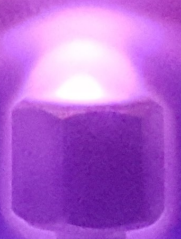
NPVM-2018

NFP-PFRC Vision Meeting

10 years of National Fusion Programme

26-28 April, 2018

Book Of Abstracts



Jointly Organized by

Institute for Plasma Research, Gandhinagar

&

Nirma University, Ahmedabad

NFP-PFRC Vision Meeting-2018

To commemorate 10 years of National Fusion Programme

26-28 April, 2018

Nirma University, Ahmedabad

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To commemorate 10 years of National Fusion Programme

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Dear Colleagues,

This meeting is being held as per the recommendations of the Plasma & Fusion Research Committee of BRNS, to commemorate 10 years of National Fusion Programme (NFP) and the R&D activities funded under BRFST and now PFRC in the areas of Plasma & Fusion Science and Technology and allied areas. This meeting will take stock of the R&D work carried out in the last 10 years and will also look ahead to the next 10 years and plan the roadmap for the new areas of R&D that potential PI's can take up in the coming years.

I hope all of you will contribute to the future of the National Fusion Programme and play a major role in India's fusion programme.

Thank you !

Dr. N. Ramasubramanian
Convener

Gandhinagar
04-April-2018

NFP-PFRC Vision Meeting (NPVM-2018)

DAY 1			**26-Apr-2018**	Proposed Speaker	Proposed area of talk
09:00	09:30		Participant Registration		
09:30	11:00		Inauguration & words from VC Nirma University / PFRC members / Scientific Secretary BRNS / Dean R&D IPR		
11:00	11:30		Tea		
Session 1 : Plenary Talks			**Session Chair : Prof. Sangita, BRNS**		
11:30	12:00	KN-1	Keynote address	P. I. John, Chairman PFRC	Broad talk on 10 years of BRFST/PFRC
12:00	12:30	PT-01	Plenary Talk-1	R. Srinivasan (IPR)	Tokamak Research in India and its future
12:30	13:00	PT-02	Plenary Talk-2	S. Mukherjee (IPR)	Societal benefits of plasma & allied technologies
13:00	14:00		Lunch		
Session 2 : Materials			**Session Chair : Dr. T. Jayakumar**		
14:00	14:30	IT-01	Materials-1	S. Saroja (IGCAR)	R&D of materials at IGCAR
14:30	15:00	IT-02	Materials-2	Paritosh Chaudhuri (IPR)	Materials for blanket applications
15:00	15:30	IT-03	Materials -3	Samir Khirwadkar (IPR)	Materials for plasma facing components
15:30	16:00	IT-04	Materials-4	Arun Chakraborty (IPR)	Joining of materials
16:00	16:20		Tea		
16:20	17:20	PD-1	Panel, Discussion -1		
17:30	18:00		Transport to IPR		
18:00	20:00	**Session 3**	**Poster session (At IPR)**		
20:00	21:30		Director's Dinner at IPR		
22:00			Back to hotels		
DAY 2			**27-Apr-2018**		
Session 4 : Magnets & Cryogenics			**Session Chair : Prof. Amit Roy**		
09:30	10:00	IT-05	Cryogenics - 1	Ranjana Gangradey (IPR)	Cryo projects - Industry Collaborations
10:00	10:30	IT-06	Cryogenics - 2	A. K. Sahu (IPR)	Magnets & Cryogenics
Session 5 : Basic Plasma & Simulation			**Session Chair : Prof. Robin Pal**		
10:30	11:00	IT-07	Basic Plasma	Pintu Bandopadhyay (IPR)	Summary and future plans of basic plasma experiments

11:00	11:30	IT-08	Simulation Studies	R. Ganesh (IPR)	Plasma simulation
11:30	12:00		TEA		
Session 6 : RF & Microwave			**Session Chair : Prof. sanjeev Gupta, DAIICT, Gandhinagar**		
12:00	12:30	IT-09	RF & Microwave - 1	P. K. Sharma (IPR)	High power RF technologies
12:30	13:00	IT-10	RF & Microwave - 2	S. K. Pathak (IPR)	Low power RF /microwave diagnostics & instrumentation
13:00	14:00		Lunch		
14:00	14:30	BRNS	BRNS Information Talk	Dr. Sangita, Scientific Secretary, BRNS	
Session 7 : Diagnostics & Societal Applications			**Session Chairman : Prof. A. K. Ray**		
14:30	15:00	IT-11	Diagnostics - 1	Malay B. Chaudhuri (IPR)	Passive (non-intrusive) diagnostics
15:00	15:30	IT-12	Diagnostics - 2	Daniel Raju (IPR)	Probe and other diagnostics
15:30	16:00	IT-13	Plasma Applications	S. K. Nema (IPR)	Plasma applications for societal benefits
16:00	16:30		TEA		
16:30	20:00	PD-02	Panel Discussion - 2		
20:00	21:30		Dinner (Nirma University)		
22:00			Back to hotel		
DAY 3 28-Apr-2018					
Session 8 : Robotics / Neutronics : Session Chairman : Dr. Dhaval Pujara (Nirma University)					
09:30	10:00	IT-14	Robotics	K. K. Gotewal (IPR)	Robotics and VR for fusion applications
10:00	10:30	IT-15	Neutronics	P. V. Subhash (IPR)	Neutronics for fusion
10:30	11:00	IT-16	Electronics	Haresh Dave (IPR)	Electronics for plasma diagnostics
11:00	11:30		TEA		
11:30	14:00	PD-03	Panel Discussion & Concluding session		
14:00	15:00		Lunch		

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INVITED TALKS

KN-01

The National Fusion Programme : Retrospect, Prospect

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Abstract

In the past decade, a programme of involving Universities, IITs, NITs and industries in research and development in fields associated with Plasma Physics and Thermonuclear Fusion was being pursued under the National Fusion Programme. The primary objective of this was to broaden the research base beyond the national laboratories. An assessment of this programme is being attempted now.

In 2006, India became a party to the ITER Treaty for building the world's first Fusion Reactor at Cadarache in France. In addition to monetary contributions, India will supply 10% of technology & machine components identified in a procurement package. The huge spectrum of technologies, the 'balance of ITER' which make up the reactor, will have to be learnt outside this activity. The imperative behind the NFP is that while IPR prepares for and delivers its commitment to ITER, it was essential that we start a long-term programme aimed at developing indigenous competence in all aspects of fusion science and technology with a view to be ready to take up designing and building a demo reactor after the successful operation of ITER.

The mandate of NFP includes nucleating and nurturing a community of non-fusion scientists and technologists within the University-IIT-NIT system who will work actively on frontier areas of fusion physics, technology and modeling, partnering with industries to help them acquire capacity to contribute to fusion technology, development of human resources and promotion of activities like conferences, symposia etc to enable the fusion community to interact and network.

A successful example of the NFP effort to reduce the technology gaps is worth mentioning. ITER will demonstrate fuel sustainability by producing Tritium from Lithium in the reactor. Preparation of Lithium bearing ceramic pebbles is a core fusion technology to be acquired. In a green field programme, a number of routes by a number of groups were tried out to prepare Lithium titanate powder. Full indigenous competence has been acquired through this effort.

To conclude, The NFP Programme has been able to nucleate and nurture a community of scientists and technologists in the multi-disciplinary field of plasma physics and fusion technologies. The activities are continuously growing, and the manpower accretion is significant.

PT-01

Tokamak Research In India And Its Future

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Abstract

For the past four decades, the tokamak research in India has grown relentlessly with a focus on fundamental research. This yielded us to identify intermittency first time in ADITYA tokamk and others followed later. The fundamental research paved way for realizing technologically challenging tokamak device SST-1 to address all the issues related to steady state operation of tokamak. This is a prerequisite to build a fusion reactor for generating electricity. In realizing SST-1, many technological challenges like fabrication of large vacuum vessel, large superconducting magnets with cryogenic facility, high power radio frequency systems, and high heat flux material are overcome with R & D labs and industrial supports. With this experience, India participated in making ITER as equal partner. This needed to bring universities, national labs and industries to address various issues through BRFST / PFRC. R&D areas like numerical simulations, tokamak diagnostics, and functional materials for tokamak applications, heating and current drive systems, plasma facing components and blanket technologies have been addressed in the past under the BRFST/PFRC programmes.

In this talk, the present achievements and future directions in tokamak research will be addressed.

PT-02

Societal Benefits Of Plasma Technologies – Alignment Of Future R&D Towards DAE 11-Point Vision

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Abstract

In the recent years, globally a lot of emphasis is laid on plasma applications. At FCIPT division of IPR, many plasma based technologies have been developed and transferred to the industries for its effective use. Some of the well known technologies that are recently transferred are

- Plasma pyrolysis for disposal of biomedical and organic waste
- Plasma nitriding for improvement of hardness of industrial components
- Plasma jet for biomedical applications
- Plasma assisted nano-powder production
- Plasma assisted surface modification of textiles

There are many other plasma technologies that are developed at IPR, which include energy recovery from waste, nanopatterning of surfaces, altering seed germination, pesticide degradation, plasma thruster development, plasma antennae, etc., the need of the hour is to focus on those plasma based technologies that have a societal benefit.

Recently DAE has released its 11-point vision document which works as a guide for all future R&D of DAE. Out of the 11 points, 3 such points are of direct societal relevance. They are

- Point 4 – Health care
- Point 5 – Food security
- Point 6 - Water & waste management

And in each of these areas plasma based technologies, either directly or indirectly, can play a key role. PFRC-BRNS can play an important role in identifying and nurturing the PIs in the universities who would not only develop plasma technologies for societal benefit but also work towards making it cost effective.

IT-01

R&D Of TBM Materials At IGCAR

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Abstract

9Cr Reduced Activation Ferritic-Martensitic (RAFM), has been selected as the structural material for the first wall of the Indian Test Blanket Module (TBM) due to its excellent void swelling resistance in addition to adequate mechanical properties and corrosion resistance in liquid metals. An intensive indigenous R&D effort by a team of scientists and engineers from IGCAR in close collaboration with IPR and Indian industries has led to the successful realization of India-specific RAFM steel. The work had several challenging components starting with (i) establishing the country's capability for producing RAFM steel with strict control on chemistry of radioactive tramp elements (Mo, Nb, B, Cu, Ni, Al, Co, Ti) and embrittlement promoting elements (S, P, As, Sb, Sn, Zr, O) for its physical and mechanical properties to match with the internationally developed RAFM steel, (ii) intensive laboratory scale R&D to optimize the composition w.r.t Tungsten and Tantalum contents to obtain the required mechanical properties and arrive at the specifications of Indian RAFM steel, (iii) commercial scale development of Indian RAFM steel, (iv) generation of a comprehensive materials database and (v) development of technologies for design and fabrication of complex components.

To start with pilot scale melting of RAFM steel similar to Eurofer 97 was carried out with selection of pure raw materials, employing vacuum induction melting and vacuum arc refining and the steel was obtained in normalized and tempered condition. The steel had a tempered martensitic microstructure with coarse carbides Cr and W rich $M_{23}C_6$ on the lath boundary and fine intralath Ta and V rich MX precipitates. The entire transformation sequence for the steel was established by calorimetry to identify the temperature windows for different thermo-mechanical treatments. The tensile, impact, fatigue and creep properties studied over a range of temperatures and stress levels were in good agreement with Eurofer 97.

In the second phase of development, steels with tungsten and tantalum contents in the range of 1-2 wt. % and 0.06-0.14 wt. % respectively were produced. Extensive characterization and structure-property correlation studies provided an in-depth understanding on the influence of W and Ta on the phase transformations, microstructural stability and mechanical properties. Based on these detailed investigations the chemical composition of the India-specific RAFM steel of 9Cr-1.4W-0.06Ta was arrived at which was designated as Indian Reduced Activation Ferritic Martensitic (INRAFM) steel. The third stage involved large scale production of the INRAFMS into product forms of different dimensions. A comprehensive material data base on various properties such as thermal expansion, thermal diffusivity, thermal conductivity, elastic properties, magnetisation behaviour, specific heat etc. has been generated at IGCAR. Evolution of secondary phases including intermetallic phases during thermal exposures and under stress and their influence on creep and impact properties has been established. Welding of INRAFM plates and dissimilar welding with SS316LN has been attempted by several methods such as narrow gap TIG, electron beam and laser methods in collaboration with national laboratories. Mock up trials for fabrication of complex parts of the TBM has also been carried. Details of the above will be covered in the talk.

IT-02

Materials for Blanket Application

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Abstract

One of the key missions of the International Thermonuclear Experimental Reactor (ITER) is to test and validate the various design concepts of tritium breeding blankets relevant to a power-producing reactor like DEMO. ITER is an unique opportunity to test the mock-up of DEMO blanket in a DEMO-relevant conditions. Testing of breeding blanket modules (TBMs) is one of the ITER goals foreseen from the very beginning of the ITER Project. The Indian fusion R&D program is focused on the development of blanket materials like structural material (IN-RAFMS), functional materials like breeding materials (Pb–Li, Li_2TiO_3), Neutron multiplier (Be), coating materials (Al_2O_3), development of technologies different process systems (Lead–Lithium Cooling System (LLCS), helium cooling system (HCS), tritium extraction system (TES) etc.) and related fabrication technologies. Lithium ceramic materials particularly the Lithium Meta Titanate (Li_2TiO_3) in the form of pebbles are used as the tritium breeding material in fusion reactor. Li_2TiO_3 powder is prepared at IPR by solution combustion reaction as well as solid state reaction route. Finally, Li_2TiO_3 pellets and pebbles are prepared from this powder followed by high temperature sintering. At every stage (powder, pellet and pebble) of preparation, extensive characterizations are being carried out to meet the desired properties of these materials. The details of the development of lithium ceramics and their R&D activities at IPR along with other institutes in INDIA will be discussed in presentation.

IT-03

Plasma Facing Components: Materials And Technologies Developments At IPR

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Abstract

High Temperature Technologies Division (HTTD) of Institute for Plasma Research (IPR), formerly called as - Divertor Technologies Division (DTD), mainly deals with R&D work related to materials and technologies relevant to Plasma Facing Components viz. Divertor and Firstwall of Tokamak [1]. This includes R&D areas such as: Plasma Facing Materials, Materials Joining Technologies, Destructive and Non-Destructive Evaluation & Testing of Materials, Engineering Design & Simulations of Plasma Facing Components, Fabrication Technologies development, Testing of Materials and Components. Significant efforts are also made by HTTD in establishment and operation of various equipment and test facilities relevant to the above mentioned R&D areas [2].

R&D work performed by various collaborators of HTTD under BRFST/ PFRC framework constitutes first part. This includes : (1) Development of copper coatings on Carbon-Fiber-Composite tiles for fabrication of Plasma Facing Components of Tokamak by Laser Cladding Process; (2) Dissimilar material joining of SS316LN (UNS S31653) and XM-19 (UNS S20910) Stainless steel joints; (3) Development of W-Cu functionally graded plasma facing material for fusion reactor.

Test facilities with HTTD, recent R&D activities and future activities of HTTD constitute remaining part. This includes materials testing facilities, high heat flux testing facility, development and testing of tungsten based plasma facing components, engineering analysis/ simulations related to performance of components.

