the dust fluid, the experiments are repeated over a range of mass flow of neutral gas over a range of discharge parameters. The parameters associated with the flow and their profiles along the axial and the radial directions are estimated and compared over a range of discharge parameters using Matlab based Particle Image Velocimetry (PIV) technique.

References:

[1] S. Jaiswal, P. Bandyopadhyay, and A. Sen, Rev. Sci. Instrum. **86**, 113503 (2015).
[2] S. Jaiswal, P. Bandyopadhyay, and A. Sen, Plasma Sources Science and Technology **25**(6), 065021, 2016.

DEVELOPMENT OF TEST SETUP FOR MEASUREMENT OF PRESSURE DROP AT CRYOGENIC TEMPERATURE

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IPR is engaged in the development of low temperature as well as high-temperature superconducting magnet and cables. Liquid Nitrogen, Sub-cooled Nitrogen and Cryogenic

gaseous Helium is used as cooling media for these applications. Whenever a cryogenic fluid is pumped through these systems, the pressure drop is observed along the length of encasing media such as steel jackets or flexible hose. The calculation of pressure drop is very much essential to determine critical parameters during operation such as the selection of pump types, pump capacity, piping network, joints and valves etc. An experimental test setup is developed to measure the pressure drop across various applications such as transfer lines, heat exchangers etc., being developed at IPR. The selection and verification of the various components for this facility are governed by cryogenic temperature as well as their suitability for gaseous or liquid cooling media. The details of the manufacturing of the test setup, its components and various instrumentation used to measure pressure drop are discussed in this paper. It is also demonstrated for the measurement of pressure drop of Liquid Nitrogen in the tube type heat exchangers for subcooled Nitrogen facility.

EXPERIMENTAL STUDY OF LASER INDUCED SHEAR FLOW IN A TWO-DIMENSIONAL YUKAWA SYSTEM

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We present the experimental study of laser induced shear flow in a DC glow discharge dusty plasma. The experiments are carried out in Dusty Plasma Experimental (DPEx) device [1] in which the glow discharge Argon plasma is produced by applying a DC voltage in between a disc shaped anode and a grounded tray cathode. Dust particles are then introduced into the plasma, which get negatively charged by collecting more electrons than ions and form a crystalline structure near the cathode sheath region by balancing the electrostatic and gravitational forces [2]. Initial dusty plasma parameters like pair correlation function, inter-particle distance, Coulomb coupling parameter and kinetic temperature are estimated using a IDL based particle tracing code. Two counter propagating laser beams are used horizontally to induce shear flow in this Coulomb crystal. The speed of the dust flow is mapped in a horizontal plane using the particle image velocimetry technique (PIV). The kinetic energy of the flow and its vorticity are deduced based on the velocity vectors obtained from PIV analysis.

References:

[1] S. Jaiswal, P. Bandyopadhyay, and A. Sen, Rev. Sci. Instrum. **86**, 113503 (2015).
[2] M. G. Hariprasad, P. Bandyopadhyay, Garima Arora, and A. Sen, Physics of Plasmas **25**, 123704 (2018)

EXPERIMENTAL STUDY OF STICKING COEFFICIENT MEASUREMENT FOR XENON, ARGON AND NITROGEN GASES ON BARE COPPER SURFACE AT 20 KELVIN TEMPERATURE FOR VACUUM PUMP APPLICATION

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Propellant like xenon, and other heavy noble gases are used in hall plasma thruster for spacecraft propulsion application. Hall plasma thruster test facility requires high pumping speed for Xenon gas [1]. Institute for Plasma Research is developing cryogenic vacuum pump for xenon gas. Sticking coefficient is an essential parameter for designing any cryogenic vacuum pump[2]. Using GM cryo-cooler, the sticking coefficient for xenon, argon and nitrogen gases is experimentally studied in Vacuum pumping environment at 20 Kelvin temperature on bare copper plate. The sticking coefficient is evaluated through an experimental pumping speed measurement using flow meter method recommended by American vacuum society [3]. The experimental pressure range was 1.0E-06mbar to 5.0E-6 mbar. The simulation was performed for the test setup to evaluate transmission probability and to predict the pressure for different sticking coefficient using MOLFLOW software. This paper describes the experimental method in detail along with the simulation and experimental results.

References:

[1] Computation of Neutral Gas Flow From a Hall Thruster Into a Vacuum Chamber Iain D. Boyd, Chunpei Cai, Mitchell L. R. Walker and Alec D. Gallimore Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI 48109

[2] Basics and applications of cryopumps by C. Day Forschungszentrum Karlsruhe, Institute of Technical Physics, 76344 Eggenstein-Leopoldshafen, Germany

[3] M.H. Hablanian, Recommended procedure for measuring pumping speeds, J. Vac. Sci. Technol. A Vacuum, Surfaces, Film. 5 (1987) 2552–2557

DESIGN AND ANALYSIS OF RECTANGULAR VACUUM VESSEL AND SUPPORT STRUCTURE FOR PLASMA GENERATION SYSTEMS

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Various systems used in plasma experiments are designed and analyzed for their functional requirements and structural integrity. Two systems, namely food grain plasma processing chamber and cryogenic turbine testing system's support structure are designed and analyzed.

The rectangular vacuum vessel will be used as food grain (i.e. seeds) radio frequency plasma processing chamber to increase its productivity and quality. The design and analysis of rectangular vacuum vessel of dimensions 750 x 750 mm cross-section and 400 mm height as per ASME code is discussed. The stresses experienced by the rectangular vessel was very high than circular vessel for similar thickness. Hence to reduce the thickness, the reinforcements were designed as per ASME code for the optimization. This paper also presents the analysis of the support structure for the vacuum vessel of 3.2 m dia. with 3 m height for cryogenic turbine testing. The design load of the vacuum vessel is ~8 ton (approx. including the weight of 10 persons) and is acting as a point load on the 4 beams kept at 4 m height using 4 columns or legs These 4 legs (with ladder) has 4m gap in between, which provide support during assembly and dismantling of chamber. This paper presents the FEM results of structural analysis, which allow design to be safe with allowable stress limits and deformation

UNDERSTANDING ONSET OF TURBULENCE IN RAYLEIGH-BENARD CONVECTION IN 2-D YUKAWA LIQUIDS

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When a fluid is subjected to an external force, the motion becomes irregular, non-periodic and chaotic, i.e. , we have turbulence at sufficiently large value of external force. Many theories have been proposed to understand the evolution of non-periodic time-dependent behaviour of the fluid: Landau proposed that the fluid goes through a large number of bifurcations before the onset of turbulence [1], whereas, Ruelle and Takens based on the abstract mathematical arguments, proposed that only three or four bifurcations are sufficient for the fluid motion to become turbulent [2].

We propose to investigate the nature of onset of turbulence in the Rayleigh-Benard system of 2D Yukawa liquids using MD simulations. When 2D Yukawa liquid is subjected to an external gravity and external temperature difference between the top and bottom plates (ΔT), it leads to the formation Rayleigh-Benard convection cells in the system which beyond some critical value of externally applied temperature difference $(\Delta T)_c$ [3] is known to become turbulent for increasing values of ΔT. We investigate the mechanism of onset of turbulence using MD simulations, the details of which will be presented.

References:

[1] L. Landau and E.M. Lifshitz, Fluid Mechanics, Chapter 3 (Pergamon, London, England, 1959).
[2] D. Ruelle and F.   Takens, Commun. Math. Phys. 20, 167 (1971).
[3] Harish Charan, PhD thesis, HBNI, 2017

ON MOMENTUM SPACE DYNAMICS OF RUNAWAY ELECTRONS IN TOKAMAK PLASMAS USING AN INTEGRATED TEST PARTICLE MODEL

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Runaway electrons (REs) generated during the plasma disruption phase can lead to serious damage to the confining structure in the tokamak if they collide with the first wall. This is particularly severe in the large size tokamaks like ITER where a large fraction of the plasma current can be converted into RE-current during the disruption phase. Therefore, understanding the avoidance and mitigation of REs is a high priority task for modern tokamaks along with theoretical model development. Developing a rigorous theoretical model can lead to better simulations that can determine the effectiveness of various suppression mechanisms of decreasing RE generation and also helps in designing better plasma scenarios for the avoidance of the same. In this paper, previously developed test particle models [1-3] were revisited and then they were integrated under a single model for the first time to take into account several forces namely force due to the toroidal electric field, plasma collisional drag force, synchrotron deceleration, pitch angle scattering due to ripple resonance and interaction with the lower hybrid waves. Inclusion of these forces captures RE dynamics close to reality and leads to better numerical predictions. The developed numerical model is then tested for its consistency and benchmarked against published results. Cumulative effects of these forces on RE dynamics is studied and reported herein.

References:

[1]. J. R. Martín-Solís, et.al., Physics of Plasmas, 6(1), pp238-252,(1999).
[2]. J. R. Martín-Solís, et.al., Physics of Plasmas, 6(10), pp3925-3933, (1999).
[3]. J. R. Martín-Solís, et.al., Physics of Plasmas, 9(5), pp1667-1675, (2002).
[4].

OHMIC POWER SUPPLY PARAMETER REGIME FOR SST-1 TOKAMAK OPERATION

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Ohmic heating power supply with wave shaper circuitry is used in SST-1 for initial plasma current drive. The ohmic coils store a magnetic flux from ohmic power supply current and high di/dt is generated by wave shaping circuit for the required loop voltage. Additional flux swing is provided by negative ohmic converter with di/dt required for plasma current drive. Operation and tuning of ohmic power supply and associated wave shaping system for the

desired loop voltage, plasma current drive and control, inverting mode operation and negative converter operation for SST-1 are described in this paper. A set of operating parameters and data are analysed and observed a certain range of operation parameter regime is also discussed in this paper.

OVERVIEW OF THE OPERATIONAL AND CONTROL PHILOSOPHY OF THE EXPERIMENTAL HELIUM COOLING FACILITY OF IPR

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Institute for Plasma Research (IPR) is developing a high-pressure (8.0 MPa) high-temperature (300-400 ^{0}C) helium gas system as a part of R&D activities in fusion blanket technologies. Blanket Cooling Section (BCS) of the Fusion Blanket Division (FBD) is responsible for the design, construction, and operation of the experimental facility. This facility is designed for testing the various components of the fusion blanket that are cooled by high-pressure helium gas. In this helium loop, primarily it is required to maintain temperature, pressure and flow at well-defined set points and these set points may vary in different modes of operations. The operating parameters are mainly dictated by process requirements; whereas limitations of some equipment also have an influence on defining the operating values. In EHCL, pressure requirement in a different mode of operations is achieved by the Pressure and Inventory Control System (PICS), which is designed to accommodate or supply the helium to maintain pressure in the loop. According to the experimental needs, it is also required to control the helium temperature and flow rate across the test mock-ups. The required temperature at the test section is achieved by operating an electrical heater, flow control valves, and bypass lines. Flow control in different modes is achieved by circulator operations and flow control valves. Plant operations are carried out as per the modes selected by the Operator. Different modes of operations are having different functionalities and in any chosen mode of operation some operations are permitted and some are prohibited. The operational and control scheme of the loop is developed so that it meets the different experimental requirements and ensures the safe operation of the loop. This paper presents the details of the operational and control system of the helium cooling facility.

References:

[1] B.K. Yadav, A. Gandhi, et al., Helium Cooling Systems for Indian LLCB TBM, Fusion Engineering and Design, 124 (2017) 710–718.
[2] B. K. Yadav, A. Gandhi et al., Conceptual design of experimental helium cooling loop for Indian TBM R&D experiments, world academy of science, engineering and technology Int. J. Phys. Nucl. Sci. Eng., 8 (2) (2014).
[3] EHCL process and safety design manual_v0.0
[4] EHCL Instrumentation Design Manual_v0.0

IN-VESSEL INSPECTION SYSTEM: DEVELOPMENT ACTIVITIES OF VACUUM AND TEMPERATURE TECHNOLOGIES FOR FUSION REMOTE HANDLING APPLICATION

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The work presented in this paper covers the fabrication development of In-Vessel Inspection System (IVIS) and storage vacuum chamber to carry out in-service visual inspection of SST-1 like tokamak under vacuum in between the plasma shots. The designed IVIS manipulator is ~2m long with 04- Degrees of Freedom (DOF), comprising of three rotary joints and one linear motion for deployment within the tokamak. The manipulator is designed to handle a cantilevered payload of ~1kg with a positional accuracy of <2mm. A feasibility assessment of suitable technologies to operate the IVIS under the SST-1 like conditions of vacuum and temperature was performed. IVIS components should sustain ~70ºC during VV inspection and UHV (~1x10^{-7} mbar) for its conditioning prior to entering the VV. Limits on out-gassing inside the VV impose serious constraints for the design (e.g. on material, on joints design, actuators and cables). This assessment was carried out through close collaboration and knowledge sharing involving Vacuum Engineering Services Division. First design of lubricant free joints is based on incorporation of MoS2 bushes instead of bearings in IVIS joints. The COTS components availability (actuators, reducers, bearings, encoders, vacuum-feedthroughs and cable tray) to match the performances compatible with high temperature, ultra-high vacuum requirements and to overcome pollution issues of the tokamak environment. The rotation axes are always in the horizontal plane. This configuration limits the torque required from the yaw actuator due to the absence of gravitational torques. DC off-the-shelf motors and their standard attached gear-boxes both hardened to the required high temperature operation and vacuum conditions are selected. At this step it has been identified the need for developments of specific new technologies in particular for hybrid bearings, ball screw, ball screw nut, guide blocks, guide rails, viewing systems, cables and electronics. Improvements to enhance IVIS operation under temperature and vacuum conditions for SST-1 like machine were reviewed and results are presented. Theoretical calculations, kinematic assessments and structural integrity analyses were carried out in detail to optimize the design.

DEVELOPMENT OF LITHIUM TITANATE CERAMIC PEBBLES BY FREEZE GRANULATION AND FREEZE DRYING METHOD

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Lithium titanate (Li_2TiO_3) is considered as one of the candidate material for tritium breeding. IPR (Institute for Plasma Research) is developing Li_2TiO_3 powder solid-state reaction method

followed by pebble preparation. Li_2CO_3 (lithium carbonate) and TiO_2 (titanium di-oxide) are used as a raw material for the Li_2TiO_3 preparation. Li_2TiO_3 powder is prepared by high energy ball milling followed by calcination at 1000°C. The reaction temperature is estimated by the thermo-gravimetric study. Pebbles are developed by freeze granulation method. An experimental set up is fabricated for freeze-granulation and freeze-drying experiments. Pebbles are prepared with different solid to liquid weight ratio of 1:2, 1:2.5 and 1:3. Effect of the nozzle size to the pebble diameter is also studied. Pebbles are sintered at different temperature and from 1000-1150°C for various sintering time. Phase purity and surface morphology of the sintered pebbles are analyzed by x-ray diffraction and scanning electron microscopy. Bulk density, porosity and pore size distribution are analyzed by the mercury porosimeter technique. Thermal conductivity, specific heat and crush strength of the pebbles are also discussed in this paper.In this paper, development route of lithium titanate powder and pebbles along with its characterization will be discussed.

THE EFFECT OF TOROIDAL ELECTRIC FIELD IN TOROIDAL MAGNETIZED PLASMA

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The toroidal magnetized plasma when compared to linear magnetized plasma exhibits better plasma performance in terms of its plasma parameters. Although the end field effects of linearly magnetized plasmas are overcome in toroidal magnetized plasmas, it give rise to loss mechanism attributed to grad-B and curvature effects. The equilibrium of toroidal magnetized plasma can also be modified by applying toroidal electric field. This can be easily achieved by inserting an Ohmic coil in the bore of the toroidal plasma device and which produces toroidal electric field or loop voltage in the plasma when the Ohmic coil is magnetized. To study the effect of parallel electric field in the toroidal plasma, an experiment has been designed and carried out in toroidal machine, having major radius of ~30cm, and minor radius of ~10.5cm. The toroidal magnetic field is formed using 8-toroidal coils and is powered by capacitor bank (0.16F, 200V). It is adjusted to form plasma employing 2.45 GHz, 500W magnetron, using ECR breakdown technique for ~8ms. The Ohmic coil is placed in the bore of the machine having diameter of ~ 13.6 cm, resistance of 72 $m\Omega$ and having 112-turns giving inductance of 0.417 mH. When it is discharged with capacitor bank of 700 microfarad, charged up to 1kV, it produces ~1volt of loop voltage in the device, which corresponds to electric field of 0.53 V/m at the major radius. The parameters of the circuit are so designed that we get oscillating electric field when the coil is discharged with capacitor bank. The data acquisition and control system is developed based on PXI module. The plasma is characterized using Langmuir probe. The density formed with ECR plasma is ~ [6-9] x 10^9 cm^{-3} and temperature of ~4eV. The results indicate that in the presence of electric field the ion saturation current measured by Langmuir probe drastically reduces. It is likely that toroidal electric field may give rise to toroidal current, and would give rise to loss of particles

along open field lines toroidally because of geometrical reasons. The temporal evolution of the plasma density with parallel electric field at a given radial location is obtained with varying loop voltage. It is observed that density increases as loop voltage (or electric field) tends to zero and reduces when it grows in magnitude. This paper would present the experimental results obtained with toroidal electric field in toroidal magnetized plasma, followed by detailed discussions

SIMULATIONS OF OBLIQUE PROPAGATION OF MAGNETOHYDRODYNAMIC WAVE STRUCTURES IN PLASMA

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Strong theoretical interest exist in analyzing obliquely propagating magnetohydrodynamic (MHD) waves that are observed in strong magnetospheric turbulent activity as well as in laboratory magnetized plasma experiments, for example in a recent experiments in Large Volume Plasma device (LVPD) [1]. In this experiment, the whistler like EMHD modes were identified to be traveling at highly oblique (quasi-longitudinal) angle with respect to the applied magnetic field. In our numerical simulation, we have attempted to analyze the oblique propagation of such a hydrodynamic wave in 2-dimensional plasma set up. The initial electrostatic and electromagnetic simulations of wave activity with their extension to low frequency regime of MHD modes in magnetized plasma will be presented.

References:

[1] Observation of reflected electrons driven quasi- longitudinal (QL) whistlers in large laboratory plasma, Physics of Plasmas **24**, 102118 (2017).

VALIDATION OF PHASE MEASUREMENT USING DIGITAL IQ TECHNIQUE ON DOWN CONVERTED IF SIGNAL

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Ion Cyclotron Radio Frequency (ICRF) Sources are used to generate 20MW of RF power in the frequency range of 35 to 60 MHz for ITER Heating & Current Drive (H&CD) applications. To meet 20 MW of RF power with ITER stringent specifications, ITER-India, IPR has to design and develop 8 RF sources and one prototype as a spare RF source [1]. Each RF Source should be capable to generate 2.5MW/CW with VSWR 2:1 or 3.0MW/CW with VSWR 1.5:1 for 3600 sec having 25% duty cycle. ITER-India, IPR has completed R &D program for finalization of final stage tube along with certain critical components. One of the major requirements for RF source is to control amplitude [2] and phase with different load conditions of plasma within specified accuracy. To achieve this, proper measurement technique of amplitude & phase is utmost requirement. ITER-India, IPR has explored the use of digital IQ technique [3] on down converted IF Signal for measurement of amplitude and phase. The same has been validated at low power level (~10mW) and at moderate power level (~5kW). The measurement technique, validation process and results along with the critical factors which affect the measurement accuracy, will be discussed in this paper.

References:

[1] **"**Progress in High Power Test of R&D Source for ITER ICRF system**",** (26th IAEA Fusion Energy Conference (FEC-2016), 17-22 Oct 2016, Kyoto, Japan)

[2] "RT Amplitude Control Loop: Testing of R&D ICRF Source at High Power", (27th IAEA Fusion Energy Conference 22–27 October 2018 Ahmedabad)

[3] "DESIGN & DEVELOPMENT OF AMPLITUDE AND PHASE MEASUREMENT OF RF SIGNAL WITH DIGITAL IQ DEMODULATOR", (Journal of Physics: Conference Series, 10th Asia Plasma and Fusion Association Conference: Conf. Series 823 (2017) 012058)

APPLICATION OF RF PRODUCED PLASMA FOR SOCIETAL BENFIT

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Plasma produced by the application of Radio Frequency wave applied externally and coupled to a system by means of capacitive or inductive can make a device useful for the various applications.With the advent of semiconductor based powerful amplifiers these devices can be made light weighted and compact.This paper will present the characteristics of this plasma and their applications.

DEVELOPMENT OF HIGH TEMPERATURE SUPERCONDUCTOR BASED MAGNETS

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The high temperature superconductor (HTS) is a promising candidate for the high magnetic field and compact coils for electro-magnetic applications including, medical and future fusion magnets. The magnets used for magnetic confinement of plasma in the contemporary tokamaks and for electro-magnetic applications are either made up of copper or low temperature superconductors (LTS). The operational limitations of copper coils are due to huge electrical power requirement due to joule heating. The LTS NbTi and Nb_3Sn superconductors have advantages over the copper coils in terms of power requirements and for steady state operation. However, LTS has limitations in terms of operating magnetic fields and the cryogenic requirements. High temperature superconductors could be a viable

solution for the future tokamaks and fusion reactors due to their higher operating temperature and operational magnetic fields. These unique properties of HTS can be utilized to design, prototype and build magnets with elevated operating temperature (20-77 K) and generate magnetic field greater than 20 T within the limited space. This is a significant step forward over the conventional LTS magnets, which generally operate at a temperature around 4 K and magnetic fields usually limited up to 13 T [1]. The design and developmental initiatives are required for the feasibility study of HTS based magnets for various applications including magnetic fusion. The R&D components for HTS based magnets are high current conductors, coil winding, low resistance terminal joints, quench detection and protection. The R&D initiatives related with HTS based magnets for various applications will be discussed in this presentation. The performances of developed HTS magnets will also be discussed.

Reference:

1. Preliminary Design of Central Solenoid of SST-2 and Demo, U. Prasad, R. Srinivasan et al., IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 26, NO. 4, JUNE 2016

ECR SYSTEM AT 2.45 GHZ. FOR SMALL SCALE SPHERICAL TOKAMAK

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The low aspect ratio machine or small scale spherical tokamak (SSST) is being designed to gain insight of its advantages in terms of improved plasma parameters like natural elongation, high beta plasma, high fraction of bootstrap current, operation at low toroidal magnetic field, etc. The designed SSST has a major/minor radius of 28cm/16cm, aspect ratio of 1.75 and plasma current of 25kA for less than 50ms and magnetic field of 0.1T at the minor axis. It provides an opportunity to form electron cyclotron resonance (ECR) produced pre-ionized plasma and also to drive plasma current non-inductively, which would increase the pulse length up to few seconds. The commercially available rf source to produce ECR plasma, around the designed toroidal magnetic field for ST is 2.45GHz. Two magnetron source, each rated for 6kW, CW rf power is chosen as high power source which would be used to pre-ionize and form electron density in the range of ~ 10^{12} cm^{-3}. The available power can also drive plasma current up to few kA. Pill box type rf window is being designed for isolating the vessel vacuum and transmission line in air and would handle the above rf power for CW operation. Alumina ceramic disc would be used as window material and would be realized by employing high temperature vacuum brazing technique to join dissimilar metals like SS and copper with metalized ceramic. This paper would describe the design details of the ECR system for ST machine.

STUDY OF PLASMA TREATED COTTON FABRIC BY USING DC GLOW DISCHARGE PLASMA

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Plasma surface modification is an alternative method in making the dye to attach on textile fabric instead of using artificial mordants which is hazardous to the environment. In this context non-thermal plasma technology plays a vital role in modifying the surface of the fabric which does not require the use of water and chemicals resulting in more economical, ecological process, drastic reduction in pollutants and corresponding cost reduction for effluent treatment[1,2]. In addition to that huge variety of chemically active functional groups can be incorporated into the surface[3]. The present work is to modify the surface of the cotton fabric by oxygen plasma treatment with operating parameters the exposure time, discharge potential and base pressure are kept constant as 5 mins, 400V and 9 Pascal respectively. Then the plasma treated fabric is compared with the mordanted fabric. The change in the chemical and morphological properties have been investigated by ATR-FTIR, SEM analyses and reported.

References

[1] Muhammad Naveed, Plasma treatment as green technology for dyeing of textile fabrics,Trends in Textile Engineering &Fashion Technology,2, 2 (2018) 168-173.
[2] A J S Ferreira, M B Goede, N T Vila, M G Silva, S Fiori, T A Nascimento, M Fernandes & A P Souto, Surface activation of textile fibers by plasma DBD for dyeing with teak leaf,IOP Conf.Series:Materials Science and Engineering, 460 (2018) 1-6.
[3] Saied Jamaliniya, Nezam Samei & Sheila ShahidiUsing low temperature plasma for surface modification of polyester fabric : dyeing and printing improvement,The Journal of The Textile Institute, (2019) 1-5.

INVESTIGATION OF QUIESCENT PLASMA TURBULENCE WITH/WITHOUT POTENTIAL PERTURBATION IN MULTI-CUSP PLASMA DEVICE (MPD)

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The Argon plasma confined by a multi-pole line cusp magnetic field (MMF) over a large cylindrical volume (1 m axial length and 40 cm diameter) [Patel et al., Rev. Sci. Instrum. 89, 043510 (2018)] has been characterized. The central plasma region is quiescent ($\delta n/n < 1\%$) and the density fluctuation is also controllable with changing pole magnetic field. This paper presents a detail investigation of plasma turbulence at the

central quiescent plasma region with a changing pole magnetic field of magnets. Moreover, it has been also investigated that the effect of the potential perturbation on background quiescent plasma turbulence.

References:

[1] A new multi-line-cusp magnetic field plasma device (MPD) with variable magnetic field for fundamental plasma studies Patel et al., Rev. Sci. Instrum. 89, 043510 (2018)

COMPOUND PENDULUM BASED THRUST MEASUREMENT DIAGNOSTICS FOR HELICON PLASMA THRUSTER

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Plasma based thrusters are routinely used to propel satellites in space. These thrusters produce a thrust ranging from few milli-Newton (mN) to few tens of milli-Newton. Many new types of thrusters are being developed in various laboratories all over the world for future space propulsion missions. One of challenges during development of electric thrusters, is to measure the thrust accurately and hence thrust measuring diagnostics is an integral part of thruster development. IPR is developing a helicon plasma thruster of thrust ranging from few micro-newton to few tens of mN. A compound pendulum based thruster diagnostics has been developed to measure the thrust produced by helicon plasma thruster. The pendulum has been calibrated for thrust ranging from 50 micro-Newton to 20 mN. The detailed measurement of thrust with newly developed compound pendulum based thruster diagnostics will be reported.

GAS FUELING IN ADITYA-U TOKAMAK

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The first indigenously built ADITYA tokamak [1] has been upgraded to ADITYA-U tokamak (R_0 = 75 cm, a =25 cm), having feasibility of having shaped plasma operation with divertor coils. In ADITYA-U tokamak plasma breakdown is generated using hydrogen gas as a fuel and toroidal electric field produced with central solenoid Ohmic transformer coils. Hydrogen gas is pre-filled, few hundred milli-seconds before the application of loop voltage. Working gas pressure is one of the most fundamental operation parameters for successful plasma breakdown and start-up of tokamak discharge [2]. In ADITYA-U, we prefill the vacuum vessel with hydrogen gas using an external trigger-pulse for the pulse operation of a

piezoelectric valve, which is placed at one of the bottom port of vacuum vessel. Normally, the amplitude of the pulse is fixed, but the pulse width is varied to change the operating pressure. Hence, there is a direct correlation between the magnitude of pulse width and reservoir pressure. For successful discharges, the relationship between reservoir pressure and the opening pulse width of piezoelectric valve is studied theoretically and empirically. A Python script is developed on the basis of this study which calculates the pre-fill pulse time as a function of reservoir pressure. Discharges failure has been restricted using this analysis. Furthermore, the flow rate and gas velocity of the gas-prefill and the supersonic molecular beam injection (SMBI) will be compared. The detailed study and analysis will be presented in this paper.

References :

[1] Aditya: The first Indian Tokamak Indian Journal of Pure and Applied Physics **27**, 710-742 (1989)

[2] Breakdown experiment on Aditya Tokamak Indian Journal of Physics **66** (5 & 6), 481-487 (1992)

FORECASTING OF DISRUPTION IN ADITYA-U TOKAMAK

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Disruptions in tokamak, is a sudden loss of magnetic confinement of plasma. A huge amount of plasma current abruptly terminate in a few milli-second. As a consequence, a huge amount of induced electric field is generated, which makes the electron highly energetic (Runaway electrons) and eddy current flows through the vessel. Hence, due to disruption there is a chance of severe damage to the system. Avoidance of disruption [1] and real time mitigation is a very important field of work in tokamak. There are many possible causes for disruption. The most important reason is growth of m=2 mode of instability. Growing instability at q=2 rational surface gives the major disruption. It is observed that higher q-value (q=6) at the edge gives the sharp falling of plasma current. Where the fall of plasma current is slower for lower q-value (q=3) at the edge [2]. The amplitude of oscillation of m=2 mode also decreases with higher q-value at the edge and increases with lower q-value at the edge. The work is focused on finding a strong correlation between q_{edge} and disruptions in ADITYA-U tokamak. Details of the study will be presented.

References :

[1] ‘Novel approaches for mitigating runaway electrons and plasma disruptions in ADITYA tokamak’, R.L. Tanna et al 2015 Nucl. Fusion 55 063010.

[2] ‘Overview of recent experimental results from the Aditya tokamak’, R.L. Tanna et al 2017 Nucl. Fusion 57 102008.

EJECTION OF HIGH SPEED MOVING PARTICLE IN HOLLOW CATHODE DUSTY PLASMA

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The dust particles introduced in the laboratory glow discharge acquire negative charge and levitate in the sheath region where there is force balance between gravity and sheath electric field. The ion drag force and the neutral drag force influence the lateral motion of dust particles. In another experiment, the dust particles were charged negatively to very high charge numbers by introducing the dust particles in the path of electron beam [1]. In these experiments, the electron beam produced at low pressure was transported through differential pumping to another chamber at high pressure. Rocca et al., [2] have produced glow discharge generated electron beams at fore pump pressure using how cathode discharges. In the earlier past, one of us has investigated dust particle dynamics in hollow cathode discharge in detail [3]. In the present work have attempted to levitate the dust particle in hollow cathode discharge and generated charged dust beam similar to electron/ion beam. It is observed in the experiments that a dust particle gets ejected along with the plasma beam. We report the experimental characterization of dust particle beam ejected from plasma hollow cathode discharge. Experiments were carried out in a SS304 vacuum chamber of 290 mm in diameter and 305 mm in length. The vacuum chamber has two large top and bottom flanges of the diameter of the chamber. It has four radial ports of 90 mm in diameter. How cathode source is made from SS304 tube of 124 mm length and 18 mm in outer diameter with 6 mm hole along the length direction. It is covered in either end with alumina ceramic. A floating SS304 sleeve is placed on the outer side of the hollow cathode discharge tube. The vacuum chamber is pumped down by rotary pump. The vacuum in the chamber is measured by convectron gauge. Alumina and silica dust particles with particle size in the range of few microns were used in the experiment. Green helium neon laser was used as diagnostic in the experiment to visualize the particle. A CCD camera mounted on tripod is used acquire the image of dust particles ejected out of the hollow cathode discharge. Discharge was produced in the pressure range of 0.1 – 0.4 mbar in argon gas. DC voltage of 200 – 400 Volts is applied between hollow cathode and the grounded chamber wall. The results of experiments are presented in this work.

References:

[1] Fortovet al., 55001 – p1 – p5, the frontiers of physics, 2011.
[2] Rocca et al., 790-797, 56(3), J. Appl. Phys, 1984.
[3] A. K. Agarwal and G. Prasad, A309, 103, Phys. Lett, 2003.

FAST IMAGING OF PLASMA DISCHARGES IN ADITYA-U TOKAMAK

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After successful commissioning of ADITYA-U tokamak, the first plasma was obtained in December 2016. Since then experimental research in ADITYA-U has been making significant progress and over ~3000 discharges in ADITYA-U have been obtained. In order to visualize plasma column movement, plasma wall interaction and some obstacle within plasma cross-section in these discharges, a 2D tangential viewing fast visible imaging video camera is installed on ADITYA-U, as followed by many tokamaks world-wide [1, 2, and 3]. It captured a wide angle panoramic view of the tokamak from the radial port in such a way that, the entire poloidal cross section including the limiter is within the field of view of the camera. Using this camera at a frame rate of 6000, we have successfully captured the video of all the plasma discharges in this tokamak and excellent images of plasma evolution at high spatial and temporal resolution are obtained. After rigorous study on these videos, several significant observations are obtained. For instance, the plasma evolution in ADITYA-U takes place towards the inboard limiter side and this is confirmed with plasma position measurement as well as fast imaging video camera. A number of phenomena, starting from plasma initiation to the movement of the plasma column, to the effect of gas puffing - from formation of plasma rings to the giant particle motion inside the field, to the plasma disruption on the vessel wall – all are studied using the post-processed images and videos. This work presents many such interesting observations and their analysis, and concludes with the future scope of works.

References:

[1] Identification of intermittent transport in the scrape-off layer of MAST through high speed imaging, Nuclear Materials and Energy, **12**, p 175-180, (2017).

[2] Filament structures at the plasma edge on MAST, Plasma Phys. Control. Fusion, **48**, p B433-b441, (2006).

[3] Optical boundary reconstruction of tokamak plasmas for feedback control of plasma position and shape, Review of Scientific Instruments, **81**, p 113504 (2010).

DATA HANDLING APPLICATION FOR DATA ACQUSITION OF PLASMA DIAGNOSTICS

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The purpose of this application is to acquire data for plasma diagnostics from multi-channels 100 KHz simultaneous sampling developed hardware. The entire application is developed on Linux platform (CentOS) for reducing time of data acquisition as compared to Windows platform. The application design facilitates all the requirements, easy maintenance and flexibility in customization according to plasma diagnostics user's need as well as central server's requirements. Application code is written in C language using GCC compiler. The code provides control and status commands to FPGA based hardware on PC/104 Bus. At application startup, it initializes all hardware and software components, and then it prompts hardware system to gets ready for hardware trigger. Upon receiving the trigger, firmware starts acquiring process by enabling the ADC (Analog to Digital Converter), reading ADC data and writing ADC data to RAM (Random Access Memory). The application off loads the data from the memory through firmware program when it receives memory full acknowledgement. The application program establishes remote connection to data acquisition server to retrieve plasma shot information viz., shot number. It generates data files as per shot number and transfers data to Server. Data Handling Application for Data acquisition system is successfully integrated to the Aditya tokamak .The detailed software design, development and testing results will be discussed in the paper.

DESIGN AND IMPLEMENTATION OF SOLAR POWERED PLASMA POWER SUPPLY

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Solar power consumption is increasing day by day. There have been attempts to convert solar power operating 12 volts or 24 volts into mains power of 230 volts single phase or 415 volts three phase. Solar power plant generates power even at high voltage and couple the power to the grid. Local application of solar power like running tube light or fan or air conditioner is already established. Some of the application of plasmas viz., plasma sterilization at atmospheric pressure, air plasma based discharge for generation of nitrogenous fertilizer, atmospheric glow discharge based volatile organic compound(VOC) destruction etc., can brought under solar power as their power consumption is very low (few tens of watts). In this work, we have attempted to make a power supply with input solar power of 24 volts and generated high voltage of 5000 volts at 100 KHz. We have coupled this power supply to Xenon iodide lamp which generates plasma discharge and produces ultraviolet radiation which kills the bacteria. Production of atmospheric glow discharge is widely established and which draws the electrical power from the mains. We have taken the input power from the

solar panel and through a storage battery. A fly back transformer is designed to operate at 100 KHz. We have used ferrite URR59/36/17 core from EPCOS. The transformer is designed based on the numerical equations given in Umand and Bhat [1]. A Switch mode power supply based the IC is designed with MOSFET STF13N60. First we have tested the circuit with transformer rated for 230 Volts. Late we have extended the voltage operation up to 5000 volts. We have operated the power supply with at operating frequency of 50 to 100 KHz. Operating input power VS frequency is presented. Further the surface temperature of the lamp with different frequency is also measured to investigate the dissipation of the source with different operating frequency.