References :

[1] http://www.ipr.res.in/httd/publications.html Website for publications of HTTD of IPR;
[2] http://www.ipr.res.in/httd/facilities.html Website for facilities of HTTD of IPR;

IT-04

Joining Technologies For Fusion Devices – Their R&D And Application

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Abstract

Experimental devices that have the objective studying the fusion plasmas have several components and subsystems that are subject to high heat flux. These components and subsystems require technologies that enable active cooling, using water at pressures of ~10 – 20 bar, as the cooling medium, for the dissipation of thermal heat flux. Such components, need to be designed, taking into account the requirements of operation in UHV conditions and in most critical areas; implying a need for high reliability of the components. The interface of the component/ subsystem, with the cooling medium is sealed for vacuum using jointing techniques of different kinds – laser welding, electron beam welding, vacuum brazing etc. They manifest in joints that are on similar and dis-similar materials and for each of the cases, the application of a jointing process is preceded by a methodical R&D on the characterization of the welds including the behavior of heat affected zone and the fatigue behaviour of the welds.

The other area of application of joints lie in the realization of the vacuum boundaries on large areas that manifest in the form of lip seals for metallic joints and ceramic to metallic bonds for the electrical insulators that apply to UHV boundaries. Extensive studies have been carried out on the development of lip sealing techniques for long boundaries. Similarly, studies have been initiated for an understanding of the brazed interlayer for the ceramic to metal interface, for a better assessment of the reliability of application of such joints on the boundary of vacuum systems.

The above mentioned studies have led to a successful implementation of the technologies in several systems in the past decade. However, it is important to note that there remain several issues to be explored, including, the development of alternate technologies.

The presentation, in the first part, shall summarise the R&D works that have been carried out & ongoing towards a better understanding. The later part shall present the alternate technology areas that need to be explored, for the development jointing methodologies and their successful application in developing important technologies for fusion R&D.

IT-05

Cryogenics Projects - Industry Collaboration

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Abstract

Collaboration between R&D sector and industry is increasingly a critical component of efficient innovation. It is critical for skills development, acquisition and adoption of knowledge (innovation and technology transfer) startups and spin offs. The benefits of R&D linkage to industry is, it can expand the relevance of research. Capacity for generating, absorbing, and implementing scientific and technological advances, both basic and applied is essential for the growth of a new field. The project of development of cryo-adsorption cryopump, at Institute for Plasma Research, could initiate working on a mix of R&D and Industry platform, for some of its technological requirements. The project could achieve basic understanding of the R& D and technological aspects by developing some required prototypes through BRFST/BRNS forum. Along with other subprojects of cryoadsorption cryopump development, the collaborated projects helped in successful development of pump. It created an example of R&D and industry collaboration bringing a product innovation. The product now finds application not only in the field of Fusion research but catering to the requirements of country's space research program.

Cryogen based cryopump is now a success and indigenous technology is well established. Looking ahead, it is important to attain self-sufficiency in closed refrigeration cycle based cryopumps, with collaboration with established industry.

IT-06

Helium Plant And Superconducting Magnet Systems For Fusion Machines

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Abstract

Tokamak fusion machines, considered as one of promising potential machines to provide electricity, need high magnetic field to constrain and shape plasma. This needs superconducting magnets, cryogenics and a vacuum cryostat to contain these. Cryogenics and superconducting magnets are still evolving technologies although many equipment/materials of these fields have been matured and available in the global market. Within India and Indian Industry, development in these direction is far below the foreign technology. High Tc superconductors have been developed to use at about 90 K, but still it is not matured and hence at present, largely one has to rely on the low Tc superconductors operated using liquid helium and supercritical helium at temperature about 5 K. This requires helium plant providing helium cooling and circulation at ~5 K and pressure ranging from 1 to ~6 bar. The refrigeration/liquefaction power of helium plant needed for bigger fusion machines, like ITER, are in the order of few tens of kW at 5 K and 80 K. For effective reduction in heat loads on superconducting magnet systems, a thermal shield operated at temperature about 80 to 100 K is used. Superconducting magnet coils involved are also huge having current supply about few tens of kA and cold mass about few hundreds of tons. These, then, further involve many cryogenics and superconducting-related technologies including room temperature helium equipment. Through BRFST/PFRC-BRNS, many projects in these fields have been done successfully and are ongoing since 2007 onward towards improvements in theoretical, practical and industry level technologies within our country. Some of these evolving technologies are, Nb3Sn based superconductor jacket materials, steady state and dynamic analysis of kW class helium plant, development of multifilamentary MgB2 High Tc superconductor, magnet coil winding machine, electrical cryogenic isolators, design and modeling of helium turbines for kW class helium plant, cryocooler for portable cooling power requirements, development of dissimilar metal joints for cryogenics, development of liquid helium transfer lines. All these and others will be discussed in detail in this paper including future requirements.

IT-07

Basic Plasma Experiments In Last Ten Years Under BRNS

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Abstract

Variety of experiments on basic plasma physics has been carried out during last 10 years under Board of Research in Nuclear Sciences (BRNS) Programme. These experiments include experimental studies of glow discharge plasmas, ultra-cold plasma, impurity study in Aditya tokamak, low temperature atmospheric and dusty plasma, development of micro-wave based negative ion source. All these experiments have been performed to understand the underlying physics in plasmas, which has either direct or indirect connection to the fusion plasma research. Some of the important findings of these experiments along with their future plans will be discussed in this talk.

IT-08

Computer Simulations As A Tool To Champion Fusion Plasmas

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Abstract

Hot plasmas confined in toroidal magnetic vessels have been demonstrated to be the most promising and relatively stable of all fusion plasmas. For example, thermal or near thermal Deuterium-Tritium plasmas confined at 100 million Kelvin and held at densities million times thinner than air, in JET Tokamak in1991 produced copious neutrons. These and several other experiments world-wide has resulted in the joint efforts culminating in ITER program.

Tokamak experiments are thus necessarily a mix of Physics, Engineering and Technological aspects with large funding support. While it is the most promising route to fusion, there are several physics, engineering and technological issues to be overcome. Growth in computer architecture, modern parallel computing facilities, development of CPU and GPU based computing and optimized numerical algorithms has lead to invasion ofcomputer simulations in fusion sciences.

In this Talk, a summary of computer simulation work carried out under the aegis of BRFST/PFRC in the past 10 years will be presented along with a discussion on fruitful areas where such effort should focus in the coming years.

IT-09

High Power RF Technologies

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Abstract

The thrust for clean energy, makes fusion, an attractive and undisputed candidate for an alternate energy source. For fusion to take place the plasma is to be ignited to a high temperature and one of the candidates for achieving it is by RF heating and current drive system. These systems operate over a wide range of frequencies (MHz to GHz), at megawatts power level (100's of MW) and in continuous wave (CW) mode. It is very challenging and demanding to build these systems. A plan with clear road map is required to address the challenging and gap areas so that over a period these challenging high power RF technologies are made robust, realizable and feasible. BRFS-PFRC has taken a step in this direction where key areas are identified, and research is pursued to address research and development challenges involved in high power RF systems.

The RF systems may be broadly classified in to four parts like high power launchers (antenna), high power RF windows, high power transmission line components and high power source. Over last ten years the Board has funded several projects and various universities/industries have participated in this program and contribute to above classifications. New RF window materials have been developed with low loss tangents and improved thermal conductivity. The brazing of dissimilar material (metal to ceramic) has been explored. The antenna has been designed and simulated along with mode convertors. The pill box RF window has been designed/simulated. The solid state based RF sources are also being designed/simulated and developed. The high-power CW circulators have been designed/simulated. These contributions have helped the fusion community within India to take a big step in developing high power circulators, passive-active-multijunction (PAM) antenna, high power pill box window using various ceramics like Al_2O_3 and AlN and solid state based RF sources.

In this presentation, the progress made in the field of high power RF technologies will be discussed along with the impact which BRNS PFRC has made in these research activities. I would also discuss key areas and future direction in which BRNS-PFRC should aim at in coming years.

IT-10

Microwave-Millimeter Wave To THz Instrumentations For Plasma Diagnostics

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Abstract

Advances in Millimeter wave technologies have paved the way for designing and development of both active and passive RF-microwave-millimeter wave to THz systems for a variety of applications such as defense and strategic applications, remote sensing, environmental measurements and **plasma diagnostics**. The most attractive feature of RF-microwave-millimeter wave to THz waves, when compared with optical and infrared waves, is their ability to penetrate the obstacles/material. Therefore, they can be used under low-visibility conditions such as in fog, rain, dust, or fire, where optical or infrared devices cannot be used. Also, as the radiometric temperatures of an object are different depending on its metallic or dielectric properties and its temperature, the sensors in this frequency range can detect deeper or inner properties of these materials or objects.

In magnetic plasmas, the conventional techniques to measure electron temperature is via a 1-D electron cyclotron emission (ECE) radiometer, and the conventional techniques to measure electron density is microwave (non-imaging) Interferometry and radar Reflectometry. In a conventional ECE radiometer, a horn antenna receives the ECE radiation at the out board side and down converted to a and Intermediate Frequency IF) with a local Oscillator and mixer, which is separated into different frequency bands, each corresponding to a different horizontal location in the plasma. Thus, time-resolved 1-D Te profiles can be obtained. To obtain multi-dimensional temperature profile and fluctuation data, a passive millimeter wave imaging technique, electron cyclotron emission imaging (ECEI) technique, has been developed at various Tokomaks. Microwave Reflectometry first saw use in probing the height of ionospheric plasmas where it was called ionosonde. It is a form of microwave radar that uses the plasma as a reflector and has been widely employed to determine the equilibrium electron density profile. From the outset, microwave Reflectometry has also been seen as a tool for helping to understand the relationship between fluctuations and transport by providing high resolution localized measurements of density turbulence in fusion plasmas. Unfortunately, this technique has limited capability in the presence of 2-D fluctuations. Thus, to capture multi-dimensional images of plasma density fluctuations, the microwave active imaging Reflectometry (MIR) concept was developed and employed at various Tokomaks.

The primary focus of this talk is on technology development in RF-microwave-millimeter wave to THz spectrum which has made real time devices development, advanced imaging and visualization, of various objects including magneto hydrodynamic (MHD) fluctuations and micro turbulence in fusion plasmas, possible. Topics of particular emphasis are: Design and development of technological system required for the real time measurements and imaging systems, Phase locked devices for highly stabilized frequency operation, Development of frequency selective surfaces and planar Schotkky diode mixer arrays, Development of electronically controlled beam shaping/steering arrays and back-end Electronics where RF-microwave-millimeter wave to THz system meets with conventional electronics.

IT-11

Passive Diagnostics For Plasmas And Its Applications And Prospects

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Abstract

Emission spectroscopy and imaging in the X-ray to NIR ranges, is one of the important diagnostics to characterize the plasma, to monitor the plasma purity and to use it in the process control dues its non-perturbing nature. However, the hardware and analysis techniques vary lots depending on both working wavelength ranges and plasma parameter. Along with that interpretation of data also depends on the associated atomic and molecular processes. In spite of that optical emission spectroscopy and imaging has been extensively used in many works, starting from basic plasma experiment to study the origin and dynamic of plasma blob in the presence of the background plasma and to the experiment for developing the tungsten coating on the graphite tiles. It has been also used to characterize the penning plasma based VUV radiation source aimed for the calibration of VUV spectrometer employed on the tokamak like high temperature plasma device. Here the effect of opacity on the plasma emissions has been also studied. In the area of tokamak plasma, high resolution X-ray and visible spectroscopy have been used to study the ion temperature and rotation velocity. Investigation of medium Z impurity transport in the tokamak plasma has been also taken up through the analysis of VUV spectral emissions. However, considering its tremendous application in the plasma physics, lots of indigenization of hardware and analysis technique is required along with studying the plasma physics. This includes developing the hardware, computational code for the data analysis and the interpretation of data using the atomic and molecular physics. The few examples are the development of the precision optical components, such as grating and EUV mirror, and detectors related technology, code on the Abel inversion and topographic reconstruction. The computational code for the collisional-radiative model on the population balance of a molecule, atom and/or ion in excited states is very much important considering its use in the estimation of plasma parameter. Not only that, works is needed to be done to develop the GUI based user friendly platform for the process control of application oriented plasma through the proper selection and use of the spectroscopic data. Another emerging R&D area is the tungsten spectroscopy considering its use as the first wall material in the tokamak. This talk will cover various aspects of the use of diagnostic in the completed and on-going projects and its future prospect.

IT-12

Current Trends In Data Acquisition And Processing Of Plasma Diagnostics

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Abstract

High quality reliable diagnostics data are required for understanding the complex physical processes in the fusion plasma experiments. The acquisition, processing, transfer and storage of such diagnostics data demand user-specific electronics and powerful computational resources, which are often very expensive as well as consume lots of power and space. It would help greatly if the specific requirements of diagnostics systems could be implemented using relatively generic vendor-supplied hardware which can be customized. Field-programmable gate array (FPGA) technology has enabled diagnostics systems to be more compact, adaptable and smart enough to function as standalone units to provide improved modularity. It has been hugely beneficial for nuclear fusion research, where the ability to quickly add new diagnostics or improve existing ones enables experiments to produce a wider range of high quality data. [1].

Fusion plasma experiments often involve multiple potentials, radio frequency waves and fast transient voltages/currents. To acquire electronic signals in such environment has always been challenging and therefore, some efforts have gone into resolving problems associated with the isolation and long cables. A recent implementation of wireless data acquisition [2] is one of such efforts, particularly addressing solution for those diagnostics systems which are more vulnerable to EMI and hazardous environment. This wireless digitizer utilizes the integrated ADC and the static RAM of microcontrollers but transfer data through wireless and demonstrates the resolution of 12 to 16 bits and sample rate of 500 to 1000 kS/s.

A few hardware implementations that are undertaken through BRFST/BRNS-PFRC projects would be discussed in this paper along with the future directions.

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IT-13

Non-Thermal Atmospheric Pressure Plasma Technologies For Societal Benefits

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Abstract

Atmospheric pressure non-thermal plasma offers unique solutions in different field. The active species present in non thermal plasma interacts with solid and liquid and gases and tailor these materials as per the requirement and provide environment friendly solution. The talk will cover some of the non thermal plasma technologies developed at FCIPT which will include –

(i) DBD plasma treatment of textiles and polymers
(ii) Plasma Jet for blood coagulation and skin diseases treatment, sterilization and to generate functional groups on polymeric surface

Further, the presentation will include important achievements of collaborative BRNS projects carried out using non-thermal plasmas and the work that will be carried out jointly with (i) Dept of Physics, Indian Institute of Engineering Science and Technology (IIEST), Shibpur, Howrah-3, (ii) Dept. of Physics, Indian Institute of Technology, Kanpur and (iii) Institute of Pharmacy, Nirma University, Ahmedabad.