References:

[1] L. Uamand and L. Bhatt, New age Inernational Publisher

MODERN MANUFACTURING TECHNIQUES FOR THE DEVELOPMENT OF TOKAMAK AND STELLARATORS BASED FUSION TECHNOLOGY

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Nuclear Fusion power offers the prospect of an almost inexhaustible source of energy for future generations, however it also presents so far insurmountable engineering and technological challenges. The main route to produce the fusion energy is focused on tokamak reactors and stellarators, which confine a deuterium-tritium plasma magnetically. Metal 3D Printing holds a unique position in modern-day product development. It allows for the direct manufacturing of complex end-use parts and facilitates tooling for conventional manufacturing technologies. This technology is also known as Direct Metal Laser Sintering (DMLS) and Selective Laser Melting (SLM). 3D printing/Additive manufacturing has wide applications in fusion technology developments as well as plasma technology developments. There exists an enormous benefits of 3D printing for the fabrication of smaller size (up to meter-scale) metal components. The technique seems particularly well adapted to unconventionally shaped objects or those with complex interior geometry & intricate shapes. 3D printing is a versatile and proactive manufacturing method to find options that can save time and cost. This method offers a more efficient and cost-effective way to manufacture complex components. The 3D printing/Additive Manufacturing, uses computer-aided design (CAD) model as a starting point to directly manufacture 3D metal objects in a more efficient and cost-effective approach that avoids the mock-ups and prototypes of traditional manufacturing particularly for a technology development or product development for Nuclear fusion/Tokamak/Stellarator. The 3D printing equipment is able to read CAD data and lay down successive layers of liquid, melted powder to form the component—a process that has many applications in the highly complex components required for Fusion technology. It has been found that 3D printed metal components meets the specifications for physical properties and mechanical stress tolerances.Various complex components of various metals such as stainless steel, INCONEL, ETP Copper, Aluminum alloy, Titanium alloy etc. are possible to manufacture for fusion applications. In this paper, possible components that can be

manufactured using 3D metal printing techniques for Tokamak/Stellarator fusion machines is discussed.

DEVELOPMENT, TESTING & COMMISSIONING OF AUTOMATIC CHARGING OF HIGH VOLTAGE CAPACITOR BANK IN ADITYA-U TOKAMAK

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Tokamaks use different pulsed power subsystems as a key subsystem. ADITYA-U tokamak possesses a 250 kJ multistage capacitor bank. The capacitor bank energizes the ohmic transformer of the tokamak with a major radius of 0.75 m, minor radius of 0.25 m, and a toroidal field of 1 T at the plasma center. Different high voltage rectifiers charges these five capacitors banks at different voltages. These capacitor banks are fired in at appropriate times, to realize an experimental demand for initial high loop voltage followed by a lower sustaining plasma loop voltage. The charging of these capacitor banks are carried out by individual transformer and rectifier circuits. The charging of these banks has now been carried out automatically using PLC based control system. The new control system consists of WAGO make PLC and motorized auto transformer. The Tokamak operator configures required charging voltages for different banks. The PLC control system charges up all capacitor from 1kV to 10kV at recommended capacities from 1 uF and upwards with voltage feedback control and motorized autotransformers. The control system monitors the charge voltage as it builds to the pre-set value and then stops. The paper describes the installation, testing, calibration and commissioning of automatic charging system of multistage 250 kJ capacitor bank.

OVERTAKING OF KINETIC ALFVÉN WAVES IN NONTHERMAL PLASMA

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Over the past many years the variety of nonlinear structures, Alfven waves and the magnetoacoustic waves (slow and fast) are the basic wave modes in the magneto-hydrodynamic (MHD) systems in which Alfvén waves are the low frequency waves (below the ion cyclotron frequency) which play a central role in many laboratory, cosmic as well as fusion plasmas where the plasma β is typically much smaller than the electron to ion mass ratio. The observational data from the Freja and the FAST satellites [1] have revealed a clear signature of solitary Alfvénic structures [2]. Kinetic Alfven waves arise when the perpendicular wavelength of ordinary Alfven wave is comparable to the ion Larmor radius.

The propagation and interaction of multi-solitons are important phenomena in plasma physics. They interact elastically and owing to this reason, the amplitudes of solitons do not change; however each soliton gets a phase shift. In the present work, we have investigated the propagation of ion acoustic kinetic Alfven waves in a low β plasma. In this regard, Korteweg de Vries equation is derived and discussed using the plasma parameters that are typically found in solar corona. The interaction of fast IAKAWs is explored by using the Hirota bilinear formalism [3], which admits multi-soliton solutions. It is pertinent to mention here that this solution describes two solitons travelling in the same direction and the soliton interaction takes place when the faster solitary wave overtakes the slower solitary wave. It is further noted that the amplitude of the respective solitary waves remain unchanged after the interaction, however, they do experience a phase shift. This study may also be helpful in understanding various non-linear coherent structures in space and astrophysical plasma environments.

References:

[1] J. S. Makela et al, Observations of mesoscale auroral plasma cavity crossings with the Freja satellite, Geophys. Res. Lett. **103**, 9391 (1998) .

[2] M. Singh et al., Kinetic Alfvén solitary waves in a plasma with two-temperature superthermal electron populations: the case of Saturn's magnetosphere , MNRAS, 486 (4), 5504 (2019)

[3] K. Singh et al, Effect of polarization force on head-on collision between multi-solitons in dusty plasma, Phys. Plasmas 25, 033705, (2018)

EXPERIMENTAL STUDY ON METAL FOIL BOLOMETER IN LAB

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Aditya-U and SST-1 tokamaks are indigenously built medium sized air core tokamaks. These devices are routinely operated and the plasma produced are studied using standard diagnostics. Bolometer is one such diagnostics that is used for the measurement of the radiation power loss from a tokamak. It is an essential diagnostics as it assists in the power balance of the tokamak and also determines the purity of the plasma. AXUV detectors are presently being used for radiation power loss and it is proposed to develop a similar diagnostic based on metal foil bolometer as a supporting diagnostic. A prototype metal foil bolometer made up of platinum, and meander resistor (50 **Ω**) has been tested in the lab. This works presents measurement of calibration coefficients viz. cooling time constant, and thermal resistance of metal foil bolometer by performing various experiments where laser is considered as an input power source. Response (r), heat capacity (C), and temperature coefficient (α) of same will be discussed in this work. Experiments will be performed on graphite coated metal foil also to enhance its absorptivity; moreover, experiments in vacuum will also be studied to study the difference between vacuum and ambient experiments.

References:
[1] A new metal resistor bolometer for measuring vacuum ultraviolet and soft x radiation by E.R. Muller and F. Mast.
[2] Bolometers by A.G. Unil Perera

COMPARISON OF TRADITIONAL MANUFACTURING TECHNOLOGY WITH ADVANCED / ADDITIVE MANUFACTURING TECHNOLOGY FOR NUCLEAR DOMAIN

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Main components of Nuclear reactor are generally large in size. Traditionally heavy forgings are machined using heavy machining equipment such as vertical turn mill, boring machine etc. which are categorized as subtractive manufacturing as material is removed from the solid block/forged block. This technique is already proven and being used since long. By considering advanced manufacturing technology such as Hot Isostatic Press (HIP) and Electron Beam Welding (EBW), a huge saving in the fabrication cost in nuclear components fabrication is anticipated [1]. There is potential of using Additive Manufacturing (AM) technique for ceramic fuel fabrication and repair of components. Canadian Nuclear Laboratory (CNL) successfully printed ceramic fuel material and work is underway to improve and refine this capability. Printing of metallic fuel is also being pursued at CNL [2]. In case of replacement of component, where original equipment manufacturer may require long lead time or may not be able to supply the material; the additive manufacturing can be utilized for in-house fabrication. However AM is not replacement for subtractive manufacturing, and user discretion is needed to find out part suitable and economical to manufacture through additive manufacturing. In this study; process capability of traditional and advanced / additive methods shall be compared and ongoing research for nuclear field shall be reviewed.

References:
[1] EPRI JOURNAL May/June 2017 No. 2 page 6 (www.eprijournal.com)
[2] http://www.nuclearsafety.gc.ca/eng/pdfs/Presentations/Guest-Speakers/2018/Speaker-Series-greg-hersak-additive-manufacturing.pdf

TRANSPORT OF THERMAL YUKAWA PARTICLES IN A CHOSEN DIRECTION - A MOLECULAR DYNAMICS STUDY

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Study of particles interacting through Yukawa potential in a background asymmetric potential called ratchet potential is investigated . Ratcheting effects or directed transport has wide applications. The focus of study is the effect of Yukawa interaction among particles on the average velocity and diffusion of particles. MD simulations are performed for different values of interaction strength ranging from strong to weak interaction. A special form of ratchet i.e. rocking ratchet is studied and it is found that the effect on transport of particles is subject to driving time scales in the system.

References:

[1] Marcin Kostur, Lukasz Machura, Peter Hänggi, Jerzy Łuczka, et al. Physica A 371 (2006) 20–24
[2] Peter Reimann. Physics Reports 361 (2002) 57 – 265

ABRASIVE WATER JET MACHINING FOR THE PLASMA EXPERIMENTAL SYSTEMS DEVELOPED AT INSTITUTE FOR PLASMA RESEARCH

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The Workshop section of MESD division is equipped with modern versatile non-conventional machine called, 3-axis abrasive water-jet machine, which cuts the hard material such as tungsten using abrasive slurry at 3800 times atmospheric pressure with high precision of 50 micron accuracy. This is a unique machine in entire DAE family with a capacity to cut 3m x1.5m size plates of different hard materials up to 100mm thickness. This machine offers advantage of cutting the materials almost at room temperature and does not allow to impair the material characteristics. Various components used for plasma experimental systems have been manufactured using Abrasive water jet machine. The programing involved for an intricate shape components such as helical and spiral antenna fabricated will be reported.
In this paper different components manufactured with this technology will be discussed and complexity involved and accuracy demanded for these.

WAVE FIELD PATTERN AND MODE CHARACTERIZATION OF MICROWAVE EXCITED IN THE VACUUM CHAMBER OF SYMPLE

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Interaction of intense electromagnetic (e.m.) radiation with an over-dense plasma ($\omega_{pe} > \omega$ where ω_{pe} and ω are angular frequencies of plasma and the frequency of the interacting e.m. wave respectively) is a subject of great interest [1], in the context of investigation of nonlinear processes in laser fusion and radio-wave propagation in ionosphere. Several interesting linear and nonlinear interactions occur between the incident e.m. wave and the inhomogeneous plasma having density gradient ∇n parallel to the normal (to the surface of wave incidence) at the critical layer ($\omega=\omega_{pe}$), leading to the absorption of the wave in the plasma, provided there is a component of the wave electric field $E_{e.m}$, parallel to ∇n. In laser-plasma experiments aimed at investigating e.m wave – plasma interaction, the condition $E_{e.m\,||}\nabla n$ is attained by choosing oblique incidence of a P-polarised wave. SYMPLE (SYstem for Microwave Plasma EXperiments) is an experimental set-up developed for investigation of wave – plasma interaction, with high power microwave (HPM) chosen as the e.m wave, thus enabling a frequency scaled down experiments of Laser-Plasma interaction. The system set-up [2] consists of a pulsed (5 μs) HPM source (Magnetron: 3 GHz, 3 MW, output in TE_{10} mode) and a washer gun based plasma system [1] with parameters $n_e \sim (1\text{-}10)\times10^{18} m^{-3}$, T_e ~10 eV and density gradient scale-length ~ 10-20 cm. The power of microwave is high enough, satisfying the condition $\frac{1}{2}\varepsilon_o E_{e.m}^2/(nkT_e) \sim 1$ so that experimental exploration of wave absorption through resonant wave – plasma interactions as well as by non-resonant processes involving excitation of various instabilities, enhanced anomalous collisions, wave breaking etc. is possible. Here, the choice of microwave gives a unique possibility as compared to laser-plasma interaction experiments that the condition $E_{e.m\,||}\nabla n$ can be satisfied, even with normal incidence of the wave on to the plasma. This is possible by incorporating a specially designed TE_{10} to TM_{01} mode converter in the HPM coupling system to ensure that the wave incident on the Plasma is in TM_{01} mode, having its electric field parallel to the propagation direction In order to validate the mode and electric field direction /distribution in the chamber prior to initiation of wave plasma interaction experiments, low power (25 dbm) experiments have been carried out by coupling microwave to the experimental chamber through the mode converter. The characteristics of the field pattern observed confirm excitation of microwave in the TM mode in the chamber. Detailed experimental observations and analysis form subject of discussions in this paper.

References :

[1] Rev. Sci. Instrum. **90**, p 013502-013509 (2019)
[2] 1V. P. Anitha, P. J. Rathod, R. Singh, and D. V. Giri, IEEE Trans. Plasma Sci. **44**, p 2226–2231 (2016).

EXPERIMENTAL MEASUREMENTS OF GAS PRESSURE DROP OF PACKED PEBBLE BEDS

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The nearly spherical shaped ceramic pebble beds in the breeder blanket of the future fusion reactor are purged by low pressure gas to channelize the generated tritium fuel into the tritium extraction system. The required pumping power for gas flow in pebble beds can be estimated using the pressure drop values across the pebble beds. The aim of this work is to experimentally measure the pressure drop across packed pebble beds as function of pebble sizes, pebble shapes, cross section area of pebble beds, pebble materials, packing density of pebble beds and gas velocity. The pebble beds are packed under the two different cylindrical shaped container having the inner diameter of 24 mm and 38 mm. The various experiments have been performed on stainless steel spheres (Diameter: 1 mm, 2 mm, 3 mm and 4 mm), alumina pebbles (Mean diameter: 1 mm, 1.5 mm, 4 mm) and lithium meta-titanate pebbles (Mean diameter: 1 mm and 1.3 mm). The gas flow has been controlled and measured using a digital mass flow controller. The static differential pressure across the pebble beds has been monitored by a differential pressure transducer. The obtained experimental results of gas pressure drop have been compared and validated with the Ergun's correlation. The details of the experimental parameters, installed sensors, pressure drop results will be discussed in detail in the paper.

MEASUREMENT OF THERMO-MECHANICAL PROPERTIES OF CERAMIC BREEDER PEBBLE BED BY STEADY STATE METHOD

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Thermo-Mechanical properties of ceramic breeder pebbles and pebble bed play a key role in the breeder blanket design. The envisaged solution for breeding blanket foresees the use of many oxide ceramic materials from which lithium metatitanate (Li_2TiO_3) is used for this study. The thermal mechanical properties of the candidate pebble bed materials are extensively investigated because they are critical for the feasibility and performances of the numerous conceptual designs which use a solid breeder. The spherical shaped pebbles (~1 mm diameter) having porosity for efficient tritium extraction. At IPR lithium ceramics are prepared and characterised for its physical, thermal, thermo-physical and thermo-mechanical properties. Characterising thermo-mechanical properties of the ceramic breeder pebble bed is an integral step off developing breeder blanket for fusion energy applications. Thermal conductivity is an important parameter to identify because of the tritium extraction from the breeder material. In granular pebble bed materials, the thermal conductivity depends on the solid pebble materials as well as any gas filling the interstitial void spaces. Thus, an effective thermal conductivity (k_{eff}) of the bulk is used. During the measurement of thermo-

mechanical properties, thermal diffusivity and thermal conductivity of sintered Li_2TiO_3 pellets are measured by laser flash technique. In the fusion reactor, the pebbles are stacked in the canister as a pebble bed. Effective thermal conductivity is one of the essential parameter for the design of fusion blanket. In this study the measurement of effective thermal conductivity is by the steady state and axial method using the experimental setup. Experiments are performed at different temperature and pressures with different gases like He, Ar and air. The experimental setup is designed in such a way that it gives ~1D heat flux. The results evaluated from the experiments are much acceptable in comparison with other published data. Simulation is also performed on ANSYS and the CFD analysis of the pebble bed is done to measure the thermo-mechanical properties. In the simulation actual geometry is replicated and the actual conditions are given as boundary conditions. The experimental results are validated with the literature data and simulation data.

PROTOTYPE DESIGN OF MULTI-CHANNEL DATA ACQUISITION SYSTEM TO CALIBRATE PROBES FOR MEASURING EDDY CURRENT IN A PLANAR SURFACE

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To measure the eddy current a calibrated magnetic probes are required and these probes are calibrated using Helmholtz coil. We need to take the signals from the planar surface which generates the eddy current at different positions on the plate at the same time simultaneously. So, multi-channel data acquisition system (DAS) is required to stores all the probes data synchronized with respect to external trigger. The generated eddy current pulse width is approx. 200us and bandwidth of approx. 20 KHz. Hence a prototype design of multi-channel DAS system with external trigger option up to 200KSa/s has been designed on Spartan-6 FPGA. The system will allow the user to customize the sampling rate and number of samples per channel. When the DAS system will get the external trigger signal from the current transformer DAS system will start acquiring the signals from all the probes simultaneously and the data will be buffered in the FIFO inside the FPGA. Later these data will be transferred to the hard disc of the computer through the FT2232H module for future analysis. This paper will describe the hardware design, PCB layout design, component selection, Driver implementation in VHDL for interfacing ADC and FT2232H mini module for the board.

References:

[1] First prototype of high-speed data acquisition system of ion source for neutral beam injection on EAST. Fusion Engineering and Design, Volume 129, April 2018, Pages 183-189, Wei Liu, Chundong Hu, Yan Wang, Sheng Liu, Yuanzhe Zhao.

[2] Embedded multi-channel data acquisition system on FPGA for Aditya Tokamak Fusion Engineering and Design, Volume 112, 15 November 2016, Pages 964-968 Rachana Rajpal, Hitesh Mandaliya, Jignesh Patel, Praveena Kumari, R. Jha.

[3] Design of FPGA based high-speed data acquisition and real-time data processing system on J-TEXT tokamak Fusion Engineering and Design, Volume 89, Issue 5, May 2014, Pages 698-701 W. Zheng, R. Liu, M. Zhang, G. Zhuang, T. Yuan

STRUCTURAL AND LOCAL GEOMETRIC INVESTIGATIONS OF HIGH TEMPERATURE PLASMA SYNTHESIZED IRON OXIDE NANOPARTICLES

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We present high temperature arc plasma route assisted iron oxide nanoparticle synthesized in air and helium ambient under different arc currents of 50A, 100A and 150A along with structural and local geometric investigations. The X-ray diffraction pattern (XRD) for air environment synthesized nanoparticles reflects the formation of cubic Fe_3O_4, alpha and gamma Fe_2O_3 phases with increasing dominance of alpha phase at higher arc current. The enthalpy of the applied plasma arc current as well as oxide concentration resulted in multicomponent product formation. However, for He ambient synthesis, it manifests a robust presence of metallic Fe phase which becomes more predominant with increasing arc current. Due to steeper temperature gradient at high arc current a substantial amount of metal vapor is generated near the plasma plume which doesn’t get sufficient time to get oxidized with subsequent nucleation and triggering a dominance of metallic Fe phase at He environment. The existence of aforementioned phases have been verified with XRD patterns along with extended X-Ray absorption fine structure (EXAFS) modelling *via* probing Fe *K* edge. These results provide a firm understanding regarding different phase formation which can be anticipated as significantly handy not only in controlling the structural properties of nanoparticles but also for the wider use of plasma based nanopowder synthesis technology.

Key words: Plasma; Iron Oxide nanoparticles**;** X-ray diffraction pattern (XRD); Extended X-ray absoprtion fine strcuture (EXAFS)

EFFECT OF EXTERNAL ELECTRODE CONFIGURATION IN PARTIALLY MAGNETIZED PLASMA TRANSPORT

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The behavior of plasma potential and density profile in presence of different configurations of magnetic field has always remained a topic of interest. Magnetized plasma has prominent role in fusion research and in many industrial applications like materials processing, sputtering, deposition of thin films, etc. In the present work, the radial plasma characteristics in a hollow conducting cylinder in presence of an axial magnetic field have been studied. The cylinder is placed coaxially inside the diffused plasma column created by hot filament cathode and a gridded anode. In presence of axial magnetic field, it is observed that the radial plasma density tends to follow a zeroth order Bessel's function irrespective of whether the cylinder is being floating or grounded. This result is in well accordance with the phenomenological model for radial plasma density in cylindrical system. However the radial plasma potential shows different trend for the two different configurations. When the cylinder is kept grounded the radial plasma potential has minima at the center, which can be explained by Simon short-circuiting effect. But when the cylinder is kept floating there is an off-centered minima in potential profile, which shows violation of the short-circuiting effect.

References:

[1] Simon, A. (1955). Ambipolar diffusion in a magnetic field. Physical Review, 98(2), 317.)
[2] Das, Satadal, and Shantanu K. Karkari. "Positive ion impediment across magnetic field in a partially magnetized plasma column." Plasma Sources Science and Technology (2019).
[3] Lieberman, M. A., & Lichtenberg, A. J. (2005). Principles of plasma discharges and materials processing. John Wiley & Sons.

EXPERIMENTAL STUDY OF ZONAL FLOWS IN LOW PRESSURE LINEAR MAGNETIZED PLASMA

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Zonal flows are secondary instabilities excited by density or temperature gradient driven drift waves. In present work, low frequency (0.2-0.3kHz, ZF) fluctuations excited in Inverse mirror plasma experimental device (IMPED) are studied and characterized to be zonal flows by measuring $k_r, k_\theta, k_\parallel$ and amplitude of potential and density fluctuations. ZF has radially sheared finite k_r with $k_\theta, k_\parallel \sim 0$ and potential fluctuations dominate over density. ZF is strongest where L_{T_e} is minimum. By using control features of IMPED, location of minima (L_{T_e}) is shifted and correspondingly strongest ZF shifted. Effect of increasing ratio of hot to cold electron population on ZF is also investigated. ZF becomes stronger with increase in this ratio. Experimental results are presented and discussed.

References :

[1] Sayak Bose, Manjit Kaur, P. K. Chattopadhyay, J. Ghosh, and Y. C. Saxena, Rev. Sci. Instrum.86, 063501(2015)
[2] P. H. Diamond, S.-I. Itoh, K. Itoh, and T. S. Hahm: Plasma Phys.Control. Fusion 47 (2005) R35

STUDY OF SST-1 TOKAMAK PLASMA USING FAST IMAGING CAMERA

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SST-1 is an indigenously built medium sized air core tokamak, with major radius 1.1 m and minor radius 0.2 m. It is routinely operated and produced plasmas are studied using various diagnostics. Fast imaging diagnostic is one of them that enables the viewing of the plasma. The diagnostic system consists of a Phantom v7.1 fast camera coupled with an imaging fiber bundle that views the tangential poloidal cross section of plasma column. High resolution images (256x256) at frame rate 2000 to 300 FPS are captured in this diagnostics. The evolution of the plasma and its movement is studied. Plasma interaction with plasma facing components (PFCs) is observed and studied through the enhancement in local visible radiation. This study involves discussion on plasma wall interaction, estimation of temporal and spatial profile of plasma column and location of resonance layer of ECRH plasma by using post processed images.

References:

[1] Dynamics of dust events in the graphite first wall equipped SST-1 tokamak, Plasma Physics and Controlled fusion, 60(9), June 2008.
[2] Dust observation in the COMPASS Tokamak Using Fast Camera, WDS'13 proceeding of contributed papers, part II, 73-79, 2013.
[3] Edge plasma study using a fast visible Imaging Camera in the COMPASS tokamak, Internation Youth Nuclear congress 2016, IYNC2016, Hangzhou, China
[4] Identification of intermittent transport in the scrape-off layer of MAST through high speed imaging, Nuclear Materials and Energy, **12**, p 175-180, (2017).
[5] Filament structures at the plasma edge on MAST, Plasma Phys. Control. Fusion, **48**, p B433-b441, (2006).

DENSITY AND POTENTIAL WAKE PAST AN INSULATING OBSTACLE IN A PARTIALLY MAGNETIZED FLOWING PLASMA

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The radial characteristics of plasma potential and density around an insulating disc obstacle, placed inside a partially magnetized plasma flow created in cylindrical chamber by hot cathode filament are presented. In the absence of obstacle, centrally sharp minima in potential and maxima in plasma density is observed; however when a macroscopic obstacle is

introduced in plasma flow, a clear radially off-centred minima in plasma potential is observed having plasma density peaking near the edge of the obstacle. The depth of potential around the obstacle depends on the axial magnetic field strength. This off-centred radial potential profile in the plasma flow gives rise to focusing of ions around the obstacle edge. Experimentally it is found that the drift velocity of focused positive ions is directly depended on the magnetic field strength and axial positive ion flow velocity. A phenomenological model based on short-circuiting effect is applied to explain the plasma density and potential in the wake region.

References:

[1] D'Angelo, N., & Merlino, R. L. (1986). The effect of a magnetic field on wake potential structures. IEEE transactions on plasma science, 14(5), 609-610.
[2] Merlino, R. L., & D'Angelo, N. (1987). The interaction of a conducting object with a supersonic plasma flow: Ion deflection near a negatively charged obstacle. Journal of plasma physics, 37(2), 185-198.
[3] Das, Satadal, and Shantanu K. Karkari. "Positive ion impediment across magnetic field in a partially magnetized plasma column." Plasma Sources Science and Technology (2019).

Er_2O_3 COATING DEVELOPMENT BY DIP COATING PROCESS FOR H_2 PERMEATION EVALUATION

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Highly electrically insulative and chemically as well as physically stable dense ceramic coatings necessary for a safe tritium breeding, recovery system and containment. Due to high stability and high resistivity, Er_2O_3 was perceived as suitable coating to mitigate Magneto Hydro Dynamic (MHD) forces in Li cooled blanket design[1]. Its excellence as tritium permeation barrier (TPB) was revealed afterwards [2]. Researchers have been studying its relevant properties and application methods suitable to actual components since then. Dip coating is one of the simplest yet effective coating methods, especially for surfaces which are inside the open volume and other complicated surfaces. The component is dipped into a liquid solution of the Er_2O_3 and subsequently withdrawn at a constant speed, so as to leave a uniform wet layer on the surface. This can be repeated multiple times after drying the surface to obtain the required thickness. Subsequently, the component is heat treated to impart Metal Organic Decomposition (MOD) into the coated layer and obtain crystalline uniform Er_2O_3 coating. However, the porosity of the coatings and substrate oxidation are the issues in this method [3]. We developed Er_2O_3 coating in cubic crystalline phase on P91, SS304 steels, Si substrates using 3 wt% erbium carboxylic acid solution in a solvent containing 50.5 wt% turpentine, 25.5 wt% n-butyl acetate, 8.4 wt% ethyl acetate, a stabilizer, and a viscosity adjustor. A dip coating system equipped with 800 C quartz tube furnace was used to prepare these coatings. The withdrawal speed was varied from 72 mm/min to lower values based on the literature survey and iterative analysis of the coatings. The crystallization and morphology behavior is studied with vaying of heat treatment temperature in the range of

500-700 C. It is also tired to improvise the uniform coverage and porosity of the coating by altering the multiple dipping cycle so that to provide heat treatment after every sub-layer formation. A significant improvement in the porosity reduction and crystallization as viewed from systematic microscopic studies in combination with X-ray Diffraction is observed. When 0.125 mm thick SS304 substrate coated with about 500-600 nm thick layer is subjected to H_2 permeation reduction measurement, no significant permeated flux was detected even at elevated temperatures. Subsequently, a sizeable permeation could be detected when the coating thickness was reduced to about 200 nm. The detailed coating process and characterization results would be presented in this paper.

References:

[1] T. Muroga**, "**Ceramic Coatings as Electrical Insulators in Fusion Blankets**,"** *Comprehensive Nuclear Materials*, **4**, 691 (2012).
[2] D. Levchuk, S. Levchuk, H. Maier, H. Bolt, A. Suzuki, J. Nucl. Mater., **367–370,** 1033 (2007).
[3] Z. Yao, A. Suzuki, D. Levchuk, T. Chikada, et al., J. Nucl. Mater. **386–388**, 700, (2009).

EVOLUTION OF DYNAMO USING A SELF-CONSISTENT MAGNETOHYDRODYNAMIC MODEL

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Generation of large scale mean magnetic field from plasma flow has been an important problem which has been investigated using a variety of models [1]. In most of these models, while the dynamics of magnetic field generation for a given flow field is addressed, the effect of including the back reaction of magnetic field affecting the flow field and altering it - is considered rarely [2]. This self-consistency is a key to construct realistic dynamos in both laboratory and astrophysical conditions. Recently, a preliminary work in this area [3] indicated promise. In the present work, we investigate the self-consistent dynamo for Arnold-Beltrami-Childress (ABC) flow using an in-house developed MHD code G-MHD3D which is a GPU based solver [4] with better spectral resolution. Physics and numerical aspects of this study will be presented along with a comparative study of results using an opensource MHD solver [5].

References:

[1] P Tzeferacos, A Rigby, AFA Bott, AR Bell, et al. , Nature communications, 9(1):591, 2018.
[2] Sadek, M., Alexakis, A., & Fauve, S. (2016), Physical review letters, 116(7), 074501.
[3] Thesis Title "TURBULENCE, FLOWS AND MAGNETIC FIELD GENERATION IN PLASMAS USING A MAGNETOHYDRODYNAMIC MODEL", by Rupak Mukherjee, 2019, IPR, India.
[4] Rupak Mukherjee, Rajaraman Ganesh, Vinod Saini, Udaya Maurya, et al. , IEEE Conference Proceedings of 25th International Conference on High Performance

Computing Workshops (HiPCW), (2018).
[5] A. Mignone The Astrophysical Journal Supplement Series, 170:228Y 242, 2007 May.

STRONGLY COUPLED PLASMAS INTERACTING WITH A QUANTUM GAS: REALIZING CRYO-PLASMAS

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Plasmas at extremely low temperatures, offer a platform to study strongly coupled plasmas and their properties. The dynamics of these plasmas are greatly controlled by the interaction with the ambient neutral gas [1], and find applications in electronics, medicine and material processing. To generate cryo-plasmas, there are a few requirements: (i) to create a cryogenic experimental ambient and (ii) to confine the discharge in a manner that ensures adequate interaction with the surrounding gas. Moreover, to restrict the increase in plasma gas temperature, the discharge geometries should be confined to the characteristic dimensions of a few micron to few hundreds of microns [2]. In recent years, dielectric barrier discharges (DBD) have been found to be efficient plasma sources for creation of cryo-plasmas [1,2]. The idea of creating a cryo-plasma and utilizing it in any application, is still in a nascent state. Hence, we want to present the gradual development of the idea, which starts with the design of a suitable multi-layered experimental chamber, comprising of a reactor which is to be cooled to liquid nitrogen or liquid helium temperature. However, designing such a chamber, which can offer proper platform to create, confine and diagnose the cryo-plasma, is non-trivial, as it involves the principles of vacuum technologies, cryogenics and high voltage electricals. Hence, the full-fledged model of the chamber, lays the foundation stone of the cryo-plasmas. The plasma reactor of the system will be a DBD of either parallel plate type or jet type. Thus, prior to starting the experiments in the cryogenic temperatures, a thorough knowledge of the DBD behavior in room temperature seems beneficial. Hence, the experimental results including, the measurement of plasma parameters of a parallel plate DBD, operating in atmospheric air and at room temperature will be presented. Parallelly, to investigate the creation and sustenance of strongly coupled plasmas, an elaborated theoretical and numerical study of the coupling parameter, (ratio of electric interaction energy to particle kinetic energy) at different experimental conditions will be presented. Also, owing to the reported connection between the behavior of coupling parameter and the second virial coefficient of the virial equation of state [1], with the change of plasma neutral gas temperature, the second virial coefficient will be evaluated numerically for various gas temperatures and interaction potentials

References:

[1] Y. Noma et al., J. Appl. Phys. **109**, 053303 (2011)
[2] S. Stauss et al., Plasma Sources Sci. Technol. **27** 023003 (2018)

PULSED PLASMA OPERATION OF ADITYA-U TOKAMAK EMPLOYING ELECTRON CYCLOTRON RESONANCE PRE-IONIZATION

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Electro Cyclotron Resonance (ECR) discharge cleaning is employed regularly in tokamak worldwide to reduce background impurity level in vacuum vessel. At present, ECR+PDC assisted wall conditioning is regularly performed on ADITYA-U tokamak using 850w ECR magnetron [1]. Recently, a 2450 MHz ECR power source with water cooled magnetron head is installed on radial port of ADITYA-U with intension to utilize ECR power source for pre-ionization assisted plasma start up in two different power supplies i.e. capacitor Bank and APPS for plasma operations. ECR forward (input) power and reflected power output will be also measured to an optimum operation regime for discharge cleaning operation of ADITYA-U. ECR Power supply operation is planned remotely using dedicated software for its precise control. We intent to perform ECR DC (Discharge Cleaning) operation in pulsed mode in-between two shots of plasma operation. Hence it enables to remove impurity as well as reduction in pumping time during plasma operation. Initial observation with operation experience and its effect on plasma operation will be discussed in this paper.

References:

[1] R.L. Tanna et al. Influence of Wall Conditioning on ADITYA Plasma Discharges

STUDIES ON THE EXISTENCE OF SOLITARY WAVES WITH AN EXACT ANALYTICAL EXPRESSION IN A DUSTY PLASMA

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The major part of the matter in our universe is in plasma state, which is a fact behind the coexistence of plasma with dust. Being motivated by this fact we have studied different nonlinear behaviours in dusty plasmas for different plasma models. With electrons following the kappa (κ) velocity distribution [1-3], an unmagnetized dusty plasma model is considered. Sagdeev's [4] pseudo potential method is used to derive an exact analytical expression to find a range of various parameters for the existence of solitary waves and other nonlinear structures as well.

References:
[1] Summers D & Thorne R M, *Phys. Fluids* B3 (1991) 1835.
[2] Baluku T K & Hellberg M A, *Phys. Plasmas* 15 (2008) 123705.
[3] R Gogoi and M khan; Physics of plasmas, 17 112311(1-7), 2010.
[4] Sagdeev R Z, *Reviews of Plasma Physics* (Consultants Bureau, New York) 4 (1966).

ION ACOUSTIC SOLITARY STRUCTURES IN A MAGNETIZED NONTHERMAL DUSTY PLASMA

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The Sagdeev potential technique has been used to investigate the arbitrary amplitude ion acoustic solitary structures in a collisionless magnetized dusty plasma consisting of negatively chargedstatic dust grains, adiabatic warm ions and nonthermal electrons. The present system supports both positive and negative potential solitary waves, the coexistence of solitary waves of both polarities, and negative potential double layers. The system does not support any positive potential double layer. Although the system supports negative potential double layers, these double layer solutions cannot restrict the occurrence of all solitary structures of same polarity. In fact, there exists a parameter regime for which the negative potential double layer is unable to restrict the occurrence of negative potential solitary waves, and in this region of the parameter space, there exist negative potential solitary waves after the formation of a negative potential double layer. Consequently, negative potential supersolitons [1] have been observed and the Mach number M corresponding to a negative potential supersoliton is restricted by the inequality $M_{NPDL} < M < M_{cr}$, but this supersoliton structure reduces to a conventional solitary wave of same polarity if $M \geq Mcr$, where M_{NPDL} is the Mach number corresponding to a negative potential double layer and M_{cr} is a critical value of M. Thus, we have seen a transition process of negative potential solitary structures, viz., soliton double layer supersoliton soliton. Different solitary structures have been investigated with the help of compositional parameter spaces and the phase portraits of the dynamical system describing the nonlinear behaviour of ion acoustic waves. The mechanism of transition of a negative potential supersoliton to a conventional soliton after the formation of a double layer of same polarity has been discussed with the help of phase portraits.

References :
[1] A. E. Dubinov and D. Y. Kolotkov, Plasma Phys. Rep. **38**, p 909 (2012)

ATTENUATION BEHAVIOUR OF SMOOTH WALLED TRANSMISSION LINES FOR ITER ECE DIAGNOSTIC SYSTEM

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The ITER electron cyclotron emission (ECE) diagnostic will be used to determine the plasma electron temperature by measuring the intensity of ECE in the frequency range 70 – 1000GHz. The typical ECE system consists of a front end optics including in-situ calibration sources, a set of transmission lines (TLs), and ECE instruments like radiometers and Michelson interferometers. However, achieving low attenuation in the long transmission line (~43m length) for broad frequency range is one of the challenging requirements for ITER ECE Diagnostic. This is particularly challenging because of the low power (~ few nW) thermal radiation emitted from the in-situ calibration sources which needs to be measured by the ECE detection system located nearly ~ 43 m away in the diagnostic building. This plays a vital role in determining the accuracy of measurements performed. In order to meet the transmission requirements of ITER ECE Diagnostic system, it is proposed to use oversized smooth walled transmission lines. Prototype transmission line system ~10m consisting of waveguides, joints and mitre bends, is designed and fabricated indigenously. Attenuation has been measured in the frequency range 70 – 1000 GHz using a black body source (Hot/cold sources) and Fourier-transform-based Michelson interferometer. In addition to that, Mode conversion losses due to misalignments (offsets, tilts) in the transmission line have been studied. Also, there is absorption of transmission in the mm wave due to water vapours, Therefore TLs are evacuated and effect of water vapour absorption on transmission is studied. It has been observed that there is a significant reduction in transmission attenuation in the evacuated TL and also continuum water vapour or atmosphere gas absorption of millimeter wave radiation above 550GHz. The details of the experimental set up and the results of the attenuation will be presented.

PARAMETRIC STUDY OF LINEAR INDUCTION MOTOR (LIM) USING COMSOL

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Linear Induction motors are coming into lime-light due to applications involving generation of traction force without physical contact [1]. Linear Induction Motor (LIMs) can produce high forces and can accelerate metallic objects to very high velocities, which makes them suitable for various projectile launch applications. LIMs may also be used in particle injector

for fast time response disruption mitigation in tokamaks. In our organization, linear induction motors (LIMs) are being used as non-contact type electromagnetic stirrer for liquid Pb-Li applications. The stator part of the LIM, when energized with three phase input, produces magnetic field moving linearly above LIM. It consequently produces eddy currents that induce motion in the liquid metal. If an aluminum sheet is placed on LIM, a thrust force is generated and the sheet is accelerated along LIM surface linearly [2]. Thus LIM forms a key element for electromagnetic launching applications. In this paper the effect on thrust of the LIM is being studied using COMSOL software for different input parameters (input current, mechanical air-gap, width of core, frequency, etc. [3].