IT-14

Robotics And Virtual Reality In Fusion Applications

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Abstract

The ever growing energy needs in India regards the significance of two important aspects of power generation: increasing the dependence on non-fossil energy resources and simultaneously curbing the emission intensities [1]. Tokamak and fusion research aims, directly or indirectly, resolve these challenges. A tokamak is a toroidal machine that uses high power super-conducting magnets to confine high density and high temperature plasma. The in-vessel components of the tokamak primarily include, plasma divertors, plasma control coils, various plasma diagnostics, shielding blankets etc. These components weigh in order of a few kilograms for diagnostics to a few thousands of kilograms for blankets and divertors. During tokamak operation, these components are subjected to a high surface heat flux of ~4–5 MW/m^2 [2] and thus vitiate over the lifetime of tokamak. The inspection and maintenance of these in-vessel systems is carried out by Remote Handling operations.

Remote Handling operations strive to perform inspection and maintenance tasks at remote locations without being physically present at the workspace. These are executed using a synergistic combination of specialized *robotics* and *virtual reality*. Unlike conventional industrial robotic systems, which are pre-programmed to do a certain task, robotic requirement in tokamak are much more complex and require man-in-the-loop operations. The robots here have a long reach (~5–10 m) and handle heavy payload (100–2000 kg) with positional accuracy of <5 mm. In many cases, the robots have inspect constrained spaces with great dexterity. As the in-vessel tokamak environment changes slightly after every plasma operation, tokamak robotic operations are highly dynamic [3].

This talk introduces various existing robotic systems like long reach robotic deployers, autonomous transport casks, dual arm manipulators etc. that can cater to tokamak inspection and maintenance requirements. An understanding of the underlying structural and control system design challenges of such systems is also outlined. The need for virtual reality and there applications in the design and operation cycle of remote handling systems is presented in detail. Lastly, futuristic technologies like nano-drones, hyper-redundant manipulators, collaborative robots artificial intelligence etc. and their possible applications in tokamak are discussed. In conclusion, a gamut of appealing research and development topics in areas of tokamak relevant robotics and virtual reality are discussed that can be accomplished with academia and industry support.

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IT-15

Neutronics For Fusion Applications

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Abstract

Nuclear activation and subsequent radiological response of structural materials within fusion reactors like ITER and beyond need to be studied for operational, safety and radiological waste management reasons. Further, the future fusion machines should be equipped with low radioactive materials optimized for the expected neutron environment. Numerical tools with extended capabilities are needed for this kind of analysis. A project named ACTYS-Project is initiated at Institute for Plasma Research to meet the requirements stated above. This effort so far developed more than five states of art codes and few innovative computational tools for analysis and design of fusion reactors. For the complete nuclear assessment, tools for the following classes are needed. Firstly, accurate neutron transport codes with necessary nuclear data, secondly nuclear activation analysis tools and finally tools for understanding the dynamics and therm -mechanical responses of irradiated materials. We have already developed state-of-the-art code suits for nuclear activation analysis. Details of the indigenously developed codes and their position in other codes available to the fusion community will be discussed.

The talk will also focus on possible paths to develop tools for the other two classes, namely neutron transport codes and codes to study the dynamics of material post irradiation. Our plan and possible opportunities for collaboration will also be detailed. There is some gap exist in nuclear data for analysis of fusion reactors, which needs to be filled. Our efforts towards that goal through ongoing BRNS projects will also be discussed in the talk.

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IT-16

Electronics, Instrumentation And Software Technological Projects Status And Vision For Future Development

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Abstract

Plasma & Fusion Research activities involves physical quantity measurement, monitoring, communicating, data processing and managing data to handle control parameters. Specialized diagnostics like magnetics, thermal, density, optical, etc., to measure physical properties and monitored for interest of experiment. This paper presents the brief overview of projects executed in the field of Electronics /Instrumentation /Software through BRFST in last 10 years and expected area of R&D for plasma related future project activities, also vision for electronics development for social benefits.

Experimental activities in IPR for plasma and fusion devices like measurement systems for diagnostics to get status and experimental results. It needs basic front end electronics, data communication, status display and information processing to observe results. There are specific custom requirements and unique principle in each of the measurement, which needs dedicated, noise free front end electronics, slow and fast deterministic real time data communication to processing units where data processed and handled efficiently. The R&D project activities includes (1) custom required electronics for physical quantity to be measured, (2) data communication networks with standardized protocol (3) modular component based data driven software modules (4) data processing units and data handling as well as data management.

Some of the project examples are custom requirements boards, magnetic and electric tomography for field distribution profiles and getting knowledge for plasma behavioral and control, thermography, and image processing for data from specialized diagnostics, etc...Other fields like health care devices which are root knowledge based like DNA array scanner, cytometry machines, etc., shall be made simplified and knowledge from these devices shall be collected to centralized units. It need efficient data processing and data handling mechanism for dieses diagnostics. Automation technology in each field shall be simplified and made common practice to use. Conversion from concepts to realizable engineering design and technology development shall be simplified. The R&D activity shall be in favor of technology development to be used for quality product development which is complete, perfectly matched with all expected requirements, modular in nature, re-usable either fully or partial, also extendable for other similar requirements. The product shall have properties like zero defect and self-explained, easy manageable, and serviceable. Also evolve in technology shall be easily adopted without any major changes. Concurrent Engineering (CE) shall be employed with quality of product life cycle including good documentation. Finally, AI and neural networks are in initial phase of technology advancement, evolving and which shall be employed in already developed technology, just change in processing units and software components in applications with domain knowledge in data.

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CONTRIBUTED PAPERS

BASIC PLASMA

BP-01

Experimental Investigation Of The Effect Of Medium Density On The Size Distribution Of Nanoparticles Produced By Laser Ablation In Liquid

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Abstract

Laser ablation in liquid is a widely used technique for fabrication of metallic nanostructures [1]. Ambient medium in which the ablation is carried out is crucial from the point of view of the end product. It is believed to have significant effect on the yield, size and size distribution of the nanoparticles produced due to ablation [2]. In view of this, experimental investigation of the effect of medium density on the size of nanoparticles produced by laser ablation in liquid has been carried out. The ablation was carried out in two different liquid ambient, *viz.* water and isopropyl alcohol. Copper was used as the metal target. The produced metallic nanoparticles were characterised for the size using SEM and these images were further processed to extract the size-distribution. The experimental results show significant differences in the sizes of the nanoparticles produced in the liquid media of different densities. The size dependence of the produced nanoparticles has been attributed to the effect of medium density on the thermalisation time of plasma [3, 4].

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BP-02

Low Temperature Atmospheric Pressure Microplasmas : Physics And Applications

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Abstract

Atmospheric pressure microplasmas are non-equilibrium plasmas with widely different electron (~ 0.5 eV) and ion temperatures (~ 0.025 eV). These plasmas have versatile applications in many fields such as biomedicine, surface modification and environment. Dielectric barrier discharge (DBD) is one of the many processes to create atmospheric pressure microplasma jet (APPJ). In the present experiment the plasma jet is created in a quartz capillary which is wrapped around by aluminum ring electrodes. The high voltage electrode is kept at ~ 3 mm distance from the orifice of the capillary, and the ground electrode at ~ 2 cm from the high voltage electrode in the upstream region. The outlet inner diameter of the capillary from where the jet emerges is ~ 0.8 mm. A high voltage sinusoidal signal having voltages in the range 7 – 15 kV peak to peak and at 10 kHz, is applied to generate the discharge. The experiment has been done with different gas flow rates. Optical emission spectroscopy (OES) of the jet shows different emission lines[1] of helium, molecular nitrogen, oxygen, including H-α and H-β lines. The electron density has been measured from the stark broadening of the H-α lines and the electron temperature has been determined from the Boltzmann plot, assuming a local thermodynamic equilibrium model.

When a strong magnetic field is applied to the plasma jet in a direction transverse to the plasma flow, the trajectory of the plasma particles deviates from its original path due to the Lorentz force[2], however, collective effects is expected to dominate in the rather high density atmospheric pressure micro plasma (with electron densities ~ 10^{20} m^{-3}). The coupling parameter is ~ 0.1, therefore two body Coulomb interaction still remain weak and kinetic effects dictate typical collective phenomena. It would therefore be interesting to investigate the effect of a strong magnetic field on the optical emissions from the plasma.

We have tried to electrically model the discharge. The DBD inside the quartz capillary tube consists of individual micro discharges that are short lived (few nanoseconds to microseconds)[3]. The electrical elements like discharge current and gap voltage are not directly accessible. Therefore, in order to understand the dynamics of the discharge inside APPJ, an electrical model is being developed for our APPJ system. The electrical circuit for the ring electrode configuration APPJ consists of gas capacitance (C_g), gas resistance (R_g) and capacitance of the quartz tube (C_d), which are in series connection with the HV electrode, however, when the discharge starts the capacitance and resistance of the gas changes non-linearly and have to be taken into account. Results of the optical emission spectroscopy and the electrical modeling will be presented in the meeting.

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BP-03

Characterization Of Carbon Dust Formation And Growth In A Co-Generated Dusty Plasma

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Abstract

Most of the tokamaks including ITER, a significant part of the plasma-facing component including diverters, limiters, etc. is comprised with graphite material. In the fusion plasma environment, the graphite gets bombarded by hydrogen and its isotope (deuterium and tritium) ions and erode graphite to a significant extent. Since such carbon particles can retain large amounts of hydrogen, dust contributes to the problem of inventory of radioactive tritium inside the fusion machine. Another impact of the dust particles in the operation of a fusion device is the possible degradation of the discharge performance. Such particles penetrating in the core plasma region can lead to discharge disruption [1]. Thus, in order to perform successful fusion experiments it is important to assess and understand the processes by which dust is formed and by which it interacts with the fusion device and its plasma. Instead of understanding processes that exactly happen inside a fusion reactor, it is always better to match some aspects of graphite-hydrogen interaction in a plasma environment in small laboratory devices, and study the physical processes. To address some of this issues, we have performed an experiment to examine the particle growth and sputtering yields in a DC glow discharge plasma in between the graphite electrodes.

To begin with, a Direct Current (DC) glow discharge argon plasma is produced in between a circular disc live anode and a grounded cathode in a cylindrical chamber. The electrodes (both the cathode and anode) are made of graphite to simulate tokamak plasma environment at some extent. Due to the ion bombardment, the carbon particles are sputtered from cathode surface at a particular discharge condition at a discharge voltage V_d = (255-265) volt and neutral pressure P = (0.08-0.95) mbar. These carbon particles are then charged negatively by collecting more electrons than ions and levitated in the cathode sheath region by balancing electrostatic force and gravitational force. A red He – Ne laser is used to illuminate the levitated carbon particles. The time evolution of scattered light from the growing carbon particles are captured using a CCD camera (with frame rate ~ 60 fps) and the images is stored in a high-speed computer. IDL based particle tracking code is then used to calculate the pair correlation function, which gives the particle density of the captured images in different plasma parameters [2-3]. In another set of experiments, the cathode is biased negatively with respect to the grounded chamber to study the enhancement of sputtering yield from cathode surface and its variation over a wide range of discharge condition.

The experimental results showed that the more carbon particle erode if the experiments have performed for longer time and higher discharge voltage and background pressure. The sputtering even becomes more efficient when the cathode is biased with negative voltage. We believe, our experimental results will be helpful to fusion community to understand the sputtering from carbon walls of various tokamaks.

BP-04

Influence Of Laser Produced Silver Plasma On The In-Situ Decoration Of Graphene Oxide With Size Controlled Nanoparticles In Liquid Media

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Abstract

Pulsed laser ablation (PLA) in liquid has been universally considered to be a physiochemical top-down approach governed by laser plasma and cavitation physics [1]. Herein, we report the influence of laser produced plasma for the improvisation of graphene oxide (GO) sheets with silver nanoparticles by tuning the plasma parameters like electron temperature (T_e) and electron number density (n_e). Natural graphite powder was used to synthesize graphene oxide (GO) with modified Hummers' method [2]. A pure solid silver target of thickness 1mm is properly placed inside a glass cuvette which contained 30ml of aqueous solution of graphene oxide. Second harmonic (532nm) of a Q-switched Nd-YAG laser beam having 8ns pulse width and 10Hz repetition rate was focused on to the silver target using a plano-convex lens of focal length 15 cm at room temperature for various laser energies. The expansion dynamics of the plasma was characterised using space resolved optical emission spectroscopy [3]. Plasma parameters like electron temperature (T_e) was measured by Boltzmann plot method and the electron number density (n_e) was estimated using stark broadened profiles of isolated lines of the optical emission spectra [4,5]. XRD, UV-Vis spectroscopy, fluorescent spectroscopy and high-resolution transmission electron microscopy upholds the structural, optical and morphological characteristics of GO/Ag nano-composite. The present study provides a simple and green strategy to decorate GO with size controlled silver nanoparticles by effectively tuning the plasma parameters via liquid phase laser ablation.

Keywords: Pulsed Laser Ablation, Optical Emission Spectroscopy, GO/Ag nano-composite

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BP-05

Interaction Of Hydrogen With Graphite Tiles In A Plasma Environment And Study Of Spatial & Temporal Evolution Of Hydrogeneted Carbonaceous Dust Formations

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Abstract

We have developed cogenerated dusty plasma system at the Department of Physics of Jadavpur University. Since we are not supplying the dust particles from outside rather generating inside, via sputtering, so this experiment is such a unique dusty plasma system, which is similar to the actual happenings inside a fusion chamber and beside us, none of the groups is working with such technique.

During the process of installing this experiment from scratch we have done:

- Experimental dusty plasma system is set-up at the Department of Physics of Jadavpur University, Kolkata in November 2011.
- Argon and air plasma was produced varying various parameters like discharge voltages, gas pressures etc.
- Initially, with and without graphite electrode, we performed Paschen curve experiment and comparison is noted.
- We used the Langmuir probe measurements for argon as well as air plasma.
- Carbon dust particles were produced by sputtering of graphite cathode in argon plasma.
- Experiments on dusty plasma setup was started properly in March 2012.
- Through laser (630 nm He-Ne laser), we illuminate sputtered dust particles. We installed CCD camera to observe the dynamics of illuminated dust particles.
- Able to generate void (a dust free region inside dusty plasma) in argon-acetylene plasma.
- Generating dust particles in argon-acetylene plasma using bi-polar pulsed power supply and observed some exciting observation (void formations, dust density waves etc.).
- Dusty plasma imaging technique, data analysis etc. also done.

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BP-06

Development Of RF Based Capacitively Coupled Plasma System For Deposition Of Tungsten Nano Layers On Graphite

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Abstract

Based on the current thermonuclear fusion research, it is quite likely that future fusion machines, DEMO and beyond, will be operating with tungsten and alloys based on tungsten as the plasma facing material on their walls and targets to dissipate the thermal as well as particle loads under extreme conditions. Tungsten is being preferred because of its superior thermo-mechanical properties as well as for its low tritium retention. However, use of pure tungsten as a structural material itself will substantially increase the manufacturing cost and overall system mass and also it is difficult to machine. Hence, tungsten coatings on light substrate such as graphite are preferred which essentially reduce the cost and structural weight considerably. In this article, we report the development of a RF based capacitively coupled plasma reactor for tungsten coating on graphite tiles using plasma assisted chemical vapour deposition at SVITS, India. Tungsten nano layers have been successfully deposited on graphite test pieces by reducing the heavy tungsten hexafluoride gas in hydrogen. Characterization and post analysis of the tungsten coated tiles has been carried out to study the presence of tungsten, thickness of the coating, thermal fatigue etc.