References:

[1] Nasar, S.A. and Boldea, I., *Linear Electric Motors*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1987.
[2] Viet Nam Hoang, "*Design of Single-Sided Linear Induction Motor*", Bachelor of Electrical Engineering Project, School of Information Technology and Electrical Engineering, University of Queensland, 2003.
[3] Jae-Hoon Jeong, Jang-Young Choi, So-Young Sung, Jong-Won Park and Jaewon Lim "*Thrust Analysis and Experiments on Low-Speed Single-Sided Linear Induction Motor"* J Electr Eng Technol.2017; 12(1): 230-235

2D PIC SIMULATIONS OF PLASMA FLOW EQUILIBRIA IN CYLINDRICALLY SYMMETRIC EXPANDING MAGNETIC FIELD

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The setups with a magnetized plasma exiting a source region along a spatially weakening magnetic field (diverging field lines) are of interest because of acceleration of steadily outflowing ions often achieved via a gridless mechanism as required in applications like space propulsion thrusters. In this work the steady-state flow equilibria of such magnetized plasma exiting through an expanding magnetic field are investigated by means of 2D Particle in Cell (PIC) numerical simulations using the 2D PIC code OOPIC(Object Oriented Particle In Cell). To start with, a plasma source model is presented to describe a source which is localized in a finite volume with specified plasma parameters such as density and source strength, for estimating temperature and corresponding outflow velocity at source exit to be used in the simulations. In experimental expanding plasma setups, the plasma is usually produced by RF sources (for e.g Helicon or ECR based plasma sources). The plasma thus generated is often localized and may not uniformly cover the entire physical volume of the bounded source chamber. In order to explore the effects of change in the localized plasma source region dimension, and an associated plasma transit length in the upstream uniform-magnetic field region, various cases with different axial lengths of the dielectric plasma source region, distinct from the location of physical expansion, are simulated. The axial potential profiles presented at various radial locations show development of a step-wise axial potential drop, producing plasma (ion) acceleration in the corresponding regions.

Considering the relevance of the studied flow equilibria to the thrust generation schemes for space propulsion, a formal estimate of thrust values associated with plasma outflow is also done for the cases simulated.

References :

[1] Francis W Perkins and YC Sun. Double layers without current. Physical Review Letters,46(2):115, 1981.
[2] Albert Meige, Rod W Boswell, Christine Charles, and Miles M Turner. One-dimensional particle-in-cell simulation of a current-free double layer in an expanding plasma. Physics of plasmas, 12(5):052317, 2005.
[3] Charles K Birdsall and A Bruce Langdon. Plasma physics via computer simulation CRC press, 2004.
[4] Francis W Perkins and YC Sun. Double layers without current. Physical Review Letters, 46(2):115, 1981.
[5] K. K. Barada, P. K. Chattopadhyay, J. Ghosh, and Y. C. Saxena. Observation of low magnetic field density peaks in helicon plasma. Physics of Plasmas, 20(4):042119, 2013.

EFFECT OF NEGATIVE ION CONCENTRATION AND MAGNETIC FIELD ON ELECTRONEGATIV PLASMA SHEATH

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Sheath plays vital role in all practical applications where plasma is closed in a bounded region. It creates a barrier between surface of wall and bulk plasma. Generally, the positive barrier is formed at the surface but it is also possible to produce negative charge barrier there by creating an electronegative plasma. The characteristics of electronegative plasma sheath has been studied using the kinetic trajectory simulation (KTS) method. The effect of negative ion and the magnetic field in the electronegative plasma sheath having cold positive and negative ions and hot electrons are studied. It has been observed that for the increment of the concentration of negative ions, the density of positive ions and electrons decrease, the potential also decreases and the magnetic presheath and electrostatic Debye sheath edge are distinctly visible. The results are compared with previous published similar works following different models and our model provides a satisfactory basis for the study of electronegative plasma sheath. This work has useful applications in industry, bio-medical, sputtering, surface modification, textile industry, etc.

[1] ZOU Xiu, Liu Jin-Yuan, WANG Zheng-Xiong, GONG Ye, LIU Yue, WANG Xiao-Gang, Chin. Phy. Lett. **21**, 8 (2004)
[2]R. Chalise, R. Khanal Material Science and Engineering **A 5**, 41 (2012)
[3] A. S. Shaw, S Kar & K. S. Goswami, Physics of Plasma. **19**, 102108 (2012)

PARTICLE-IN-CELL SIMULATION STUDIES OF MAGNETOSONIC PRECURSOR SOLITONS EXCITED BY CHARGED OBJECTS MOVING IN PLASMA

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The nature of fore-wake excitations created by a charged object moving in a magnetized plasma is investigated using particle-in-cell simulations. Our studies establish for the first time the existence of precursor magneto-sonic solitons [1] traveling ahead of a charged object that is moving plasma. The nature of these excitations and the conditions governing their existence are delineated. We also confirm earlier molecular dynamic and fluid simulation results related to electrostatic precursor solitons [2, 3] obtained in the absence of a magnetic field and discuss the effect of a magnetic field on such structures. The electromagnetic precursors could have interesting practical applications such as in the interpretation of observed nonlinear structures during the interaction of the solar wind with the earth and the moon and may also serve as useful tracking signatures of charged space debris traveling in the ionosphere.

References:

[1] Excitation of KdV Alfven solitons by a pulsed CO_2 laser in plasma in the presence of an external magnetic field, A. Kumar et. al., Plasma Phys. Control. Fusion, 61, 065009 (2019).
[2] Fore-wake excitations from moving charged objects in a complex plasma, S. Tiwari and A. Sen, Phys. Plasmas, 23, 10 (2016).
[2] Nonlinear wave excitations by orbiting charged space debris objects, A. Sen et. al., Advances in Space Research, 56, 3 (2015)

DESIGN AND ELECTROMAGNETIC SIMULATION OF A CENTER-FED ICRF ANTENNA FOR ADITYA-U TOKAMAK

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A new center-fed ICRF antenna is designed to excite Fast Waves at plasma edge to propagate in to high density plasma and finally absorbed at various resonances that present inside the bulk. For an efficient antenna plasma coupling, a foremost requirement is to maximize antenna loading. This in turn dictates the maximum instantaneous RF voltage appearing on the antenna structure. Part of the loading goes in to the plasma density and thickness of evanescent layer in front of the antenna, whereas the other prominent part is the design of antenna structure. In the present design, the later part is investigated to optimize various structural components of the antenna so as to maximize the loading, minimize the surface current density, structure of electric field etc. In the present design, poloidal symmetry of wave electric field across the poloidal flux is taken into consideration. On Aditya-U the antenna is designed to cover close to half of the poloidal circumference and the RF voltage if fed at the center, creating a symmetric wave field across the mid-plane. The faraday screen is optimized for maximum transparency and to minimize the sheath induced rectification. Rods are aligned with the resultant local magnetic field to reduce the impurity generation. The electromagnetic simulation is done in CST-MWS and Ansys HFSS. The mesh dimensions are greatly optimized to make balance between accuracy and simulation time. Antenna plasma loading is simulated by simulating the plasma through a dielectric medium with varying thickness and distance followed by a perfectly matched layer before placing metal boundary as in case of a reasonably actual tokamak plasma scenario. Various lessons learnt, optimization techniques adopted and few preliminary results would be presented.

DESIGN OF A COMPACT COAXIAL WIDEBAND DC BREAK FOR USE IN HIGH POWER ICRF SYSTEM.

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High power coaxial DC break is imperative in ICRF system in tokamaks, stellarators, linear accelerators and other Radio Frequency devices, where the radiating antenna needs to be isolated electrically at extremely low frequencies from the RF source driving it. A coaxial transmission line having both inner and outer conductors need to be isolated simultaneously from the electrical ground of the machine vessel to reduce the vessel wall and antenna box mutual coupling and reduce parasitic excitation and power loss. The DC break should allow RF power to flow unhindered across up to antenna without significant power loss and reflection. Traditionally developed such components are tend to become bigger in dimension due to long wavelength of operation making them difficult to use in practical application.

The present work is an effort to make the component less bulky and having a wide range of frequency response. A coaxial DC break which separates both inner and outer conductors is designed for different standard rigid transmission line sections viz. $3^1/_8$”, $6^1/_8$” , and $9^3/_{16}$” . The design is optimized using Ansys High Frequency Structure Simulator. The designed DC break is having excellent insertion loss of < -0.1 dB and return loss < -35 dB for a wide range of frequency 10-60 MHz. The DC break is compact in diameter i.e. same as the rest of the transmission line and having a length of less than $\lambda/20$. The design details, optimization procedure, and results would be discussed.

DESIGN, TESTS AND FIRST RESULTS OF FAST ACTUATING SOL PROBE (FASP) FOR ICRH ANTENNA ON ADITYA-U

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A triple Langmuir probe housed on a modified pneumatic actuator primarily used for sample transfer job is designed, tested in lab conditions and integrated on Aditya-U machine. Plasma density and temperature profiles near ICRH antenna determines not only antenna load impedance, but also affects the way the correct choice of wave couples to the plasma. ICRF power also modifies these SOL profiles and measurements of these parameters can be useful to study transport, flow drive among others. Rectified RF field also tends to modify edge electric field profile and may have an impact on turbulence suppression and rotation induced suppression of island growth. Measurement of SOL profiles traditionally being done in shot to shot basis is cumbersome and introduce large errors due to varied plasma conditions. To alleviate these concerns, a simple pneumatic actuation based diagnostics is developed by modifying a sample transfer feedthrough to actuate a set of miniature Langmuir probes to scan the SOL during plasma current (I_p) flattop. The light weight probe system actuates 100mm with a speed of 1.5m/s scanning the last 10mm of scape off layer region in less than 7 ms. The probe measures absolute and gradient of electron density, electron temperature and radial electric field in SOL region of Aditya-U tokamak. The actuator movement is controlled by a pneumatic cylinder and air pressure is timed by a fast response solenoid valve (35ms response time to open with ±1ms repeatability). Two limit switches detect timings of actual movement of the actuator, which has a fixed stroke of 10cm. An inhouse designed SSR based simple control electronics module is used to control and monitor the probe movement so that the probe tip reaches the SOL during flattop of I_p. The USP of this diagnostics is simple to construct, cheap (< ₹80K) compared to the complex and expensive reciprocating probe and is easy to operate, however, presently capable of scanning only SOL region. This diagnostic can be used to measure plasma spatial variation within a short time in tokamak as well as in basic plasma devices.

MECHANICAL DESIGN AND SIMULATION OF A PRESSURIZED PHASE SHIFTER FOR HIGH POWER ICRF SYSTEM IN TOKAMAKS

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High power radio frequency waves in the megahertz frequency range have a wide range of application like tokamak fusion reactor, accelerators, aerospace and defense sector. The RF waves can be transmitted via rigid coaxial transmission lines (TL) at high power. In order to radiate the desired wave spectrum from an antenna, it is imperative to use line stretcher to change the phase of the travelling wave inside the TL. This is achieved by altering the electrical length of the TL. Since they change the phase of the wave that reaches at the antenna, they are called as Phase Shifter. For high power application and especially where high RF voltage presents in the high VSWR regions in unmatched line section, pressurization with air, dry nitrogen or SF6 is highly advantageous to increase the power handling capacity. The pressurized phase shifter (PPS) should have the provision of changing the phase without depressurizing it. This condition led to a requirement of housing the entire mechanism in a pressure vessel. In this work, the mechanical design consideration for the pressure vessel that can hold up to 3 bar differential pressure is discussed. The vessel thicknesses have been iterated and optimized to verify the structural integrity at its operating conditions. PPS system in-vessel components, e.g. pipe in pipe assembly, lead screw assembly are also checked for its design criteria (buckling and critical frequency at maximum loading). The vessel and in-vessel components design are carried out with the help of ANSYS. The detailed design and analysis are presented in this paper.

DEVELOPMENT OF DIELECTRIC BARRIER DISCHARGE PLASMA JET FOR THE APPLICATION OF PLASMA ACTIVATED WATER

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Agriculture is one of the most important industry which consumes large amounts of water in various stages. When the ordinary water is exposed to plasma to change its chemical nature for the better, it is called plasma activated water (PAW). PAW finds various applications in agriculture like promoting seed germination, plant growth, fungal removal and surface cleaning. The dielectric barrier discharge (DBD) plasma is a type of cold plasma and has been used for producing PAW. In the present work it is explained on the development of a DBD plasma source in the form of a jet, which has been successfully used for producing PAW. The jet uses a co-axial electrode arrangement with the use of a quartz tube as the necessary dielectric material. Ambient air is used as the plasmagen gas. A high voltage – high frequency (HVHF) power source has been developed and used for generating the DBD plasma jet. The design of this torch will be explained in detail.

HYDRAULIC ANALYSIS OF ITER COMPONENT COOLING WATER SYSTEM LOOP 2A

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ITER Cooling Water System is made of loops namely Tokamak Cooling Water System (TCWS), Component Cooling Water System (CCWS), Chilled Water System (CHWS) and Heat Rejection System (HRS). The CCWS is further divided into CCWS-1, CCWS-2A, CCWS-2B, CCWS-2C and CCWS-2D loops to meet the unique requirements in terms of

water chemistry. Among the CCWS loops, CCWS-2A is responsible to remove the heat load generated by SN & FDU components, ELM Coil power supplies & busbars, Gyrotron with vertical transmission line, power supplies, RF sources, etc.As part of the engineering design, in order to ensure the uniform flow and pressure with the available pressure drop during the operation under steady and transient conditions, it is mandatory to carry out steady state and transient hydraulic analysis of water distribution networks. The CCWS-2B hydraulic analysis model was developed using the AFT Fathom code to conduct the steady state hydraulic analysis of the system and the transient analysis was carried out using AFT Impulse code. In this steady state hydraulic analysis model, the critical path with the largest pressure loss was used to determine the pump head, while the pressure losses on the control valves were used to establish the required flow balance at each piping connection. The possible operational and occasional transient conditions were simulated in the transient analysis to make sure the piping network withstands such surges without loss of performance. This paper presents the results of the steady state and transient hydraulic analyses including the required pump head of the CCWS-2A loop and the main thermal-hydraulic parameters for each client (i.e. flow rate, pressure drops and outlet temperatures).

DESIGN OF HELMHOLTZ COILS AND BENCHMARKING USING COMSOL

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Helmholtz coils are one of the simplest ways to produce uniform magnetic fields required in laboratories for research purposes. Their design and size varies with the magnitude of required field, volume of interest and allowable tolerance. Magnetics and Dynamics Section, IPR designed and developed such Helmholtz coils for custom requirements of various groups. Considering their repetitive requirement, a generalized COMSOL program is developed, which provides estimated filed profiles in the regions of interest. This paper describes details of 2D axisymmetric model, presents the details of input / output parameters to COMSOL program. The results of one Helmholtz coil, designed and fabricated for hall probe calibration are also included.

References :

[1] Magnetic field of a Helmholtz coil. https://www.comsol.co.in/model/magnetic-field-of-a-helmholtz-coil-15

DESIGN AND DEVELOPMENT OF AN EXPERIMENTAL TEST FACILITY BASED ON TRANSIENT HOT WIRE TECHNIQUES FOR EFFECTIVE THERMAL CONDUCTIVITY MEASUREMENT OF CERAMIC PEBBLE BEDS

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Lithium based ceramics in the form of pebble beds have been considered as a tritium breeder material in the breeder blanket in the fusion reactors. Pebble beds are proposed because of their properties such as high surface area, uniform pore network, ability to get filled in complex shapes, resistance to thermal expansion and fatigue strength. Lithium meta-titanate (Li_2TiO_3) pebbles of ~1 mm diameter in the form of packed pebble bed will be kept in breeder blanket. In the fusion environment, pebble beds will be subjected to severe conditions such as neutron irradiation, cyclic mechanical compression and high thermal flux. The effective thermal conductivity of a packed bed is one of the important parameter for the design of the breeder blanket modules of a future fusion reactor.
Several experimental investigations have been performed to study the effective thermal conductivity of the ceramic breeder pebble bed using steady-state and transient methods. Test facility based on transient method is developed in present work. The transient hot wire technique was used to measure effective thermal conductivity of Indian made Li_2TiO_3 pebble bed. Finite element simulation was performed to optimize dimensions (length, diameter and thickness) of pebble bed container. Pebble beds of Li_2TiO_3 pebbles (1 ± 0.15 mm diameter) packed with approximately 63 % packing fraction. The effective thermal conductivity was measured as a function of temperature from room temperature to 650°C. A clear dependence of the effective thermal conductivity on the temperature of the pebble bed was observed. Results are compared with previous experimental studies with nearly same diameter, packing fraction and same material. Experiments were performed in helium, argon and air atmospheres in the pressure ranging from 0.05 bar to 3 bar gauge pressure. The empirical correlations for effective thermal conductivity of pebble bed as a function of temperature and gas pressure have been proposed.

LITHIUM WALL CONDITIONING USING NEWLY DEVELOPED LITHIUM EVAPORATOR FOR ADITYA-U TOKAMAK

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In fusion devices, different types of wall coating is performed using low-z materials like lithium, boron, carbon, silicon to get better plasma parameters such as density, temperature and confinement time. lithium coating is widely used due to its low atomic mass compare to other low-z substances. lithium coating on Plasma Facing Components (PFC) and vessel wall is a proven technique for wall conditioning in various tokamak devices. A well-established technique in ADITYA [1] and ADITYA-U, the lithium coating has been carried out using lithium rods insertion in glow discharge wall conditioning (GDC). Recently, a new technique of lithiumization has been introduced in ADITYA-U using a lithium evaporator system. The lithium evaporator system for ADITYA-U has been indigenously designed and developed. The systematic experimental study of the lithium evaporator system has been carried out in UHV test-setup and ADITYA-U tokamak. Design, development and performance testing, along with the preliminary effect of lithiumization by the evaporator during ADITYA-U plasma discharge operation will be presented in this paper.

References:

[1] S.B. Bhatt, Ajai Kumar, B. K. Das et al., IEEE Transaction in Plasma Science, Vol.**40**, No.6, June 2012

STUDY OF ELONGATED ANODE GLOW GENERATED AFTER TRANSVERSE INJECTION OF GUN PLASMA/NEUTRALS INTO THE PARALLEL PLATE PLASMA SYSTEM

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Experiment is being performed in a Compact Plasma System (CPS) [1] to study the interaction of plasma blobs and background plasma. For this purpose the washer plasma gun [2] as a source of pulsed plasma and a parallel plate type static plasma system (background plasma) [3] are designed, fabricated and successfully installed in the CPS. Along with this experiment a new phenomenon such that elongated anode glow in the shape of a spherical ball (fire ball) is observed on the anode surface after transverse injection of gun plasma/neutrals from the washer plasma gun into the static background plasma with minimum fill pressure of 30 psi in the washer gun at base pressure 0.6 mbar in CPS. Argon gas is used as working gas to produce plasma for both the gun plasma and background plasma. Potential fluctuations of this elongated anode glow are recorded by an array of Langmuir probes consisting of 4 probes separated by 1cm near cathode glow region. Primary power spectral analysis shows a coherent peak in the low frequency regime and fluctuation cross-correlation seems to be showing a delay. Further analysis is being done to probe possibility of wave and instability in anode sheath region. Analysed data and the fire ball evolution and structure will be presented in the conference.

References:

[1] G Sahoo, et al., A compact plasma system (CPS) for experimental study, Applied Mechanics and Materials, **278–280**, p 90–100, (2013)

[2] K. K. Jain, P.I. John, A. M. Punithavelu, P. P. Rao. Gas injected washer plasma gun. J. Phys. E: Sci. Instrum., **13**, p 928-930, (1980)

[3] S. Samantaray, et al., Characterization of the Background Plasma in a Compact Plasma System, Research Journal of Physical Sciences, **3(6),** p 10-15, (2015)

PROPAGATION OF ION ACOUSTIC WAVES IN A PLASMA CONTAINING TWO SPECIES OF ELECTRON TEMPERATURE

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An experimental study of the propagation of the ion-acoustic waves (IAW) has been carried out in a plasma having two distinct electron temperatures. In this work, an attempt has been made to investigate the effect of two temperature electrons on the propagation of the IAW in the presence and absence of dust grains. In order to produce plasma having two temperature electrons, low-pressure hot cathode discharge method is opted by inserting two magnetic cages with cusp magnetic field of different strengths in the same chamber. The dust grains are introduced into the plasma with the help of a dust dropper, which gains negative charge by interacting with the plasma. The IAW is excited with the help of a grid inserted into the plasma. The grid is negatively biased and a tone bursts sinusoidal voltage signal is applied to it. This results in a density perturbation near the grid which then propagates through the plasma as an IAW. A planar Langmuir probe has been used to detect the IAW. Phase and amplitude measurements are done by moving the Langmuir probe along the axis of the plasma column. The phase velocities of IAW are measured from the time-of-flight technique [1]. It is observed that the electron group with lower temperature has a dominant effect on IAW than the group with a higher temperature in the absence of dust grains [2]. In the presence of dust grains, the low-temperature electron species are mostly observed to participate in the charging of dust grains. It causes a decrease in the density of cold electron species. Therefore, in the presence of dust grains, it is believed that the hot electron species may have an effect on IAW. The results of the study may help to understand the IAW stabilization mechanism [3].

References:

[1] A. Barkan, N. D’Angelo and R. L. Merlino, Planet. Space. sci., 44, 239(1996)
[2] W. D. Jones, A. Lee, S. M. Gleman, and H. J. Doucet, Phys. Rev. Lett., 35**,** 1349(1975)
[3] I. Kourakis and P. K. Shukla, J. Phys. A: Math. Gen. 36**,** 11901(2003)

EFFECT OF DUST ON TWO-TEMPERATURE ELECTRON PLASMA

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The interest in the field of dusty plasmas is due to its ability to explain the different astrophysical phenomena and its relevance in industrial plasma research. The focus in the last few decades has been on the presence of dust in the fusion devices. However, the dust charging phenomena in laboratory plasmas have always been a keen interest for researchers. In the present work, the effect of dust on electron energy distribution function (EEDF) is investigated for different working pressures in a two-temperature electron plasma. A two-temperature hydrogen plasma is produced in a low- pressure hot cathode discharge in a dusty plasma experimental device. Multi cusps magnetic cages of different field strengths are used for confining the plasma elements. The plasma thus produced is allowed to diffuse at the junction of the magnetic cages, and as a result, two distinct electron groups having different temperatures are being observed. Moreover, with the introduction of micron-sized dust particles, the lower energetic electrons are attached to the dust surface and acquire a negative charge. This attachment process leads to an increase of the effective electron temperature. It is indicated by a shift in the root mean square peak in the distribution curve. Suitable diagnostics are employed to determine the different plasma parameters and evaluate the EEDF for different working pressures. A detailed discussion of the work done would be made during the presentation.

References:

[1] B. Kakati, D. Kalita, S. S. Kausik, M. Bandyopadhyay, and B. K. Saikia Phys. Plasmas **21**, 083704 (2014).
[2] A. V. Filippov, A. F. Pal’, A. N. Starostin, A. V. Gavrikov, V. E. Fortov, O. F. Petrov, and M. N. Vasil’ev Phys. Plasmas **16**, 093702 (2009).
[3] D. Kalita, B. Kakati, S. S. Kausik, B. K. Saikia, and M. Bandyopadhyay, Journal of Plasma Physics, **85**, 905850402(2019).

STUDY OF TWO ELECTRON TEMPERATURE PLASMA WITH COLD POSITIVE IONS

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The physics of Landau damping of waves in plasmas has been a classic problem for researchers for several decades. In the present work, the effect of two electron temperature on the Landau damping of Ion Acoustic Waves has been studied. Two low-temperature plasmas are produced separately by low pressure filament discharge method in a dusty plasma device by inserting two magnetic cages with cusp magnetic field of different strengths. Both the plasmas are allowed to diffuse in the central region of the chamber. Since magnetic cages have different field strengths and different discharge currents are maintained, it is expected to have plasma with electrons having two distinct temperatures [1, 2]. Langmuir probe is used as a diagnostic tool for determination of plasma parameters. An analysis of electron energy distribution function (EEDF) has been carried out in order to find out the influence of the confinement system on the plasma. The results of the experimental study have been compared with the results of a kinetic simulation of the experimental model. The present work is an extension of our previous theoretical study of plasma sheath in presence of two temperature electrons [3]. The study is supposed to help in understanding the role of two temperatures of electrons in the propagation of waves and instabilities in plasma.

References

[1] T. E. Sheridan, M. J. Goeckner, and J. Goree, *J. Vac. Sci. Technol. A* 9 688 (1991)
[2] R. J. Armstrong**,** W. J. Weberand, and J. Trulsen, *Phys. Lett.* 74A 5 (1979)
[3] G. Sharma, S. Adhikari, R. Moulick, S. S. Kausik, and B. K. Saikia, *Phys. Scr.* (Communicated, August, 2019)

MISMATCH IN FLOATING POTENTIAL AND HOT ELECTRON TEMPERATURE MEASURED BY DIFFERENT DIMENSION LANGMUIR PROBE HEADS IN FILAMENT PRODUCED PLASMA

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Langmuir probes are widely used to characterize plasma properties like floating potential, plasma potential, electron temperature and density. These measured plasma properties play a crucial role to relate experimental results with appropriate theories. We have measured and analyzed[1-5] the current-voltage (I-V) characteristic for different size probe heads (diameter 0.75mm, 2mm, 3mm, 8mm) in filament produced plasma. However, the comparison of the

floating potential measured by different size probe heads in both radial and axial direction of the device in same discharge condition shows significant mismatch. Further comparison for hot and cold electron temperature reveals mismatching in hot electron temperature measured by different probe heads in same discharge conditions. According to probe theories[4-7] probe dimension should be bigger than the Debye length. All probes diameter are bigger than the Debye length for cold electron component; however, only 8mm diameter probe is bigger than the Debye length for hot electron component, the details of which will be presented.

References:

[1] Understanding Langmuir probe current-voltage characteristics, Robert L. Merlino, American Journal of Physics 75, 1078 (2007); doi: 10.1119/1.2772282
[2] N. Hershkowitz, How Langmuir Probes Work, in Plasma Diagnostics, Vol. 1, ed. by O. Auciello and D.L. Flamm (Academic Press, Boston, 1989), Chap. 3.
[3] F. F. Chen, "Electric Probes," in Plasma Diagnostic Techniques, edited by R. H. Huddlestone and S. L. Leonard Academic, New York, 1965,Chap. 4
[4] F.F. Chen. Lecture notes on Langmuir probe diagnostics. Mini course on plasma disgnostics, IEEE-ICOPS meeting. Jeju, Korea (2003). Available from the web page of the author: http://www.ee.ucla.edu/ ffchen/Publs/Chen210R.pdf.
[5] Conde, Luis. "An introduction to Langmuir probe diagnostics of plasmas." Madrid: Dept. Física. ETSI Aeronáut ngenieros Aeronáuticos Universidad Politécnica de Madrid (2011).
[6] S.V. Ratynskaia, V.I. Demidov, and K. Rypdal, Rev. Sci. Instrum. 71, 1367 (2000)
[7] "How big is a small Langmuir probe?" Physics of Plasmas 7, 3084 (2000); https://doi.org/10.1063/1.874162

EQUILIBRIUM RECONSTRUCTION OF SST1 TOKAMAK

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External magnetic measurements with flux loops and magnetic pick-up coils in tokamaks have provided vital information on the shape of the plasma column and also global current profile parameters, such as the sum of the poloidal beta (βp) and the internal inductance (ℓi) [1]. Such a reconstruction needs to be fast and sufficiently accurate such that it can be used routinely as a complementary input with other experimentally measured parameters for any sort of physics analysis of the plasma discharges. Toroidal continuity of the vacuum vessel, passive stabilizer and the cryostat leads to the generation of large eddy currents in these passive structures during the Ohmic phase of the steady state superconducting tokamak SST 1. This reduces the magnitude of the loop voltage seen by the plasma as also delays its buildup. During the ramping down of the Ohmic transformer current (OT), the resultant eddy currents flowing in the passive conductors play a crucial role in governing the plasma equilibrium. For the accurate reconstruction of plasma equilibrium the effect of eddy current in the toroidally continuous conducting structures like the vacuum vessel and the cryostat with super conducting poloidal field (PF) coil to be included in the calculations of equilibrium code. Here we present a method which can be used to proficiently reconstruct the current profile parameters, the plasma shapes, and a current density profile satisfying the MHD equilibrium constraint, reasonably conserving the external magnetic measurements. A Grad-Shafranov (GS) equation solver, named as IPREQ [1], has been developed in IPR to reconstruct the plasma equilibrium through searching for the best-fit current density profile. Ohmic transformer current (OT), vertical field coil current (BV), currents in the passive filaments along with the plasma pressure (p) and current (Ip) profiles are used as inputs to the IPREQ code to reconstruct the equilibrium consistently with the flux loop measurements and the poloidal flux, plasma shape, βp and the safety factor (q). In SST1 there are 12 magnetic pick-up coils aligned to measure the poloidal magnetic field (*B*p) during a plasma discharge. Vacuum shots with OT and BV and no fill gas are used to calibrate these coils and loops. Measurement from these coils and flux loops are used to reconstruct the equilibrium consistently with the peak density and temperature measurements [2].

References:

[1] L. L. Lao *et al.*, "Reconstruction of current profile parameters and plasma shapes in tokamaks," *Nucl. Fusion*, **25**, 1611 (1985).

[2] Tokamak equilibrium code-IPREQ, R. Srinivasan and S. P. Deshpande IPR/RR-393/2007 (August, 2007).

EQUILIBRIUM STRUCTURE FORMATION OF STRONGLY COUPLED DUSTY PLASMAS: A MOLECULAR DYNAMICS STUDY

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Dusty plasma medium is an ideal test bed to study macroscopic phenomena emerging from microscopic dynamics at individual particle level that can be tracked. Dusty plasma is essentially a multicomponent complex system consisting of electrons, ions, neutrals and nano/micrometer sized dust grains which get charged by the plasma electrons and ions sticking on its surface. Very low value of charge to mass ratio makes the response time scales associated with the dust dynamics very slow so that they can be observed even by unaided eyes. The high charge on dust in the plasma environment often renders the average inter-grain potential energy to exceed the value of average thermal energy of the dust particles. This renders the dust species to behave like a strongly coupled medium. In the strong coupling regime, the dusty plasma medium has traits often similar to soft matter, visco–elastic and crystalline system. Molecular dynamics studies have been carried out for the dusty plasma medium to investigate a variety of interesting phenomena. The lighter electron and ion species in the plasma are treated by the inertialess Boltzmann response contributing to the shielding of the dust charge leading to an effective Yukawa interaction amidst the dust particles. The equilibrium structure formation of the dust particles in two-dimensions (2-D) and three-dimensions (3-D) have been studied in detail. The conditions for the formation of layered structure in 3-D in the presence of both gravitational force and force associated with the sheath electric field (typically present in experiments) have been identified. The form of the crystalline patterns (e.g. triangular and square patterns) are recognized with various diagnostic tools. The possibility of structural phase transition and the presence of a re-entrant phase has been identified.

References:

[1] S. Maity, A. Das, S. Kumar, and S. K. Tiwari, Phys. Plasmas 25, 043705 (2018).
[2] H. Totsuji, T. Kishimoto, and C. Totsuji, Phys. Rev. Lett. 78, 3113 (1997).
[3] S. Maity, A. Das, Phys. Plasmas 26, 023703 (2019).

STRAIN PROPAGATION DYNAMICS IN GAP (111) CRYSTAL AT PICO-SECOND TIME SCALE

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Strain propagation dynamics in GaP (111) single crystal is studied by time resolved x-ray diffraction (TXRD) technique. In this method, first the sample is excited by an ultra-short (pump) laser pulse and then the change in the crystal lattice is probed by an ultra-short x-ray (probe) pulse. X-ray pulse is generated by the interaction of ultra-short laser pulse with copper wire target. The x-ray pulses generated by this method have duration similar to the laser pulse duration. The semiconductor sample can be efficiently excited by ultrashort laser in single photon absorption. This is possible only when the photon energy of the excitation laser is more than the effective band gap of the semiconductor sample. A 1 kHz Ti:Sapphire laser operating at 800 nm, generating laser pulses of 6.5 mJ energy and 45 fs pulse duration was used in this experiment. Since the band gap of the GaP crystal is ~2.25 eV which is considerably higher than the photon energy of the Ti:sapphire laser (~1.54 eV). We have first converted a part of the laser into second harmonic (photon energy ~3.08 eV) and then used it as pump pulse. The sample was pumped at laser fluence of ~10 mJ/cm^2, which is below the damage threshold fluence of the sample. Laser excitation of the sample launches a thermal strain in the crystal which resulted in the expansion of the crystal. This strain (change in the spacing of crystal) is manifested in terms of change in the angle of the diffracted x-ray. The strain propagation is probed by changing the delay between the pump and the probe pulses. The 2 ps time step is the resolution of our setup (limited by its geometry). The maximum strain of $\sim 2\times10^{-3}$ generated initially which decreases gradually at larger delays. At delay ~14 ns after crystal excitation, the strain become $\sim 2\times10^{-4}$. The study of strain propagation dynamics will be helpful in understanding the sample behaviour under intense photo excitation by ultrashort intense pulses and will be helpful in designing the fast semiconductor devices.

PLASMA PARAMETERS ENHANCEMENT IN ADITYA-U TOKAMAK

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Since the last IAEA Fusion Energy Conference in 2018 [1], the ADITYA Upgrade (ADITYA-U) (R_0 = 75 cm, a = 25 cm) experiments have been focused on attaining the plasma parameters close to the design parameters in circular limiter plasmas operations. Recently, 42 GHz ECR [2] assisted low loop voltage (~ 10 V) start-up experiments along with negative convertor operation has been performed on ADITYA-U to enhance the plasma parameters. The maximum toroidal magnetic field operated during this experiment was ~1.4 T (~93% of the design parameter). Consistent plasma discharges of plasma currents of the order of ~170 kA–177 kA, plasma duration of ~300 ms–335 ms were obtained. Successful recovery of volt–sec along with real-time horizontal plasma position control leads to the achievement of longer discharge duration. In addition to that repeated cycles of baking of ADITYA-U vacuum vessel up to 135° C followed by extensive wall conditioning resulted in substantial reduction in partial pressures of various mass spices and achievement of minimum base pressure of the order of ~ 9 x 10^-9 torr. The chord-averaged electron density of the order of ~3.0–4.0 × 10^19 m^-3 was obtained using multiple hydrogen gas puffs and an electron temperature of the order of maximum ~400 eV, has been reported. Apart from this the operational parameters regimes for generation of runaway beam and its avoidance also studied in ADITYA-U. Experimental results and operational aspects for plasma discharge parameters enhancement will be discuss in this paper.

References:

[1] 'Overview of operation and experiments in the ADITYA-U tokamak', R.L. Tanna et al, Nucl. Fusion 59 (2019) 112006.
[2] 'Commissioning of Electron Cyclotron Resonance Heating (ECRH) system on tokamak ADITYA-U', Fusion Engineering and Design 146 (2019) 2083 – 2086.

LOW FREQUENCY MAGNETOSONIC ROGONS IN PAIR ION PLASMA

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The study of the propagation properties of magnetosonic waves are of great interest because of their important roles in plasma heating and acceleration of charged particles. They are often observed in earth's mesosphere, laboratory plasmas and in solar wind plasmas. Magnetosonic wave is a kind of fundamental mode in magnetized plasma which propagates in the perpendicular direction of external magnetic field. The term pair-ion is generally referred to a plasma containing oppositely charged ions with nearly the same mass. Electron-positron plasma is an example of pair plasma and such pair ion plasma exists in pulsar magnetosphere, neutron stars and active galactic nuclei. Rogons also known as rogue waves are highly energetic waves with large amplitudes and have a small possibility of appearing instantly. Rogue waves are studied from the rational solutions of nonlinear Schrodinger equation (NLSE). Keeping in view the importance of rogue waves, magnetosonic rogue waves in pair-ion plasma are investigated. As per our knowledge, no investigation for magnetosonic rogue waves in pure pair-ion plasma has been reported so far. Thus, it seems interesting to investigate the nonlinear magnetosonic rogue waves in such type of plasma. We have considered two dimensional nonlinear magnetosonic rogue waves propagating perpendicular to the applied magnetic field in pair ion plasma. Kadomstev-Petviashvili (KP) equation is obtained using reductive perturbation technique and on modulating KP equation, NLSE is derived. Various parameters such as strength of magnetic field, electron temperature etc, significantly modify the characteristics of rogue wave profile. Both first- and second- order magnetosonic rogue wave profiles are studied. This study may also be of great importance to study freak waves in laboratory experiments with dust impurities and space environments.

References:

[1] F. Verheest, Nonlinear acoustic waves in nonthermal dusty or pair plasmas, Physics of Plasmas, 17, 2010, 062302
[2] A. Ankiewicz, N.Devine, N.Akhmediev, Are rogue waves robust against perturbations?, Phys. Lett A., 373, 2009, 3997

A PRE-PULSE DELAY LINE SET UP AT 150 TW 25 fs Ti: SAPPHIRE LASER SYSTEM FOR CONTROLLED PRE-PLASMA GENERATION

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Interaction of relativistic intensity ultra-short laser pulses with thin foil targets for the generation of fast electrons (few MeV energy) is a subject of current experimental investigations. The presence of preplasma has a significant effect on these studies. Generally, the preplasma is produced due to prepulses which are generated mainly by amplified spontaneous emission (ASE) from high energy amplifiers and leakage of mode-locked pulses through the Pockel cell in the regenerative amplifier in chirped pulse amplification based ultrashort laser systems. These pre-pulses are difficult to control. In our recent study, we have observed effect of pre-plasma on laser absorption and subsequent fast electron generation. The pre-plasma scale length was changed by varying the duration of ASE prepulse over a limited intensity contrast. Moreover, the ASE pre-pulse has larger divergence and therefore focuses to a larger size which further limits the range for studying the role of preplasma on the laser plasma interaction mechanism. It is therefore necessary to set up a separate pre-pulse delay line with controlled delay and intensity prior to the main laser pulse to generate controlled preplasma. A pre-pulse delay line of uncompressed laser beam consisting of beam splitters and mirrors has been setup at 150 TW laser system. The output from main laser amplifier was split using an AR coated fused silica wafer in a 1:6 ratio with 86% of the beam (main pulse) fed to the pulse compressor whereas the remaining 14% as a controlled prepulse on the target with a delay line of 1.5 meter travel range (delay range ~5 ns). The maximum energy of prepulse was measured to be ~300 mJ which can be attenuated with the neutral density filter. The uncompressed prepulse duration (~ 530 ps) and delay between the two pulses was measured by collecting the scatter light from target surface with fast photodiode (rise time ~100 ps) coupled to 5 GHz oscilloscope. The time delay between the two pulses can be controlled from -3 ns (prepulse arrived before main pulse) to + 2 ns (arrived after main pulse) with provision to increase the negative delay up to 8.5 ns. The prepulse of ~33 mm diameter was focused with a lens of 10 cm focal length to a size of 6.2 ± 0.5 μm x 7.7 ± 1 μm (FWHM) containing 30% energy. The focal spot size was measured by imaging the focal region with the 40 X microscopic objective on to 14 bit CCD camera. The peak intensity of the prepulse was estimated to be ~3.9 x 10^{14} W/cm^2. Investigation on role of pre plasma spatial extent in MeV fast electron generation using 150 TW laser system with variable delay (hence controlled preplasma extent) would be carried out.

INSULATION OF SUPERCONDUCTING PF#3 COILS CURRENT LEADS OF SST-1

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The conventional copper current leads are a vital component for superconducting magnet system of SST- 1 tokamak. These leads are located in vacuum chamber known as ‘current feeder system’ (CFS) of superconducting magnets. As a warm to cold transition section (from 300-4.2 K) these leads carry 10 kA of currents from power supply to the magnet terminals. In past SST-1 campaign, during OT discharge, severe arcing incidence was observed in CFS chamber between high potential surface of these leads and ground [1]. Similar incidences have also been observed in other tokamaks like KSTAR, EAST and W7-X Stellarator. To avoid such incidence, a composite insulation has been applied on the outer surface of these current leads. This insulation system consist of two half overlap layer of polyimide film on the outer surface of leads and then four layer of glass fiber with epoxy resin. The main body of these leads has a cylindrical shape but its heat exchanger, cooling inlet outlet lines, transition section, flange section have complex irregular surfaces. So insulation wrapping and curing techniques for these locations have to be optimized for the uniform electrical and mechanical performances of insulation at cold temperature. In this presentation, the latest insulation progress for PF#3 current leads, high voltage electrical and Paschen test results of cured insulation will be presented.

References:

[1] Preventive Measures to Avoid Electrical Arcing Incidences in SST-1 PF Current leads [FIP-P7/26], Swati Roy, Nitish Kumar, M Ghate, D kanabar, Upendra Prasad and R. Srinivasan.Presented inFEC-2018

DESIGN AND MULTIPHYSICS ANALYSIS OF A 2.45 GHZ, 25 KW CW RF WINDOW FOR SMALL SCALE SPHERICAL TOKAMAK (SSST)

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The low aspect ratio machine or Small Scale Spherical Tokamak (SSST) is being designed to gain insight of its advantages in terms of improved plasma parameters like natural elongation, high beta plasma, high fraction of bootstrap current, operation at low toroidal magnetic field, etc. The designed SSST has a major/minor radius of 28 cm/16 cm, aspect ratio of 1.75 and plasma current of 25 kA for less than 50 ms and magnetic field of 0.1T at the minor axis. It provides an opportunity to form Electron Cyclotron Resonance (ECR) produced pre-ionized plasma and also to drive plasma current non-inductively, which would increase the pulse

length up to few seconds. The commercially available RF source to produce ECR plasma, around the designed toroidal magnetic field for SSST is 2.45 GHz [1]. To isolate the vacuum vessel and the launching structure in atmosphere, the RF vacuum window with a high return loss for microwaves is designed [2][3][4]. The ceramic used for this isolation is 99.7% pure alumina having a loss tangent of 3×10^{-4}, with rectangular waveguides on either side. The RF and Multiphysics simulations are performed in COMSOL Multiphysics. The simulation yields a return loss of more than 40 dB and an insertion loss of less than 0.1 dB. The thermal and stress analysis confirms the requirement of cooling channels for CW operations around the ceramic periphery and along the rectangular waveguides. Post cooling arrangements, the window achieved an acceptable steady state temperature. The fabrication of the window is in progress based on the above analysis. This poster presents and discusses the RF design constraints and Multiphysics simulation results of the RF window.

References:

[1] C. Danani, "Preliminary Design and Analysis of a Small Scale Spherical Tokamak at IPR," in *this conference*.

[2] Y. M. Jain, P. K. Sharma, H. V. Dixit, A. Jadhav, and P. Parmar, "Design and multiphysics analysis of a high power RF window for LHCD system of tokamaks," in *Progress in Electromagnetics Research Symposium (PIERS-Fall)*, 2017.

[3] J. Hillairet *et al.*, "Design and Tests of 500 kW RF Windows for the ITER LHCD System," *Fusion Eng. Des.*, vol. 94, no. 1, pp. 1–23, 2015.

[4] C. Wang *et al.*, "Development of RF Window for 3.7-GHz LHCD System on HL-2A," *Fusion Sci. Technol.*, vol. 1055, pp. 1–6, 2017.

PROFILE MEASUREMENT OF THE PASSIVE ACTIVE MULTIJUNCTION (PAM) LAUNCHER FOR LHCD SYSTEM OF ADITYA –UPGRADE TOKAMAK

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The Passive Active Multijunction (PAM) Launcher has been designed [1][2] and developed [3] for the Lower Hybrid Current Drive (LHCD) system of the ADITYA –Upgrade tokamak. The launcher has been tested for its mechanical properties and the RF characterization of the launcher has been observed. A novel technique has been employed to measure the $N_{||}$ profile and the 2D face plot of the waves launched by the launcher experimentally. This technique uses the Vector Network Analyzer (VNA) to measure the E-field of the waves launched and further obtains the $N_{||}$ profile by MATLAB post processing. The profiles obtained peaked at $N_{||}$ of 2.25 as desired and are in good agreement with those obtained from the Advanced Lower Hybrid Antenna (ALOHA) simulation code [4]. The measured profile is further verified using CST Microwave studio. This poster discusses the measurement technique and compares the measured profile with the results obtained through simulation code in 2D and commercial software (CST studio) in 3D.

References:

[1] Y. M. Jain *et al.*, “RF design of Passive Active Multijunction (PAM) launcher for LHCD system of ADITYA-Upgrade tokamak,” *Fusion Eng. Des.*, vol. 134, no. 9, pp. 109–117, 2018.
[2] Y. M. Jain, P. K. Sharma, and H. V. Dixit, “Multiphysics analysis of the Passive Active Multijunction (PAM) launcher for LHCD system of ADITYA-Upgrade tokamak,” *Fusion Eng. Des.*, vol. 147, p. 111225, Oct. 2019.
[3] Y. M. et. al. Jain, “Development and Qualification of Passive Active Multijunction (PAM) Launcher for LHCD System of ADITYA -Upgrade Tokamak,” in *27th IAEA Fusion Energy Conference (FEC 2018)*, 2018.
[4] J. Hillairet *et al.*, “ALOHA: an Advanced LOwer Hybrid Antenna coupling code,” *Nucl. Fusion*, vol. 50, no. 125010, pp. 1–17, 2010.

CO_2 CONVERSION TO METHANOL OVER NI-CU-FE CATALYST USING HYBRID NON THERMAL PLASMA REACTOR

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Rising CO_2 levels in atmosphere is serious threaten the mere existence of human life. Several combat methodologies are available but they lack important aspects that makes them undesirable [1]. Non Thermal Plasma (NTP) is an emerging technique that can be employed for CO_2 conversion which is effective to overcome thermodynamic barriers [2]. In current work we showcase CO_2 conversion to methanol over Cu-Fe and Ni-Fe composite. The present study combines thermal and plasma catalysis (PTC) and exploits the synergism of NTP/catalyst hybrid setup. In the study materials are synthesised using sol gel technique and loaded on quartz wool using dip coating method. Series of catalyst i.e. CuO, NiO, Fe_2O_3, NiO-Fe_2O_3, CuO-Fe_2O_3 are tested for CO_2 conversion and methanol production. It is observed that 5%.wt CuO/Fe_2O_3, at 200 °C and 2.0 W input power, showed about 17% CO_2 conversion and about 40% methanol selectivity. Interestingly, without plasma discharge less than 1.5% CO_2 conversion is obtained with about 46% methanol selectivity. It is demonstrated that the methanol yield significantly increased from 7 $mmol.hr^{-1}.gcat^{-1}$ (for thermal alone) to 12.6 $mmol.hr^{-1}.gcat^{-1}$ when plasma discharge is combined. Indeed, it is also evidenced that the increase in temperature and plasma input power have shown negative effect on CH_3OH yield. This study successively has shown that plasma discharge could be used as an efficient tool to overcome high reactivity barriers.

References :

[1] Catalysis for the valorization of exhaust carbon: from CO_2 to chemicals, materials, and fuels. Technological use of CO_2. Chemical reviews, **114(3)**, p 1709-1742, (2013)

[2] Atmospheric Pressure and Room Temperature Synthesis of Methanol through Plasma-Catalytic Hydrogenation of CO_2. ACS Catalysis, 8, p 90-100, (2017)

A VERSATILE HYPER-REDUNDANT MANIPULATOR FOR TOKAMAK INSPECTION APPLICATIONS

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Remote Handling (RH) activities form a major part of the tokamak maintenance by continuously monitoring the health of the in-vessel components. Activities such as routine visual and NDT inspections, replacement of in-vessel components and periodic component upgrades are essential ensure a low downtime of the tokamak. Such RH activities are conducted using various robotic equipment that are developed to suit the constraints levied by the tokamak. The choice and thereafter the design of robotic equipment is largely governed by the cruciality of the operation involved as well as the geometrical and temporal constraints. Hyper-redundant manipulators are an alternative to serial manipulators that can be used for inspection and maintenance in constrained location. They are highly suitable for inspections in tokamak environment, where the robotic systems need to have multiple degrees of freedom, light weight, fast deployment and retrieval mechanism with high dexterity. This paper presents the design and development of 8-DOF hyper-redundant robot for narrow space inspections in tokamak environment. The robot consist of 4 links that are joined using universal joints to provide a spherical workspace. Two pairs of linear motors with steel tendons are used to control the spatial movement of each link thus providing 2-DOF to each joint. An Ether-net based multi-motor control architecture is developed to simultaneously control the movement of the four links using forward and inverse kinematics. The control architecture is linked to a master controller with Python interface to solve the required joint angles and thereby the movement of the individual motors. A virtual reality interface provides the exact configuration of the system during operation. The robot has been tested to show a high reliability with tool end-point accuracy of <1mm. This paper outlines the mechanical design guidelines, choice of the robot kinematics and shape control simulations, details of the control algorithm, controller development and test results for the developed hyper-redundant robot.

LASER WAKEFIELD ACCELERATION OF ELECTRONS BY DOUBLE LASER PULSE IN PLASMAS

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Laser-driven plasma accelerators are of great interest because of their ability to sustain large acceleration gradient (~100 GV/m), which is almost three orders of magnitude higher than the conventional accelerators (~100 MV/m) [1]. There are various methods by which plasma wave can be excited. In laser wakefield acceleration (LWFA), a short intense laser pulse drives the plasma wave to accelerate the plasma electrons to GeV energy [2,3] We here propose to study the laser wakefield acceleration of electrons in double-pulse regime using particle-in-cell simulations. The open source code Fourier-Bessel particle-in-cell (FBPIC) is used for these simulations [4]. A Gaussian laser pulse of moderate intensity excites the wakefield to accelerate the electrons to an appropriate energy level. The second laser pulse launched after a delay assists to amplify the primary wakefield. Thus, the electrons are accelerated to even higher energy by this amplified wakefield. The injection of electrons are significantly enhanced by preheating of electrons in double laser pulse case. The electron charge is significantly enhanced in the first bucket travelling behind the driver pulse in plasma. The obtained electron beam with high charge, low emittance and narrow energy spread can be used efficiently for many applications. These results immediately find applications in driving very compact X-ray sources and with widespread utility in ultrafast science, technology, and medicine.

References:
[1] T. Tajima and J. Dowson, Phys. Rev. Lett. 43 (1979) 267.
[2] J. Faure et al., Nature 431 (2004) 541.
[3] L. M. Gorbunov, S. Yu. Kalmykova, and P. Mora, Phys. Plasmas 12 (2005) 033101.
[4] Remi Lehe et al., Computer Phys. Commun. 203 (2016) 66.

MICROWAVE PLASMA DIAGNOSTICS FOR FUSION RESEARCH MACHINES

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Diagnostics are very important to characterize the fusion plasma by measuring plasma parameters such as ' density, distribution function over energy, temperature, their spatial profiles and dynamics. There are mainly two categories of the plasma diagnostics namely; (i) passive methods in which electromagnetic (EM) radiation from microwave to X-ray, emitted by the fusion plasma are monitored to derive the plasma parameters, (ii) active methods EM radiations produced by external sources are used to interact with the fusion plasma to determine the plasma parameters. Brief description about basic principles and characteristics of various diagnostics techniques will be covered in the talk. Among all these, various microwave and millimeter wave fusion plasma diagnostics will be discussed. Further, in case of fusion research machine, there are neutron radiation, high magnetic field and high power RF stray radiation. Difficulties faced in setting up the microwave diagnostic system on the fusion research machine and to determine accurate and reliable measurements of the plasma parameters will also be addressed. The description about techniques to accomplish the plasma parameters measurements in such environment will also discussed.

DEVELOPMENT OF ROGOWSKI COIL FOR THE MEASUREMENT OF CURRENT OF THE DISCHARGE DRIVEN BY AC OHMIC VOLTAGE

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A Rogowski coil has been designed and fabricated to measure a plasma current of amplitude 10-50 A with 0.5 ms rise time. A wire was wound uniformly over toroidal core (ID=163mm and OD =190mm) with rectangular cross-section (25 mm x 27mm). A return path was provided to make it immune to stray field. For protecting from heat flux of plasma and electrostatic pickup, it will be placed inside a SS enclosure. For turn area, na= 0.81 m^2, output voltage of Rogowski coil will be 20– 100mV. Response time (L/R= 1.2 μs) is sufficient for the current to be measured. The output voltage which is proportional to time rate of current, will be integrated electronically to obtain current. The detailed design and the initial results will be presented in the paper.

IDENTIFICATION AND QUANTIFICATION OF CONTAMINANTS IN RF PLASMA

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ROBIN [1, 2], an inductively coupled negative hydrogen source is being operated presently with total beam extraction area of ~ 73.38 cm^2 (146 apertures of 8mm diameter). The three grid electrostatic accelerator system of ROBIN is fed by high voltage DC power supplies (Extraction power supply: 11kV, 35A and Acceleration power supply 35kV, 15A). The plasma is monitored non-invasively by EMICON MC – 4channel, 200 – 1100nm spectral range with 1.5nm spectral resolution, and is used for this impurity study. Source

contamination has a vital role in performance of source in surface mode when Cs vapour is injected into the source to create low work function surface. However, if impurities are present in the ion source volume, it react with Cs and prevented to get low work function surface and so negative ion yield is impacted. With control of contaminant better source performance can be achieved. Monitoring of contaminant is essential for optimum operation of the ion source. Present study is focused on identification of contaminant from the plasma emission spectrum. This is done by using library spectra of expected elements from a standard source [3]. By comparing intensities of obtained spectra and standard spectra, unknown element can be predicted and their probability of prediction is dependent on other intense peaks of the same element. Quantitative measurement of the species can be done by using suitable weight factor for individual species. Moisture is the main contaminant in the present experimental campaign which is also supported by residual gas analyzer (RGA) spectrum.

References:

[1] M. J. Singh, M. Bandyopadhyay, G. Bansal, A. Gahlaut, J. Soni, Sunil Kumar, K. Pandya, K.G. Parmar, J. Sonara, Ratnakar Yadava, A.K. Chakraborty (IPR, India), W. Kraus, B. Heinemann, R. Riedl, S. Obermayer, C. Martens, P. Franzen, U. Fantz (IPP, Germany), AIP Conf. Proc. 1390, 604, (2012).IEEE Editorial Style Manual, IEEE Periodicals, Piscataway, NJ, USA, Oct. 2014, pp. 34-52.

[2] Gourab Bansal, Agrajit Gahlaut, Jignesh Soni, Kaushal Pandya, Kanu G. Parmar, Ravi Pandey, Mahesh Vuppugal-la, Bhavesh Prajapati, Amee Patel, Hiren Mistery, Arun Chakraborty, Mainak Bandyopadhyay, Mahendrajit J. Singh, Arindam Phukan, Ratnakar K. Yadav, Deepak Parmar, Fusion Eng. & Design, 88, 778– 782 (2013).

[3] https://physics.nist.gov/PhysRefData/ASD/lines_form.html

PILOT TESTING OF $LaBr_3$ (Ce) SCINTILLATOR BASED HARD X-RAY SPECTROMETER IN TIME STAMPED LIST MODE

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Scintillator based Hard X-Ray diagnostics is routinely operated in various tokamak to study the runaway electron energy distribution in plasma discharges and its temporal evolution. In general, Pulse height analysis is used for providing the histogram of Hard X-Ray photon energy vs no. of counts for different time slots by triggering the diagnostics at specific time interval. Here temporal information of individual count is missing. But with the advancement of Digital Signal Processing, it is now possible to time stamped individual count with its energy information. Here, we have developed a data acquisition software using the software development kit (SDK) provided with LaBR3 (Ce) scintillator based Hard X-Ray spectrometer, in python, for the operation of hard X-ray spectrometer in the time stamped list mode. This software has the ability to acquire the data for the varied time lengths of the discharge and then distribute it in time bunches of any required time scales like 5ms, 10 ms etc. This provides an advantage of having the full data and viewing it in different forms or time scales. This report describes the basic functionality of the diagnostics in Time Stamped list mode as tested in the laboratory and its preliminary results obtained while operation on the SST-1 and Aditya_U tokamak.

THE EFFECT OF FRINGING FIELDS AND ELECTRIC FIELD NON-UNIFORMITY ON THE PERFORMANCE OF PARALLEL PLATE ELECTROSTATIC ANALYSER

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One of the methods to estimate the energy of charged particles in a beam is to pass the beam through anelectric, magnetic, or electromagnetic field. Electrostatic analyzers are more commonly used than the magnetic ones, because static electric fields are normally easier to produce. Various types of energy analyser design exist; however in all types of electrostatic analyzers a charged particle is separated according to its E/q rather than its absolute velocity.A parallel plate electrostatic analyzer uses a pair of plane parallel platesas bias plates to create a uniform electric field.Though the idea of a parallel plate electrostatic analyzer is very simple, there are design challenges to be considered. The entrance and exit apertures in the entrance plate act as lenses due to the electric fields, producing undesired aberrations. The fringing fields in between the plates and the non-uniformity of electric fields due to finite size of aperturescan pose problems in measurement or affect the charge particle trajectories.Also, stray fields due to external sources can affect the instrument’s performance hence proper shielding is required. This paper will compare the energy resolution and focusing properties of different analyzer designs and also explain the effect of fringing fields and electric field non-uniformity on the performance of parallel plate electrostatic analyser.

RECENT ADVANCES IN PULSED LASER DEPOSITION TECHNIQUE

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Pulsed laser deposition (PLD) is one of the most versatile and promising growth techniques to realize high-quality thin films of a variety of multi-element compounds. The advent of interest in this technique took place when the stoichiometric deposition of the high-quality thin film of YBa2Cu3O7−δ superconductor has been demonstrated by using this technique. For the last two decades, PLD has contributed remarkably in revolutionizing the research on advanced functional oxides. The paper gives an overview of the recent advances in the PLD technique, for example, large-area deposition, monitoring growth and study growth kinetics using reflection high-energy electron diffraction [1]. The paper concludes by briefing some important issues that still have to be resolved to evolve it as a technique for industrial use.

References:

[1] Dave H A Blank, Matthijn Dekkers and Guus Rijnders, J. Phys. D: Appl. Phys. 47 (2014) 034006

PHASE NOISE AND ITS EFFECTS ON LINEARISATION OF VCO FOR THE KA BAND O-MODE REFLECTOMETRY AT IPR

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Reflectometry uses an ultra wide band Voltage Controlled Oscillator (VCO) as the primary frequency source and hence its phase noise is critical in determining the overall frequency linearity of the microwave system. Repeated attemps to linearize the VCO using the static method i.e. by measuring voltage required for a unit step change in frequency output failed and the change in beat frequency was seen to be in hundereds of kHz upto about 1MHz. Extensive testing suggested that the phase noise of the source currently employed had deteriorated from the specified values. To confirm that non linearity is due to phase noise of the VCO we replaced the source by a highly stable Signal Generator which has excellent phase noise by more than 25dB. The results obtained clearly show that variation in beat frequency has reduced drastically and the beat frequency variation is now less than 10kHz only.

STIMULATED RAMAN SCATTERING OF X-MODE LASER IN A PLASMA CHANNEL

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Stimulated Raman forward scattering (SRFS) of an intense X- mode laser pump in a preformed parabolic plasma density profile, is investigated. The laser pump excites a plasma wave and two electromagnetic sideband waves. Laser and the sidebands exert a ponderomotive force on electrons driving the plasma wave. The nonlinear currents happen to be at sideband frequencies. The density perturbation due to plasma wave beats with the oscillatory velocity due to pump to drive the sidebands.

References:

[1] Vyas, Ashish, Singh, Ram kishor and Sharma, R. P. *Laser Part. Beams*, **32**, 657.

[2] Kirkwood, R. K., Macgowan, B. J., Montgomery, D. S., Afeyan, B. B., Kruer, W. L., Moody, J. D., Estabrook, K. G., Back, C. A., Glenzer, S. H., B, M. A., Williams, E. A., Berger, R. L. and Lasinski, B. F., *Phys. Rev. Lett.*, **77**, 2706(1996).

[3] BERGER, R. L., STILL, C. H., WILLIAMS, E. A. and LANGDON, A. B. Phys. Plasmas. *Phys. Plasmas*, **5**, 4337(1998).

THE NON LOCAL THEORY OF WEIBEL INSTABILITY DRIVEN BY RELATIVISTIC ELECTRON BEAM IN LOW DENSITY PLASMA

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Weibel instability in fully and partially electron evacuated plasma channel, of a relativistic electron beam, is developed in the slab geometry. For beam density greater than the plasma density ($n_{0b} \geq n_0$), the beam of finite spot size pushes the plasma electrons radially outward and forming a channel and imparts return velocity to plasma electrons in the outer region. The relative drift between the inner region beam electrons and outer region plasma electrons drives the electromagnetic perturbation with transverse scale length comparable to the spot size of the beam. The growth rate increases with the parallel wave number and tends to saturate.

References:

[1] Rahul Kumar, David Eichler and Michael Gedalin, Astrophysical Journal, **806**, 165 (2015).
[2] M. A. Garasev and E. V. Derisev, Radiophysics and Quantum Electronics, **60**, 931-941(2018).
[3] F. Fiuza, R. A. Fonseca, J. Tonge, W. B. Mori and L. O. Silva, Phys. Rev. Lett., **108**, 235004 (2012).
[4] K. I. Nishikawa, P. Hardee, G. Richardson, R. Preece, H. Sol and G. J. Fishman, Astrophys.J **595**, 555-563 (2003).

NON LOCAL THEORY OF EXCITATION OF ELECTRON BERNSTEIN WAVE IN MAGNETIZED BEAM PLASMA SYSTEM

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We have developed a nonlocal theory of excitation of electron Bernstein waves in a magnetized plasma slab by a relativistic electron beam. Here, we use the kinetic theory for solving the equation of motion and to obtain the beam response to the field of the Bernstein wave[1-2]. For describing the plasma background, we have taken the parabolic density profile and electron beam of uniform density and finite width is assumed.[3] The growth rate have been calculated for the Cerenkov and slow cyclotron interactions of beam plasma system in infinite medium which is proportional to ${\omega_{b0}}^{1/3}$ and ω_{b0} respectively. The excitation of Bernstein wave is determined by large $k_\perp$ and since here we assumed $k_y \gg k_x$, hence k_x does not play any significant roll on this system.

References:
[1] V. K. Jain and V. K. Tripathi, Nonlocal theory of beam-driven electron Bernstein waves, Physics of Fluids, 30(3), 909, (1987)
[2] A. Kumar and V.K. Tripathi, Excitation of ion Bernstein and ion cyclotron waves by a gyrating ion beam in a plasma column, Laser and Particle Beams 30(01), 9-16, (2012)
[3] J Urban et al, A survey of electron Bernstein wave heating and current drive potential for spherical tokamaks, Nucl. Fusion 51, 083050, (2011).

EFFECT OF TRAPPED ELECTRON ON DUST-ION ACOUSTIC WAVES IN DUSTY PLASMA WITH CHARGE VARIATION

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Sagdeev's Potential Equation which is derived by a Non- Perturbative Technique used to study the effect of non isothermal (trapped) electrons on dust-ion-acoustic waves in dusty plasma. Here, we have considered ions and dust are in fluid description and electrons are considered as Maxwellian with dust charge variation. Solution is obtained in the form of *Sech* equation. With the different parameters like wave Mach number, density ratio, temperature ratio ad mass ratio; variation of amplitude and width of solitary waves can be seen.

Keywords: dusty plasma, non-thermal electrons, Non- Perturbative Technique, Sagdeev's Potential Equation

ENERGETIC PARTICLE DRIVEN RADIO FREQUENCY EMISSIONS FROM KSTAR TOKAMAK PLASMAS

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Interactions of energetic particles with turbulence and macroscopic fluid modes are critical research issues for magnetically confined fusion plasma. A range of Alfven waves driven by fusion-born energetic ions or neutral beam deposited fast ions in toroidal confinement fusion devices is a well-known consequence of such interaction. Recently, electromagnetic burst emissions from plasmas in relatively high frequency range (0.1~1 GHz) have been detected by antennas outside the viewports of KSTAR tokamak. The radio frequency (RF) emission spectrum evolves in multiple steps prior to and through the collapse of the edge confinement barrier (called pedestal) [1]. Several robust features in the RF emission include (1) narrowband emission corresponding to the lower hybrid frequency at the edge and high harmonics of ion cyclotron emission (ICE) prior to the crash, and (2) intensification of the

ICEs with the appearance of a non-modal filamentary perturbation [2]. (Note that the burst onset of the filament initiates the collapse of the pedestal.) These observations indicate high frequency waves produced by energetic ion interaction with macroscopic plasma profiles and fluid modes. In more recent observations, the neutral beam injection in KSTAR low confinement mode plasmas is also found leading to RF emission with diverse spectral features and evolution. In summary, the RF emission from tokamak plasmas provide crucial information on ion dynamics and potentially a novel diagnosing scheme for ELM crashes and other transient events.

References:

[1] Dynamic spectra of radio frequency bursts associated with edge-localized modes, Plasma Phys. Control. Fusion 58, p 065003 7pp, (2016).
[2] Distinct stages of radio frequency emission at the onset of pedestal collapse in KSTAR H-mode plasmas, Nuclear Fusion 58, p 096034 6pp, (2018).

EVOLUTION OF DUST ION ACOUSTIC SOLITARY WAVE IN MAGNETIZED NON-THERMAL DUSTY PLASMA

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A theoretical investigation of the characteristics of dust ion acoustic (DIA) wave in a magnetized multicomponent dusty plasma consisting of positive ions, negative ions, nonthermal distribution of electrons and positrons is presented. Three dimensional Zakarov-Kuznetsov (Z-K) equation is derived here for studying the primary features of small amplitude DIA solitary wave evolution in plasma by using reductive perturbation method. The mass ratios of different ion groups which are found in Earth's ionosphere (D, E, F region) are discussed here [1]. It is observed that for certain critical concentrations of negative ions as well as due to the effect of nonthermal electron parameter in plasma, the evolution of both compressive and rarefactive solitary waves exist in the plasma system. However, it is also noticed that the temperature ratio of electron to positron plays an important role for determining whether plasma supports evolution of only compressive solitary wave or both compressive and rarefactive solitary waves in the system. This work provides supplement to the field of DIA solitary wave propagation in multicomponent space plasma environments such as D, E, F region of earth's ionosphere, mesosphere region, solar photosphere and Titan's ionosphere [2].

References:
[1] Nonlinear Phenomena in the Ionosphere (Springer, New York, 1978).
[2] Discovery of heavy negative ions in Titan's ionosphere, Geophysical research letters, p 1-6, (2007).

DEVELOPMENT OF SUPERHYDROPHOBIC POLY ETHYLENE TEREPHTHALATE SURFACE BY IMPREGNATION OF CARBON NANO PARTICLES FOR BLOOD CONTACT DEVICE APPLICATIONS

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The Polyethylene Terephthalate (PET) surface was impregnated by nanosized Carbon for which acetylene plasma was used for the purpose. Ultrasonic cleaned PET samples were cut into 5x5 cm and was admitted for different plasma processing period of 10, 20 and 30 minutes with 60:60 sccm of acetylene-argon gas mixture respectively. The plasma processed samples were analysed with respect to structural, optical properties, hydrophobic surface properties. The contact angle measurement was done for the plasma processed samples which was found about to be 153° which is pertained to be superhydrophobic in nature. Further, the processed samples were subjected to hemocompatibility analysis for determining its possible usage in blood compatible device applications. stretching and carboxylic bonds with carbon which presented the effect of plasma process was found by Raman spectroscopy and the presence of functional groups with respect to the stretching and bending modes found by using FTIR spectroscopy. The presence of UV absorption and emission bands were observed via UV-visible spectroscopy and Photoluminescence spectroscopy respectively. Moreover, the plasma processed PET samples showed improved superhydrophobic activity with respect to the increase in density of carbon over the samples further improving the Hemo-compatible activity which is used in blood storage containers and flow tubes in the medical field.

MESH REFINEMENT BASED FLUID SIMULATIONS OF PLASMA DYNAMICS DURING HIGH POWER MICROWAVE BREAKDOWN

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There is a renewed interest in accurate investigation of High Power Microwave (HPM) breakdown at high pressures involving complex plasma dynamics because of its wide-scale applications in aerodynamic flow control, plasma propulsions, combustion ignition, etc. [1, 2]. This phenomenon is highly non-linear and requires a multi-scale modeling due to the presence of multiple time and space scales to accommodate the three critical stages: the interaction of the EM wave with plasma, spatial and temporal plasma evolution, and finally, gas heating. To investigate the first two stages, fluid-based simulations of this phenomenon are carried out using a computational model wherein Maxwell's equations are coupled with a plasma continuity equation [1, 3]. The numerical solution of these equations is computationally costly due to the stringent requirements on grid spacing and time steps due to the presence of sharp gradients in electric field and plasma density. There lies a trade-off in terms of grid spacing and the accuracy of the model. Efficient parallelization techniques have been proposed in [3], wherein a homogeneous mesh has been used to solve both the Maxwell's as well as the plasma continuity equation, which significantly reduces the runtime of 2D simulations from around a month to few hours on an HPC cluster. However, we require more sophisticated mesh refinement based algorithms to achieve accuracy with less computational/ memory requirements and also for more realistic 3D simulations.
In this work, mesh refinement based fluid simulations have been performed by hierarchically reducing the grid size in a selective region with sharp gradients in Electric field and plasma density. The parallel algorithm with a single homogeneous mesh throughout the problem domain requires more computational resources than the mesh refinement based technique. Thus, mesh refinement based method has an advantage of less overall computation with higher accuracy [4]. We present the details of our implementation and comparison of the results of the mesh refinement based model with the available results from uniform mesh for different input physical parameters (E field, pressure), and finally, the speedup obtained with the mesh refinement based strategy.

References :

[1] Jean-Pierre Boeuf, Bhaskar Chaudhury, and Guo Qiang Zhu, "Theory and Modeling of Self-Organization and Propagation of Filamentary Plasma Arrays in Microwave Breakdown at Atmospheric Pressure", Physical Review Letters 104, 015002, 2010.
[2] K. V. Khodataev, "Microwave Discharges and Possible Applications in Aerospace Technologies," J. Propuls. Power, 24, no. 5, pp. 962–972, 2008.
[3] Bhaskar Chaudhury et al, Accelerated Simulation of Microwave Breakdown in Gases on Xeon Phi based cluster-Application to Self-organized Plasma Pattern Formation", Computer Physics Communications, Elsevier, Computer Physics Communications, 229,p 20-35, (2018)
[4] C. D. Sarris, Adaptive Mesh Refinement for Time-Domain Numerical Electromagnetics, Morgan & Claypool, p 65-82, 2007.

DEVELOPMENT OF A CALIBRATION SET UP OF MAGNETIC PROBES FOR CHARACTERISING EDDY CURRENT GENERATED ON A PLANAR SURFACE

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Characterising the eddy current formed on structures and surfaces due to the pulsating fields is an important aspect, especially for experiments involving high current pulsing or drastic variations in currents like in a tokamak. The generated eddy current sometimes interfere in the experiments as it may generate magnetic fields. Hence quantifying the eddy current is an important aspect for such kind of experiments. The quantification of eddy currents can be performed using magnetic probes. However, the precise calibration of magnetics probe is essential to characterise the generation of eddy currents. In this work a detailed description about the calibration setup is presented, which includes the design and development of a Helmholtz coil for characterising the magnetic probes developed for the purpose of measuring the eddy current.

LATE SUBMISSIONS

ABATEMENT OF MICROORGANISMS USING OXYGEN PLASMA

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The safeguarding and restoration of archival documents is a concern for modern day archivists. Deterioration of archival documents is attributed to several environmental causes, such as microbial contamination, oxidation, acidification, and others [1]. Plasma treatment is a novel but less implemented technology in the field of conservation and protection of archival documents which has shown promising results [2]. The main objective of this study was to eradicate microbial contamination from papers using oxygen plasma treatment. Two types of papers were used in this study. They were sprayed with specific fungal and bacterial samples that could mimic the natural process of deterioration. These papers after being treated with oxygen plasma treatment, were observed for reduction in microbial load. Plasma treatments were optimized as a function of power and time based on its effectiveness to eradicate maximal number of microorganisms. The study thus successfully recommends use of oxygen plasma at 60W for 5 min for complete abatement of micro-organisms from initial seeding load of 10^6 CFUs from the paper surface without affecting the paper in any ways..

References:

[1] F. Cappitelli and C. Sorlini, "From papyrus to compact disc: the microbial deterioration of documentary heritage", *Crit. Rev. Microbiol.*, vol. 31, no. 1919, pp. 1–10, (2005).
[2] L. Laguardia, E. Vassallo, F. Cappitelli, and E. Mesto, "Investigation of the effects of plasma treatments on biodeteriorated ancient paper," vol. 252, pp. 1159–1166, (2005).

DRESSED SOLITON IN DENSE DUSTY PLASMA HAVING ULTRA-RELATIVISTIC DEGENERATE TWO TEMPERATURE ELECTRONS

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Considering higher order nonlinear and dispersive effects the dressed ion-acoustic solitary waves in dense dusty plasma consisting of cold inertial ions and ultrarelativistic degenerate two temperature electrons have been theoretically studied using the Bogoliubov-Mitropolosky method. The expression of pseudo-potential is derived and from the nonlinear

equation the solution of dressed ion acoustic solitary wave upto second order approximation are obtained. The profiles of dressed solitary waves are drawn for different values of the ultra-relativistic degenerate electrons. It is seen that degenerate two temperature electrons has important role on the shape of dressed solitary waves in degenerate plasma.

References:

[1] K. Roy , P. Chatterjee, S. Kundu, Dust acoustic dressed solitons in a four component dusty plasma with nonthermal electron, Advances in Space Research, **50** , 1288 (2012).

[2] N. Roy , M.S. Zobaer and A.A. Mamun, Propagation of electrostatic waves in an ultra-relativistic dense dusty electron-positron-ion plasma, Journal of Modern Physics, **3,** 850 **(**2012).