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BP-07

Direct Plasma Treatment On Human Skin Fungal Disease: *Tinea Corporis*

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Abstract:

In recent years, non-thermal/cold atmospheric plasmas have emerging field of interest in biomedical application. Different designs have been investigated for their ability to treat heat sensitive surface and for prospective use in medical applications. Cold plasma can potentially offer a minimally-invasive surgery option that allows specific cell removal without influencing the whole tissue [1-3].

The objective of this work is the atmospheric pressure plasma application on human fungal skin disease treatment. The non-thermal characteristic of plasma plays an important role for using this device for biomedical applications. Plasma jet of Ar (99%) mixed with O_2 (1%) gas is formed in the principle of dielectric barrier discharge at mid frequency range (50 kHz). The high electron temperature enhances the plasma chemistry processes while the plasma gas remains close to room temperature. The average plasma plume temperature is about 35 ^oC (at the top of the plasma plume). The plasma (Ar +O_2) is applied on the skin followed by a standard operating process successively on three patients with ICMR (Indian Council of Medical Research) guide lines at SSKM Hospital, Kolkata, W.B., India. The patient has been treated once per week. The dosimeter scale is set according to the average surface area of the patches. The plasma is applied on the skin followed by a standard operating process which we are experienced ourselves during the treatment process. Three patients are clinically cured after 1st seating of plasma treatment. After one year of observation it is experienced that the previous patches are not appeared/seen at plasma treated area.

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CONTRIBUTED PAPERS

CRYOGENICS & MAGNETS

CRYO-01

Studies Of Adsorption Characteristics Of Activated Carbons Down To 4.5K For The Development Of Cryosorption Pumps For Fusion Systems

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Abstract

Cryosorption pump is the only possible device to pump helium, hydrogen and its isotopes in fusion environment with high magnetic field and increased plasma temperatures. Activated Carbons (ACs) are known to be the most suitable adsorbent for their development. In particular, the temperature range from 5 to 20 K is seen to be useful for exploiting the cryosorption mechanisms in cryopumps for fusion applications. The knowledge of adsorption characteristics of Activated Carbons is essential for the selection of the right sorbent for use in the development of these pumps. But this data is very scarce in the literature, in particular below 77K.

For obtaining the above data, an experimental set up has been built which can measure the adsorption characteristics of Activated Carbons (ACs) in the temperature range from 4.5 K to 77 K. This system is built using the commercially available Micropore Analyser (Quantachrome: Model ASIQ) along with a two-stage Gifford McMahon Cryocooler (Sumitomo: Model SRDK415D) which allows the sample to reach temperatures down to 4.5 K. The sample chamber is coupled to the Cryocooler through a heat switch, which enables the variation of sample temperature in the range from 5 K to 77 K, without affecting the performance of the Cryocooler. The above setup enables studies of adsorption characteristics over a wide range of pressures, from ambient down to 10^{-4} Pa.

This paper presents the experimental studies of adsorption isotherms measured for different types of activated carbon samples in the form of granules, globules, flake knitted and non-woven types in the temperature range between 4.5 K and 10 K using Helium gas as the adsorbate. The results have been analyzed to obtain the pore size distributions and the micro-porous surface areas of the activated carbons. The effect of the adhesive used in bonding the activated carbons to the panels has also been investigated. These results have been found to be quite useful to select the right Activated Carbon to be used in the development of cryosorption pumps for fusion systems.

CRYO-02

Performance Studies Of Cryocooler Based Cryosorption Pumps With Indigenous Activated Carbons For Fusion Applications

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Abstract

Good vacuum and good surface conditions are very critical for the performance of a Tokamak. With the operational pressure requirements in the range from 10^{-8} mbar during fuel pulses and 10^{-10} mbar in their absence, the only pumping system that is suitable is the cryosorption pump in view of its high pumping speed and its ability to operate in harsh environments. The development of a cryosorption pump for the Tokamak application will need the right Activated Carbons (ACs) with large micro-porous high surface areas along with suitable adhesives to bind them onto the metallic panels with liquid helium (LHe) flow channels.

While the adsorption characteristics of ACs for specific gases such as helium in the temperature range from 4.5 K to 10 K can be studied using the Micropore Analyser coupled with a GM Cryocooler to maintain the sample temperature in the required range, the performance evaluation as a cryosorption pump of life size will require large quantities of liquid helium. Alternatively, these pumps can be built with small size cryopanels adhered with ACs and cooled by a two stage cryocooler.

The paper describes the development of a cryocooler based cryosorption pump and is built using a commercial cryocooler (Sumitomo SRDK415D), with a refrigeration power of 1.5W at 4.2 K at its second stage. The cryocooler based Cryosorption pump is developed such that one can mount the standard commercial cryopanel of a Varian Ebara SP8 pump on its second stage cold head. The first stage refrigeration power of the cryocooler serves to cool the radiation shield surrounding the above. The main advantage of the above is that the cryopanels with identical physical dimensions can be fabricated and bonded by a suitable adhesive with different indigenously developed ACs such as granules, pellets, ACF-FK2 and knitted carbon (IPR) cloth etc. and comparative studies can be made against the standard commercial panel as a bench mark.

The experimental studies of pumping speeds for various gases such as helium, hydrogen, argon and nitrogen have been carried out for different AC panels following the procedures outlined by American Vacuum Society (AVS) and these are presented in this work. The above experimental studies provide the clue to arrive at the right ACs and adhesives for the development of large scale cryosorption pumps with liquid helium flow.

CRYO-03

Development Of Aluminium-Stainless Steel Transition Pipe Joints For Cryogenic And Vacuum Applications Using Cold Metal Transfer Process

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Abstract

Cryogenic process plants usually contain several aluminium heat exchangers which need to be connected to other components via stainless steel (e.g. AISI 304/304L) piping. Because aluminum cannot be conveniently bonded to stainless steel in normal shop environment, such connection requires prefabricated Al-SS transition joints which can be bonded to Al and SS pipes at their respective ends using normal TIG welding Process. Till date, pre-fabricated Al-SS transition joints have been made by friction stir welding (FSW) and other friction welding processes, which are expensive and generally unavailable in ordinary institutions and industry. In our country such transition pieces are normally imported at a high cost and uncertain supply to sensitive institutions. The CMT (cold Metal Transfer) process, recently invented by Fronius [1] of Austria, offers a possible cheap and convenient alternative, which we propose to investigate. CMT is a new process which is comparable to the regular MIG process, but with additional hardware and software that move the electrode up and down at about 90 Hz ensuring alternate touching, arc formation and arc extinguishment. A few recent papers [2, 3] have established the feasibility of achieving strong Al-SS joints with great weld efficiency. But the suitability of the CMT process to achieve leak free joints, particularly at low temperature is not established yet.

Objectives of this project are to establish CMT process parameters for dissimilar pipe joint of aluminium and stainless steel; to investigate welding defects, leak rates and quality of joints by Non-destructive testing methods; to explore the effect of CMT process parameters on microstructural and mechanical characteristics for improved performance of welded joints; to develop an efficient mathematical model for CMT process to predict responses of dissimilar Aluminium-Stainless Steel transition pipe joint, covering thermal profile.
If successful this research project will offer multiple advantages; (1) import substitution, (2) cost reduction, (3) thinner pipe section joints (4) Global patents from India and consequent benefits.

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CRYO-04

Development Of Void Fraction Sensors For Cryogenic Fluids: Phase I: Design Of Electronic Circuits By Liquid Level Sensor Development

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Abstract

Towards our objective of developing capacitance based sensors to measure void fraction in flowing cryogenic fluids, the need arises for the appropriate design of electrodes for the sensors as well as the electronic circuits for the same. At the initial phase, the problem may be simplified by considering a static fluid, instead of the flowing fluid. In such a case, since the liquid vapour boundaries are separated, the system is simplified to that of liquid level measurements of the cryogenic fluids. Now the design of both the capacitance sensors as well as the electronic circuits can be carried out to monitor the dielectric constant changes between the liquid and the vapour.

Hence, in the first phase, we have taken up the development of a liquid level sensor for cryogenic fluids. This uses a capacitance sensor of coaxial type and it will be suitable also for the void fraction measurements. The electronic circuits developed for liquid level measurements can also be adopted with suitable modifications for latter.

In a liquid level sensor, the changes in the capacitance of the coaxial type sensor with the liquid level are in the range of picofarads and hence there is a need for the fabrication of the appropriate electronic circuits with appropriate shielding so that one can measure small variations in the capacitance. Both 555 timer circuits as well as differentiator based electronic circuits have been developed and found to work satisfactorily for liquid level measurements. The developed level sensor which uses a 40 cm long coaxial capacitor has been used for the measurements of liquid levels both in water as well as in liquid nitrogen. The accuracy of measurement is found to ± 2 %. Simulations have also been used to confirm the performance of the developed electronic circuits. The above details are presented in this paper. The developed sensor as well as the electronic circuits with appropriate modifications will be used in the development of void fraction sensors for cryogenic fluids.

CRYO-05

CFD Studies On A Hydrogen Twin Screw Extruder

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Abstract

Of various methods of pellet production for the plasma reactors, a counter rotating, intermeshing twin-screw extruder is found to be more reliable and stable. It is required to design an extruder to extrude at the specified rate with minimum viscous dissipation as it determines the size of the motor and the cryocooler capacity. Contradictorily, the volume of the extruder has to be minimum to minimize the radioactive tritium inventory. Hence, development of a prototype extruder involves multiple design iteration process. This necessitates to develop a reliable CFD model to predict the performance of a twin-screw extruder. CFD modeling of a twin-screw extruder imposes many challenges. One of the challenges is computational/FEM meshing of the intermeshing counter-rotating screws which produce pumping effect due to positive displacement effect. The non-Newtonian and non-isothermal behavior of solid hydrogen further complicates the analysis.

In the present study, a CFD modeling has been successfully carried out using POLYFLOW module of ANSYS, which employs the Mesh Superposition Technique. The shear rate dependent shear stress of solid hydrogen is modeled using Herschel-Bulkley equation. A three-dimensional computation neglecting inertia and gravity effects has been carried out to simulate the flow through the extruder which involves leakage flows through the calendar, tetrahedron, flight and side gaps. The flow characteristics of the die has been simulated independently and superimposed with the extruder pumping characteristics to arrive at the operating point. A systematic parametric analysis was carried and thus an optimum design of the extruder has been arrived at to produce a 3 mm diameter filament at the rate of 500 mm^3/s. It is observed that when the flight angle is increased, the pressure build-up in the extruder decreases. Moreover, when the mechanical clearances increases, the pressure build-up decreases. From the simulation results of the die, an optimum geometry can be arrived so as to minimize the unyielded region.

CRYO-06

Development of A Capacitance Based Liquid Level Sensor For Cryogenic Liquids

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Abstract

Level measurements of the cryogenic fluids such nitrogen, oxygen, hydrogen and helium are quite important for proper utilization of these fluids for applications. The techniques which are normally used for liquid level measurements are: dipstick, mechanical float type gauges, ultrasonic sensors, visualization techniques, optical methods, etc. However, many of them do not provide accurate liquid level measurements and further may not be suitable for harsh environments. However, the capacitance based level sensors are found to be quite rugged as well as provide accurate measurements of liquid levels. Hence they are being used in the cryogenic storage tanks of launch vehicles with triple redundancy. In view of this, as well as their insensitivity to the magnetic field environments, they are useful for several end applications.

In our efforts to develop capacitance based sensors to measure void fraction in flowing cryogenic fluids, the initial efforts were directed towards the development of capacitance based liquid level sensors. In this work, we present the development of a coaxial capacitance type liquid nitrogen level sensor along with the suitable electronic circuitry for the display of the measured liquid levels. The accuracy and the precision of the level measurements depend both on the sensor design as well as on the electronics used for measurement. The changes in the capacitance of the sensor with the liquid level are in the range of picofarads and hence there is a necessity of suitable electronics circuits with appropriate shielding to measure small variations in the capacitance. Both 555 timer circuits as well as differentiator based electronic circuits have been developed and found to work satisfactorily for level measurements in liquid nitrogen, with an accuracy of ± 2 % using a 40 cm long coaxial capacitance sensor. Simulations have also been used to confirm the performance of the developed electronic circuits.

The developed sensor as well as the electronic circuits will be useful for our development of void fraction sensors for cryogenic fluid flow.

CRYO-07

Emissivity Measurements At Cryogenic Temperatures Based On Calorimetric Method

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Abstract

In the design of cryogenic system to estimate heat loads information regarding radiative properties of various materials and materials with various coatings is required over a wide range of temperatures, from operational cryogenic temperature to ambient. Data about radiative property especially emissivity at cryogenic temperatures is not much available in the published literature. To measure emissivity, two methods are used for emissivity measurements at cryogenic temperatures and they are based on calorimetric method and on heat flux method. The present paper describes a calorimetric based experimental setup to measure the emissivity of various surfaces and coatings down to 90 K. The inner vacuum vessel is placed inside the experimental cryostat. The heater is suspended in the inner vacuum vessel. Sample can be coated either on the heater or on the receiver surface. By measuring the temperatures, heater powers etc. the sample emissivity can be determined. The experimentally measured values of emissivity of samples such as stainless steel, aluminum foil, copper foil and black paint are ~0.12, 0.04, 0.03 and 0.9 respectively, at 90K. The measured values are found to be reasonably in good agreement with the literature values. The uncertainty analysis performed for the emissivity measurement shows the error of ~ 8 %.

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CRYO-08

Numerical And Experimental Investigations On Pressure Drop And Cool-down Of Vacuum Insulated Flexible Transfer Line For Liquid Helium Application

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Abstract

Transfer of cryogenic fluids is a daily occurrence in laboratories and industries for various end applications. As the latent heat of vaporization of these fluids is very low, vacuum or super insulated transfer lines are generally used for transfer the cryogens to minimize the evaporation due to heat transfer. Both rigid and flexible transfer lines are used depending on the end applications. Flexible transfer lines are most convenient to transfer cryogenic fluids in view of manoeuvrability of the lines especially under space constraints, although they lead to higher heat load and pressure drop compared to rigid transfer line. Institute for Plasma Research are in need of cryogenic transfer lines for the in-house development of liquid helium plant and transfer of liquid helium from the helium liquefier to the Tokomak. There are considerable challenges in the development of large size transfer lines for liquid helium applications. This paper deals with the design and development of a flexible transfer line of 25.4 mm ID and 3 m long along with the pressure drop and cool-down behaviour with liquid nitrogen as cryogen. Numerical modelling and estimation of the pressure drop and cool-down time has been done using ANSYS Fluent software and the same has been validated through experimental investigations. The numerical and the experimental results are in good agreement with each other. The developed transfer line will be handed over to IPR for their end applications.