EFFECTS OF BEAM IONS AND KAPPA- DISTRIBUTED ELECTRONS ON ION ACOUSTIC SOLITONS AND DOUBLE LAYERS IN WARM ION PLASMA

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Arbitrary amplitude ion-acoustic solitary waves and double layers have been theoretically studied in a non-collisional plasma consisting of warm positive ions and beam ions, and kappa distributed electrons using pseudo-potential (effective potential) method. The solutions of the arbitrary amplitude solitary waves and double layers are obtained and the profiles of solitary waves and double layers are drawn taking different values of the plasma parameters. It has been observed that both compressive and rarefactive solitary waves and double layers would be excited in presence of beam ions and kappa distributed electron in the plasma. The variation of width of solitons and double layers are also shown graphically and discussed.

References:

[1] Zank, G.P. & McKenzie, J.F., Solitons in an ion-beam plasma, J. Plasma Phys. **39**, 183(2009).

[2] S Devanandhan, S V Singh and G S Lakhina, Electron acoustic solitary waves with kappa-distributed electrons, *Phys. Scripta*, **84**, 025507 (2011).

ENVELOPE SOLITONS IN ELECTRON-ION-POSITRON PLASMA HAVING WARM IONS AND TSALLIS DISTRIBUTEDELECTRONS

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Envelope soliton of ion acoustic wave is studied using Fried and Ichikawa method in an electron-ion-positron plasma having warm ions are warm , isothermal positrons and Tsallis distributed electrons. The nonlinear Schrodinger equation is derived and the solution of envelope soliton is obtained. It is found that both dark- soliton and bright- soliton may be excited in the plasma. The stability criteria are established and studied graphically by varying the positron density, positron temperature , ion temperature and Tsallis distributed electrons. The profiles of bright envelope soliton and dark emvelope solitons are drawn for different values of plasma parameters.It is found that Tsallis distributed electrons has considerable effect on the excitatation of Tsallis distributed electrons in the plasma.

References:

[1] B.D.Fried and Y.H. Ichikawa , On the Nonlinear Schrödinger Equation for Langmuir Waves, J Phys Soc Japan, **34 ,** 1073 (1973).
[2] C. Tsallis, Introduction to Nonextensive Statistical Mechanics: Approaching a Complex World; Springer Science Media: New York, NY, USA: 2009.

EFFECT OF POLARIZATION FORCE ON THE ROGUE WAVES IN DUSTY PLASMA

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Rogue wave has been theretically studied in dusty plasma having nonthermal ions, Maxwelian electrons and negatively charged mobile dust under the influence of polarization force acting on micron size dust particles in plasma. Nonlinear Scrodinger equation is derived using Fried and Ichikawa method and from the nonlinear equation the solution of rogue waves in the dusty plasma is obtained. The profiles of rogue waves are drawn and discussed for different values the plasma parameters. It is found that nonthermal ions and polarization force has considerable impact on the rogue waves in the dusty plasma.

References:

[1].P Bandyopadhyay, U Konopka, S A Khrapak, G E Morfill and A Sen, Effect of polarization force on the propagation of dust acoustic solitary waves, New Jour. Phys. **12** 073002 (2010).
[2]. M. Asaduzzaman and A. A. Mamun, Effects of nonthermal ions and polarization force on dust-acoustic waves in a density-varying dusty plasma, Phys. Rev. E **86**, 016409 (2012).

MODULATIONAL INSTABILITY OF ION ACOUSTIC WAVES IN FULLY RELATIVISTIC PLASMA HAVING SUPERTHERMAL ELECTRONS

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In this paper, modulation instability of ion acoustic wave has been theoretically studied in a cold unmagnetized fully relativistic plasma consisting of cold positive ions and supertheral (kappa distributed) electrons using the method of Fried and Ichikawa. The expression of nonlinear Schrodinger equation in fully relativistic plasma has been derived and the condition for the existence of modulational instability of wave are obtained. The growth rate of modulationally unstable wave are graphically diascussed for different values of plasma parameters. From the nonlinear Schrodinger equation, the solution for envelope solitons in the fully relativistic plasma are also obtained. The profiles of envelope solitons are drawn and discussed taking different values of ion stream velocity and density of superthermal electrons. The results are applicable for the study of ion acoustic envelope solitons both in weak- and ultra- relativistic plasma.

References:

[1] T. K. Baluku,M. A. Hellberg,I. Kourakisand N. S. Saini, Dust ion acoustic solitons in a plasma with kappa-distributed electrons , Phys. Plasmas, **17**, 053702 (2010).

[2] B. Ghosh and S. Banerjee,Modulational instability of ion-acoustic waves in fully relativistic two-component plasma , J. Plasma Physics, **81**, 905810308 (2015).

MAGNETIC MOMENT FIELD DUE TO RESONANT INTERACTION OF WAVES IN LASER INDUCED RELATIVISTIC PLASMA

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In laser produced plasmas self-generated magnetic fields have been of much interest because of their role in the design of inertial confinement fusion (ICF) targets. This magnetic field can affect strongly several transport mechanisms which influence the performance of ICF target. In this paper, theory of the generation of magnetic moment field from resonant interaction of four high frequency electromagnetic waves in magnetized dense electron plasma is developed considering the relativistic change of electron mass. It is shown that the inclusion of relativistic effect enhances the magnetic moment field. For high intensity laser beams this

moment field may be of the order of a few mega gauss. Such a high magnetic field can considerably affect the transport of electrons in fusion plasma.

References:
[1]. J.A Stamper, K.Papadopoulas, R.N.Sudan, S.O.Dean, E.A.McLean and J.M.Dawson, Spontaneous magnetic fields in laser-produced plasmas‟‟‟Phys.Rev.Lett**., 26,** 1012(1971).
[2]. A.D. Steiger and C.H.Woods, Intensity-dependent propagation characteristics of circularly polarized high-power laser radiation in a dense electron plasma, Phys.Rev.**A, 5,** 1467(1972).

ELECTROSTATIC WAVES IN FULLY NONLINEAR DEGENERATE ELECTRON-ION-POSITRON PLASMA

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Electrostatic solitary waves and double-layers in a fully nonlinear relativistically degenerate electron-ion-positron unmagnetized plasma are studied using pseudo potential approach. Expression of Sagdeev potential is derived and the critical value of Mach number for the excitation of ion-acoustic solitary wave is obtained. The solutions of solitary waves and double layers are obtained and their structures are graphically shown for different parameters of the plasma. It has been observed that both compressive and rarefactive solitary waves and double layers would be excited in presence of positrons in the degenerate plasma.

References:
1. S. N. Paul, C. Das, I. Paul, B. Bandyopadhyay, S.Chattopadhya and S .S. De , Ion - acoustic solitary waves in an electron-ion-positron plasma , Ind. J. Phys., **86**, 545 (2012).
2. S. Chandra · S. N. Paul ,B. Ghosh**,** Electron-acoustic solitary waves in a relativistically degenerate quantum plasma with two-temperature electrons, Astrophys. Space Sci, **343 ,** 213 (2013).

CONTROL OF CHAOTICITY IN MAGNETIZED FILAMENTARY DISCHARGE PLASMA DUE TO THE PRESENCE OF CYLINDRICAL MESH GRID

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This study is highlighting the experimental evidence of controlling chaos and its nonlinear behavior of fluctuations in the filamentary discharge magnetized plasma system. The

cylindrical mesh grid of 80% optical transparency has been introduced in the plasma. Argon plasma is produced in the cylindrical chamber of dimension 350 mm in length and 400 mm in diameter. The cylindrical mesh grid of 90 mm in height and 120 mm in diameter placed in the bulk plasma. The chamber is evacuated down to 1.2×10^{-5} mbar using both diffusion and rotary pump. Argon gas is injected by a needle valve into the chamber at working pressure of 2×10^{-4} mbar. The electrical Langmuir probe has been extensively used for collecting the plasma fluctuations at various positions in and around the mesh grid. The oscillation pattern shows that at the farther most position from the grid, onset of chaos occurs at a lower value of magnetic field compared to the position which is at the center of the cylindrical grid. The dynamical transition has been explained using several non-linear techniques such as Fast Fourier Transform, Phase Space Plot, Recurrence plot, Empirical mode decomposition etc. Therefore, it can be speculated that grid is playing a major role in controlling the chaotic behavior of the plasma oscillations.

NITROGEN PLASMA TREATED COTTON FABRICS COATED WITH SIO_2 FOLLOWED BY RGO DEPOSITION FOR WATER PURIFICATION PROCESS

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Experimental investigations have been carried out to modify the surface properties of using using low temperature DC glow discharge nitrogen plasma. Plasma treatment is an eco-friendly, dry and clean process over wet chemical method and does not suffer from any environmental and health concerns [1]. The important plasma parameters such as power and working pressure are kept constant with various treatment times (5, 15, 30, and 60 mins). The plasma-treated cotton fabrics are optimized by XRD, FTIR, and SEM. A comparatives study has been done for the untreated and different treated fibers. Pure SiO2 is coated on untreated and nitrogen plasma treated cotton fabrics by sputtering method. The samples are coated for different sputtering times (10, 30 min and 60 min). Finally RGO is coated on the plasma treated Sio2 fabrics. RGO is prepared by modified hummers methods [2]. Our results provide a way to develop a filter for water purification.

References :

[1]Shahidi, S., Ghoranneviss, M., &Moazzenchi, B. Application of plasma in different branches of industries. In *Proceedings of The 4th RMUTP International Conference: Textiles & Fashion*.(2012).

[2] Abdolhosseinzadeh, Sina, HamedAsgharzadeh, and HyoungSeop Kim. "Fast and fully-scalable synthesis of reduced graphene oxide." *Scientific reports* 5 (2015): 10160.

EXPERIMENTAL OBSERVATION OF INTERMITTENT ROUTE TO CHAOS IN MAGNETIZED FILAMENTARY DISCHARGE PLASMA DUE TO THE CYLINDRICAL PLASMA BUBBLE

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We report an experimental observation of the effect of magnetic field along with mesh grid biasing in presence of cylindrical plasma bubble in a filamentary discharge magnetized plasma system. Cylindrical mesh grid of 80% optical transparency has been negatively biased and introduced in the plasma for creating plasma bubble. Plasma floating potential fluctuations have been taken outside (LP1) and inside (LP2) of the plasma bubble. It has been observed that the oscillation pattern shows intermittent route to chaos as the system evolved from regular type of relaxation oscillations (of larger amplitude) to an irregular type of oscillations (of smaller amplitude) as the external magnetic field is increased. We have used recurrence quantification analysis (RQA) to the observed intermittency to chaos in the plasma. The main measures of RQA are Laminarity (LAM) and Determinism (DET). The laminarity measure can be associated with the average time between the chaotic burst in the intermittency. It has also been observed that the DET depends on the control parameter and decreases exponentially. Other features like a dip in skewness and a hump in the kurtosis with the variation of control parameter have been noticed, which are the strong evidence of intermittent behaviour of the system. Further, a numerical model has been developed to satisfy the observed experimental analysis of intermittent route to chaos.

RECONFIGURABLE NON CONVENTIONAL ANTENNA

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In IPR, we have developed a non-conventional antenna which is reconfigurable in the frequency range (100 – 300) MHZ. This antenna can be switched on when required and switched off when not in use. Conventional antennae, for ex: metallic antennae can be detected by RADAR. This antenna has a very low RADAR cross section, hence cannot easily be detected. This type of antenna can be used for some specialized applications where detectability is an issue. This antenna does not need much space and supporting structures as conventional antennae need. In this, a conducting liquid is used to perform the function of an antenna. We have transmitted and received the signals using this antenna. Varying the parameters, such as diameter and height of the column/jet, we can vary the central frequency and bandwidth of the signals being received / transmitted.

DEVELOPMENT OF ELECTRICAL ISOLATOR BOXES FOR NBI CRYOGENIC LINES

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The Neutral Beam Injector (NBI) system is required for the purpose of heating the plasma of SST-1 tokomak. NBI system generates a beam of energetic hydrogen atoms for injection into the SST-1. During the operation of NBI, the necessary vacuum of 10^-6 torr is maintained by means of cryopumps. Cryopumps require supply of liquid nitrogen (LN2) and liquid helium (LHe) during their operation. The vacuum vessel which houses these cryopumps and the plant system which supplies liquid Helium supply are at different electric potentials during operation of NBI. The electrical isolator boxes act as interface between the vacuum vessel and the helium plant system thereby avoiding any possible damages to the instrumentation of the liquid helium plant. This paper describes the design and development of isolator boxes for two process pipe cryogenic lines using ceramic isolators. Various design aspects of fault identification during failure e.g. vacuum degradation are presented. Design considerations made on the basis of space availability, easy replacement of isolators during failure, and no direct interface with the main vessel vacuum are described.

TURBULENT STATES IN MULTIPLE ANODIC DOUBLE LAYERS IN GLOW DISCHARGE PLASMA

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The Complexities in the Turbulence is attracting many scientists since three hundred years ago. Turbulence can be found in Gases, liquids etc. Turbulent fluid flow is a complex, nonlinear multiscale phenomenon. It has Practical importance in making predictions for example, heat transfer in nuclear reactors, drag in oil pipelines, the weather, the circulation of atmosphere and the oceans [1]. Double Layers in plasma is a non-neutral region consisting of two adjacent layers of opposite charge with a potential drop $|\phi_0| > KT_e/e$ across the layers. After increasing certain voltage, the critical stage occurs in Multiple Anodic Double Layers and collapses, followed by supercritical stage which leads to the rise of turbulence in the system [2]. This turbulence can happen because of the instabilities in plasma, where the electron drift velocity relative to the ions exceeds the electron thermal velocity. These conditions produce a strong and unstable electrostatic wave that grows until it traps most of the electrons.

References:

[1] The Turbulence Problem, An experimentalist's Perspective, Los Alamos Science, 29 (2005)
[2] Self-Organized Criticality in a cold plasma, Physics of Plasmas 24, 120701(2017)

STUDY OF FAST ELECTRON TRANSPORT IN ULTRAHIGH INTENSITY LASER MATTER INTERACTION BY 2D IMAGING OF CU KA X-RAYS

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Understanding and controlling fast electron transport inside solid material is important for the success of fast ignition concept to inertial confinement fusion. The MeV fast electrons generate x-rays (both line radiation and bremsstrahlung) during its propagation. The measurement of x-ray source size at the front and rear of the target is a widely used technique to obtain direct insight about electron transport process manifested through the divergence of the electron beam. The experiment was carried out with Ti:Sa laser focused to an intensity ~7×10^{19}W/cm^2 on a Cu foil of thickness 7µm at an incidence angle of 30°. We have performed 2D imaging of Cu Kα (8.048 KeV) source at target front and rear surface using a spherically bent quartz crystal spectrograph. The spectrograph uses a spherically bent quartz crystal (lattice spacing 1.542 Å, ROC: 250mm) to image the source. Front side source size was ~38 ± 2 µm. The rear side source size was estimated to be ~47 ± 2 µm and 58±4 µm for Cu 7 µm and Cu 25 µm foil respectively. A fast electron half divergence angle of ~17° inside target material was calculated from the measured source sizes. Such small divergence indicates the collimation of the beam by self-generated magnetic fields at the relativistic laser intensity. Angular distribution of hard x-ray bremsstrahlung radiation was carried out in the incidence plane using array of direct reading dosimeters (DRD). The x-ray distribution was highly anisotropic and was similar to the electron angular distribution i.e. along target surface and laser propagation direction. The x-rays enhanced nearly two fold in case of higher ASE prepulse for 70° incidence angle. Moreover, the x-ray signals were higher for 50 µm foil compared to 7µm foil. In this paper details of experimental setup and our current understanding on the results will be presented.

FAST ELECTRON ANGULAR DISTRIBUTION FROM THIN FOIL TARGETS AT LASER INTENSITY 7X10^{19} W/CM^2

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Intense laser produced MeV fast electrons are instrumental for the success of fast ignition concept to inertial confinement fusion along with other applications including development of high energy proton/ion beam and ultrashort duration x-rays. We have performed an angular distribution study of these fast electrons to understand their emission characteristics to be useful for various applications. The experiment was carried out on 150 TW laser facility with 25 fs, 2.2 J Ti:Sa laser beam focused by an off-axis parabolic mirror to an intensity ~

$7x10^{19}W/cm^2$ on a Cu foil of thickness 7µm at an incidence angle of 40°. The electron beams were observed along laser propagation direction through the target rear surface indicating the JXB heating mechanism for fast electron acceleration. Further, highly collimated (divergence angle <10°) electron beams were also observed along the target surface direction at the rear side suggesting the role of surface generated quasistatic fields in collimating and guiding the electrons along the target surface. The electron flux reduced by ~ 2.8X on reducing the laser intensity by a factor of ~2.5. Further, the electron flux reduced by ~2.4X on changing the laser polarization from p to s. The energy of electron beam extends up to ~7 MeV with a derived electron temperature of ~2.1 MeV from the electron spectrum. The fast electron emission angle changes from nearly laser propagation direction to target surface direction in the specular side with a higher beam charge on increasing the incidence angle form 40° to 70°. Further, we have observed increase in charge for s polarization compared to p. In this paper details of experimental setup and our current understanding on the results will be presented.

STUDY OF HIGH-VELOCITY PLASMA STREAM IN THE PRESENCE OF TRANSVERSE EXTERNAL MAGNETIC FIELD

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A pulsed plasma accelerator system has been developed at CPP-IPR that produces a high density (~1021/m3) and a high velocity (~ 20 km/s) plasma stream [1,2]. A 200 kJ pulsed power system powers the accelerator. The device utilizes the self-generated Lorentz force that accelerates the plasma and ejects it out of the electrode channel. The plasma thus produced is suitable to study plasma matter interaction relevant to the tokamak device as well as to study different plasma phenomena. In this experiment, the effect of the interaction between the plasma stream with a background transverse magnetic field is being studied [3,4]. The introduction of an external transverse magnetic field is expected to modify the density and confinement time. For this purpose, an electromagnet of field strength ~0.4 T is being designed, fabricated, and installed between the source and target chamber of the plasma accelerator. The magnetic field is simulated using Poisson-Superfish code and finite element magnetics method. A study is being thereafter conducted to characterize the plasma in the presence and absence of the transverse magnetic field by using different diagnostics. The results will be presented during the conference.

References:

[1] S. Borthakur et al., *Fus. Eng. Des*. **122** ,131, (2017)
[2] S. Borthakur et al., *Phys. Plasmas.* **25**, 013532 (2018)
[3] H. M. Soliman et al., *Contrib. Plasma Phys*. **34 (4)**, 587-591,(1994)
[4] Y. Zhang et al., *Phys. Plasmas* **25**, 055709 (2018)

MODELLING OF PLASMA FLOATING POTENTIAL OSCILLATIONS UNDER MADL CONDITIONS USING FORCED ANHARMONIC OSCILLATOR

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Predicting the evolution of various non-linear oscillations and instabilities is of great importance in various plasma-based applications. Modeling those oscillations with Forced driven Anharmonic Oscillator (FAO) is helpful to understand the dynamics of plasma species. In the present investigation, we have reported the modelling of nonlinear oscillations and its frequency responses under typical multiple anodic double layer (MADL) plasma condition. Under, MADL condition, we consider, the sources of forcing to the oscillator is from two different independent source of power supply which are used in the experiment. The equation solved using the method of multi-scale and its bifurcation sequence of the harmonic, sub-harmonic oscillatory state performed by numerically. The results of the anharmonic oscillator model with two forcing shows excellent agreement with obtained floating oscillation under MADL condition. Thus, the present analysis illustrate that two forcing anharmonic oscillator model would be an ideal candidate to study the non-linear dynamics of MADL in a glow discharge.

References:

[1] Nonlinear plasma instability effects for and harmonic forcing oscillation, J. Phys. A: Gen. Phys,**5**, p 152-165, (1972)
[2] Nonlinear dynamics of plasma oscillation modeled by an harmonic oscillator, Phys. Plasma **15**, 032308, (2008)
[3] Investigation of complexity dynamics of inverse and normal homoclinic bifurcation a Glow discharge plasma. Phys. Plasma **21**, 032301, (2008)

ABSTRACTS

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Optical Emission Spectroscopic study of Capacitively Coupled discharge

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Abstract

Low-temperature plasmas are also called as non-local thermodynamic equilibrium plasma. In such plasmas, each species of the plasma is having different temperatures, energy modes. In comparison with other species, electrons are having higher kinetic energy and because of that the whole plasma kinetics and parameters are controlled by electrons. Therefore, electron density and temperature are the crucial parameters of the low-temperature plasmas. Low-temperature RF discharges are widely used in material processing industries [1]. Radiofrequency waves used to create the RF discharge interfere in the measurements of the electric probe and scale up the measurement errors. To overcome such hurdles and make measurement simpler Optical Emission Spectroscopy (OES) is widely used as a diagnostic tool for RF Plasmas [2]. In this work, capacitively coupled plasma discharge created using parallel plate electrodes with 13.56 MHz radiofrequency for RF power 20W, 30W, 40W, 50W and corresponding optical spectra recorded using the spectrometer is reported. As per raw OES data the intensity of spectral line having the wavelength λ = 750.39 nm is the highest value among the other spectral lines as well as with increasing the RF power the intensity of the spectral lines increases. The electron density of the capacitive discharge calculated by using OES for the RF power values 20 to 50 W varies from 2E16 m-3 to 3.3E16 m-3 respectively.

References:

[1] P. Chabert and N. Braithwaite. 2011 Physics of Radio-Frequency Plasma (Cambridge University Press)

[2] G. P. Canal, H. Luna, R. M. O. Galv´ao and R. Castell. 2009 J. Phys. D: Appl. Phys. 42 135202

Time dependent analyses of linear motion of various rotor materials of linear induction motor (LIM)

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Abstract

Now a days, linear induction motors (LIM) are being used in widespread applications. Among them, use of LIM in high speed applications like UAV launcher and aircraft launchers is well established. LIM has been used at IPR, for preliminary experiments as an electromagnetic launcher in Magnetics and Dynamics section. The LIM was earlier being used as non-contact type liquid Pb-Li stirrer in TBM division. The stator part of the LIM is made up of laminated sheets of magnetic material which has slotted configuration. In the slots, the insulated conductors are wound as per the three phase double layer winding in diamond configuration. In the present work, similar geometry of the stator part of the LIM is modelled in FEM software [1,2] and the thrust force experienced by different rotor materials like copper, aluminium and SS with different thickness are estimated. The enhancement of the thrust force in the rotor material with the addition of CRGO sheet is also studied in simulation. This paper presents the transient magnetic field profile, induced current density and the Lorentz force acting on different rotor materials of different thickness. This work will be used as initial reference analyses for indigenous development of LIM of higher thrust force and optimization of its rotor material.

References:

[1] 3-D finite element analysis of a linear induction motor, T. Yamaguchi, Y. Kawase, M. Yoshida, Y. Saito, Y. Ohdachi, IEEE Transactions on Magnetics, Vol 37, Issue 5, Sept. 2001, p 3668 – 3671.

[2] Performance Optimization of Linear Induction Motor by Eddy Current and Flux Density Distribution Analyses, M.S. Manna, S.Marwaha, A.Marwaha, Journal of engineering Science and Technology, **6** , p 769-776, (2011).

PIC SIMULATION OF ION DYNAMICS IN AN INERTIAL ELECTROSTATIC CONFINEMENT FUSION DEVICE

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Abstract

Kinetic simulations are performed using PIC (Particle-in-Cell) method to study the ion behavior inside a table top neutron source known as Inertial Electrostatic Confinement Fusion (IECF) device. In this device, lighter ions are accelerated by using an electrostatic field. These ions are capable of producing fusion at the core region inside the cathode [1, 2]. An open source PIC code, XOOPIC [3] is used to simulate the ion dynamics for different experimental conditions. The potential structure from the simulation indicates the formation of multiple potential well inside the cathode depending upon the applied cathode voltage (ranging from -1kV to -5kV). The ion density at the core region of this device has been observed of the order of 10^{16} m^{-3}, which closely resembles the exact experimental condition. The ion energy distribution function (IEDF) has been measured from the phase space at different location to identify the pattern of ion dynamics for different grid assembly and experimental conditions. Finally, these simulated results are compared with the available experimental profiles measured using different Langmuir probes and Retarding Field Analyzers (RFA).

References:

[1] R. Hirsch, J. Appl. Phys., 38, 4522 (1967).

[2] N. Buzarbaruah, S.R. Mohanty and E. Hotta, Nucl. Instrum. Methods Phys. Res. Sec. A, 911, 66 (2018).

[3] J.P. Verboncoeur, A.B. Langdon and N.T. Gladd, "An Object-Oriented Electromagnetic PIC Code", Comp. Phys. Comm., 87, 199 (1995).

Highlights of Version 2.0 of Three Dimensional Fully Electromagnetic Relativistic Particle-in-Cell Code PASUPAT

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Abstract

In PLASMA 2017, we presented version 1.0 of our three dimensional fully electromagnetic relativistic Particle-In-Cell (PIC) code named 'PArallel Simulation Utility using PArticle-in-cell Technique (PASUPAT)'. Subsequently the code was released for users at Bhabha Atomic Research Centre, Mumbai in April, 2018. Since then several new modules/capabilities have been added to the code. Notable among them are: (a) Space Charge Limited Emission and Advanced Field Emission Model from staircase as well as triangulated curved emitting surfaces (b) Multigrid Electrostatic Solver (c) MPI Parallelization for simple domain decomposition (d) Advanced Domain Decomposition scheme which increased the efficiency of OpenMP parallelization (this scheme will also help in dynamic load balancing in distributed memory based MPI parallelization). Apart from these, the Graphical User Interface (GUI) of the code has also been upgraded. We shall present these features and their validations.

References:

[1] R. Kumar, G. Singh, D. Biswas, V. Duggal, and K. Bhatt, PASUPAT: A Three Dimensional Fully Electromagnetic Relativistic Particle-In-Cell Code, Abstract Book, 32nd National Symposium on Plasma Science and Technology(Plasma 2017), **108/CM-08/P**, page 119 ,2017.

[2] C. K. Birdsall and A. B. Langdon, Plasma Physics Via Computer Simulation, McGraw-Hill Inc. 1985.

[3] A. Taflove, and S. C. Hagness, Computation Electrodynamics, Artech House, Boston, 2000.

[4] T. Zh. Esirkepov, Computer Physics Communications, **135**, p 144-153 (2001).

A Novel Plasma Source for Treatment of Ragi Flour to Modify the Physico-Chemical, Structural and Thermal Properties

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Abstract

Recently plasma based technology has its high demands in modification of physico-chemical, structural and thermal properties of ragi flour by the impact of energetic N2 extracted from nitrogen glow discharge plasma to inactivate infectious micro-organisms. Plasma technology find applications in food, agricultural and biological sciences. In typical glow discharge plasma conditions large number of energetic neutrals are generated. In this present investigation, we modified the physico-chemical and thermal properties of ragi flour by the impact of energetic N2 extracted from nitrogen glow discharge plasma. In the present experiment, plasma treatment of ragi flour is carried out at -900 V cathode bias for a duration of 90 minutes. Plasma treatment of ragi flour significantly increases its surface roughness and thermal degradation profiles. When observed with X-ray diffraction (XRD) and Fourier transform infrared (FTIR) spectra, it has been confirmed that there is an increase in surface oxygen content and appearance of new oxygenated chemical groups on the ragi flour. Scanning electron microscope (SEM) micrographs of samples showed a substantial difference in surface morphology on the starch granular surface by the effect of energetic neutral nitrogen atoms. In room temperature, the thermal properties of the different Plasma treated ragi flour samples are measured by using differential scanning calorimetry (DSC) and confirm if the plasma treated starches have lower gelatinization temperature as compared to native flour. These results prove the novel physico-chemical modification technique, may be used in the food processing industry.

References:

[1] Suraj K. S., & Mukherjee, S. (2005a). Effect of ion neutral collisions on the ion and neutral velocity distribution on negatively biased electrodes. *Surface and Coatings Technology, 196(1–3 SPEC. ISS.), 267–270*.

[2] Impact of energetic neutral nitrogen atoms created by glow discharge air plasma on the physico- chemical and rheological properties of kithul starch, K V Sunooj, C Sudheesh, Suraj K Sinha, P Johnsy George, Sunny Kumar, Perumal M, Saravanan A, Ashwath Kumar, Vallayil Appukuttan Sajeevkumar, *Elsevier, Food Chemistry, 294 (2019), 194-202.*

Energetic Neutrals for Food Processing

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Abstract

Dc glow discharge plasma based methods are rapidly emerging and serve as an alternative means for self-life extension and decontamination in food processing technology. In this work, a theoretical model has been developed and reported for charge exchange (CX) collisions inside the collision ion-sheath. In a dc glow discharge plasma, there is generation of a significant number of energetic neutrals. We demonstrate by the experiments that treatment with energetic neutrals extracted from dc glow discharge plasma results in modification of physico-chemical, rheological and thermal properties of the sample. The theoretical and experimental condition is compared with the neutral velocity distribution estimated by integrating the ion velocity distribution and the CX collision over the entire sheath thickness. For a nitrogen dc glow discharge, up-to 90% of total discharge power is carried by these energetic neutrals generated by charge CX collisions. The present investigation of the neutrals contributes a large significant modification of the sample and may be highly useful for food processing industry.

References:

[1] Suraj K. S., & Mukherjee, S. (2005a). Effect of ion neutral collisions on the ion and neutral velocity distribution on negatively biased electrodes. *Surface and Coatings Technology, 196(1–3 SPEC. ISS.), 267–270.*

[2] Impact of energetic neutral nitrogen atoms created by glow discharge air plasma on the physico- chemical and rheological properties of kithul starch, K V Sunooj, C Sudheesh, Suraj K Sinha, P Johnsy George, Sunny Kumar, Perumal M, Saravanan A, Ashwath Kumar, Vallayil Appukuttan Sajeevkumar, *Elsevier, Food Chemistry, 294 (2019), 194-202.*

COMPARATIVE STUDY ON *p-NITROPHENOL* DEGRADATION BY MICROPLASMA DISCHARGE BY DIFFERENT PLASMA GASES

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Abstract

Non-thermal plasma assisted degradation of organic pollutant is an efficient method of all other available degradation techniques [1]. In this technique, plasma forming gas is an important factor governing the degradation [2]. In the present work, non-thermal plasma assisted degradation is applied to treat the 4NP (p-nitrophenol) present in the aqueous solution. In order to study the effect of various plasma forming gases like Air, Nitrogen, Oxygen and Argon, over the degradation of 4NP, experiments were carried out using the in-house reactor setup. The degradation kinetics of various plasma forming gases were studied, which reveal first order kinetic for all the cases and the nitrogen gas medium showed the highest rate constant of all other gases. Furthermore, the hydrogen peroxide production was analyzed in both plasma treated water and 4NP aqueous solution. The energy yield was calculated for different gas medium and the findings reveal high energy yield in nitrogen gas followed by oxygen, argon and air. The degradation mechanism of 4NP is proposed based on LCMS analysis.

References:

[1] Effective degradation of organic water pollutants by atmospheric non-thermal plasma torch and analysis of degradation process, Chemosphere, 167, p 396-405, (2017)

[2] Quantification of plasma produced OH radical density for water sterilization, Plasma process ploym, 15, p e1700241, (2018)

CHARACTERISTICS OF ANODIC DOUBLE LAYER OBSERVED IN A TYPICAL DC GLOW DISCHARGE PLASMA

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Abstract

Anodic double layers are adjacent regions of opposite space charge formed due to Buneman instability [1, 3]. The various experimental parameters like pressure, cathode, anode voltages etc. are varied to obtain a stable anodic double layer in this modified glow discharge set up and the corresponding floating potential fluctuations are observed, noted and stored in a digital oscilloscope. These floating potential fluctuations are studied and analyzed by using Fast Fourier Transform (FFT) and Wavelet Transform (WT) revealing certain interesting aspects and features – such as in ascertaining about the formation of time domain structures and spectral features evolve over time [2].

In this set-up experiment, a stable double layer (DL) is first produced. The pressure varies in the ranges from (1-0.01mbar), the cathode voltage V_C (-500V) is kept constant between the vacuum chamber and the ground and the anode voltage V_A is increased in few steps (from +30V to +50V). With respect to these certain conditions, the floating potential fluctuations is observed, noted and recorded in a DSO Lecroy 500 MHzwavejet oscilloscope that provides a sample rate of 2 GS/s coupled using high impedance passive probe (10MΩ) with system attenuation of 10 x ±2% . The generated DL is kept maintained stable throughout the whole experiment.

Upon analysis the power spectrum, FFT provides the frequency representation of the sampled time domain data and WT gives the time-scale representation of the signal and is useful for analysis non-stationary signals since it is localized in both time and frequency domain. An interesting feature is that the wavelet co-efficient obtained possess some striking similarity with the bipolar time domain structures obtained by FAST satellite.

References:

[1] Lars. P. Block, Astrophysics and space science 55, 59-83, 1978

[2] J. P. Bravo, S. Roque, R. Estrela, I. C. Leão, and J. R. De Medeiros, A&A 568, A34 (2014)

[3] Prince Alex, Saravanan Arumugham and Suraj Kumar Sinha, "Triggering of Buneman Instability and Existence of Multiple Double Layers in Laboratory plasma", Physics Letters A 381 (2017) 3652-3658

MICROPLASMA SYNTHESIS OF NANOSTRUCTURED MnO_2 FOR THE ELECTROCHEMICAL SENSING OF H_2O_2

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Abstract

Hydrogen peroxide (H_2O_2) is a biologically important component in all living systems while its deficiency leads to many disorders hence its accurate detection has a significant role. The short life time, high cost and the influence of temperature, toxic chemicals and pH are the important factors which affect enzymatic sensors. So it is necessary to develop a non-enzymatic sensor with low cost, high stability and ecofriendly for the accurate detection of H_2O_2. The metal oxide sensors will give above mentioned salient features, hence are widely used in sensor fields. The MnO_2 metal oxide nanoparticles, particularly α phase is vastly used for H_2O_2 sensors [1]. Herein we synthesized α-MnO_2 nanoparticles by microplasma discharge method which is a rapid, single step and economically feasible method to environment. To date it is a suitable method for the nanomaterial synthesis due to its interesting properties like high electron density, continuous flow, small dimension and non-thermal plasma characteristics. Microplasma generated from air was exposed over 50 ml of potassium permanganate solution (precursor) for 30 minutes. This lead to the formation of black coloured precipitates (about 20 mg) in the solution within 30 minutes of treatment time. These precipitates were collected by centrifugation and annealing process and were subjected to characterization techniques. The XRD study reveals that the particles are α-MnO_2. The surface morphology was examined *via* FE-SEM analysis indicating that the MnO_2 particles have nanoflake structure and EDX confirms the chemical composition. The application of α MnO_2 nanoflakes on H_2O_2 sensor with high stability and detection range are explained in detail.

References :

[1] A hollow urchin-like α-MnO_2 as an electrochemical sensor for hydrogen peroxide and dopamine with high selectivity and sensitivity, Microchimica Acta **186**, p 210, (2019)

BUTI AWARD PRESENTATIONS

CHARACTERISTICE OF PLASMAS CONFINED IN A DIPOLE MAGNETIC FIELD

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Abstract- For an understanding of the properties of plasmas confined in a dipole magnetic field, keeping in view easier plasma accessibility and steady-state operation, a compact table-top experiment employing microwaves of 2.45 GHz has been developed [1], by using a single water-cooled cylindrical permanent magnet (NdFeB). The plasma is generated by electron cyclotron resonance (ECR) heating. Visual observations (in terms of digital images) of the plasma shows alternate bright and relatively less bright regions with resemblance to trapped charged particles in the earth's radiation belts. The report includes the results of measurements of plasma parameters such as electron temperature (T_e), ion (N_i) and electron density (N_e), space potential (V_s), ion saturation current (I_{is}) including plasma beta (β). Assuming azimuthal symmetry a mathematical model for particle diffusion has been developed. A numerical solution of the radial and angular components of the diffusion equation, yields the plasma density profiles, which are compared with those obtained experimentally and found to agree reasonably well.

I. Introduction

There has been a long quest to understand charged particle behavior and underlying complex processes of a plasma confined in a dipole magnetic field. Such plasmas have unique properties in terms of confinement [2], transport [3] instability [2, 4] and fluctuations [3,5], that govern variety of interesting wave and radiation phenomena. Because of its relevance to magnetospheric plasmas that occur in nature in planetary environments [6, 7] makes the study more exciting, and has been a subject of research for a long time both in laboratory and space plasma environments.

Recently a compact table top dipole plasma source has been designed to investigate the plasma confined by a single dipole permanent magnet [1]. The device employs water cooling of the magnet which makes it unique in terms of design, low cost with simple technology, and an additional benefit that continuous wave mode operation is made possible, which was challenging in the earlier larger devices [2, 3]. Thereafter, some basic properties of the generated plasma are investigated.

Further, to understand the mechanism of particle diffusion in the dipole plasma, a mathematical formulation has been constructed by considering the fluid equation of motion [8], continuity equation [8], Fick's law [8] along with magnetostatic fields and gradients in the plasma potential. The equations are written in spherical polar coordinates (r, θ and φ), to address the dipole variation of the magnetic field. The resulting diffusion equation is solved using the Runge-Kutta (RK4) method with appropriate boundary conditions [8] to obtain the plasma density profiles.

The paper has been arranged as follows. In section II, the experimental setup and the methodology including the magnetic field measurement is described. Section III is devoted to theoretical modelling for particle diffusion. In section IV the results are presented and discussed. Finally, in section V the main results are summarized, and conclusions are drawn.

II. Experimental setup and methodology

A. Plasma experimental setup

A schematic of the experimental setup is shown in figure 1. The set-up consists of a microwave system of 2.45 GHz connected to a spherical stainless-steel (SS, grade: 304) vacuum chamber (VC) having outer and inner diameters of 50 cm and 49 cm respectively (earlier a cylindrical plasma system of length 60 cm and diameter 20 cm was employed) with numerous ports for pumping, gas inlet, vacuum gauges and plasma diagnostics. A strong cylindrical permanent magnet (NdFeB) having length 41 mm and diameter 23 mm is suspended from a top flange to the center of VC, with the help of a magnet holder made of SS, which is further connected to a water chiller (Equitron 4.0 L) for water inlet and outlet. Chilled water maintained at 15^{o} C from a water chiller is circulated through the magnet holder to absorb the heat due to generation of plasma and the microwaves and to keep the magnet cool. Moreover, the design ensures complete water and vacuum-tight conditions during steady-state plasma operation. Most of the experimental details appear in reference [1].

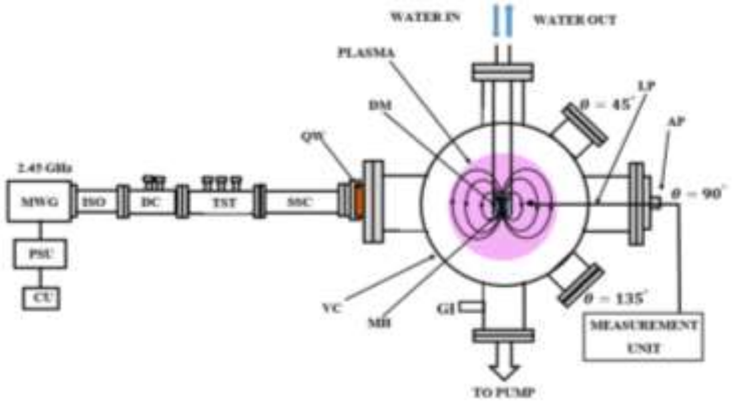

Figure 1. (a) Schematic of the experimental setup. VC: Vacuum Chamber, QW: Quartz Window, SSC: Straight Section, TST: Triple Stub Tuner, DC: Directional Coupler, ISO: Isolator, MWG: Microwave Generator, PSU and CU: Power Supply Unit and Control Unit for the MWG, AP: Axial Port, DM: Dipole Magnet, LP: Langmuir Probe, MH: Magnet Holder, GI: Gas Inlet

During the experiments, the chamber is evacuated to a base pressure of 1×10^{-6} Torr. Thereafter, VC is filled with the test gas Argon in the range of 0.2 – 2 mTorr. A planar Langmuir probe (LP) and emissive probe are employed to measure the plasma parameters. The method for calculating the density from a Langmuir probe may be found in reference [1, 9, 10].

B. **Measurement of dipole magnetic field of magnet**

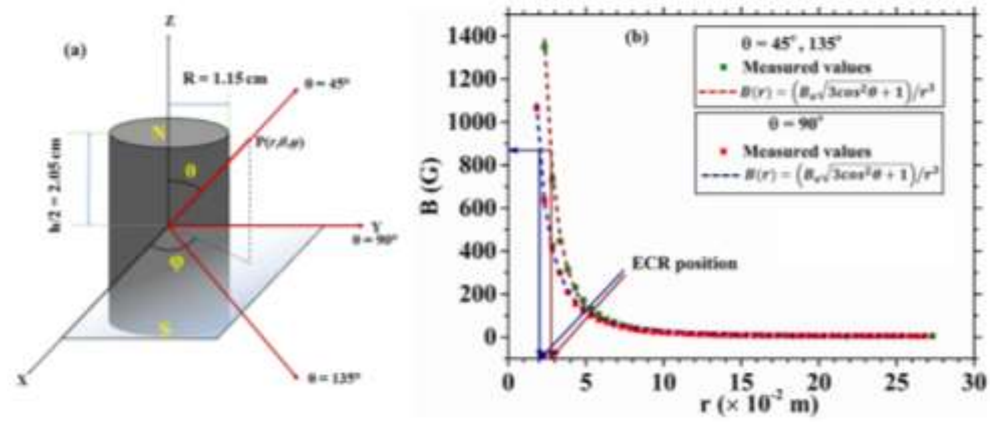

Figure 2. (a) Schematic of the dipole magnet (b) Measurement of the radial magnetic field profile for θ = 45°, 90°, 135°.

Detailed mapping of the magnetic field of the dipole magnet is carried out. The magnetic field at any point in space is given by $B(r) = \sqrt{B_r^2 + B_\theta^2 + B_\varphi^2}$. Experimental measurement of radial profile of each component of magnetic field is carried out using a gauss meter (lakeshore 421) by varying radial distance (r) along polar angle (θ) 45°, 90° and 135° as shown in the schematic of the dipole magnet in figure 2(a). For waves of 2.45 GHz, the magnetic field corresponding to ECR condition given by $\omega_c = eB/m_e$, comes out to be 875 G where, ω_c is the angular microwave frequency, e is the electronic charge, B is the magnetic field of magnet and m_e is the mass of an electron. From measurements of the magnetic field (Fig. 2(b)), it is seen that the ECR condition is satisfied at a distance of 2.1 cm from the center of the magnet for θ= 90° while it is 2.7 cm for θ = 45° and 135° and indicated in the figure. The measured magnetic field fit well with the formula $B(r) = \left(B_o\sqrt{3cos^2\theta + 1}\right)/r^3$, representing a dipole magnetic field [11] where B_o is a lumped constant analogous to $B_o = \mu_0 m / 4\pi$, with μ_0 and m being the permeability of free space and magnetic moment.

III. Theoretical analysis for diffusion

To understand the mechanism of particle diffusion in plasma confined in a dipole magnetic field, a mathematical formulation has been constructed by considering the fluid equation of motion. The Governing equations are the continuity equation and Fick's law given by Eqn. (1) and (2) respectively.

$$\frac{\partial N_e}{\partial t} + \vec{\nabla}.\vec{\Gamma} = \nu_i N_e \quad (1)$$

$$\vec{\Gamma} = -\mu_e N_e \vec{E} - \mathrm{D}\,\vec{\nabla} N_e \quad (2)$$

where, N_e , $\vec{\Gamma}$, μ_e, E, D and ν_i are electron density, electron flux, electron mobility, electric field, diffusion coefficient and ionization frequency respectively. On solving in spherical polar coordinates and assuming azimuthal symmetry, the resulting diffusion equation is obtained as,

$$\left[\mu_e N_e \frac{\partial E_r}{\partial r} + \frac{2\mu_e N_e}{r} E_r + E_r \frac{\partial(\mu_e N_e)}{\partial r} + \frac{\partial D}{\partial r}\frac{\partial N_e}{\partial r} + D\frac{\partial^2 N_e}{\partial r^2} + \frac{2D}{r}\frac{\partial N_e}{\partial r}\right] + \left[\frac{\mu_e N_e}{r}\frac{\partial E_\theta}{\partial \theta} + \frac{\mu_e N_e E_\theta}{r} cot\theta + \frac{E_\theta}{r}\frac{\partial(\mu_e N_e)}{\partial \theta} + \frac{1}{r^2}\frac{\partial D}{\partial \theta}\frac{\partial N_e}{\partial \theta} + \frac{Dcot\theta}{r^2}\frac{\partial N_e}{\partial \theta} + \frac{D}{r^2}\frac{\partial^2 N_e}{\partial \theta^2}\right] + \nu_i N_e = 0 \quad (3)$$

IV. Results and discussion

A. General plasma properties

1. Visual observation

Figure 3. Digital picture of Argon plasma in the dipole magnetic field, at a neutral pressure of 0.2 mTorr and microwave power of 300 Watt.

Figure 3 shows the digital picture of the dipole plasma created at a neutral pressure of 0.2 mTorr and power of 300 W. One can clearly see the bright and relatively less bright regions of the plasma. This is similar to the radiation belts of our earth magnetosphere [2, 5-7]. The brightest region alongside the magnet is the ECR region. Towards the wall of the VC, weaker magnetic field results in a diffused plasma. The plasma density and temperature are expected to be different in these regions.

2. Measurement of plasma parameters

Figure 4(a) shows the radial variation of T_e at different neutral pressures. The results show that T_e is higher near the surface of the magnet and decreases as we go away from the magnet. The higher T_e near the surface of the magnet is due to intense ECR heating occurring in that region, as explained in Sec. II.B. We also found a local peak around r = 6 – 7 cm from the center of the magnet, this indicates that there are some hot electrons trapped in this region, which could arise because of inward diffusion but needs to be verified in the future in this experiment.

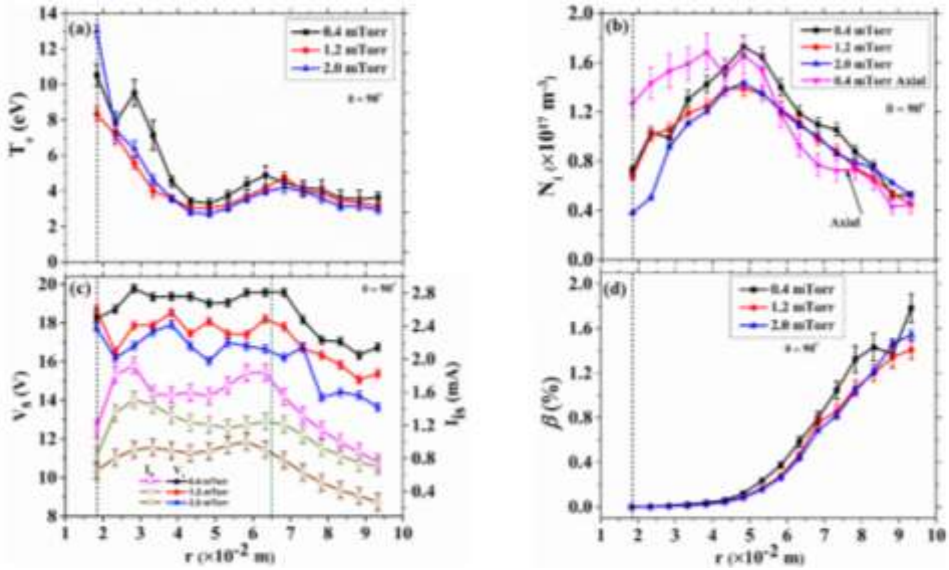

Figure 4. Radial variation of (a) electron temperature (T_e) (b) plasma (ion) density (N_i) (c) space potential (V_s) (left y-axis) and ion saturation current (I_{is}) (right y-axis and (d) plasma beta (β) (in percentage) with pressure. The wave power is kept fixed at 216 W for these measurements. The dashed vertical line represents the surface of the magnet holder.

N_+ is less near the magnet and is maximum at a region around r = 4 – 7 cm from the center of the magnet and then again decreases for large towards the wall of VC as shown by figure 4(b). This could be possibly due to the combined effect of radial transport from ECR zone to the outer plane and inner diffusion process reported in earlier dipole plasma experiments [2, 3].

Figure 4(c) shows the radial variation of V_s and I_{is}. It is observed that V_s is more or less uniform in the central region, depending upon the pressure, and then decreases rather sharply as we move toward the edge of VC. A sharp drop in V_s, would mean that electrons from the outer region of the plasma would be accelerated inward by the higher value of V_s. The radial variation of I_{is} is shown in the left y-axis, which indicates that I_{is} at first increases with r, dips in the middle and then increases again, before finally decreasing beyond r ~ 6.5 – 7 cm. The hills and valley in I_{is} is expected to be a result of the combined effects of diffusion and ionization. The sharp fall in V_s and I_{is} after r ~ 6.5 -7 cm implies that the particles are trapped in this range and will find it relatively difficult to escape outward due to the potential barrier which also indicates that the plasma has better confinement in this region.

The β which tells us about the ratio of the average kinetic forces to the magnetic forces on the particles is investigated next. The radial variation of β is shown by figure 4(d). The results show that the plasma has radially increasing β from the surface of the magnet to toward the edge of the chamber. A maximum β of ~ 2% is realized in the present experimental system. The above measured parameters are seen to decrease with increase in neutral gas pressure. This could be because of the ECR action becoming more effective at a lower pressure and leading to enhanced ionization and more number of electron neutral collisions taking place at a higher pressure and reduction in average electron energy.

B. Particle diffusion

Figure 5(a) and 5(b) shows the radial and angular numerical solution obtained from Eqn. (3). The radial solution is shown for θ = 45^o, 90^o and 135^o at a neutral pressure of 0.4 mTorr and microwave power of 300 W. The results show that N_e is less near the magnet and maximum in the middle region around r ~ 4 – 8 cm from the center of the magnet for θ = 90^o while it peaks around r ~ 2 – 4 cm for θ = 45^o and 135^o and then decreases again as we move further away from the magnet. The reason for maximum density is same as mentioned above in section IV 2. It may be noted that the result for N_e in figure 5(a) is amplified by an amplification factor mentioned alongside corresponding data as shown in the figure for a better display of the plots. Figure 5(b) shows N_e as function of θ at a fixed distance r = 9.65 cm from the center of the magnet at different pressures. The result shows the maximum density generation at θ = 90^o and is also observed in radial measurements. The resulting numerical solution for density profile is compared with the experimentally obtained data (open dots). The numerical results are in good agreement with the results obtained from experiments.

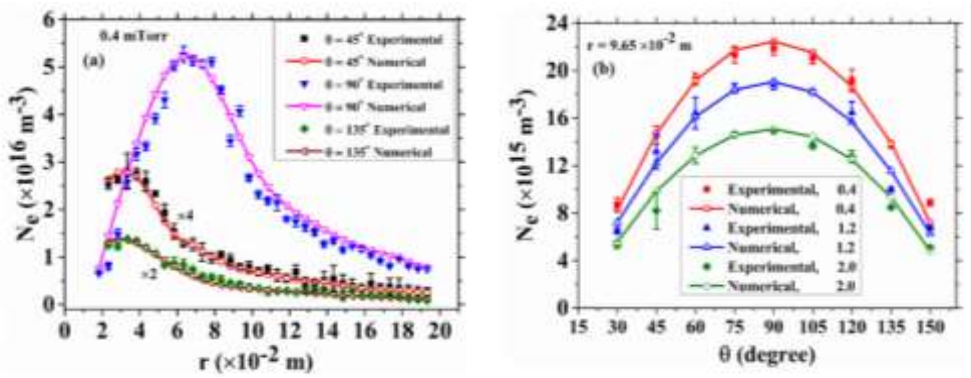

Figure 5. The numerical solution and comparison with the experimental result for the dipole plasma of (a) radial part of the diffusion equation at a neutral pressure of 0.4 mTorr (b) Angular part of the diffusion equation. The wave power is kept fixed at 300 W for experimental measurements.

V. Summary and Conclusion

In summary, the characteristics of a plasma confined in a dipolar magnetic field including solution of the diffusion equation for determining the plasma density profiles, are investigated. The plasma is heated by ECR using microwaves of 2.45 GHz. The dipole plasma shows alternate bright and dark regions. T_e is found to lie in the range of 2 -13 eV while the peak values of the plasma demnsity N_+ is of the order of 10^{17} m^{-3}. It is found that the density peak occurs away from the magnet. This is possibly due the combined effect of inner diffusion of particles from outer region and the particle diffusing away from the ECR region and longitudinal particle transport from the axial ECR zone to the outer mid-plane region along the field lines, with their confinement in the dipole mirror field. V_s and I_{is} is more or less uniform in the central region. A maximum β for the present experimental system is ~ 2%. The numerical solution of the diffusion equation employs the experimentally obtained plasma space potential and electron temperature as input. The results of the plasma density obtained numerically and those directly from the Langmuir probe measurements are compared and are found to be in good agreement with each other.

References

[1] A. R. Baitha, A. Kumar and S. Bhattacharjee, Rev. Sci. Instrum., **89,** p 023503-6 (2018).
[2] A. C. Boxer Nature Phys., **6**, p 207 – 212, (2010).
[3] H. P. Warren and M. E. Mauel, Phys. Plasmas, **2**, p 4185-94 (1995).
[4] G.G. Howes, Phys. Plasmas, **25**, p 055501-27(2018).
[5] D. N. Baker et. al, Nature Lett., **432**, p 878- 881 (2004).
[6] Y. Chen, G. D Reeves and R. H. W Friedel, Nat. Phys., **3**, p 614-17 (2007).
[7] J.G Lyon, Science, **288**, p 1987–91 (2000).
[8] F.F.Chen, Introduction to Plasma Physics and Controlled Fusion, second edition **1** Ch. 5 (Springer, Berlin) (1983)
[9] S. Bhattacharjee and H. Amemiya Rev. Sci. Instrum., **70,** p3332-37 (1999).
[10] S. Bhattacharjee, I. Dey, K.C.Roy, D. Sahu, S. Pandey and S. Chatterjee, Phys. Plasmas **21**, p 012111-7 (2014).
[11] D. J. Griffiths, Introduction to Electrodynamics, fourth edition Ch. 5 (Pearson Education) (1991).

CREATION AND STUDIES OF MICRO-ION BEAMS FROM INTENSE ELECTROMAGNETIC WAVE GENERATED PLASMAS

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Abstract

A compact microwave plasma has been employed as an ion source for focused ion beam applications which can provide non-toxic and rapid processing of materials without introducing any metallic contamination. A variety of microstructures with high aspect ratio (~100-1000) are created using 26 keV Ar, Kr and Ne ion beams. A mathematical formulation is developed to calculate the impact of the beam to the target sample by defining a new parameter called “current normalized force” which is total momentum transferred per unit time and normalized with the beam current. Capillary guiding of the plasma ion beams has demonstrated the self focusing of the beam which can be employed to reduce the source size (plasma electrode aperture) for the reduction of beam size for a constant demagnification of the electrostatic lens. A particle in cell (PIC) simulation is performed to interpret the experimental results of self focusing. Hysteresis in beam current with ion energy is observed and hysteresis area is used to calculate the dissipated charge from the beam while beam transmission. The effect of plasma and beam parameters on focal dimensions has been investigated, and a unique feature of enhanced nonlinear demagnification is observed when the plasma electrode aperture is reduced to below the Debye length.

I. Introduction

Ion beams have become an important tool in today’s science and technology for applications such as patterning, modification of surface properties, milling, implantation, high resolution imaging, including studies of optical and field emission properties of created nano-structures [1,2]. Conventionally Ga based FIBs are employed which has some limitations such as (i) primarily Ga ions are available (ii) Ga introduces metallic contamination to the substrate [3] (iii) small beam current, therefore it takes long milling time to process the sample. To overcome these limitations, plasma based focused ion beam are being developed worldwide which has emerging research applications and can provide non-toxic and rapid processing of the materials [4]. Plasma ion beam processing of biomaterials are important for applications in artificial heart valves and orthopedic prostheses [5]. A microwave plasma based multi-element focused ion beam (MEFIB) system has been developed [4] in our laboratory, which has significant advantages over conventional FIB systems and can provide variable projectile masses by employing different gaseous plasma ions and higher beam currents.

For further reduction of beam size, source size (plasma electrode aperture) can be reduced for a constant demagnification of the lens. Micro-glass capillary can be employed to reduce the source size which guides the ion beam without significantly loss of the beam current. It is found that while beam transmission, incoming ions get deposited on the inner wall of the capillary which further guides the ions towards the capillary axis due to repulsion force and maintain the initial charge state of ions [6-8].

Knowledge of focal point (FP) is important for fabrication of samples because beam current density is maximum at FP and beam size is minimum. Therefore sample needs to be kept at the FP for rapid fabrication of the sample with highest resolution. In optics, FP can be determined from the information of the lens geometry and properties of the material. However, in plasma based FIBs, FP determination is difficult and depends on plasma parameters such as space potential, initial kinetic energy related to the Bohm velocity, ion current density, electron and ion temperature, ion mass, and beam parameters such as beam energy, geometry of the lenses, plasma electrode and beam limiter aperture size, potential applied to the lenses [9].

The present article reports high aspect ratio microstructuring using MEFIB system. Further, guiding capability of the micro-glass capillary has been demonstrated which can be employed to reduce the source size for reduction of beam size. Variation of beam size and demagnification factor with plasma electrode (PLE) aperture size is presented where enhanced nonlinear demagnification is observed when PLE aperture size is reduced to below the Debye length.

II. Experimental Setup

The experimental system has mainly four parts which are plasma column, beam column, experimental chamber and stage manipulator as shown in Fig. 1(a) [4]. In plasma column, microwaves of frequency 2.45 GHz is launched into a vacuum chamber (~10^{-7} Torr) and a high density (~10^{11} cm^{-3}) plasma is formed which is confined using an octupole magnetic multicusp. The working pressure of the neutral gas is maintained ~0.25 mTorr, ion and electron temperatures are ~0.2 eV and 10 eV respectively, and plasma frequency is calculated to be ~2.83 GHz [9]. Wave propagation through a bounded overdense plasma has been earlier demonstrated [10]. Beam column has many electrodes which are used to extract and focus the beam. The first electrode which faces the plasma, is called plasma electrode (PLE) and at PLE, plasma sheath (a layer of negative charges) is formed which further helps to extract the ions. The sheath accelerates the surrounding ions toward the PLE wall and ions come out through the aperture. Then decel-accel type Einzel lens EL_1 is used to accelerate the ions towards the lens axis, beam limiter trims the beam and finally EL_2 provides required focusing and energy to the beam. In experimental chamber, experiments are performed such as beam current measurement, beam writing, etc. Microstructures are created by moving the sample in X and Y directions, and sample is positioned along beam direction by Z-axis using $XYZ\theta$ stage manipulator.

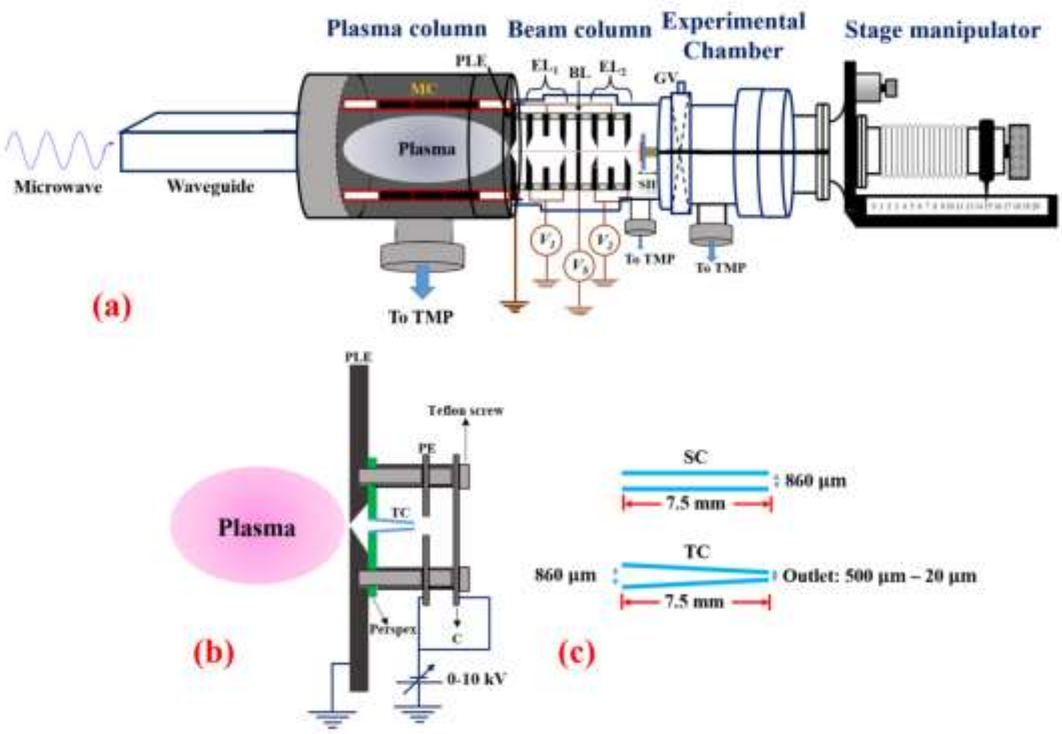

Figure 1. Schematic diagram of (a) MEFIB experimental setup, PLE: plasma electrode, MC: muticusp, TMP: turbo molecular pump, EL_1 and EL_2: Einzel lenses, BL: beam limiter, SH: sample holder, GV: gate valve, V_1, V_S and V_2: high negative voltages applied to the lenses [9] (b) capillary guiding experimental setup, PE: puller electrode, C: collector, TC: tapered capillary (c) straight (SC) and tapered capillaries (TC) [7].

For capillary guiding experiment, beam column is replaced with the capillary experimental setup as shown in Fig. 1(b) [7]. A straight capillary (SC) or tapered capillary (TC) is attached to the PLE with the help of Perspex holder and ion beam is extracted by negative high voltages applied to PE. Beam current is measured at the collector, which is floated at the similar voltage as PE, using collector current measurement unit (Ionics Ltd., India). Figure 1(c) shows different capillaries of inlet inner diameter (ID) 860 µm and outlet ID 500 µm, 300 µm, 200 µm, 110 µm, 45 µm, and 20 µm.

III. Results and Discussions

Beam current is measured for Ar, Kr and Ne ion beams and focal point (FP) is determined for each ion beam by considering minimum irradiation time [4]. Then sample is kept at FP and beam writing is performed for 40 µm PLE aperture. Lines are created on Cu thin film for different writing speed i.e. dwell time using 26 keV Ar, Kr and Ne ion beams. Aspect ratio a_r (line width/depth) is calculated and a variable high aspect ratio in the range ~100-1000 is obtained as shown in Fig. 2(a) [4]. For Ar ion beams, clear lines are obtained at higher writing speed because Ar has balanced beam current and ion mass (neither it has low beam current like Kr nor does it have low ion mass like Ne). Aspect ratio is found to be higher for Ne ion beams because Ne has higher beam current (~20 nA) and therefore higher line width due to self-coulomb repulsion and smaller line depth because of low ion mass. Grating like microstructures are created on 50 nm Cu thin film employing 26 keV Ar, Kr and Ne ion beams for 40 µm PLE as shown in Fig. 2(b)-(d). To calculate the impact of the beam on the target sample, a parameter called "current normalized force" is defined as total momentum transferred per unit time and normalized with the beam current, which is given as [4],

$$\gamma = \frac{p}{t\,I} = \frac{N M_i v_z}{t\,I}\left[\frac{2\cos\theta_{max}+\sin^2\theta_{max}+4}{3\cos\theta_{max}(1+\cos\theta_{max})}\right], \quad (1)$$

where, N, M_i, v_z are number of ions, ion mass and axial velocity of ion respectively, and θ_{max} is the maximum beam angle at FP. t and I are the beam irradiation time and beam current respectively.

To reduce the beam size further, source size (PLE aperture size) can be reduced for a constant demagnification. Micro-glass capillary can be employed to reduce the source size. Guiding capability of the capillary has demonstrated. Current density is measured at the capillary outlet for different capillaries and a high current density ~600 Am^{-2} is observed [7]. Beam guiding is demonstrated while tilting the capillary from -5° to +5° relative to the incident beam axis.

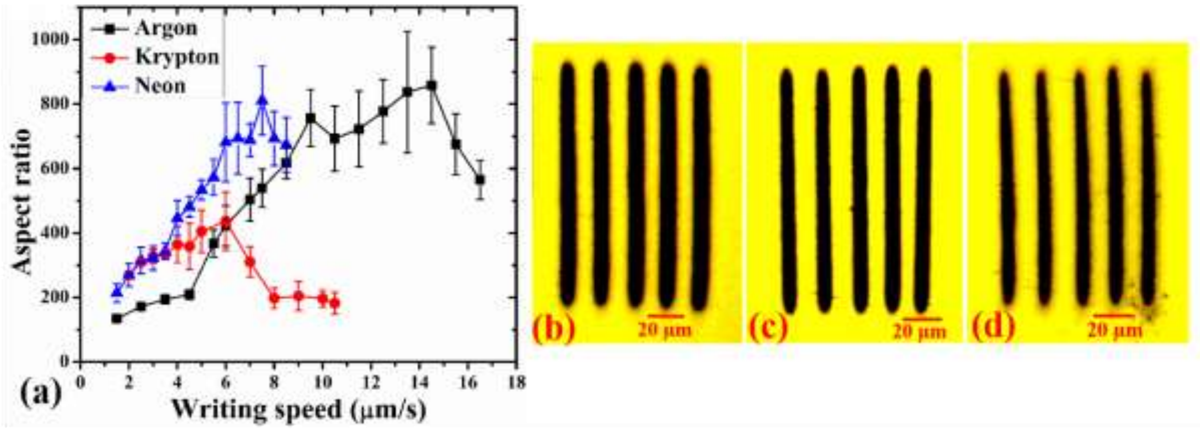

Figure 2. (a) Variation of aspect ratio with writing speed for Ar, Kr and Ne ion beams. [4] (b)-(d) Optical microscopy images of grating like microstructures created using 26 keV Ar, Kr and Ne plasma ion beams respectively [4].

Hysteresis in beam current with ion energy is observed as shown in Fig. 3(a) and reason of hysteresis is explained below. While increasing the extraction voltage *V*, charges start to accumulate on the inner wall of the capillary and a retarding potential barrier develops and therefore beam current is negligible up to 8 kV. When ion energy is greater than the retarding potential barrier, most of the deposited charges diffuse to the electrode and sudden increase in beam current is observed, and this particular extraction voltage is called "upper threshold voltage". While decreasing *V*, beam current is obtained up to 2 kV because retarding potential has decreased due to diffusion of deposited charges and therefore hysteresis is observed due to dissipation of charges [7]. The sharp decrease in current occurs at a particular voltage called "lower threshold voltage". Dissipated charge is calculated from the hysteresis area by dividing the area into n vertical strips of width ΔV and heights $I_{k\uparrow}$ and $I_{k\downarrow}$, where $I_{k\uparrow}$ and $I_{k\downarrow}$ denote beam current while increasing and decreasing *V* for k^{th} strip, and is found to be [7],

$$Q = \frac{\Delta t}{\Delta V} P_d \,, \quad (2)$$

where, Δt is the time taken to increase the extraction voltage ΔV, P_d is the dissipated power which is hysteresis area. Variation of dissipated charge Q with capillary outlet ID is shown in

Fig. 3(b) and it is observed that dissipated charge is maximum for 300 µm due to higher hysteresis area which is effect of higher beam current and large difference in upper and lower threshold voltage.

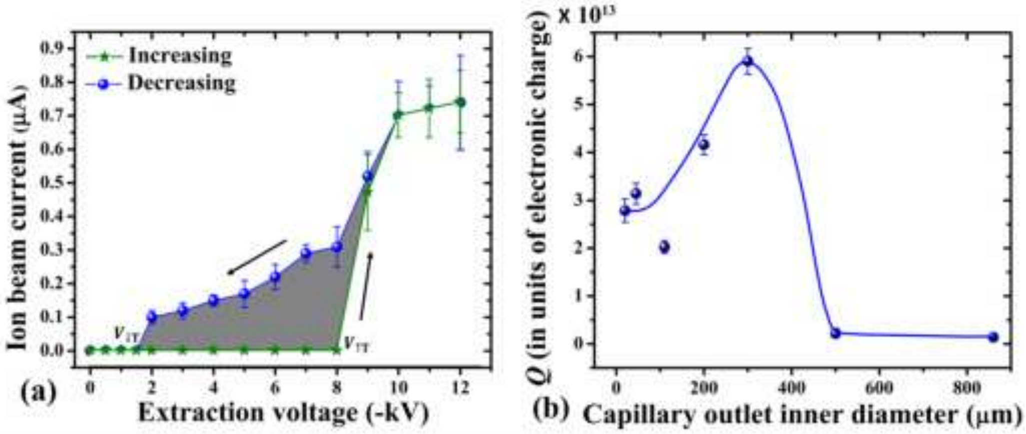

Figure 3. (a) Variation of beam current with extraction voltage. (b) Dissipated charge for capillaries of different outlet IDs [7].

Further, beam spots are created for different capillary outlet ID and it is found that spot size is smaller than the capillary outlet ID i.e. self-focusing of the beam is observed [7]. A self-focusing factor is defined as the ratio of capillary outlet ID to the beam size and is calculated for each capillary. A particle in cell (PIC) simulation is carried which clearly shows the self-focusing of the beam which decreases for smaller capillary as shown in Fig. 4 [7].

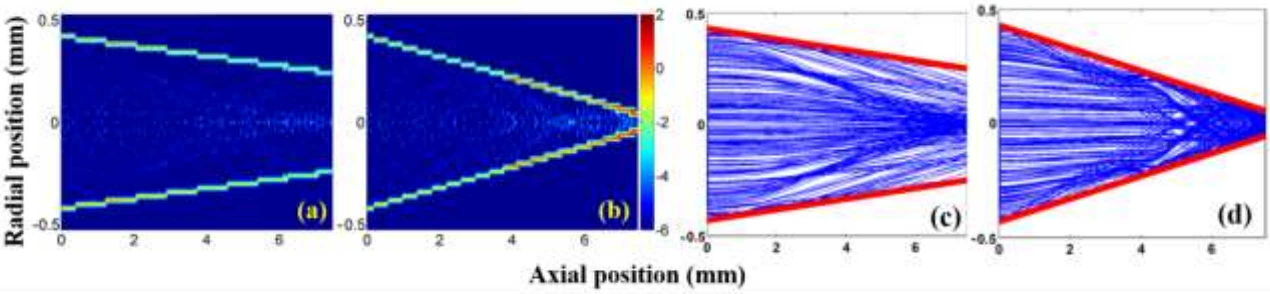

Figure 4. (a)-(b) beam transmission, (c)-(d) ion beam trajectory, for TC of outlet ID 500 µm and 110 µm respectively, indicating self-focusing of the beam [7].

Further, effect of plasma parameters and beam parameters on focal dimensions are investigated [9]. Figure 5 shows that for plasma based MEFIB, sudden decrease in beam size is observed below the Debye length (~100 µm) and enhanced nonlinear demagnification (beam size/PLE aperture) is obtained because penetration of electric field into the plasma becomes weak below the Debye length and beam extraction reduces and therefore beam size due to reduction in space charge effects [9].

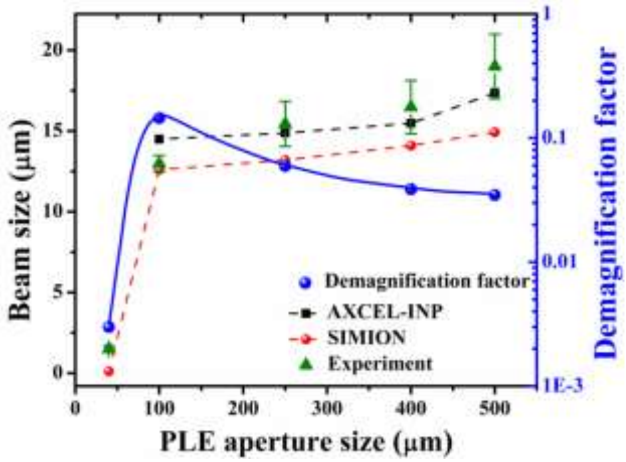

Figure 5. Variation of beam size and demagnification factor with PLE aperture size [9].

IV. Conclusions

High aspect ratio microstructures (~100-1000) are created employing plasma based MEFIB system. A mathematical formulation is developed to calculate the total momentum transferred from the beam to the target sample by defining a new parameter "current normalized force". Capillary guiding of plasma ion beams has demonstrated self-focusing of the beam which can be employed to reduce the plasma electrode aperture size for reduction of beam size. Effect of plasma and beam parameters on focal dimensions is investigated and an enhanced nonlinear demagnification is observed below the plasma Debye length.

References :

[1] L. D. Menard and J. M. Ramsey, Nano Lett. **11**, 512 (2011).
[2] L. A. Giannuzzi and F. A. Stevie, Micron **30**, 197 (1999).
[3] X. Jiang, Q. Ji, A. Chang and K. N. Leung, Rev. Sci. Instrum., **74**, 2288 (2003).
[4] S. K. Maurya, S. Paul, J. K. Shah, S. Chatterjee, and S. Bhattacharjee, J. Appl. Phys. **121**,123302 (2017).
[5] F. Z. Cui and Z. S. Luo, Surf. Coat. Technol. **112**, 278–285 (1999).
[6] N. Stolterfoht, J. H. Bremer, V. Hoffmann, R. Hellhammer, D. Fink, A. Petrov and B. Sulik, Phys. Rev. Lett. **88**, 133201 (2002).
[7] S. K. Maurya, S. Barman and S. Bhattacharjee, J. Phys. D: Appl. Phys. **52**, 055205 (2019).
[8] T Ikeda, Y Kanai, T M Kojima, Y Iwai, T Kambara, Y Yamazaki, M Hoshino, T Nebiki and T Narusawa, Appl. Phys. Lett. **89**, 163502 (2006)
[9] S. K. Maurya, S. Barman, N. Pan, and S. Bhattacharjee, Phys. Plasmas **26**, 063103 (2019).
[10] Indranuj Dey and Sudeep Bhattacharjee, Phys. Plasmas **18**, 022101 (2011).