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CONTRIBUTED PAPERS

MATERIALS

MAT-01

Development Of Seven Layered W–Cu FGM By PM Route

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Abstract

W-Cu functionally graded material (FGM) with excellent properties and microstructure is extremely significant in the development of fusion reactors. Plasma facing components (PFCs) consist of a plasma facing and a heat sink material. These must fulfill different functions that require different material properties, for example high melting point of tungsten and excellent thermal conductivity of copper. But it is difficult to prepare and sustain in high heat loads because of high residual and thermal stresses induced at the interfaces due to vast difference in thermal expansion coefficients, $15.4x10^{-6}$/K (W) to $4.5x10^{-6}$/K (Cu)([1]. To reduce residual stresses at the interface, W-Cu FGM was prepared by spark plasma sintering process (SPS), which acts as an interlayer to decrease thermal-induced stress effectively and to avoid delamination and damage. SPS is a pressure sintering method, based on high temperature plasma momentarily generated in the gaps between powder particles [2].

In present work seven-layered W/Cu FGM (100W, 80W-20Cu, 60W-40Cu, 50W-50Cu, 40W-60Cu, 20W-80Cu, 100Cu (wt. %) were fabricated by a spark plasma sintering process at a pressure of 60MPa. The influences of sintering temperature on microstructure, physical and mechanical properties were investigated. The experimental results indicated that the graded structure of the composite could be well densified after the SPS process and study of microstructure reveals that the graded structure can be retained at a sintering temperature of 1050^0C. The sample sintered at 1050^0C exhibited excellent mechanical and physical properties with higher hardness 239±5 Hv and maximum densification has been achieved 94.45% of their theoretical density. The result demonstrates that SPS is promising and more suitable process for fabrication of W-Cu functionally graded materials.

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MAT-02

Hydrogen Adsorption And Stability Of Li_2tio_3 Beads

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Abstract

Among various ceramic based tritium breeding materials, the lithium titanates beads are promising candidate due to its high tritium release properties. In this study, hydrogen adsorption and stability of lithium titanate beads were studied under thermal and humid environment. While the hydrogen adsorption study of Li_2TiO_3 beads was conducted at various temperatures using thermal conductivity detector (TCD) in presence of pure hydrogen (99.999%). The stability of Li_2TiO_3 under humid condition was studied for 8 months at 75% RH. The stability of the Li_2TiO_3 at high temperature was studied at different temperatures (900^0C, 1100^0C, 1200^0C and 1300^0C) for 1 h. The beads were analyzed by XRD and SEM to investigate the change in the crystal level properties and variation of morphology. The adsorption study shows that hydrogen is not adsorbing on the lithium titanate beads. The XRD and SEM results show that beads are stable after exposing them at high humidity for long time as there was no significant change in XRD pattern and morphology. The stability of beads at high temperature through XRD shows that there are no new phases formed. However, there is a small change in intensity which is yet to be analyzed.

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MAT-03

Experimental Study On Pebbles Packing Mechanism For The LLCB TBM

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Abstract

The detailed study of pebble bed filling mechanism were studied which will be very useful for Indian LLCB TBM. In LLCB TBM Li_2TiO_3 pebbles are used as the tritium breeder materials. The blanket design requires at knowledge of the packing factor (ratio of pebble volume to canister volume), and the information on the arrangement of the pebbles in the canister. It was observed that the packing factor will affect the flow of Helium gas for purging the tritium generated in the pebbles. Therefore, the detailed study of the pebble filling mechanism which gives the packing factor are very important for LLCB blanket design requirement. So far there is not fully explore the understanding of the fundamental problems on the filling of pebbles for LLCB TBM.

The effect of various parameters (size of the pebble, shape of the canister, gas flow velocity etc.) of Li_2TiO_3 were studied. Pebble bed packing factor were also studied for single size (mono size) and binary pebble bed. For pebble bed densification after filling, both vibration and/or knocking were applied. Studies of gas flow through the pebble bed was performed and well matching with the simulation results. Helium leak detect testing has been performed using Helium Spray method. Pebble experiments have been performed on the transparent Perspex contained to visualize the pouring of pebble in the container, how they are stacked and their effect on estimation of the packing fraction as well as SS 304 container. The packing factor was found to be >63%.

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MAT-04

Characterization And Comparison Of Copper Coatings Developed By Low Pressure Cold Spraying And Laser Cladding Techniques

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Abstract

Copper coatings of 3-mm thickness were developed by both cold spraying and laser cladding techniques on SS316 steel [1–2]. The developed coatings were then characterized with various techniques to evaluate metallurgical and mechanical properties [1–3]. Tensile strength (170 MPa) of the cold sprayed coating was found to be comparable with that of the laser cladded coating, whereas %age elongation of laser cladding (11%) was almost double (6%) of that for the cold sprayed coating. Porosity was found to be low in the cold sprayed coating as compared to that in the laser cladding, which indicates that the former technique could give a denser coating. This difference in porosity led to relatively higher electrical and thermal conductivity in the cold sprayed coating as compared to the laser cladding. X-ray diffraction and electron disperse spectroscopy analyses revealed the absence of oxide formation in the cold sprayed coating, however oxides were seen in the laser cladding. Also, a large heat affected zone (HAZ) was detected in the laser cladding, whereas no HAZ was observed in the cold sprayed coating. Hardening was observed along the interface and HAZ of the cladded steel, which may be attributed to the diffusion of carbon from the substrate.

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MAT-05

Microwave Hydrothermal Synthesized $Lanbo_4$ Nanocrystalline As Electrolyte For Electrochemical Hydrogen Pump

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Abstract

In recent years, proton conducting oxides have been widely studied as an electrolyte material for electrochemical hydrogen pumps, hydrogen sensors, fuel cells, etc. The perovskite-type structure (ABO3) based on cerate or zirconates are commonly studied materials. The disadvantage of the cerates and BaZrO3 based electrolytes are high sintering temperatures and high intrinsic grain boundary resistance. The scheelite-type $LaNbO_4$ material easily substitute the above electrolyte with low sintering temperature. The pure proton conduction in this material establish great interest for applications such as hydrogen and humidity sensors at temperatures below 700°C. There are various synthetic methods, such as solid state reaction, spray-pyrolysis, solgel and co-precipitation have been used to prepare fine powders of $LaNbO_4$.

The preparative method plays a crucial role in designing the properties of the ceramic materials, controlling the morphology. The transport properties of the ceramic materials mainly depend on ceramic microstructure. Recently, microwave-assisted hydrothermal (MWH) synthesis method has been widely used to synthesis oxide, hydroxide, and sulfide nanoparticles with various morphologies. The advantages of MWH are quick reaction, simple medium, short time to reach the suitable temperature for reaction, and its morphology of particles.

Lanthanum niobate ($LaNbO_4$) nanocrystalline scheelite-type ceramic has been synthesized by a microwave hydrothermal method. The phase formation and morphology of scheelite-type $LaNbO_4$ are characterized by X-ray diffraction (XRD) and scanning electron microscope (SEM). Impedance analysis carried out at different temperatures under wet oxygen and wet hydrogen. The conductivities are evaluated by analyzing the measured impedance data, using Z-view software for scheelite type $LaNbO_4$. The details will be discussed in the poster

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MAT-06

Electrospun Synthesized One-Dimensional Nanofibrous Lithium Orthosilicate Ceramic For Tritium Breeder

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Abstract

Lithium-containing ceramics such as Li_2O, $LiAlO_2$, Li_2TiO_3, Li_2ZrO_3, Li_2SiO_3 and Li_4SiO_4 are recognized as promising tritium breeding materials. Among these, lithium orthosilicate [1] and lithium metasilicate are possessing high lithium content relative to other lithium-containing ceramics and low neutron activation behavior of Si, (Li_4SiO_4) ceramic pebble. To achieve a high packing factor a small diameter pebbles packed bed and low thermal stresses in the pebbles are optimum. In fusion reactor tritium breeding modules (TBM) design generally tailored for close packing of Li4SiO4 ceramic pebbles have a small diameter (0.5–1.0 mm). Several methods have been indentified to synthesise Li4SiO4 ceramic nanopowder, including rotating granulation, Wet process, extrusion-spheronization, sol-gel, solid state methods and etc..

The fibrous morphology of Li_4SiO_4 for tritium breeding materials may be an ideal material, which can exhibit higher thermal and electric conductivities than others. Electrospun is currently one of the versatile method of fabricate continuous fibrous morphology with diameters down to a few nanometre. The unique morphological characteristics of electrospun nanofibers, e.g. open structure providing low resistance to mass transport, and large volumetric surface area, are expected to lead to diverse applications. Therefore, the present work focuses on the development of one-dimensional lithium orthosilicate nanofiber via sol-gel followed by the electrospinning process.

Lithium silicate nanofibres have been synthesized via electrospun method using with and without PVA polymer. Thermal behavior of the lithium silicate nanofibre was studied using TG/DTA. The phase formation and structure properties of lithium silicate nanofibre are characterized by X-ray diffraction (XRD), scanning electron microscope (SEM). The conductivities are evaluated by analyzing the measured impedance data, using winfit software. The lithium silicate nanofibre showed conductivity of $1x10^{-4}$ Scm^{-1} at 300^oC.

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MAT-07

Molecular Dynamics Studies Of Primary Damage In β-LI_2TIO_3

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Abstract

Monoclinic lithium meta titanate (Li_2TiO_3) is one of the materials used to breed tritium in fusion reactors because of its high thermal conductivity, high tritium release and low chemical reactivity. For the first time, classical molecular dynamics simulations have been employed to study the radiation damage in Li_2TiO_3. Collision cascades are initiated with either Li, Ti or O as the primary knock on atom (PKA) with an energy of 2 Kev. Furthermore, three different crystallographic orientations, [100], [010] and [001] for the PKA are also chosen. Ti PKA produced maximum damage due to its higher mass. The production of total defects was highest for [100] followed by [010] and [001]. Lithium & titanium antisites in each other shows direction independent behavior, magnitude of the same is very less compare to other defects. The production of lithium defects is higher followed by oxygen and titanium. The lithium diffusion was also found to be dependent on total number of defects produced in cascade. Titanium shows almost never diffuses within structure, when compared to lithium and oxygen.

*Keywords**:** Irradiation, Collision, Cascade, Defects, Cluster*

MAT-08

Thermo-Fluidic Study On Nanofluids As A Coolant In Fusion Reactors

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Abstract

The issue of ultra-fast cooling requirement in plasma facing components is a major concern. The development and application of suitable coolant with superior cooling capacity for plasma facing components is of paramount importance. Choi et al.[1] of Argonne National Laboratory were first to proposed a novel strategy to increase the heat transfer potential of traditional working fluids by dispersing ultra-fine particles of nanometer range and designated the term 'Nanofluids' to such liquid suspensions. After the invention of Nanofluids, innumerable experimental and theoretical studies have been reported accounting the diverse application of such working fluids including electronic cooling, heat pipes, heat exchangers and nuclear reactors[2]. The thermal conductivity of nanofluids showed an impressive enhancement compared to their basefluids[3]. Convective heat transfer coefficient also got enhancement[4]. Further and later, studies show significant enhancement in pool boiling and flow boiling heat transfer with nanofluids. However, all the experimentation were lab scale and their industrial implementation is still a big question due to proneness of nanofluids for coagulation. Although the thermal performance is enriched with the addition of nanoparticles in base fluids, they are very unstable if the particle inclusion is more. The unstable nanofluids show totally different thermal properties from its stable counterpart. Moreover, there is a lot of contradiction between experimental and theoretical results. No standardized database has been generated yet for the thermo-physical properties of nanofluids.

Therefore, this scientific contribution aims to express our intention to produce different water based nanofluids (such as Al_2O_3/Water, TiO_2/Water, ZnO/Water nanofluids), their stability evaluation, thermo-physical property measurements leading to design and fabrication of an experimental facility to thoroughly investigate the pool boiling and flow boiling heat transfer in nanofluids and its response to the change of thermo-physical and flow parameters.

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MAT-09

Synthesis Of Nanocrystalline Li_2TiO_3 By High Energy Ball Milling For Nuclear Fusion Reactor Application

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Abstract

The nanocrystalline Li_2TiO_3 ceramics were prepared at room temperature by high energy ball milling (HEBM) technique without any external heat treatment. It is also prepared by conventional route followed with calcination temperature at 700^0C for 2h. The electrical properties of Lithium titanate (Li_2TiO_3) has been determined with AC impedance spectroscopy. AC conductivity (σ_{ac}), susceptance (B) and frequency exponent behavior of Li_2TiO_3 samples were analyzed with different sintering temperatures (800^0C - 1000^0C) was measured in the processing temperature range (325^0C to 450^0C). The experimental results found, low activation energy (E_a) and high conductivity in the range of 10^{-3} Scm^{-1} with all sintering at 1 MHz frequency. It was found that, the E_a of AC conductivity at 10 KHz frequency is approximately equal to the E_a of relaxation time (τ). The microstructures of the samples were determined by SEM, good crystalline nature was observed at 1000^0C sintering sample. The temperature dependence of AC conductivity variations clearly indicates the negative temperature coefficient of resistance (NTCR) behavior. The frequency exponents (n_1, n_2) were calculated by using the double power law followed with Arrhenius relation. It was observed that nanocrystalline sample prepared by high energy ball milling is more conducting than the bulk sample.

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MAT-10

Laser Shock Peening Of 316LN Stainless Steel And Structured Metal Surfaces

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Abstract

Most of the structural engineering failures are due to fatigue of the critical components. Surface engineering is one of the best ways to extend the fatigue life. Over the past decade laser based surface engineering have become popular due to the ease of use, minimal variation of surface roughness and reliability. Laser shock peening (LSP) has been implemented on stainless steel plates (SS304 and SS316LN) with various sacrificial layers (SLs) for both the confinement of plasma and to protect the sample surface. The effect of different sacrificial layers (absorptive paint, transparent and absorbent adhesive tapes) and laser parameters (energy and pulse duration) have been optimized to achieve high compressive residual stresses and minimum surface roughness values. Of the different SLs studied the absorbing adhesive tape has resulted in an average surface roughness of about 0.04 μm, a ten-fold improvement compared to the others. Cross-sectional SEM results confirmed the same. For both 7 ns and 30 ps laser pulse durations used in the project, absorbent adhesive tape has always resulted in compressive residual stresses (-805 ± 45 MPa with 7 ns, 90 mJ) whereas other SLs resulted in tensile residual stresses. Texture observed in (111) reflection of X-ray diffractograms and the center of the peak has also gradually shifted to left with increase in laser energy, confirming the compressive residual stress. The X-ray line profile analysis showed that the microstrain (ranging from 1.1×10^{-3} to 4.1×10^{-3}) and the dislocation densities (ranging from 28×10^{13} m^{-2} to 298×10^{13} m^{-2}) have increased with increase in laser energy for both the pulse durations in SS304 samples. The deformation characteristics of the laser peened samples such as strain rate sensitivity and activation volume evaluated from the nanoindentation data from constant load method. The influence of LSP using absorptive adhesive tape as SL on fatigue behavior of 316LN stainless steel has been studied at 298K by conducting fully reversed stress controlled fatigue tests in the range 200-300 MPa. A study is made of cyclic stress-strain response in both virgin and peened states. The information on fatigue crack initiation and propagation was generated by observing the fractured surface and surface of the specimens subjected to fatigue loading. The peened material showed better fatigue strength and life at low stress amplitudes pertaining to high cycle fatigue regime. Altogether, the absorbent adhesive tape as a sacrificial layer for both the stainless steel targets showed an excellent performance to achieve high compressive residual stresses, lower surface roughness that will reduce the crack initiation and propagation.