Excitation of pinned structures in flowing complex plasma

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Abstract

We report experimental observations on the excitation of stationary solitary structures in a flowing complex plasma. The experiments are performed in a π- shaped Dusty Plasma Experimental (DPEx) device where a DC glow discharge Ar plasma is created in between a disc shaped anode and a long tray shaped cathode. A dusty plasma is then formed using poly-dispersive kaoline particles. A floating copper wire mounted radially on the cathode creates a sheath around it in the plasma environment and acts as a charged object for the flowing dusty plasma fluid. The flow of dust cloud is initiated by lowering the potential of the charged object from ground potential and the flow speed is controlled precisely by connecting the wire from grounded potential to various intermediate potentials including floating potential. It is found that for particular discharge conditions and critical velocities of the fluid flow, high amplitude non-linear standing structures get excited. The amplitude, width and number of the excited structures are studied for different flow velocities of the dust cloud. It is noticed that with the increase in the flow velocity, the amplitude of the stationary structures increases whereas the number increases from one, two and many. These solutions are distinct from previously observed non-stationary precursor solitons and constitute a new class of driven nonlinear structures. The experimental observations are compared with special solutions of a model forced-Korteweg de Vries (f-KdV) equation and found to be in good qualitative agreement. The potential applications of such excitations in the context of solar wind interaction with planets and satellite interaction with ionosphere plasmas are discussed.

I. Introduction:

Solitons are stable localized nonlinear structures found in variety of natural and laboratory events including oceanography [1], optical fibers [2, 3], semiconductors [4, 5], plasma [6–8], laser plasma interaction [9–11], etc. The Korteweg-de Vries (KDV) equation [12–15] has been served as a successful mathematical model for the study of weakly dispersive non-linear waves for a long time. There are also another class of the solitons which are generated by the driven force and widely studied in hydrodynamic literature. These driven solitons are found to be generated ahead of the boat (called precursors) [16–19] on the water surface when the boat velocity exceeds the phase velocity of the linear surface waves. This fascinating phenomenon of precursor solitons has received much attention in the hydrodynamic region and has been explained well by forced version of KdV equation f-KdV [20–24].

Dusty plasma [25–29] has proved an appropriate medium to study these neutral fluid problems in the plasmas. Such a medium, consist of highly charged (mostly negative) heavy micron particles immersed in a normal plasma having electrons, ions and neutrals. Inclusions of these heavy micron sized dust particles makes the plasma to show a rich variety of collective phenomenon occurred at a longer time scale giving the opportunity to see the dynamics by naked eyes or fast CCD camera. There have been various experimental studies shows the existence of linear waves like Dust Acoustic Wave (DAW) [30,31], Dust Ion Acoustic Wave (DIW) [32], Dust Lattice Wave (DLW) [33] and non linear waves like Dust Acoustic Solitary Waves (DASw) [34,35], shock waves [36–38], voids [39–41], vortices [42,43], precursor solitons [24], wakes [23] etc. More recently, Jaiswal *et al.* [24] showed the excitation of precursor solitons (against the flow) and wakes (in the direction of flow) in the dusty plasma by flowing the dust fluid over a charged object. The observations are successfully modeled with f-KdV equation and compared qualitatively with the solutions of numerically obtained results. The detailed investigation of these propagation characteristics on the shape and size of the charged object on the precursor solitons for the supersonic flow regime are discussed in Ref. [24].

Recently, Sanat *et al.* [22, 25] showed another class of solitons which is also the part of driven systems called pinned solitons by putting forcing term in the fluid equations and solving numerically the stationary solutions of the systems. These solitons move at the same speed with the source called pinned solitons and are stationary with respect to the laboratory frame. Surprisingly, no one has reported experimentally the existence of pinned solitons in a flowing plasma or dusty plasmas. Here, in this paper, we report the first ever experimental observation of the excitation of pinned solitons along with the wakes structures in a flowing dusty plasma.

II. EXPERIMENTAL SET-UP AND PROCEDURE:

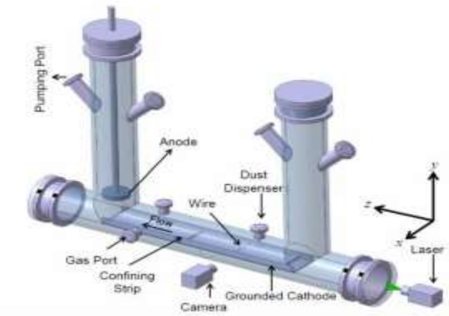

Fig. 1. A schematic diagram of Dusty Plasma Experimental (DPEx) device.

Figure.1 shows the schematic diagram of Dusty Plasma Experimental (DPEx) device where the experiments are executed. The detailed description of size and the dimensions of DPEx device have been discussed in detail in [44]. It is an inverted Π shaped experimental device which has one main cylindrical glass chamber and two secondary chamber radially attached to the main chamber. There are several radial and axial ports connected with main as well secondary chamber served for different purposes. One of the radial ports of the main chamber is used for gas feeding called Gas Port and the chamber is evacuated with the rotary pump connected radially to the left secondary chamber called pumping port. A disc shaped anode hung axially to the left secondary cylindrical glass chamber and tray type configuration grounded cathode lying on the main chamber served as an electrode for plasma generation. Two confining potential strips are also placed to both the ends of the cathode for axial confinement of dusty plasma and the angled ends of the cathode are used for radially confinement. A copper wire of diameter 1 mm and length 50 mm is mounted radially to the cathode which acts as a charged object for the excitation of pinned structures. The wire can be kept at various potential ranging from grounded to intermediate as well as floating potential by using a variable resistor ranging from 10 KΩ-10 MΩ through a switch. A Direct Current (DC) (2K, 500mA) power supply is used to power the electrode for Argon plasma generation. Micron particles of diameter ranging 2-5 μm sprinkled on the cathode in between the wire and the right strip before closing the chamber for the production of dusty plasma. These particles get negatively charged in the presence of plasma as the thermal speed of electrons are higher than the ions and levitate in the cathode sheath by the balance of gravitational force in downward direction and sheath electric field force in the upward direction. The averaged mass of these suspended dust particles is 8.6×10^{-14} kg. These micro particles can be seen by shining the green laser light and their dynamics are captured by fast CCD camera looking in x-z plane.

First, the chamber is pumped down to base pressure 0.1 Pa by fully opening the gate valve attached at the mouth of the pump used for controlling the pumping speed. A working pressure is set to 9-15 Pa by closing the gate valve to 20 % opening the flow meter attached to the gas port to 5-10 %. An equilibrium pressure is maintained by the balancing the pumping speed and gas injection speed. A plasma is formed by applying a voltage range 290-360 V using a DC glow discharge power supply. Langmuir probe and emissive probe are used for the range of discharge parameters before the dusty plasma creation. The plasma density for this range is $n_i \sim 0.5\text{-}1.5 \times 10^{15}$ /m^3 and plasma temperature T_e is 5 -2 eV. The plasma parameters profiles in the radial and axial directions over a wide range of discharge parameters are presented in Ref. [44].

To create dusty plasma, first the equilibrium pressure P = 10 Pa is set and then the voltage is increased to 400 V so that a high electric field is created and particles on the cathode base before gets charged. The voltage is reduced to 300 V so that a high sheet dense cloud is seen to be floating in between the wire and the right confining strip. At present the wire is kept at grounded potential and these particles are confined in between the wire and the right strip. The discharge parameters are chosen to be very low as compared to the past experiments by Jaiswal *et al.* [24] to make these dust micro particles levitate at a height much above the wire for the excitation of pinned structures. The plasma parameters are $n_i \sim 0.5\times 10^{15}$ /m^3, $T_e \sim 5$ eV measured from single Langmuir probe and the dust density $n_d \sim 10^{11}$ /m^3 are measured from the intensity calibrated for single particle to get the density of the equilibrium dust cloud. The charge $Q_d \sim 10^4 e$ is estimated from Collision Enhanced Plasma Collection [45, 46] (CEC) Model for the present set of discharge conditions. As these dust particles are in liquid state, it is very difficult to visualize each and every particle and hence to estimate the dust temperature, the tail part of the cloud (the dust density is low there) is focused with greater resolution and dust temperature is measured using super Particle Identification Tracking (sPIT) [47] code which comes out to be Td ~ 0.6-1.2 eV. These experiments are associated with the flowing dusty plasma and hence dust acoustic speed is calculated theoretically from the above parameters Cda~22-25 mm/sec which is quite similar to the experimental measured value [48]. The experiments are related to flowing dusty plasma and hence various types of flow of the dust cloud ranging M=1.5 to 3 is initiated for a particular discharge condition. The flow in the dust cloud is generated by switching the wire from grounded potential to an intermediate potential.

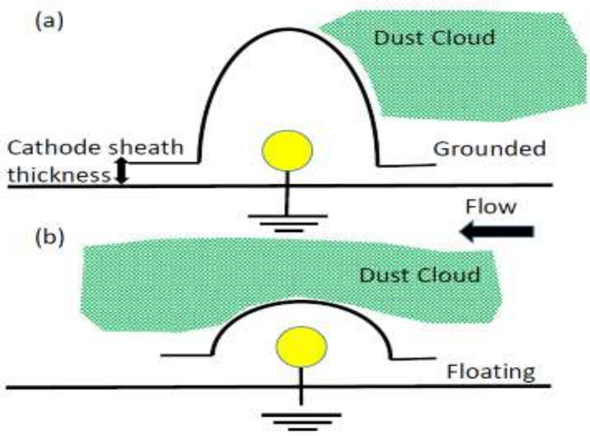

Fig. 2. (a) Equilibrium configuration of dust cloud before generating the flow. (b) Flow in the dust fluid after the flow. The yellow circle represents the location of the charged object.

Figure 2 (a) shows the y-z plane view of the dust particles confined in between the grounded wire and the right strip. As the grounded potential is negative with respect to the dust, they cannot escape above the wire and levitating quietly with no translation motion except thermal motion. The height of the hill is suddenly reduced from grounded potential to some potential which is less negative with respect to the particles, generates the flow of the dust cloud and the whole dust fluid moves from right to left. During their flow these micro particles attain constant velocity [49] due to neutral drag force [44, 48] and excite some nonlinear structures depending on the M number. The flow velocity for each type of flows ranging from subsonic to supersonic can be estimated using

Particle Image Velocimetry (PIV) technique [50]. In this case, the flow is highly supersonic ranging M = 1.5-3. This can be achieved by adjusting the discharge parameters and focusing the topmost layer of the dust fluid. The discharge pressure and voltage are chosen in such a way so that the particles levitate at a height far above the wire and the cathode sheath but still confined within the sheath above the wire thus making the flow velocity to be highly supersonic and exciting some nonlinear structures in the laboratory frame. Here, p=10 Pa and V= 300 V is set so that the sheath thickness around the grounded cathode as well as the wire increases so that the whole, cloud shifted to a height greater than the previous experiments performed.

III. RESULTS AND DISCUSSION

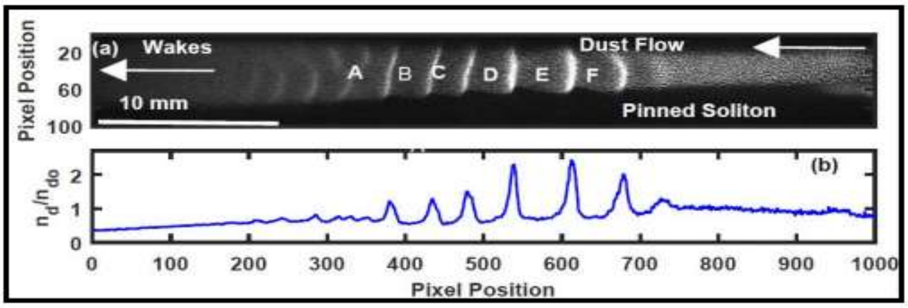

Fig. 3. (a) Typical images of multiple pinned structures. (b) Intensity profile of high amplitude sharp structures.

The flow technique discussed in Sec. II generates the flow of dust cloud ranging from M~1.6- 3. Figure.3 (a) shows the experimental image of high amplitude structures excited in the dust cloud when the flow velocity is maximum i.e. M~3. Here, in this configuration the height of the hill created by the charged object changed from grounded potential to floating potential and dust fluid flows moves from right to left. The figure shows that six nonlinear structures are excited around the wire. The low amplitude are wakes and seen to propagate in the direction of flow. Figure 3(b) shows the intensity profile of these excited structures extracted from Figure 3(a). One can see that these structures have sharp peaks and high compression factor which indicates the presence of non-linearity in these excited structures. The amplitude (A), full width (L) at half maxima and soliton parameter (AL^2) are measured for these structures named A to F for number of frames. It is seen that the high amplitude structures have lower width than the lower amplitude structure and they are maintaining constant AL^2 relationship which clearly suggests that they are indeed KdV type solitons.
The time evolution of these high amplitude solitary structures along with the small amplitude wakes is plotted in Figure 4. The straight line joining the high amplitude structures shows that the solitons are not propagating and stationary in their respective position with respect to the laboratory frame. In the frame of fluid, the object is moving left to right and these solitons are moving with the same velocity as that of the object and pinned to the object called pinned solitons. The amplitude and width are not showing any sufficient change in time and they are standing still t = 55 msec till the whole dust fluid flow over the wire.
In order to get the more insights on the excitation of pinned solitons, flow velocity is varied by keeping the discharge parameters same. Interestingly it is noticed that the number of pinned solitons gets excited depending upon the flow velocity of the dust fluid. Two pinned structures get excited for M~2.2, whereas only a stationary structure gets excited when the fluid velocity is decreased to M~1.7. Hence, it can be concluded that with the increase in flow velocity of dust fluid number of excited pinned solitons increases.

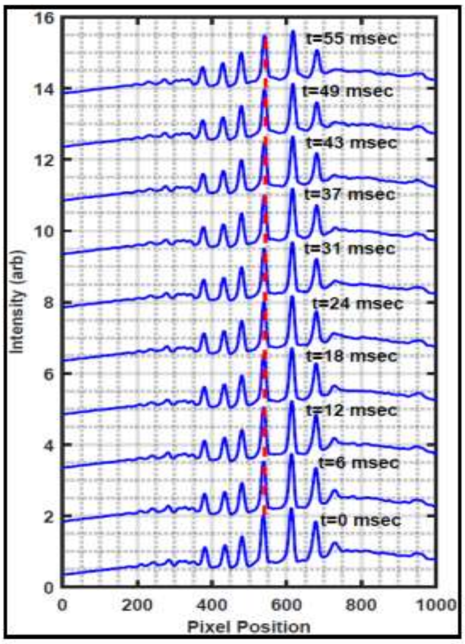

Fig. 4. Intensity profile of multiple pinned structures over the time. The straight line shows the peaks are not moving with time.

To carry out the quantitative investigation of amplitude of these excited pinned stationary structures with different flow velocity or Mach number M, same experiments are carried out for various flow velocities and are shown in Figure 5. It can be seen that with the increase in M or the flow velocity mean amplitude of the excited stationary structures increases parabolically. It can be understood as follows with the increase in flow velocity which means increase in the velocity of charged object means more accumulation of density in front of it creating highly non-linearity and breaking into more compressed structures in the frame of fluid hence increasing the amplitude of nonlinear structures.

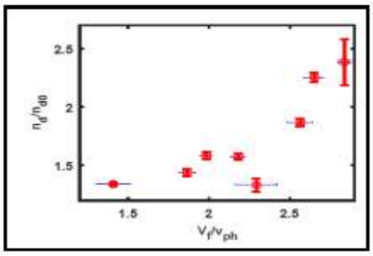

Fig. 5. Variation of n_d/n_{do} with v_f/v_{ph}

To compare our experimental findings qualitatively, we have solved numerically forced KortewegdeVries (f-KdV) model equation in which the source term is present in normal KdV equation represented by S2 which is playing the role of charged object (here wire) in the following Equation Eq.1

$$\frac{\partial n_{d1}}{\partial t} + A n_{d1}\frac{\partial n_{d1}}{\partial \xi} + \frac{1}{2}\frac{\partial^3 n_{d1}}{\partial \xi^3} = \frac{1}{2}\frac{\partial S_2}{\partial \xi}, \qquad (1)$$

n_{d1} is the perturbed density normalized to equilibrium density n_{do} and $\xi = (z - u_{ph}t)$ is the coordinate in the wave frame moving at phase velocity u_{ph} normalized to the dust acoustic speed. The coefficient where δ and σ are the ratio of ion to electron density and temperature, respectively. It is to be noted that the parameters of Source function S_2 are chosen to replicate our experimental discharge parameters and v_d value is chosen to be high for the generation of pinned structures in comparison to our previous experiments.

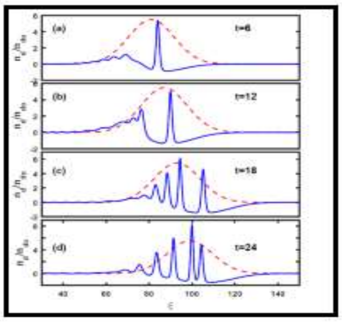

Fig. 6. Time evolution of pinned structures as well as source function obtained from the numerical solution of forced KdV equation.

The time evolution of S_2 and numerically obtained n_d is shown in Figure 6(b) to (e) for t = 6, 12, 18, [24]. The red line shows the source function peaking at $\xi = 75$ which is shown in 6(a). We have taken the profile of the source function to be Gaussian from the past experiments discussed in [51]. It can be seen that some solitons are generated with time and moving with the source velocity i.e. with in the envelope of source function. Here, in this case four solitons are generated at t = 24 and their peaks are also following somewhat Gaussian trend like in our experiments shown in Figure 3. These structures are called pinned structures and matching with our experimental obtained results. We have solved Eq.1 again to show that with the decrease in v_d the number of excited pinned stationary structures decreases and their amplitude decreases.

IV. SUMMARY AND CONCLUSION

To conclude, excitation of new class of solitons called pinned solitons are reported in the flowing complex plasma. These experiments were performed in a Π shaped Dusty Plasma Experimental Device in which a large dust cloud is created in DC glow discharge Argon plasma. The flow of the dust cloud is generated by changing the height of the hill used for the axial confinement. A highly supersonic flow is generated by tuning the discharge parameters and focused the top most layer of dust cloud from the base of the cathode. The flow is controlled by changing the potential of the charged object from maximum negative potential (grounded) potential to minimum (intermediate) potential to least minimum (floating) potential. This can be achieved by connecting various resistances in parallel to the wire and grounded potential. Maximum number of pinned solitons with higher amplitude and lower width are excited when the flow of the dust cloud is maximum. These solitons are stationary in laboratory frame and called pinned solitons. The amplitude shows parabolic increase with the increase in flow velocity whereas the number also increases with the increase in dust flow velocity. The results are compared with the numerical solution of f-KdV equation by taking Gaussian profile of Source function moving with higher velocity. All the numerical results are qualitatively matching with the experimental findings as well as the stationary solutions of fluid equations from the theoretical paper by Sanat. *et al*.. Our results thus proved experimentally the existence of pinned solitons in the laboratory and thus can prove useful for understanding such type of observations in the natural phenomenon such as interaction of space plasma with charge debris objects as well as the laboratory plasmas where the supersonic flows are involved.

References

1 A. New and R. Pingree, "Large-amplitude internal soliton pack- ets in the central bay of biscay," Deep Sea Research Part A. Oceanographic Research Papers 37, 513–524 (1990).

2 M. Gedalin, T. Scott, and Y. Band, "Optical solitary waves in the higher order nonlinear schr¨odinger equation," Physical review letters 78, 448 (1997).

3 H. A. Haus and W. S. Wong, "Solitons in optical communications," Reviews of modern physics 68, 423 (1996).

4 S. Barland, J. R. Tredicce, M. Brambilla, L. A. Lugiato, S. Balle, M. Giudici, T. Maggipinto, L. Spinelli, G. Tissoni, T. Knoedl, et al., "Cavity solitons as pixels in semiconductor microcavities," Nature 419, 699 (2002).

5 B. Stephane, J. R. Tredicce, B. Massimo, L. A. Lugiato, B. Salvador, G. Massimo, M. Tommaso, L. Spinelli, T. Giovanna, K. Thomas, et al., "Cavity solitons as pixels in semiconductor microcavities," Nature 419, 699–702 (2002).

6 N. J. Zabusky and M. D. Kruskal, "Interaction of" solitons" in a collisionless plasma and the recurrence of initial states," Physical review letters 15, 240 (1965).

7 P. Shukla and B. Eliasson, "Nonlinear dynamics of large amplitude dust acoustic shocks and solitary pulses in dusty plas- mas," Physical Review E 86, 046402 (2012).

8 S. Kumar, S. K. Tiwari, and A. Das, "Observation of the korteweg-de vries soliton in molecular dynamics simulations of a dusty plasma medium," Physics of Plasmas 24, 033711 (2017).

9 P. Kaw, A. Sen, and T. Katsouleas, "Nonlinear 1d laser pulse solitons in a plasma," Physical review letters 68, 3172 (1992).

10 S. Sundar, A. Das, V. Saxena, P. Kaw, and A. Sen, "Relativistic electromagnetic flat top solitons and their stability," Physics of Plasmas 18, 112112 (2011).

11 A. Kumar, C. Shukla, D. Verma, A. Das, and P. Kaw, "Excitation of kdv magnetosonic solitons in plasma in the presence of an external magnetic field," Plasma Physics and Controlled Fusion 61, 065009 (2019).

12 D. J. Korteweg and G. De Vries, Xli. "On the change of form of long waves advancing in a rectangular canal, and on a new type of long stationary waves," The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science 39, 422– 443 (1895).

13 R. M. Miura, "The korteweg–devries equation: A survey of results," SIAM review 18, 412–459 (1976).

14 H. Ikezi, "Experiments on ion-acoustic solitary waves," The Physics of Fluids 16, 1668–1675 (1973).

15 J. N. Dinkel, C. Setzer, S. Rawal, and K. E. Lonngren, "Soliton propagation and interaction on a two-dimensional nonlinear transmission line," Chaos, Solitons & Fractals 12, 91–96 (2001).

16 T. Y.-T. Wu, "Generation of upstream advancing solitons by moving disturbances," Journal of fluid mechanics 184, 75–99 (1987).

17 S.-J. Lee, G. T. Yates, and T. Y. Wu, "Experiments and anal- yses of upstream-advancing solitary waves generated by moving disturbances," Journal of Fluid Mechanics 199, 569–593 (1989).

18 M. Sun, "The evolution of waves created by a ship in a shallow canal," The 60th Anniversary Volume Mechanics Essays, 17–25 (1985).

19 B. J. Binder, M. G. Blyth, and S. Balasuriya, "Non-uniqueness of steady free-surface flow at critical froude number,"EPL (Eu- rophysics Letters) 105, 44003 (2014).

20 N. F. Smyth, "Formation of one-dimensional waves for resonantflow in a channel,"pure and applied geophysics 133, 619–633 (1990).

21 A. Sen, S. Tiwari, S. Mishra, and P. Kaw, "Nonlinear wave excitations by orbiting charged space debris objects,"Advances in Space Research 56, 429 – 435 (2015), advances in Asteroid and Space Debris Science and Technology - Part 1.

22 S. Kumar Tiwari and A. Sen, "Wakes and precursor soliton excitations by a moving charged object in a plasma," Physics of Plasmas 23, 022301 (2016), https://doi.org/10.1063/1.4941092.
23 S. K. Tiwari and A. Sen, "Fore-wake excitations from moving charged objects in a complex plasma,"Physics of Plasmas 23, 100705 (2016), https://doi.org/10.1063/1.4964908.
24 S. Jaiswal, P. Bandyopadhyay, and A. Sen, "Experimental observation of precursor solitons in a flowing complex plasma,"Phys. Rev. E 93, 041201 (2016).
25 C. Tsang, B. A. Malomed, C. Lam, and K. Chow, "Solitons pinned to hot spots," The European Physical Journal D 59, 81– 89 (2010).
26 P. Shukla, "Aa mamun introduction to dusty plasma physics iop publishing ltd," (2002).
27 V. E. Fortov and G. E. Morfill, Complex and dusty plasmas: from laboratory to space (CRC Press, 2009).
28 G. E. Morfill and A. V. Ivlev, "Complex plasmas: An interdisciplinary research field,"Rev. Mod. Phys. 81, 1353–1404 (2009).
29 M. Bonitz, C. Henning, and D. Block, "Complex plasmas: a lab- oratory for strong correlations," Reports on Progress in Physics 73, 066501 (2010).
30 N. Rao, P. Shukla, and M. Yu, "Dust-acoustic waves in dusty plasmas", Planetary and Space Science 38, 543 – 546 (1990).
31 A. Barkan, R. L. Merlino, and N. DAngelo, "Laboratory obser- vation of the dustacoustic wave mode,"Physics of Plasmas 2, 3563–3565 (1995), https://doi.org/10.1063/1.871121.
32 P. K. Shukla and V. P. Silin, "Dust ion-acoustic wave,"Physica Scripta 45, 508 (1992).
33 F. Melandso/, "Lattice waves in dust plasma crystals,"Physics of Plasmas 3, 3890–3901 (1996), https://doi.org/10.1063/1.871577.
34 P. Bandyopadhyay, G. Prasad, A. Sen, and P. K. Kaw, "Experi- mental study of nonlinear dust acoustic solitary waves in a dusty plasma," Phys. Rev. Lett. 101, 065006 (2008).
35 D. Samsonov, A. V. Ivlev, R. A. Quinn, G. Morfill, and S. Zh- danov, "Dissipative longitudinal solitons in a two-dimensional strongly coupled complex (dusty) plasma,"Phys. Rev. Lett. 88, 095004 (2002).
36 J. Heinrich, S.-H. Kim, and R. L. Merlino, "Laboratory observations of self-excited dust acoustic shocks,"Phys. Rev. Lett. 103, 115002 (2009).
37 Y. Saitou, Y. Nakamura, T. Kamimura, and O. Ishihara, "Bowshock formation in a complex plasma,"Phys. Rev. Lett. 108, 065004 (2012).
38 A. Usachev, A. Zobnin, O. Petrov, V. Fortov, M. H. Thoma, H. Hfner, M. Fink, A. Ivlev, and G. Morfill, "Externally excited planar dust acoustic shock waves in a strongly coupled dusty plasma under microgravity conditions,"New Journal of Physics16, 053028 (2014).
39 E. Thomas, K. Avinash, and R. L. Merlino, "Probe induced voids in a dusty plasma,"Physics of Plasmas 11, 1770–1774 (2004).
40 J. Goree, G. E. Morfill, V. N. Tsytovich, and S. V. Vladimirov, "Theory of dust voids in plasmas," Phys. Rev. E 59, 7055–7067 (1999).
41 A. M. Lipaev, S. A. Khrapak, V. I. Molotkov, G. E. Morfill,
V. E. Fortov, A. V. Ivlev, H. M. Thomas, A. G. Khrapak, V. N. Naumkin, A. I. Ivanov, S. E. Tretschev, and G. I. Padalka, "Void closure in complex plasmas under microgravity conditions," Phys. Rev. Lett. 98, 265006 (2007).
42 M. Kaur, S. Bose, P. K. Chattopadhyay, D. Sharma, J. Ghosh, and Y. C. Saxena, "Observation of dust torus with poloidal rota- tion in direct current glow discharge plasma,"Physics of Plasmas 22, 033703 (2015).
43 M. Choudhary, S. Mukherjee, and P. Bandyopadhyay, "Experimental observation of self-excited co-rotating multiple vortices in a dusty plasma with inhomogeneous plasma background," Physics of Plasmas 24, 033703 (2017).
44 S. Jaiswal, P. Bandyopadhyay, and A. Sen, "Dusty plasma experimental (dpex) device for complex plasma experiments with flow,"Review of Scientific Instruments 86, 113503 (2015), https://aip.scitation.org/doi/pdf/10.1063/1.4935608.
45 S. A. Khrapak, S. V. Ratynskaia, A. V. Zobnin, A. D. Usachev, V. V. Yaroshenko, M. H. Thoma, M. Kretschmer, H. H¨ofner, G. E. Morfill, O. F. Petrov, and V. E. Fortov, "Particle charge in the bulk of gas discharges,"Phys. Rev. E 72, 016406 (2005).
46 S. A. Khrapak and G. E. Morfill, "Grain surface temperature in noble gas discharges: Refined

analytical model,"Physics of Plasmas 13, 104506 (2006), https://doi.org/10.1063/1.2359282.
47 Y. Feng, J. Goree, and B. Liu, "Accurate particle position measurement from images,"Review of Scientific Instruments 78, 053704 (2007), https://doi.org/10.1063/1.2735920.
48 S. Jaiswal, P. Bandyopadhyay, and A. Sen, "Flowing dusty plasma experiments: generation of flow and measurement tech- niques,"Plasma Sources Science and Technology 25, 065021 (2016).
49 G. Arora, P. Bandyopadhyay, M. G. Hariprasad, and A. Sen, "Micro-dynamics of neutral flow induced dusty plasma flow,"Physics of Plasmas 26, 023701 (2019), https://doi.org/10.1063/1.5078866.
50 W. Thielicke and E. Stamhuis, "Pivlab-time-resolved digital particle image velocimetry tool for matlab (version: 1.35)," J. Open Res. Software 2, e30 (2014).
51 G. Arora, P. Bandyopadhyay, M. G. Hariprasad, and A. Sen, "A dust particle based technique to measure potential profiles in a plasma,"Physics of Plasmas 25, 083711 (2018)

Exploring Thruster Potential of Compact ECR Plasma Source

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Abstract

The performance of a plasma thruster is assessed for efficient propulsion by analysing the unique characteristics of plasma produced by a Compact ECR Plasma Source (CEPS). For this purpose CEPS [1] was attached coaxially to two different sizes of expansion chamber, namely Small Volume Plasma System (SVPS, ID = 15 cm, Length = 37 cm) and Medium Volume Plasma System (MVPS, ID = 48.2 cm, Length = 75 cm). Argon plasma produced by CEPS at 2.45 GHz, cw, microwave frequencies was characterized using a cylindrical Langmuir Probe (LP) along the axis over a wide range of pressure. In the first study where the CEPS was attached to the SVPS, only the downstream plasma in the SVPS could be evaluated for its thruster properties since *no measurements could be performed within the harsh plasma environment of the CEPS* and so that plasma properties within the CEPS were unknown at the time. Within the SVPS, typical bulk and warm electron density, $n \approx 10^{11}$ cm^{-3} and $n_w \approx 10^8$ cm^{-3} respectively were measured at 0.5 mTorr and 500 W of microwave power. *A unique feature was the n/B = const. scaling observed along the axis over a wide range of argon pressure*. Bulk and warm electron temperatures ($T_e \approx 2.5$ eV and $T_w \approx 50$-60 eV) were uniform along the axis with the plasma potential dropping gently from $V_p \approx 27$ V to 18 V along the axis. Steady state equation of motion for ion was solved to calculate the ion flow velocity to evaluate the thrust produced by the system. Estimates yield peak thrusts of ~2.5 mN (at 0.5 mTorr) and 7.5 mN (at 0.05 mTorr), for moderately low microwave powers of ~500 W [2]. The MVPS experiments were conducted to accommodate low-pressure operation for reducing friction. Apart from other differences with the SVPS, a major difference is that the MVPS plasma *does not obey* the *n/B = const.* scaling seen in the SVPS. A completely new LP was designed and fabricated to withstand the plasma within CEPS, for assessing if the CEPS can provide significant thrust *on its own*. Inside the CEPS, at ≈ 0.5 mTorr and 600W, high plasma densities (≈ 10^{12} cm^{-3}) and high bulk electron temperatures (15-20 eV) were observed. Apart from this, the most unique feature of the CEPS plasma is the presence of *very high plasma potentials that are dropped sharply within a short distance by about ≈ 65 V, inside the CEPS itself* [3]. The latter drop can accelerate ions efficiently and the computed thrust *due to the CEPS alone* was found to be ≈ 38 mN. The latter values are *very high in comparison to existing thrusters like the helicon thrusters* (≈ few mN). This suggests that it might be possible to develop the CEPS into an efficient standalone thruster.

References:

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[1] Ganguli A and Tarey R D 2006 Permanent Magnet Compact Electron Cyclotron Resonance Plasma Generator Indian Patent # 301583, Patentee: IIT Delhi

[2] Ganguli A et. al. Plasma Sources Sci. Technol. **28**, 035014, (2019)

[3] Verma A et. al. Plasma Res. Express **1**, 035012, (2019)

Exploring Thruster Potential of Compact ECR Plasma Source

1. Introduction

Electric propulsion systems are the best candidate for long duration spacecraft control in deep space and interplanetary flights since they can produce high specific impulse at very small propellent mass flow rates [1]. Hall thrusters and gridded ion thrusters are among the most matured electric propulsion technologies employing electrostatic grids for ion acceleration [1, 2]. However, continuous need for neutralizers (external cathode) to neutralize the ion flux limits the thruster life since cathodes are prone to erosion. Helicon Plasma Thrusters (thrusts reported ~ few mN) and Variable Specific Impulse Magnetoplasma Rocket (VASIMR) (with additional ion heating to boost the thrust level up to ~ few N using kW of microwave power) [1, 2] are plasma based propulsion systems where the requirement of neutralizer is circumvented. Propellent in the form of plasma expands and accelerates through magnetic nozzles via internally generated ambipolar potential or double layer type of structures. However the need for bulky electromagnets and their power supplies increases the payload and remains a point of concern. Permanent magnet based plasma sources are therefore preferable to reduce the payloads. ECR plasma thrusters also utilize a combination of an ECR plasma source with a magnetic nozzle [3]. In this context, the development of ECR plasma thrusters has remained in a relatively nascent stage as these have not been explored very thoroughly, even though they have the advantages of electrodeless operation, negligible wall sputtering, high plasma densities and ability to operate at low pressures (10^{-5}-10^{-3} Torr).

Ganguli et. al. designed and built a permanent magnet based Compact ECR Plasma Source (CEPS) [4] and demonstrated its efficacy towards plasma production in various configurations and for different gases[5-7]. In the present work, CEPS was evaluated for thruster application. The initial experiments were performed in a small size expansion chamber; following these the expansion chamber was greatly increased in size to accommodate longer mean ion free paths for low pressure operation so that friction to ion flow may be minimized. *Ion energy is the most important plasma parameter for thrusters and the novelty of this work lies in harnessing the ECR mechanism for ion acceleration.* It is expected that efficient energy transfer via ECR mechanism can heat the electrons up to very high energies leading to high plasma potentials. The ion energies are commensurate with the generated ambipolar plasma potential and therefore appropriate for thrusters. The current studies were undertaken with this viewpoint, to understand the nature of plasma produced by CEPS and explore its thruster potential.

2. Experimental setup:

2.1 The CEPS: The CEPS are permanent magnet based, highly portable, high density plasma sources that afford great flexibility in the manner in which they may be used. The schematic of CEPS is shown in Fig1(a). The Plasma Source Section (PSS) comprises a stainless steel tube (ID 9.1 cm × Length 11.6 cm) in which plasma is produced by 2.45 GHz, cw, at different microwave power and gas pressure. The microwave is coupled to the plasma through a quartz window located at the back of CEPS. The PSS acts as a plasma loaded waveguide for the microwaves, where it is absorbed by the ECR process. The magnetic field is produced by a set of suitably designed NdFeB ring magnets placed around the PSS. By changing the position of magnet relative to the PSS, one can control the location of ECR layer. In the current studies, the latter lies near the centre, at z = -5.3 cm, z = 0 corresponds to the exit plane of the CEPS.

2.2 Expansion Chamber: Two different sizes of expansion chambers were used: (i) a Small Volume Plasma System (SVPS, ID 15 cm × Length 37 cm) and (ii) Medium Volume Plasma System (MVPS, ID 48.2 cm × Length 75 cm). The CEPS was attached coaxially to the respective expansion chamber as shown in Fig. 1(b). The diverging magnetic field of the source magnet penetrates into the expansion chamber and falls exponentially along the axis [$B = B_0 \exp(-z/\lambda_M)$, $\lambda_M = 9.2$ cm] as shown in Fig 1(c). Experiments were performed at different pressures ≤ 10 mTorr of argon gas and microwave power 500 W.

3. Results and Discussion:

3.1 SVPS: A cylindrical Langmuir probe (0.25 mm dia × 4 mm long Tungsten wire) was used to measure the on-axis plasma parameters downstream starting from z = 4.25 cm in SVPS. Plasma production results in SVPS at 0.5 mTorr argon pressure and 500 W microwave power are shown in Fig. 2. Profiles for bulk electron density, n and warm electron density, n_w are decaying exponentially along the axis with maxima ≈ 1.1×10^{11} cm^{-3} and 1.2×10^{8} cm^{-3} respectively at z ≈ 4.25 cm as shown in Fig. 2(a). The average $T_e \approx 2.5$ eV and $T_w \approx 55$ eV with their profiles uniformly constant along the axis as depicted in Fig. 2(b). Warm electrons are detected everywhere along axis and their significance lies in the fact that they have higher ionization cross sections that help to maintain the high plasma density. Fig. 2(c) illustrates the profile of plasma potential, V_p decreasing linearly very gently from 26.6 V to 18 V which in turn creates an ambipolar field to trap the bulk electrons and prevent wall losses. Electrons being highly magnetized are bound to the field lines and flow downward due to their thermal pressure. The ambipolar field pulls the ions along with the electrons so that a quasineutral plasma is maintained in the chamber.