MAT-11

Development Of Level Sensor For Lead-Lithium Loop System

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Abstract

In Indian liquid breeder blanket, Lead lithium (Pb-Li) alloy is used as a coolant. The system operates at a temperature of around 300-480 C. Continuous Level measurement in lead lithium system is a challenge due to high temperature and the chemical behavior of the liquid metal alloy. Since lead lithium is a good conductor of electricity, mutual inductance type continuous level sensors is one of the possible choices. However currently these level sensors are not available in open market internationally and nationally since, their calibration, and sensitivity completely will depend on the type of Liquid metal used and its operational temperature. Indira Gandhi Centre for Atomic Research has developed probes for liquid sodium level measurement and the technology was transferred to an industry in Bangalore. The sensitivity of the level probes depends on resistivity of the liquid metal, temperature coefficient of resistivity, electrical resistivity of the pocket of the probe, bobbin of the probe and the resistivity of the coil winding material. The design of level probes suitable for lead lithium system is currently being performed at PIs institute as part of this project.

Following the conceptual design of the Pb-Li Level sensor probe, the Finite Element Analysis of the same has been performed out using FEMM software. The expected secondary output voltages of the probe for various Pb-Li levels are determined and the sensitivity of the probe has been predicted. All these results will be presented in the poster.

MAT-12

Laser Beam Welding Technique For Sealing Vacuum Boundary Of DNB Vessel In A Lip Seal Configuration

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Abstract

The purpose of this project was to establish an understanding on Lip seal laser welding technique, which will be beneficial for the ultrahigh vacuum sealing applications with better maintainability requirement in the various fusion devices. The project considered developing the lip seal (formed by 2mm thick sheet of stainless steel) for non-circular geometries by using laser beam welding technology, design & fabrication of clamping device for maintaining the gap within the tolerance and the weld samples qualification based on various destructive and non- destructive examinations.

The development includes (1) methodical study of variables which affect the penetration characteristics, weldability and quality of weld (2) defining the tolerance band of these variable by carrying out the experiments (3) repeatability study (4) investigation of mechanical and microstructural aspect of the weld, heat affect zone and base material through characterization (5) qualification of the welding process, technique and parameters in accordance with codes and standards (6) establishing the scalability by demonstrating process reliability initially on the small scale and then moving to the bigger scale lip seal configuration.

The project was executed in three different stages; Stage 1: Development of the Laser Beam welding parameters for large scale lip seal of size 3.5 m * 1.5 m (1/3rd size of large rectangular vacuum vessel Lip Seal) with the required penetration of 3mm and consistent weld quality. Stage 2: Design, fabrication and testing of clamp tool for closing the gap between sheets. Stage3: Non-Circular Lip seal configuration with size of 1 m length with 1.2 m diameter (Actual size of High Voltage Bushing Lip Seal), design & fabrication, welding of the sample and Helium leak testing after welding.

The deliverables of this project (along with the subsequent stages of the project) would help establish the procedure for the weld in a shape that is adequately complex to be extrapolated for all applicable geometries

MAT-13

Development Of Laser Welding Technique For Dissimilar Materials In Different Forms

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Abstract

This project primarily involved laser welding of copper and stainless steel. Objective of the project was to study the welding behavior and find a parameter window for acceptable laser welding for different thickness of copper and steel sheets/plates in butt joint configuration. Detailed study for 1mm thick plates was carried out .Welding of plates up to 2mm seemed feasible with then installed laser capacity at Magod Laser of 2kW CO_2 Laser. The joint strength obtained was comparable with that of the weaker material in the joint. The ductility of the joint was also satisfactory as it could withstand 180 deg. bend test. Some trials of lap joints and pipes were also carried out with limited success.

Based on the data gathered in the project, a relation between Laser power requirement and the sheet thickness for welding was suggested.

MAT-014

Development Li_4SiO_4 Ceramics For Test Blanket Module: Addressing Some Critical Issues From Powder Synthesis To Pebble Fabrication

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Abstract

Lithium-based ceramics have long been recognized as promising tritium-breeding materials for fusion reactor blankets [1]. Recently, Li_4SiO_4 has been selected as one of the most promising candidates for solid tritium breeding materials in fusion reactors because of its high lithium atom density, favorable tritium release behaviors and high thermal conductivity compared to other lithium ceramic. Lithium orthosilicate (Li_4SiO_4) is commonly synthesized using traditional solid state methods. These processes typically require heat treating the precursors at high temperatures usually above 900° C for a prolonged period. Li_4SiO_4 is formed at a composition around 50 wt% silica and 50 wt% Li_2O. According to phase diagram Li_4SiO_4 decomposes before melting around 1000°C. High temperature solid state methods lead to a myriad of problems including contamination, volatilization and lack of control on the microstructure and composition [2]. Instability of Li_4SiO_4 above 900°C is a major concern for synthesizing phase pure powder by solid state method. Recently, a water based sol-gel route was developed to synthesize Li_4SiO_4 nano powders. For this purpose aerosol (SiO_2) and fumed silica were used as the silica precursors, which were expensive [3]. Rice Husk Ash (RHA) mainly contains amorphous silica with minor other metal impurities and can be a cheap source of silica for sol-gel synthesis of various ceramic materials. Silicic acid is another synthetic material can be a cheap source of silica. Pebble making by extrusion and spherodization is one of the best method for preparation of pebbles in large scale. But there is no information available in public domain on effects of different binders on final properties of Li_4SiO_4 pebbles. Phase pure lithium orthosilicate (Li_4SiO_4) was prepared by the solution - combustion technique as well as solid state method using rice husk ash (RHA) and silicic acid as silica source. It was found that by controlling the metal to citrate ratio of the starting solution, phase pure powder can be prepared at 650°C for RHA and 700°C silicic acid. However in solid state method, higher calcination (800°C) was required to achieve phase purity. In combustion method nanosize and high surface area can be prepared. It was found that Li_4SiO_4 powder can be sintered at a temperature as low as 900°C with a density ~ 84% of the theoretical density. In case of solid state method prepared powder, maximum 80% of the theoretical density could be achieved. Phase stability in the sintered sample was studied.

Effect of the different binders and moisture content were studied to fabricate the Li_4SiO_4 pebbles by extrusion and spheronisation technique. Properties of the prepared pebbles were characterized for sphericity, pore size distribution, grain size, crushing load strength. The values were found to be conforming to the desired properties for use as a solid breeder.

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MAT-15

Development Of Li_4SiO_4-Li_2TiO_3 Composite Pebble Using Extrusion And Spherodization Technique With Improved Crush Load And Moisture Stability

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Abstract

Nuclear fusion energy has recently returned to centre stage, in view of the present global concern about energy security and the greenhouse effect. Lithium containing ceramics are of research interest for tritium breeding as tritium is not available naturally. Lithium orthosilicate (Li_4SiO_4) have been studied as attractive ceramic solid breeder material due to its high lithium atom density, low neutron activation characteristics and prominent tritium release rate at low temperatures [1]. However, it is very difficult to achieve more than 80% of true density with open porosity (around 10%) and uniform small grain size distribution (<10μm) in final pebble, which is essential for tritium breeder application [2]. Li_4SiO_4 is the best candidate for tritium breeding blanket in fusion reactor, however, suffers from poor density and strength. Little work has been done to fabricate Li_4SiO_4 - Li_2TiO_3 composite pebbles with better strength and optimized porosity.

The effect of different amount of Li_2TiO_3(LT) (0-15wt%) addition on the properties of composite Li_4SiO_4 (LS) ceramic pebble was studied. The Li_4SiO_4-Li_2TiO_3 composite powder was prepared in-situ using solid state method at a calcination temperature as low as 800^{o}C. The composite pebbles were fabricated using a cost-effective and simple technique called extrusion-spherodization. The sintered pebbles were characterized for density, grain size, pore size distribution, crush load and moisture stability. The density of Li_4SiO_4 composite pebble was enhanced by ~10% for LS-5wt% LT in comparison to LS pebbles when fired at 1000^{o}C. Moreover, the LS grain size in the composite pebble was reduced greatly by ~28.4% when compared to LS pebbles. We also found that the average crush load value of the LS-5wt% LT composite pebble had been improved by nearly 100% (33N) to that of the pure LS pebbles (17N). The LS-5wt% LT pebbles showed an excellent stability to moisture.

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MAT-16

Studies And Current Status Of W/W-Y-Cr Based Double Layer Structure Development

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Abstract

Tungsten is a prime material candidate for the first wall of a future fusion reactor. In the case of a loss-of-coolant accident (LOCA), wall temperatures could reach as high as 1450K and could lead to the formation and release of highly volatile and radioactive tungsten trioxide (WO3) [1]. Self-passivating tungsten-based alloy coating is expected to provide a significant safety to pure tungsten since this coating can suppress the sublimation of the radioactive WO3 by forming the other stable oxides layer [2].

In this work, new alloys containing yttrium (Y) has been developed which can feature a remarkable suppression of mass increase due to oxidation as compared to that of pure tungsten's initial oxidation. Furthermore, in this contribution, we present the study of different W alloys containing Cr and Y, developed using activated sintering route. Activated sintering campaign under reducing condition with at least two different metal binder additives, with various alloy composition and sintering temperatures, were optimized preliminary based upon the resulting density. The present route is proven to be much simplistic and of great potential compared to other high-end complex methods such as hot isostatic pressing (HIP), etc. The densification of the sintered product was experimentally determined (95-97% theoretical). Further, it was observed that the addition of Y inhibited grain growth and resulted in the homogenous microstructures. There is a marginal increase in hardness by the addition of 1wt% Y (8.2GPa) relative to the W-Cr alloy composition (7.6GPa). Using the developed W-Y-Cr alloy, a sputter target (2 inches in diameter and 3mm thick) is prepared for depositing the dual layer W/W-Y-Cr coating. Pure W coating has already been prepared and optimized for its phase stability. Pure films deposited with higher pressure are found to be possessing higher hardness and crack propagation resistance (CPR).

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MAT-17

Development of Hybrid GNP Based Thermal Conductive Adhesives for Thermal Interface Materials (TIMs) Application

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Abstract

In this work, new novel Graphite Nanoplatelets (GNP) was introduced in order to improve the thermal conductivity of Epoxy. A hybrid Expanded Graphite/Graphene nano platelet (EG/GNP) based conductive epoxy composite were synthesized at different filler loading. From Scanning Electron Microscopy, formation of a conducting network through hybrid expanded graphite and GNPs were observed lowering thermal interface resistance of the developed composite. Thermal conductivity of hybrid expanded graphite/GNP–Epoxy composites at 33 wt % filler loading measured by using ASTM E1530 method at 60 ^{o}C demonstrated increment in conductivity value up to 3.6 W/mK. Large effect on rheology of the adhesive paste was observed with higher viscosity, storage modulus and loss moduli values compared to neat epoxy. Higher tensile and elongation strength were observed at room temperature and liquid nitrogen environment, exhibits its suitability for commercial use as a conductive thermal interface materials (TIMs) and temperature sensor interconnection applications.

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MAT-18

Distortion Validation Of Laser Beam Welded SS316 Steel Plates

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Abstract

A finite element modeling starts with the heat equation, heat flux input and thermal modeling and the material definition. In this study a laser welding model with conduction mode of heat transfer is defined and analyzed for a 2mm thick SS316 material, the temperature dependent thermal and structural properties are taken for analysis. The laser has not formed the key hole yet lateral conduction form the weld bead will progress and convection & radiation from the top surface. Modeling of these thermal inputs with symmetric BCs of heat at the fusion zone centre was used in modeling ANSYS solid70 element to obtain the Thermal temperature distribution. Sequentially, this thermal load is given as input to the solid45 to obtain the structural distortion. An orthogonal Array of 9 experiments with three levels of Laser Power, Weld speed and Shield gas flow rate were conducted and analyzed. The optimum levels obtained were 2750Watts, 2500 mm/min and 10LPM. The shield gas flow rate was related to the convective heat transfer coefficient, h in the model. Experimental validation of distortion by experiments had within 8% agreement.

Suresh et al [1] had developed the weld model for studying of distortion and residual stress for similar and dissimilar weldments using the ANSYS software. Distortion & residual stresses for a 1mm thin plate is simulated also validated with experiments [2]. Heat source definition is essential for welding simulation in realistic models. The Gaussian heat source is used for simulation analysis for laser processes [3].

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MAT-19

Tungsten-Tantalum (W-Ta) Composite Film As A First Wall Coating For Fusion Blanket

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Abstract

An ideal plasma facing material is still a target to achieve in fusion device. The DBTT (Ductile to Brittle Transmission Temperature) and the bubble formation due to Deuterium and Tritium in Tungsten are limiting the usage of it in Tokamaks [1-4]. Tungsten thin films are preferred instead of Tungsten blocks inside a Tokamak due to as a while lesser static weight of the Tokamak without decreasing the functionality of the material. In this work, the composite thin films of Tungsten and Tantalum are prepared and compared with of pure Tungsten films to observe its improved ductility property and reduction in crack propagation due to induced secondary phase. Tungsten coatings initially coated without plasma etching on RAFM substrates are found to be scratched out from the surface. Substrates after plasma etching in Ar environment showed better adhesion strength of thin films. The concept of interlayer is being explored to study the adhesion characteristics. Proper interlayer coating has been incorporated to increase the coating adhesion on RAFM substrate. Experiments have been performed considering 25% Tantalum and 75% Tungsten materials using two magnetrons in a single sputtering system. Mechanical and surface properties of the composite coating have been analyzed using micro and nano indentation, XRD, SEM etc. Adhesion property of the coating has been understood by scratch testing.

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MAT-20

Functionally Graded W-Cu Composites Using Ball Milling And Spark Plasma Sintering

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Abstract

Plasma facing materials (PFMs) are one of the most important materials in a nuclear fusion reactor. W is considered as a major candidate material for the armour of PFMs due to its excellent properties such as high melting point, good thermal stability and low thermal expansion. In addition, Cu is known as an ideal heat sink material due to its high thermal conductivity [1]. However, it is very difficult to join W armor and Cu heat sink due to their large difference in coefficient of thermal expansion ($\propto_{Cu} = 4\propto_{W}$) and elastic modulus ($E_{Cu} = 0.2E_{W}$) [2]. Therefore, when heat passes from W armor to Cu heat sink, large stress at the interface is generated. This leads to cracking and delamination and reduces the life time of the component. Furthermore, it is very difficult to fabricate this material with high density using conventional sintering techniques due to the large difference in sintering temperature and mutual insolubility of the two metals [3]. All these problems can be overcome by introducing W/Cu based functionally graded material (FGM) between the PFMs (W) and heat sink material (Cu), which acts as an interlayer to decrease the thermally induced stresses at the interface [4].

In the present study, we have optimized high energy ball milling and spark plasma sintering (SPS) parameters for to develop W-Cu functionally graded nanocomposites. High density three-layered (W-$W_{50}Cu_{50}$-Cu), four-layered (W-$W_{80}Cu_{20}$-$W_{20}Cu_{80}$-Cu), five-layered (W-$W_{80}Cu_{20}$-$W_{50}Cu_{50}$-$W_{20}Cu_{80}$-Cu) and six-layered (W-$W_{80}Cu_{20}$-$W_{60}Cu_{40}$-$W_{40}Cu_{60}$-$W_{20}Cu_{80}$-Cu) (all compositions in wt.%) W-Cu functionally graded composites (FGCs) were fabricated with optimized parameters by a new approach through high energy ball milling followed by SPS. The resulted FGCs were characterized for their microstructure, hardness, coefficient of thermal expansion (CTE) and thermal conductivity.

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MAT-21

Development Of Dissimilar Friction Welding Joint For Al-SS And SS-Cu Materials

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Abstract

Dissimilar joints of aluminum (Al) to stainless steel (SS) and stainless steel (SS) to copper (Cu) are applied at the cryogenic applications of the heat exchangers. Tube to tube joint configuration is recommended for the shell and tube type heat exchanger and plate and fin type heat exchanger. Working fluid of helium is used at the tubes of Al-SS and SS-Cu joints. Along with the aforementioned discussed challenges, the additional difficulties of dissimilar joints are formation of defects due to material contraction that occurs because of thermal shocks. The thermal coefficient of expansion is also different for these dissimilar materials. The joint strength is another issue of dissimilar joints of cryogenic application as the joint must be able to handle the pressure of the fluid. Previous reports have investigated these joints in a limited manner hitherto. Hence, it is worthwhile to investigate the dissimilar Al-SS and SS-Cu friction welding joints for the tube to tube joint configuration.

The objectives of the present investigations are as follows: To establish the suitable process parameters of friction welding for Al-SS and SS-Cu dissimilar systems for tube to tube joint configuration, Develop the fixture for tube to tube type configuration, To set up the effect of process parameters on properties of dissimilar joints, Investigations on joint properties include mechanical testing, metallurgical characterization, nondestructive testing, pneumatic and hydraulic leak test, and test for sustainability at cryogenic temperature., To reduce the formation of IMCs at the joint area.

From the investigations, following outcomes are expected: To obtain a defect free dissimilar Al-SS and Cu-SS joints and establish the process parameters for the same, To develop the dissimilar joints that can pass non-destructive test of Radiography as per ASTM standards, To develop the dissimilar joints that can sustain MSLD 80 K cryogenic temperature and hydrostatic pressure 14 bar, To achieve tensile strength 70 % of the Al and Cu base material for Al-SS and Cu-SS dissimilar systems respectively, To exhibit the understanding of mechanical properties and metallurgical characterization including formation of intermetallic compounds (IMCs) of dissimilar joints.

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MAT-22

Investigations On Bead Geometry And Ferrite Content Of Dissimilar Welds Between 316LN And XM-19 By GMAW Process

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Abstract

Amongst conventional and newly developed materials for specific application in various parts of International Thermonuclear Experimental Reactor (ITER), 316LN (ITER Grade- henceforth will be referred as 316L (N)-(IG) and XM-19 finds its application in divertor component. Both the specified materials belong to the category of nitrogen strengthened austenitic stainless steel, which has higher strength and allowable stress compared to conventional austenitic grade steels [1-2]. Fabrication of some parts of divertor component requires weld joint between this two dissimilar grade austenitic stainless steel [3-6]. Thus, current research work investigated the effects of GMAW process parameters with 316L filler wire for welding of 316LN and XM-19 grade steels specifically, by examining bead geometry via microstructure analysis. Additionally, measurement of residual delta ferrite content are also been carried out which is important criteria for the development of welding technologies for the specified dissimilar materials. Furthermore, the comparison has also been made based on the results obtained for 316LN and XM-19 grades of steel. It was concluded from experimental work and subsequent results that XM-19 can be easily welded with ER316L type filler wire using GMAW process. All the defined parameters can be subsequently used based on groove geometry and weld profile requirement. However, parameters for 197 A, 27 V, 350 mm Per Minute Travel speed gave good bead profile in specific and average ferrite content in the middle section for both the plate. Thus the parameters can be considered ideal combination for further development of welding techniques for the specified dissimilar joint.

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MAT-23

Investigation Of Friction Stir Welding Between Dissimilar Materials Copper To Aluminum

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Abstract

In the present investigation, dissimilar system of Cu-Al FSW is investigated for its tool design, process parameters, joint mechanisms and properties, microstructural changes and hybrid approaches such as heating assisted FSW and cooling enhanced FSW.

Present study reveals that, the process parameters such as tool pin profile, tool tilt angle, tool pin offset and welding speed significantly affects the weldability and properties of dissimilar Cu-Al FSW. Tool pin profiles of taper and polygonal shapes have adversely affected the welds while cylindrical tool pin profile is most suitable for defect free butt joint configuration. Fragmental defects are increased as the number of polygonal edges decreased. Defect free dissimilar Cu-Al friction stir welds are achieved by tool tilt angles of 2°, 3° and 4° whereas major defects are reported for tool tilt angles of 0° and 1°. Complex and heterogeneous microstructures are reported in the stir zone due to different size and shape of Cu particles in Al matrix. Material flow of dissimilar Cu-Al stir zone is affected by shape and size of Cu particles dispersed from Cu base material. Phases of IMCs such as CuAl, CuAl2, Cu3Al and Cu9Al4 are presented in the stir zone of dissimilar Cu-Al joints. Super hard stir zone is reported due to presence of different IMCs. Non-uniform hardness profile is reported across the cross section of dissimilar Cu-Al FS welds. HFSW at low preheating current of 80 Amp is attributed to improve the tensile strength up to some extent (nearly of 10 %), while major defects are reported at the higher preheating current of 120 Amp that consequently deteriorated the tensile strength. Besides, significant improvement in tensile strength is reported for cooling enhanced
FSW technology relative to Normal FSW and HFSW. The maximum tensile strength of 158 MPa (76 % of the Cu base material) is reported at CFSW of water. The amount of IMCs formed in stir zone is increased with increase in preheating current in case of HFSW, while the formation of IMCs is drastically reduced with cooling effect in case of CFSW relative to NFSW.

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MAT-24

TIG Welding Of RAFM Steels

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Abstract

Reduced activation ferritic/martensitic (RAFM) steels have been selected as a major structural material for test blanket in International Thermonuclear Experimental Reactor (ITER).The selection of joining processes is dedicated by the need to minimize the size of the fused metal zone, heat affected zone and minimum use of edge preparation and filler wires.

Twelve different single component oxide fluxes such as Al_2O_3, CaO, Co_3O_4, CrO_3, CuO,Fe_2O_3, HgO, MnO_2, MoO_3, NiO, TiO_2 and ZnO and two different carrier solvent such as acetone and methanol are used for the present study. Out of all the experimental trials, the most appropriate combination, capable of finger-like penetration incorporating reduced bead width and enhanced weld penetration is achieved with flux TiO2 mixed with methanol. Subsequently, from the weld bead profiles and peak welding temperatures, it was analyzed that two different depth enhancing mechanism (reversed Marangoni effect and arc constriction) were prevalent during A-TIG welding. The standard size butt welding coupons were welded with the finalized parameters and fluxcarrier solvent combination and full penetration of 7.8 mm in 6mm thick LAFM steel plate was achieved in a single pass. The coupons were subsequently subjected to single and double post-weld heat treatment (PWHT) at 760°C for 02 hours followed by tempering in still air, effect of this single, as well as double PWHT on mechanical and metallurgical properties, are analyzed.

A-TIG welded joint undergone double PWHT having highest yield strength. The ductility of the A-TIG weld joint undergone double PWHT was improved as compared to ATIG weld joint undergone single PWHT and even greater than the base metal. Impact toughness of the welded joints was inferior to the base metal, however, an improvement in these values observed for A-TIG weld joints undergone double PWHT. The ductile to brittle transition temperature (DBTT) values achieved for A-TIG weld joints undergone single and double PWHT were -5°C and -11°C respectively. The presence of delta ferrite and carbides of type M23C6 and MX type are confirmed in microstructures. The microhardness values of the weld joint after double PWHT was similar to base metal indicating that the selected PWHT cycle was appropriate. A-TIG welded joint properties were also compared with normal TIG and LBW joints.

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CONTRIBUTED PAPERS

RF & MICROWAVE

MW-01

Design And Development Of Transmission Line Components At 42GHz For Startup Studies In Aditya Tokamak

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Abstract

For Electron Cyclotron Resonance Heating (ECRH) applications, Gyrotron is the source of power generation. Under the aegis of Department of Science and Technology (DST), a multi-institutional program for the development of a gyrotron operating at 42±0.2GHz/200kW/3secs in TE_{03} mode has been undertaken [1]. The gyrotron is currently in an advance stage of test and commissioning at IPR (Institute for Plasma Research). For efficient plasma coupling the output mode of gyrotron in TE_{03} mode is to be converted to HE_{11} mode [2]. The Electric field distribution of HE_{11} mode (TEM_{00} mode), is very close to that of an ideal Gaussian mode. This gaussian like mode is preferred for high-power transmission through overmoded corrugated waveguides, which gives insertion loss lower than that of any other modes. The proposed design of transmission line system converts unpolarized TE_{03} mode into polarized HE_{11} mode.

The transmission system includes two design approaches, whose performances are compared in terms of insertion loss, bandwidth and cost effective manufacturing. A simulation study of the proposed system was verified using CST-MWS. The total insertion loss for both the methodologies is between 1.3 to 1.5 dB. Performance optimization has been carried out prior to fabrication process. Manufacturing of transmission line components is 90% completed. As a part of a design, transmission line system is mechanically compatible to high vacuum and 1bar pressurization.

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MW-02

Design And Development Of Calorimetric Dummy Load For 42GHz/200kW/3sec Gyrotron

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Abstract

A calorimetric dummy load is a high power one port device projected to terminate a transmission line. The objective of this project is to Design and Fabrication of Calorimetric Dummy Load (CDL) to absorb maximum power of 200 kW at 42GHz microwave frequency applied for 3 seconds in manifestation of efficient cooling medium. The power initiated from gyrotron has to pass through the sequence of transmission line components while estimating purity of 87% during travelling, it reaches in Gaussian HE_{11} mode at the mouth of Dummy Load. Innovative focusing mechanism have to be assembled within the dummy load to cater the energy to absorbing media allied by active cooling for taking away the heat. The material for subcomponents which are going to assemble in CDL system have to be chosen by keeping an eye on their electrical properties (i.e. Dissipation factor tan δ, dielectric constant (єr), maximum electric field handling capacity) and mechanical properties (Cp, k, melting point, flash point) to avoid catastrophic failure during operation. The key parameters of a CDL design are pressure handling capacity (>3 bar), volumetric flow rate of active cooling system (~100 LPM), Power handling capacity and predominantly VSWR (Voltage standing wave ratio, 1.0-1.1). In the current design of CDL, the temperature generated during this operation plays critical role in heat transfer phenomena so that detailed CFD analysis using ANSYS has been carried out to find the temperature contour, pressure contour of water passing through the helical tube along with the reflection field pattern for defocusing metal mirror has also been evaluated.

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MW-03

Antenna Options For MM-Wave Fusion Plasma Diagnostics System

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Abstract

In the situation of energy scarcity, fusion plasma energy is one of the vital energy sources [1]. For fusion plasma, diagnostics play an important role to know the parameters of plasma, such as plasma density, temperature, impurities, pressure, total energy, currents of plasma accurately [2]. For microwave and millimeter wave diagnostic system, the antenna is one of the essential components. In order to detect the plasma parameters accurately, the antenna should generate a Gaussian like pattern. Such pattern also ensures better antenna gain, low losses, low cross-polarization, minimum side-lobes and very good coupling with quasi-optical system [3]. For this, TE_{11} and TM_{11} modes need to be added in proper amplitude and phase to generate hybrid HE_{11} mode. It is reported that the HE_{11} mode is almost linearly polarized and nearly matched with the Gaussian beam [3]. Amongst variety of horn antennas, a few antenna configurations can only propagate hybrid mode to form a Gaussian like radiation pattern.

This paper covers various D-band horn antenna options that can be used for the fusion plasma diagnostics systems. Various antenna configurations such as, conical, pyramidal, corrugated, spline, etc. [4] are designed and simulated for the plasma diagnostics applications. For all antennas under consideration, a detailed comparison in terms of performance parameters, such as return-loss, gain, cross-polarization, side-lobe level, etc. is presented. In addition, possibilities to reduce the antenna design and fabrication complexities, especially for millimeter wave antenna are discussed.

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MW-04

Development of Barium Zinc Tantalate (BZT) Ceramics for Microwave Window Application in Fusion System

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Abstract

Barium Zinc Tantalate (BZT) ceramics has long been identified as a potential material for microwave window application in fusion system because of its excellent microwave dielectric properties. But, extremely high sintering temperature (> 1600 ^{o}C) followed by prolonged annealing time (~ 100 hrs) pose a serious problem in processing this material with acceptable properties suitable for such application. The current investigation involves the processing of this novel material with dimension suitable for window sections in fusion reactor. Sintering studies have been conducted to identify optimum condition to lower the sintering temperature. Microwave sintering has been investigated to lower the sintering temperature as well as to evaluate the need for prolonged annealing to establish appropriate ordering in the system. Different colloidal processing has been adopted to prepare the sections with proper dimension. The sintered ceramics have been characterized for structural, microstructural, thermal and microwave dielectric properties and the obtained properties have been correlated with the structure of BZT ceramics.

MW-05

Efforts In Indigenous Design And Development Of High Power Microwave Devices

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Abstract

The Current drive LHCD System generates power of 2 MW CW at 3.7 GHz and delivers to the SST- 1 tokamak via a grill antenna through a phased array of waveguides. The existing system incorporates 4 Klystrons, circulators and waveguide power dividers and combiners. A few efforts have been carried out to design and develop these high power microwave devices indigenously. One of them has been the design of a high power circulator at 3.7 GHz capable to handle 500 kW CW power. There is another requirement of a compact, low cost solid state source which can give an output of 50W to 200W at 3.7 GHz with a very narrow bandwidth. This paper gives an overview on the design of circulator and also presents a modular design comprising of multiple solid state power amplifiers in parallel, with power combiner/divider and couplers operating at 3.7 GHz.

Circulator Design: A 3.7 GHz, 500 kW CW circulator has been designed and is currently being fabricated. RF, thermal and hydraulic design and analysis was carried out so as to present a design which can satisfactorily operate at the above specified ranges.

Solid state driver : The modular design represents 4:1 / 8:1 way power divider/ combiner approach. The system level computer simulation based on behavioural model is performed using Virtual system simulator software [2]. The system efficiency and power distribution considering the losses incurred, is analyzed. The analysis helps to determine the power handling capacity of individual stage, prior to system integration. Based on system analysis, the paper presents the design of an oscillator to drive an amplifier at 3.7 GHz. Linear and non-linear analysis [1] has been performed on the design to ascertain its performance. The oscillator delivered a power of 10dBm at 3.7 GHz. The amplifier provides a gain of 14 dB at 3.7 GHz. The system analysis results and individual stage results helps to decide the architecture of complete solid state driver module.