Experiments were also carried out to ascertain the plasma characteristics with pressure. Fig. 3 compares axial profiles of n at ≈ 0.5, ≈ 5 and ≈ 10 mTorr pressure normalized with respect to their maximum values at z ≈ 4.25 cm. Normalized magnetic field intensity is also shown for reference. As expected, n increases with pressure on account of decreasing ionization mean free paths, while T_e and V_p decrease with pressure because of reduced electron energy (due to higher collisions) and reduced electron loss resulting in smaller ambipolar fields. Irrespective

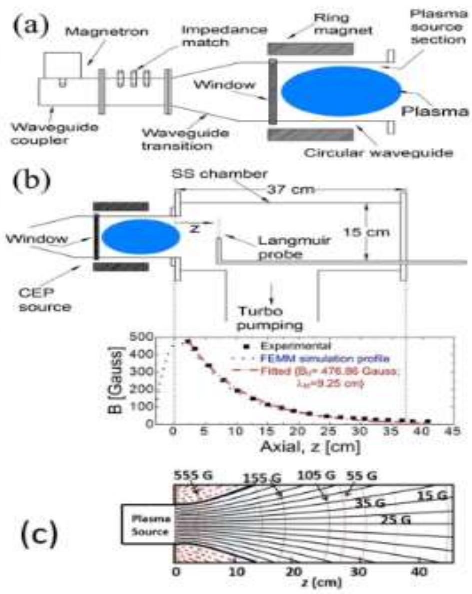

Figure 1. Schematic of: (a) the CEPS showing its various component; (b) thruster configuration showing schematic of CEPS attached with SVPS and LP placement. On-axis Magnetic field strength decaying exponentially after z = 2.5 cm. Please note that expansion chamber starts at z = 0 cm; (c) magnetic field lines in SVPS.

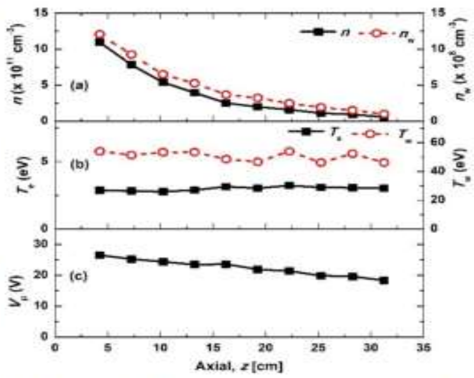

Figure 2 Axial profiles of plasma parameters at argon pressure ≈ 0.5 mTorr and microwave power ≈ 500 W in SVPS. (a) Bulk and warm electron density, n and n_w; (b) bulk and warm electron temperature, T_e, and T_w; (c) plasma potential, V_p.

of pressure, warm electrons were observed along the axis with even density scaling $n/n_w \approx 10^{-3}$. Fig. 3 also reveals the unique characteristic feature of SVPS where axial plasma density profile follows the axial magnetic field profile very accurately so that n/B = constant along the axis over a wide range of pressure. This unique feature results from the absence of transverse diffusion inside SVPS. Since most of the field lines inside SVPS are originated from inside of CEPS as seen from Fig 1 (c). These lines are preloaded with plasma. There are very few lines that enter the SVPS from outside CEPS and hence are not pre-loaded with plasma. Because of low cross-field diffusion of plasma, such lines remain unloaded, aiding the n/B scaling. For simplicity, one can restricts oneself to a thin tube (not a flux tube) centred near the axis for further evaluation of CEPS; this also allows one to treat all quantities as functions of z only ($r \approx 0$).

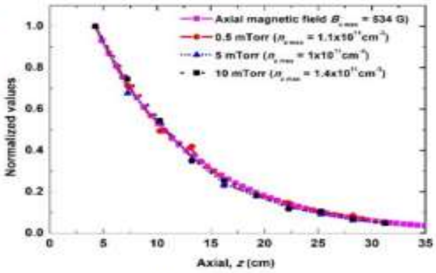

Figure 3 Normalized axial profiles of n (at different argon pressures) and B, normalized with respect to their corresponding values at z = 4.25 cm. Peak value of B at z = 2.5 cm is also shown for reference.

The plasma properties presented above can be regarded as a consequence of the double adiabatic equation of state

$$\frac{(p_\perp)^2 p_\parallel}{n^5} = const \qquad (1)$$

where $p_\perp(p_\parallel)$ are electron thermal pressure perpendicular (parallel) to the magnetic field. Using the definitions of thermal pressure $p_\perp(p_\parallel) = nT_\perp(T_\parallel)$ along with the experimental observation $n/B = const$ and condition of constant magnetic moment yield

$$\frac{(T_\perp)^2 T_\parallel}{n^2} = const \; \rightarrow \frac{(T_\perp)^2 T_\parallel}{B^2} = const \; \rightarrow T_\parallel = const \qquad (2)$$

Since $T_{e\parallel}$ is also constant in the present scenario, it helps the bulk electrons attain thermal equilibrium parallel to the magnetic field separately.

3.2 Thruster analysis: To evaluate thruster performance and determine its operation limits based on the measured on-axis data (Fig. 2 and Fig. 3), a simple ion flow model was developed for computing the steady state ion fluid velocity along the system [8]. The model includes the ambipolar field and friction (collision) inside the plasma.

$$nMu\frac{du}{dz} = neE - nMu\nu_i - nMu\nu_b - n_w Mu\nu_w \qquad (3)$$

Here, u is the ion fluid velocity, E is the ambipolar electric field, M is the ion mass, ν_i is the effective ion-neutral collision frequency (including elastic and charge-exchange collisions), ν_b and ν_w are the respective ionization frequencies due to impact of the bulk and warm electrons, on neutral atoms. Since no LP measurement could be possible inside the CEPS and only downstream plasma was characterized, the CEPS coupled with SVPS, was treated as the thruster. It was assumed that ions exit the source with their thermal energy ($\approx$ 0.025 eV), which was used as the

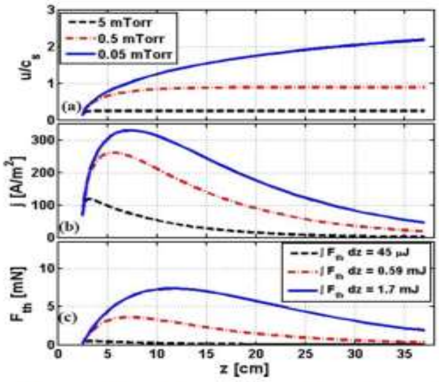

Figure 4 Simulated plots of (a) normalized ion velocities, u/c_s; (b) ion current densities, j [A/m^2]; (c) thrust F_{th} [mN] for three different pressures 5 mTorr, 0.5 mTorr and 0.05 mTorr in SVPS.

initial ion energy to solve equation (3). Using the profiles of the ion velocity and the plasma parameters one may determine the thrust profile ($F_{th} = nMu^2A$) along the system, where A denotes the areas of the constant z planes. The energy ($=E_{kin}$) imparted to the system *in a single pass of the plasma* can be computed from $E_{kin} = \int_0^L F_{th}dz$, where L is the system length. In general, F_{th} is not constant along the expansion chamber and so, E_{kin} may be used to compute the average thrust $F_{th,av}$ ($=E_{kin}/L$). The estimated axial profiles for current density, j and F_{th} are shown in Figs. 4((b) and (c)) respectively for different pressures. The average thrust values obtained for the system are ≈ 1.6 mN and 4.6 mN at 0.5 mTorr and 0.05 mTorr respectively; the corresponding peak values are 2.5 mN and 7.5 mN.

In this work, it was the *combination of the CEPS and the test chamber* that was regarded as the complete thruster and the estimated thrust values are quite encouraging. However, *it remains to be checked if it would be possible to regard the CEPS as a standalone thruster in its own right.* Therefore new experiments were planned in MVPS to enable low-pressure operation at ≈ 0.05 mTorr or so since ion mean free path are very large (≈ 60 cm at 0.05 mTorr) and friction can be reduced. *A special LP was designed and fabricated to probe the plasma inside the CEPS.* This would enable us to assess if the CEPS can provide significant thrust *on its own*.

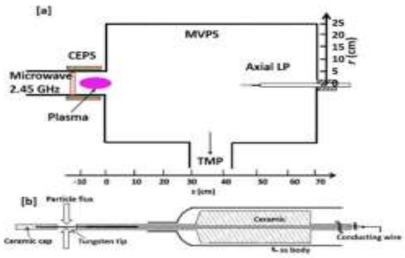

Figure 5 (a) MVPS with Langmuir probe alignment and (b) Enlarged view of LP

3.3 MVPS: The mounting of the MVPS and the LP placement are shown in Fig. 5(a). As shown in Fig 5(b) the LP was covered with a ceramic cap to avoid head-on bombardment by the plasma. This design arrived after many failures, allowed axial profiles of plasma parameters inside the CEPS. Data recorded starting from z = -3.5 cm (closest one could approach ECR layer at ≈ -5.3 cm) are shown in Fig. 6 for argon pressure ≈ 0.5 mTorr and microwave power ≈ 600 W. The figure also shows the best analytic fits to the experimental data. The different parameters are found to be: $n \approx 10^{12}$ cm^{-3}, bulk electron temperature, $T_e \approx 20$ eV and plasma potential, $V_p \approx 104$ V at $z \approx$ -3.5 cm. A small component of the warm electron population is also observed beyond $z \approx$ -1 cm with $n_w \approx 8\times10^9$ cm^{-3}, $T_w \approx 54$ eV at $z \approx$ -1 cm. However, by $z \approx 0$, bulk density *rises* to, $n \approx 2.25\times10^{12}$ cm^{-3} *with a concomitant decrease in* T_e (≈ 5 eV). Following these initial variations, n decreases very rapidly from $z \approx 0$ to $z \approx 7.5$ cm and more slowly after that to ≈ 3×10^{11} cm^{-3} by $z \approx 45$ cm. Also, after the initial sharp fall in temperature within the CEPS from ≈ 20 eV to ≈ 5 eV, T_e decreases slowly with z (to ≈ 2.4 eV upto $z \approx 20$ cm), settling finally at ≈ 2 eV at $z \approx 45$ cm. It is observed that plasma potential, V_p drops by about ≈ 65 V (from ≈ 104 V at $z \approx$ -3.5 cm to ≈ 39 V at $z \approx$ 0) for ≈ 0.5 mTorr. Beyond $z \approx 0$, V_p drops gradually (ignoring the kinks), decreasing to about ≈ 20 V by $z \approx 45$ cm. The sharp drop in V_p of about ≈ 65 V (within a span of 3.5 cm) inside the CEPS indicates that ions can be accelerated very efficiently as they exit the CEPS. Following this, V_p decreases more gradually, providing an ambipolar field that can help in overcoming

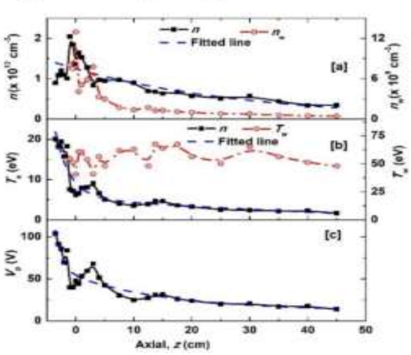

Figure 6 Axial profile of Argon plasma parameters at 0.5 mTorr and 600 W. Blue dashed line represent the analytical fit to the respective parameters.

friction due to collisions of ions with neutral atoms and maintaining the ion energy. Thus CEPS can be looked upon as an efficient thruster.

To see the effect of the geometric and magnetic field expansion, profiles of on-axis magnetic field and plasma density n (normalized with respect to their values at $z \approx 0$), have been plotted for pressures, ≈ 0.3, ≈ 0.5 and ≈ 1 mTorr in Fig. 7. Irrespective of pressures, it is seen that *densities fall faster than B* in an initial region from $z \approx 0$ up to $z \approx 5 - 7.5$ cm following a short transition region, $z \approx 10 - 15$ cm beyond which *densities fall slower than B* up to about, $z \approx 55$ cm. At this time, considerbale deviations from n/B scaling can be seen evidently.

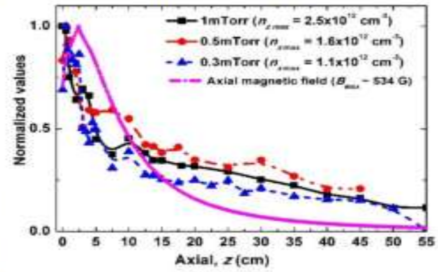

Figure 7 Axial n profiles at different pressures in MVPS normalized with respect to their corresponding value at $z = 0$ cm. Axial profile of B normalized with respect to its maximum value at $z = 2.5$ cm is also shown for reference.

The average thrust computed for the CEPS only using equation (3) (thus relieving the expansion chamber) was found $F_{th,av} \approx 38$ mN at 0.5 mTorr and ≈ 30 mN at 1 mTorr respectively. The specific impulse, I_{sp} (= $F_{th,av}/\dot{m}g$, where $\dot{m}$ is the mass flow rate and g is the acceleration due to gravity) may be estimated thus and yields $I_{sp} \approx 5265$ s, also the effective exhaust velocity, u (=$F_{th,av}/\dot{m}$) $\approx 5.16\times10^4$ m/s at 0.5 mTorr. The values of $F_{th,av}$ and I_{sp} computed here are high as seen from Fig. 8 and considerably larger than those achieved in typical helicon thrusters (maximum ~15 mN) till date.

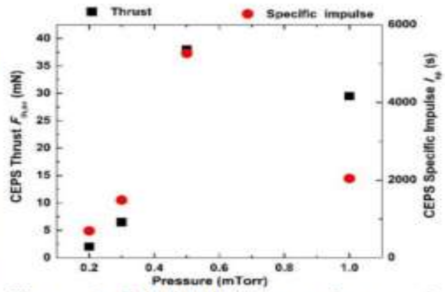

Figure 8 Calculated average thrust and specific impulse of CEPS.

4. Conclusion

In summary, argon plasma characterization results produced by CEPS attached to a small volume plasma system (SVPS) and medium volume plasma system (MVPS) are presented and analyzed to seek the efficacy of CEPS as a plasma thruster. Development and measurement of large plasma potentials inside CEPS was the main challenge and achieved with MVPS. As a result, large ion acceleration is predictable. A simple model, calculating the ion velocity exiting CEPS, yield fairly attractive values of $F_{th,av}$ and I_{sp} *for the CEPS* at moderate microwave power.

In addition, a global model including plasma expansion was also developed that succesfully reproduced the plasma parameters inside CEPS and estimated the thrust of CEPS in space like conditions. These results are not shown here but the thrust produced by this method also report the similar kind of outcomes encouraging us to see the CEPS as an efficient plasma thruster.

5. References:

1. Bathgate S N et. al. 2017 *Plasma Sci. Technol.* **19** 083001
2. Charles C 2009 *J. Phy. D: Appl. Phy.* **42** 163001
3. Ahedo E 2011 *Plasma Phys. Control. Fusion* **53** 124037
4. Ganguli A and Tarey R D 2006 Permanent Magnet Compact Electron Cyclotron Resonance Plasma Generator Indian Patent # 301583, Patentee: IIT Delhi
5. Ganguli A et. al. 2016 *Plasma Sources Sci. Technol.* **25** 025026
6. Tarey R D et. al. 2017 *Plasma Sources Sci. Technol.* **26** 015009
7. Verma A et. al. 2019 *Plasma Res. Express* **1** 035012
8. Ganguli A et. al. 2019 *Plasma Sources Sci. Technol.* **28** 035014

Multi-wavelength signatures of build up, activation and eruption of a magnetic flux rope from the solar atmosphere

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1. Introduction

The 'standard flare model'; also known as CSHKP model [1] recognizes the preexistence of a magnetic flux rope (MFR) in the AR prior to eruptive flares. MFRs are defined as a set of magnetic field lines which are twisted around its central axis more than once. These complex structures are believed to be formed as a result of flux cancellation over the PIL through photospheric shearing and converging motions; however, the exact mechanism for flux rope formation is still unclear and debatable. Successful eruption of an MFR results in to a CME. To explain the triggering of eruption, two different classes of models have been proposed: ideal instability and resistive instability. The resistive instabilities rely on initial reconnection on a current sheet in order to trigger the eruption of an MFR. Two models for reconnection based triggering-tether cutting [2] and breakout model [3] include pre-flare reconnection in active regions with different magnetic configurations. The tether cutting model involves highly sheared magnetic arcades in a bipolar active region where the initial reconnection takes place deep inside the sheared core field. According to this model, the triggering occurs below the MFR and the energy released during the small-scale pre-flare reconnection pushes the MFR upwards. On the contrary, the breakout model involves much complex active regions with at least four distinct sets of strong magnetic flux systems and a magnetic null well above the core flux where a breakout current sheet is formed. Triggering occurs in the form of initial reconnection at the breakout current sheet which removes the downward magnetic tension allowing the core field to erupt. Once the MFR attains eruptive motion, standard flare reconnection sets in beneath the erupting MFR between the inflow magnetic fields and the multi-wavelength signatures of standard flares (i.e., footpoint and looptop hard X-ray (HXR) sources, chromospheric flare ribbons, post-flare arcades, cusp structures following the passage of the MFR etc.) are observed thereafter.

The temporal evolution of a typical eruptive flare can be summarized in three phases: pre-flare/ precursor phase, impulsive phase, and gradual phase. While the processes occurring during the impulsive and gradual phases are well explained by the CSHKP model, the pre-flare phase remains unexplained. Pre-flare activities prior to a flare, are considered to be important in order to understand the physical conditions that lead to flares and associated eruptions [4]-[7]. Statistical study conducted based on Yokoh/SXT observations suggested that pre-flare activities can be classified into three categories: co-spatial, adjacent (or overlapping), and distant; depending on the spatial separation between the pre-flare and flare activity sites in the same field of view. While the abundance of co-spatial and adjacent pre-flare activities and their physical connection with the main flare have been reported before by many case studies; distant pre-flare activities and their involvement in triggering the main flare have been reported rarely. In this article we are reporting multiwavelength analysis of a unique dual-peak M-class flare associated with a distant pre-flare activity on 2015 June 21 from the famous active region NOAA 12371. Our analysis successfully explains the occurrence of the pre-flare energy release and by employing non-linear force free field (NLFFF) [8]; we have investigated the role of the pre-flare activity toward triggering the main flare.

2. Observational Data and methods

For observing the Sun in (E)UV wavelengths, we use high resolution (0."6 pixel^{-1}), 4096×4096 pixel full disk observations from the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (SDO) [9]. For photospheric observation, we use 45 s cadence line of sight (LOS) magnetograms and intensity images observed by Helioseismic and Magnetic Imager (HMI) on board SDO, which takes continuous full disk observation of the solar photosphere with spatial resolution of 0."5 pixel$^{-1.}$ Coronal magnetic field extrapolation was done by employing the optimization based non-linear force free field (NLFFF) extrapolation method developed by [8]. The Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) [10] provided uninterrupted X-ray observations of the Sun during most of the flaring activity

3. Pre-flare magnetic field variations

In Figure 1, we plot the evolution of the LOS magnetic flux through the whole AR12371 as well as only from the trailing sunspot region from 2015 June 20 12:00 UT to 2015 June 21 05:00 UT. The trailing sunspot group has been shown within the box in Figure 1(a). Notably, the eruptive flare under investigation triggered from this region. The north-western part of the trailing sunspot group was associated with striking moving features. From Figure 1(b)-(c), we readily find that both the positive and negative flux from AR 12371 increased during ≈13:30 UT- ≈23:00 UT (Phase 1) and thereafter decreased till the onset of the flare at 01:05 UT on 2015 June 21 (Phase 2) from the whole active region, as well as the flaring region. To have an understanding of flaring activity in the active region, we have plotted the variation of GOES SXR flux along with AIA 94 intensity during 2015 June 20 12:00 UT to 2015 June 21 05:00 UT in Figure 1(d). We find that during this interval, there was no appreciable enhancement of SXR and EUV fluxes prior to the onset of the M-class flare on 2015 June 21 ≈01:05 UT.

4. Coronal magnetic field modeling and flux rope manifestation

In order to understand the coronal connectivities between the different photospheric regions, we performed non-linear force free field (NLFFF) extrapolation of the active region prior to the onset of the impulsive phase of the M-class flare. In Figures 2(a) and (b), we display different sets of NLFFF field lines associated with the trailing sunspot group, from top and side views, respectively. The NLFFF results readily suggest the presence of an extended flux rope over the PIL which was enveloped by a set of low coronal closed loop connecting the opposite polarity regions of the trailing sunspot group. The region associated with multiple moving magnetic features along with several flux appearance and decay of both polarities

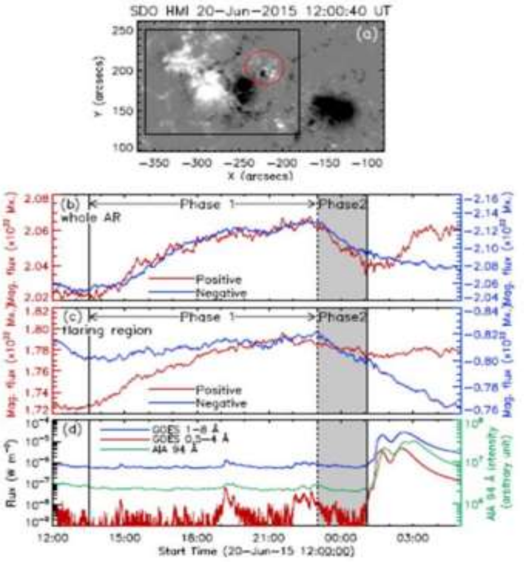

Figure 1. Panel a: HMI LOS magnetogram of AR 12371. We outline the flaring region in the AR by the black box. Panel b: Evolution of magnetic flux in the whole active region from 2015 June 20 12:00 UT to 2015 June 21 05:00 UT. Panel c: Evolution of magnetic flux in the flaring region (within the box in panel a) in the same interval as in panel b. In panel d, we plot GOES SXR light curves in both the channels as well as the AIA 94 Å intensity variation during the same interval as in panels d and e. In panels b-d, the interval marked as `Phase 1' depicts flux emergence of both polarities in the active region as well as flaring region. `Phase 1' was followed by a period of flux cancellation of both polarities ('Phase 2'; the shaded region) up to the initiation of the M-class are on 2015 June 21.

(the region within the circle in Figure 1(a), displayed a complex configuration where closed magnetic loops are distributed in a chaotic manner which is suitable for initiating magnetic reconnection. In Figure 2, we display extrapolated loops of this region by the pink lines. Also notably, this region was connected with the trailing sunspot region by the orange loops. Further, we identified a set of closed field lines (shown by the yellow colored lines) connecting the opposite polarity sunspots in the trailing sunspot region, a part of with were situated at a very close proximity of the pink lines. A different set of field lines (shown by the sky colored lines in Figure 2(b)) were generated at the moving positive magnetic patches and terminated at the negative sunspot in the trailing

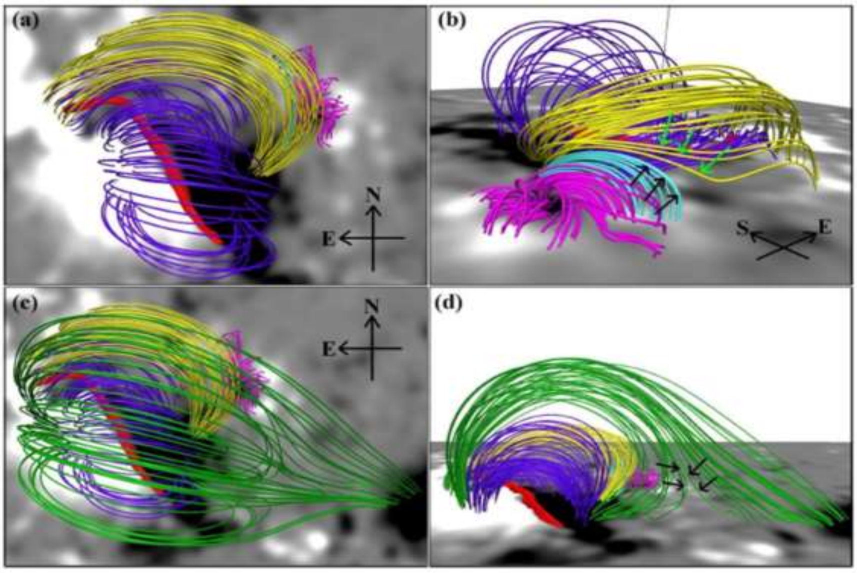

Figure 2. Non-linear force free field extrapolation results during the pre-flare phase indicating the presence of a flux rope over the main polarity inversion line of the trailing sunspot (red lines), a set of low coronal overlying field lines enveloping the flux rope (blue lines), a set of large high coronal field lines (shown by the green color). Notably, the region associated with few randomly oriented field lines (shown by pink lines) displayed striking photospheric changes including moving and rotational motion. A set of field lines originated at the negative sunspot (the yellow lines) connected the northern part of the positive sunspot, a part of which was at a very close proximity to the pink lines. We identified another set of field lines (sky lines) in between the yellow lines and pink lines, which constructed a quasi-separatrix layer (QSL). In panels (a) and (b), we focus on the coronal magnetic field configuration associated with the flaring region from two different angles. In panels (c) and (d), we show the coronal configuration in the whole active region from different angles. For directional reference, we have plotted compass in panels (a)-(c). The background white region in panel (d), direct to the northern side.

sunspot group, separating the yellow lines from the pink lines. Notably, few of the yellow lines and the sky colored lines displayed drastic change in the field-line linkage (indicated by black and green arrows in 2(b)) which are known as "quasi-separatrix layers" (QSLs) [27]. In Figure 2(c) and (d), we display the coronal connectivities in the whole active region from top and side views, respectively. Apart from the complex distribution of magnetic loops in the trailing sunspot group, we find large coronal loops connecting positive regions of the trailing sunspot group to the leading sunspot groups (shown by green lines in Figure 2(c)-(d)). Notably, a part of the green lines originating at the positive polarity region was connected with the adjacent negative polarity region. Interestingly, these two sets of green lines also constituted a QSL which we indicate by black arrows in Figure 2(d)

5. EUV observation and results

In Figure 3, we plot a series of AIA 94 Å images displaying the active region NOAA 12371 during. different phases of the M-class flare. We readily observe the presence of a prominent hot channel at the core of the active region during the pre-flare phase (marked by the yellow arrow in Figure 3(b)). Comparison of the location of the hot channel with the HMI LOS magnetogram contours in Figure 3(a)

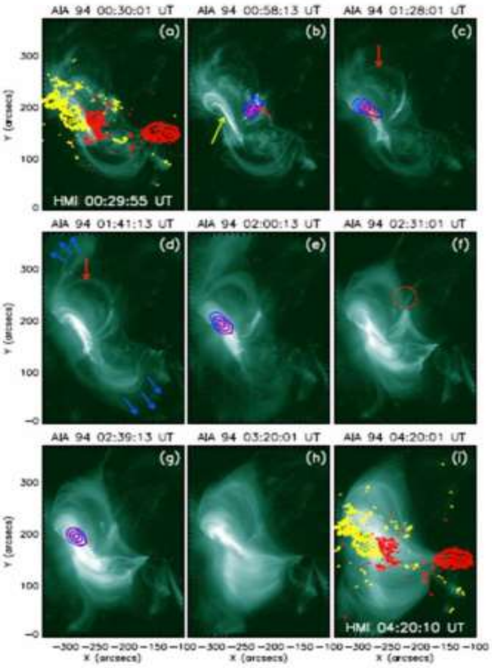

Figure 3. Series of AIA 94 Å images showing the evolution of the M-class flare on 2015 June 21 from the active region NOAA 12371. A distinct hot channel was observed during the pre-flare phase over the polarity inversion line in the active region which is marked by the yellow arrow in panel (b). A remote brightening observed prior to the onset of the flare is indicated by the red arrow in panel (b). The red arrows in panels (c) and (d) indicate a slipping reconnection region connecting the remote region and the northern leg of the hot channel. The blue arrows in panel (d) indicate the direction of erupting plasma during the impulsive phase of the flare. The red dashed circle in panel (f), indicate a QSL structure which possibly involved the yellow and sky colored lines of Figure 2. Co-temporal HMI LOS magnetogram contours are overplotted in panels (a) and (i) at ±(500; 800; 1500; 2000) G. Red and yellow contours refer to negative and positive polarity, respectively. Co-temporal RHESSI contours in the energy bands 6-12 keV (red) and 12-25 keV (blue) are overplotted in selective panels. Contour levels are 60%, 80% and 95% of the corresponding peak flux. All the images are derotated to 21-Jun-2015 00:30 UT.

confirms that the hot channel was lying over the PIL in the trailing sunspot of the active region. After ≈00:52 UT, we observed a localized yet prominent brightening from a location near to the hot channel (marked by the red arrow in Figure 3(b)). Brightness of this localized region initially increased up to ≈01:05 UT and then decreased till ≈01:10 UT before increasing again. Notably, the pre-flare episodic brightness observed in AIA 94 Å images are exactly co-temporal with the GOES SXR precursors observed at ≈01:05 UT and ≈01:14 UT. A very interesting phenomenon was observed at ≈01:28 UT in the form of slipping reconnection from this region to the northern leg of the hot channel through a closed coronal loop. In Figure 3(c), we indicate slipping brightness by the red arrow. Comparing the brightness of the loop at 01:28 UT and 01:08 UT (Figure 3(c) and (b), respectively), one can find clear impressions of the enhanced brightness caused by the slipping reconnection. Notably, the flare had already entered in the impulsive rise phase by that time since the hot channel got activated. During this time, we noted HXR emission of energies up to ≈25 keV predominantly from the northern part of the hot channel. The slippage of brightness from the adjacent brightening to the northern end of the hot channel was immediately followed by eruption of the hot channel. In Figure 3(d), we indicate the direction of the hot channel eruption by the blue arrows. The eruption phase was followed by formation of post flare arcade in the trailing sunspot (Figure 3(e)) which are associated with HXR emission of energies up to ≈25 keV. A second phase of the eruption was observed between ≈01:53 UT and ≈02:05 UT followed by further restructuring of the active region loops at even larger scales, as inferred from the formation of large post flare arcade connecting the trailing sunspot with the leading sunspot. Interestingly, during this time, we could observe the QSL structure formed by the sky and yellow field lines (see Figure 2, Section 3) even in the direct observations (indicated by the dotted circle in Figure 3(f)). The large post flare arcade was associated with strong diffused emission till ≈02:40 UT (Figure 3(g)) when the flare reached its second peak. The active region did not show any morphological change afterwards till the end of our studied period except the brightness of the large post flare arcade slowly reduced as the flare had moved into the gradual phase (Figures 3(h) and (i)). The above observations led [11] to conclude that two distinct phases of magnetic reconnection occurred in the wake of single, large hot channel eruption.

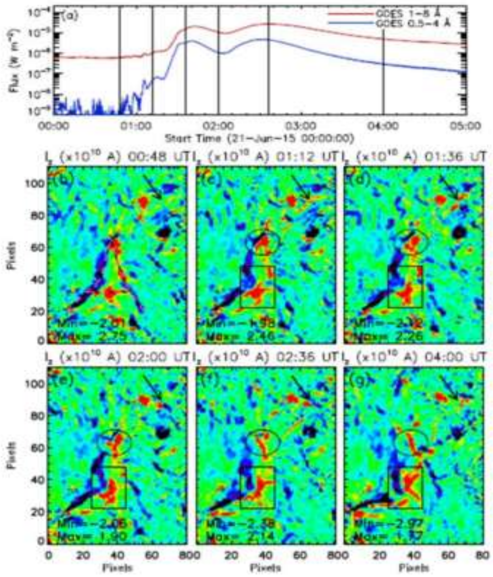

Figure 4. Panel (a): GOES SXR lightcurves showing the evolution of the M-class flare on 2015 June 21. We select six instances during the evolution of the flare (marked by the vertical lines). In panels (b)-(g), we plot the distribution of vertical component of photospheric current in the triggering at those instances. Notably, few regions of strong current of opposite polarity constitute a structure similar to the English letter 'Λ' which is outlined by the black-pink dashed lines in panel (b). We highlight few major changes in the distribution of current by the arrow, oval and box in panels (c)-(g). For better visualization, values of I_z are saturated at $\pm0.5\times10^{10}$ A. Maximum and minimum values of I_z with order of 10^{10} A within the selected fov are indicated in each of these panels.

6. Pre-flare activity

From AIA EUV images (Figures 3) it is clearly understood that the earliest flare brightening occurred west of the pre-existing hot channel (i.e., MFR) which evolved with time but within a localized region. For further investigation of the triggering region, we computed photospheric current density from the triggering region. The vertical component of current density (j_z) on the photosphere can be calculated from horizontal components of magnetic field (B_x and B_y) using the Ampere's law [12]:

$$j_z = \frac{1}{\mu_0}\left(\frac{dB_y}{dx} - \frac{dB_x}{dy}\right)\ldots\text{(i)}$$

From current density (j_z), we derive current (I_z) by multiplying j_z with the area of one pixel i.e., $\approx13.14\times10^{10}$ m^2. From the spatial distribution of I_z prior to the hot channel activation, we find that the PIL region in the trailing sunspot had a large concentration of negative current with the maximum and minimum values of I_z in the active region being 2.09×10^{10} A and -2.24×10^{10} A, respectively. It is noteworthy that the region displaying precursor brightenings in the corona and underlying moving magnetic features in the photosphere exhibited a complex distribution of I_z. We have indicated this region by the circle in Figure 1(a) and identify this as the triggering region. In Figure 4, we show the evolution of the spatial distribution of I_z in the triggering. For convenience, we have plotted GOES SXR lightcurves are plotted in Figure 4(a) where the timings of the Figures 4(b)-(g) are indicated by the vertical lines. We find that, in the triggering region, small-scale regions of both positive and negative I_z were mostly distributed randomly. However, an interesting structure of the shape 'Λ' formed by I_z was very clear in the region during the pre-flare phase. In the 'Λ' shaped distribution, the left arm was completely made of negative I_z while the right arm was consisted by the positive I_z in the northern part and negative I_z in the southern part. The connecting part of the arms in the 'Λ' was consisted of positive I_z. During the SXR pre-flare enhancement, in the northern tip of the structure (outlined by the oval shape in Figures 4(b)-(g)), I_z of opposite polarities became very close to each other (Figures 4(b) and (c)) which may be ideal for dissipation of current in the form of magnetic reconnection. As Figures 4(d)-(g) suggests, with the evolution of the flare, strength of I_z at the tip of the 'Λ' was significantly decreased and the left arm of the 'Λ' became fragmented (indicated within the box in Figures 4(b)-(g)). We spotted another interesting feature from Figures 4(b)-(g) in the form of appearance and decay of a positive current region which we indicate by the black arrows.

7. Summary and conclusions

In summary, the active region NOAA 12371 went through an elaborate phase of flux enhancement followed by a phase of significant flux cancellation which led to build up and activation of a flux rope along the PIL in the trailing sunspot group. The active region was associated with highly dynamical features including photospheric motion and rotation which led to formation of localized regions of high photospheric current densities. The remote pre-flare location of associated of such strong current regions of opposite polarities in very close proximity which possibly initiated the early pre-flare reconnection. Once the initiation of pre-flare reconnection, it quickly induced a series of activities similar to domino effect that includes enhanced thermal and non-thermal emission from the remote region, triggering of slipping reconnection between the remote region and the northern end of the flux rope, triggering of the already metastable flux rope toward eruption.

References

[1] Priest, E. R., & Forbes, T. G. 2002, A&A Rev., 10, 313
[2] Moore, R. L., & Roumeliotis, G. 1992, in IAU Coll. 133, Eruptive Solar Flares 399, ed. Z. Svestka, B. V. Jackson, & M. E. Machado (Berlin: Springer), 69
[3] Wyper, P. F., Antiochos, S. K., & DeVore, C. R. 2017, Nature, 544, 452
[4] Chifor, C., Tripathi, D., Mason, H. E., & Dennis, B. R. 2007, A&A, 472, 967
[5] Joshi, B., Veronig, A. M., Lee, J., et al. 2011, ApJ, 743, 195
[6] Joshi, B., Kushwaha, U., Cho, K.-S., & Veronig, A. M. 2013, ApJ, 771, 1
[7] Mitra, P.K., Joshi, B., 2019, arXiv:1908.04059.
[8] Wiegelmann, T., Thalmann, J.K., Inhester, B., et al., SoPh. 2012, 281, 37
[9] Pesnell, W. D., Thompson, B. J., & Chamberlin, P. C. 2012, SoPh, 275, 3
[10] Lin, R. P., Dennis, B. R., Hurford, G. J., et al. 2002, SoPh, 210, 3
[11] Joshi, B., Ibrahim, M.S., Shanmugaraju, A., Chakrabarty, D., 2018, SoPh, 293, 107
[12] Kontogiannis, I., Georgoulis, M.K., Park, S.-H., Guerra, J.A., 2017, SoPh, 292, 159


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