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MW-06

A Brief Review On MgO-TiO_2 Microwave Resonator And Window Materials

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Abstract

The rapid progress of the wireless communication provides a continuous driving force for the discovery and growth of new microwave window and resonator materials. Low loss dielectric ceramics are gaining much attention in this field. Dielectric measurements and properties in microwave range along with sintering temperature of the material are the main area of interest of the researchers which are contributing in the development of smart microwave window materials. Density and microstructure of the material play an important role for getting good microwave dielectric properties. Further, different types of material synthesis process are implemented to get best material. The MgO-TiO_2 based low loss ceramics are one of the preeminent materials in microwave domain due to their high dielectric constant, low loss, and low temperature coefficient of the resonant frequency. The $MgTiO_3$ ceramics have promising dielectric response at microwave frequencies: $\varepsilon_r \sim 17$, quality factor ($Q \times f_o \sim$ 1,60,000 GHz at 8 GHz) and $\tau_f \sim$ -50 ppm/^oC [1]. A number of materials based on MgO-TiO_2 binary system have been explored by adding different types of additives and substituting different dopants [2, 3, 4]. As for many practical applications, it is necessary to lower the sintering temperature of $MgTiO_3$ ceramics, research has been carried out to reduce the sintering temperature. There are two effective methods to reduce the sintering temperature of these materials: addition of liquid phase (or) other low melting point material and small particle size (nano range) of the sintering materials. In this report the various types of MgO-TiO_2 based low loss ceramics, their synthesis methods, characterizations and properties are presented which have been showing their immense presence in microwave window industries.

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MW-07

Structural, Optical And Microwave Dielectric Studies Of Mg_2TiO_4-$xBa_5Nb_4O_{15}$ Composite Ceramics

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Abstract

(1-*x*) Mg_2TiO_4(MTO)-*x*$Ba_5Nb_4O_{15}$(BNO) (*x* = 0.2 to 1 mole wt%) composite ceramics have been prepared via solid state reaction method. A systematic study on the structural, microstructural, optical and electrical properties of the MTO-BNO composites has been reported. The structural studies revealed presence of independent crystalline MTO and BNO phases along with minor secondary peaks. The vibrational modes of the composites studied by Raman Spectroscopy complemented the XRD results. The FESEM micrographs showed well packed grains with uniform microstructures. The electrical properties were studied in MIM structure using LCR meter (1kHz – 100kHz). The dielectric constant of composites found to be improved with an increase in BNO concentration (26 - 32). The obtained dielectric constant almost remained constant with temperature (30- 300℃) across the measurement temperature. In addition, the optical band gaps of the composites also shown variation with different BNO concentration due to different defect and vacancies associated with the samples. The microwave dielectric properties of these ceramics were in the range of $Q \times f_o \sim$ 60,000 to 40,900 GHz and $\varepsilon_r \sim 20 - 30$ at 10.465 GHz. The optical, dielectric and microwave dielectric properties of the composites could be tuned with the BNO concentration. The obtained microwave dielectric, optical and structural properties of the composite ceramics are promising for filters, antennas and as MIC substrates.

MW-08

Development Of Ferrite Material For Microwave Application Of High Power CW Circulator At 3.7 /5.00 GHz

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Abstract

Steady State Superconducting Tokamak (SST)-1 comprises of four high power circulators to protect klystrons (supplying 500 kW CW each at 3.7 GHz) which power the system. The current report focuses on the development of ferrite material for high frequency microwave CW power circulator. High power microwave circulator requires saturation magnetization >800 $4\pi M_s$ Gauss and line width 10Oe.

Spinal ferrite and garnets are one of the promising candidate that possess this property and can be tailored for its application for microwave circulator. Cobalt ferrite was successfully developed by sol-gel method with saturation magnetization $4\pi M_s$ 600 Gauss.

Ca-Vanded Garnet material was also developed by high energy ball milling (HEBM) and conventional route with very low loss tanδ, $<10^{-2}$ at 1MHz frequency and magnetization $4\pi M_s$ ~ 800 Gauss with line width ~10Oe. The Samples were calcined at 1250^{o}C for 4 hrs and sintered at 1300^{o}C for 10 Hrs. The formed samples were 92% dense. This material is very much suitable for microwave application of high power CW circulator at 3.7 /5.0 GHz. Further research is going on to explore microwave application for High Power CW Circulator.

MW-09

Design And Development Of GUI And A Prototype Hardware Interfacing Module For Data Acquisition For Phase And Power Measurement Of LHCD Channels

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Abstract

A prototype hardware module to measure power for 16 LHCD channels is designed and tested successfully [1]. A stack of four such modules will be implemented for power measurement of 64 reverse channels of LHCD. The design of this module is based on an IC LTC5508 from Linear Technology. The output (in volts) from that IC is then mapped to obtain the power value in dBm and the same is displayed on a monitor through a designed hardware interface exploiting a state of the art embedded module Raspberry Pi. 3.7GHz signal is down converted to 15MHz, in order to measure phase in a forward channel of KHCD precisely. Two modules of AD8302, from Analog Devices, are incorporated, one of which gives the absolute phase difference and the other provides the sign of the phase difference between a reference signal and a signal from a channel. The collected data is displayed on GUI, stored and manipulated in an MS Excel file and retrieved from the same to transfer to another computer via Ethernet cable for distance monitoring and post processing. The operation of entire system is programmed as a python script in Raspberry Pi. The communication between the hardware components is enabled by the means of SPI protocol which is accredited by Raspberry Pi GPIOs. Python packages called Tkinter for designing GUI and xlswriter for manipulating data in the form of a Miscrosoft Excel file have been incorporated. Numerous functions are nested together in the Python script to facilitate the foreground processes such as, formation of tabular display in GUID and updating and indicating the variations in data being displayed, and background processes, such as, switching and reading channel of ADCs, mapping the values of the phase and power, managing the data in MS Excel files, transferring the data for distant monitoring.

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MW-10

Design And Development Of Mock-Up ICRH System Of Tokamak For Fast Matching Of Variable Load

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Abstract

Tokamak is a magnetic confinement device which is used to control and confines the high-temperature plasma to have controlled fusion reaction for future energy generation. In a tokamak, RF power of few MW is to be feed to Ion Cyclotron resonance heating (ICRH) antenna for heating of plasma for the fusion reaction. As plasma has the property of continuously variable mismatched load. The antenna loading can also be affected and the changes occur in both the real and imaginary parts of the antenna impedance. The fast variations are very difficult to match and to a certain extent developed matching networks are failed to cope with faster variation of the plasma load impedance. As the ICRH system of tokamak are spatially distributed and is very difficult to utilize such a diversified system. Therefore, a low power load resilient mock-up ICRH system of tokamak for fast matching has been developed and emulated on a test bench. The mock-up ICRH system comprises of various components such as a 3dB hybrid coupler, co-axial transmission lines, directional coupler, matching network, RF antennae, water load etc. These components are indigenously designed, developed and scaled at five times of ICRH frequency to reduce the size as in real ICRH system of a tokamak. Here, to emulate the plasma load variation, a movable water tank based variable load has been utilized. The implementation of matching network on a test bench consists of a combination of variable stub tuner, line stretcher, de-coupler, service stubs, etc. which enhances the capability of the system to deliver maximum power to the load at any mismatched condition. The components have been simulated, optimized for better results and then fabricated with rigid co-axial transmission line providing the power capability up to 2kW. These devices are attached to electrically controlled fast drives for providing needful mechanical movement for the required matching. The mock-up ICRH system of tokamak consists of feedback loops connected to the drives and program logic controller (PLC). The test response of each component has been presented and compared with the simulated results and found in good agreement. Each component is combined to form an integrated system of the tokamak. The combined test result has been analyzed and provides better impedance matching result in terms of Voltage standing wave ratio. The developed mock-up has been optimized and tested for the highly efficient, load resilient and fast matching network. The work presented in this article is useful for the development of load resilient ICRH system for SST-1 tokamak and can be utilized in ITER ICRH tokamak. Also, each component used in the ICRH system has an important application in the field of radar, satellite, radio communication and broadcasting etc.

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MW-11

Fabrication Of Large Area High Temperature Black Body Source

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Abstract

A black body source is characterized by complete absorption and emission of electromagnetic waves in the frequency region of interest. Depending on the dimension of the black body source and the operating temperature, the complexity in the design and fabrication increase. This paper brings up the challenges, one can encounter, while developing a 20 cm diameter 750 ^{o}C black body source that operate with the frequency span between 60 and 100 GHz. The paper also discusses the methods to test the black body source at 94 GHz.

CONTRIBUTED PAPERS

NEUTRONICS

NUCL-01

Cure Behavior, Mechanical Analysis And Theoretical Neutron Shielding Studies Of Natural Rubber/Low Density Polyethylene/Borax Composites

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Abstract

Thermoplastic elastomer composites are gaining wider acceptance which combines favorable properties of vulcanized rubbers with the ease of process ability of thermoplastics. it is well known that the hard plastic segment and the soft elastomer segments must be thermodynamically incompatible with each other so that they do not penetrate each other but act as individual phases. In the present work the effect of cheap neutron absorber borax compound on the cure, mechanical and neutron shielding properties of Natural rubber/ Low density polyethylene/HAF carbon black were studied.

Natural rubber /Low density Polyethylene (100/10) with 30phr HAF carbon black and varying borax compound (0-30) where prepared in two roll mixing mill followed by compression molding. The cure behavior of the composites indicates that the cure time and scorch time decreased with addition of borax. As filler content increased, the tensile strength, elongation, and tear strength of the composites were reduced, while there is only slight variations in 100% modulus. The 30phr Borax composites shows a total neutron absorption cross-section of 2.94 cm^{-1} and mean free path is 0.34 cm. Which reveals that the addition of borax compound improves the total macroscopic cross-section by 40 %.

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NUCL-02

Evaluation Of The PCB Technology Based 3D Positive Ion Detector For Nanodosimetry

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Abstract

A new experimental technique known as Nanodosimetry has been evolved for the qualitative and quantitative description of ionizing radiation at nano level. To develop a compact track structure detector with nanometric resolution, a new hole type 2D position sensitive positive ion detector based on the multilayer printed circuit board technology that combines the working principle of thick gas electron multipliers (THGEM) and resistive plate counters was designed and tested by Bashkirov et al.[1-2]. To achieve localized events in nanometric resolution, positive ions rather than electrons were registered in these detectors. The measuring method of these positive ion detectors is based on the detection of single ionization in a gas of low pressure, simulating target volumes of about 1 μg cm^{-2} mass per area. Based on this, an upgraded 3D positive ion detector that works under the principle of ion induced impact ionization was fabricated, and characterized that is presented here. To improve the performance of the detector, cathodes with different insulators (Bakelite plate and Steatite Ceramics) and conducting layers (ITO, FTO, and Gold coated cathode) were studied under various gaseous media (propane, methane, argon, nitrogen, and air) using Am-241, Co-60, Co-57, Na-22, Cs-137, and Ba-133 sources. From this study, it is confirmed that the novel 3D positive ion detector that has been upgraded using gold as strip material, tungsten coated copper as the core wire, gold coated ceramic as cathode, and thickness of 3.483 mm showed 9.2% efficiency under methane medium at 0.9 Torr pressure using an Am-241 source that is approximately five times higher than the reported one.

The maximum efficiency of the Nanodosimeter was ~ 12 % in presence of µCi activity Co-60 source under propane medium at 1 Torr pressure using 3.483 mm thick detector. In this case, the observed pulse height, rise time, fall time, ion drift time, dead time, resolving time, and amplification factor of the detector signal was found to be approximately 156 V, 2.5 ms, 495 µs, 13 µs, 2.5 ms, 1.24 ms, and 1.8 x 10^5 respectively. The response time of the detector was observed in the order few sec. From this study, it is concluded that the indigenously fabricated Nanodosimeter would be used an effective detector for low energy and low activity alpha, beta and gamma sources. However, the present study requires further investigation to confirm the dynamic energy range of the detector.

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NUCL-03

Gas Production Estimation On Long Lived Radio-Nuclides (A~50-60) Due To Neutron Irradiation

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Abstract

In magnetic-confinement fusion reactors a huge flux of high-energy neutrons are generated in the plasma by deuterium-tritium fusion reaction. These neutrons escape from the plasma and irradiate the materials that make up the reactor vessel. The neutrons impact the properties of material by initializing various nuclear reactions leading to the formation of radionuclides, production of gas atoms, atomic displacement within the materials, resulting in defect generation and accumulation **[1]**. In fusion reactors, gas production is a more serious problem than in fission. Earlier it was considered that the gas production (mainly He and H) is due to stable nuclides present in reactor material, but now it is accepted that second generation reaction on radionuclides also leads to the formation of gases in significant amount inside reactor environment **[2, 3]**. In the present work, we have done a detailed study based on TALYS-1.8 of the spectra of recoils or PKA at 14 MeV neutron energy due to reaction channels like (n,n'), (n,2n), (n,p), (n,α), (n,γ) in different radionuclides produced in fusion reactor environment in mass region 50-60. We have also calculated gas production cross section which estimated helium and hydrogen production due to different radionuclides. This feature has been compared for the stable isotope. The calculation of the amount of helium and hydrogen produced in the fusion reactor environment due to these reactions is also done using nuclear activation analysis code ACTYS**[4].**

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CONTRIBUTED PAPERS

PLASMA DIAGNOSTICS

PD-01

Analysis Of Impurities Deposited On The Surface Of The Plasma Facing Components Of The Aditya Tokamak Using Laser Induced Breakdown Spectroscopy

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Abstract

The Aditya Tokamak uses different plasma facing component to keep the plasma away from the Tokamak wall. Limiter is the first surface which comes in contact with the hot plasma in Tokomak. Our objective in the present work is to develop a suitable analytical technique for on-line analysis of the impurities deposited on these components. Laser Induced Breakdown Spectroscopy (LIBS) is an atomic spectroscopic technique for elemental analysis of sample in any phase (solid, liquid or gas) with no or little sample preparation. Therefore, we have developed an experimental facility of LIBS for online analysis of the element composition of the impurities deposited on limiter in air and vacuum. The variation of spectral intensity of impurity elements with successive number of laser shots have been studied and observed that the impurity deposition of the elements is not homogeneous on limiter. In a similar way we have studied the variation of spectral intensity of impurity elements deposited on the surface of optical window and flange of the Aditya Tokamak in air atmosphere. The results of these work have already been published in different international journals [1,3]. Study of variation of spectral intensity of impurity elements deposited on the surface of the plasma facing components in vacuum is under progress. The detail of the work will be presented in this meeting.

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PD-02

Transverse Cooled Lithium Beam For Plasma Diagnostics

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Abstract

The plasma edge of a Tokamak is characterized by steep gradients of the plasma parameters (the decay length of the electron density is < 1 cm) and by the presence of neutral particles from walls and limiters. Electron densities are measured by injecting a beam of neutral atoms, which get excited by interaction of electrons and subsequently fluoresce. The fluorescence density is therefore a direct measurement of electron density. However, the steep gradients and lack of axial symmetry demands a measurement resolution of less than few millimeters and a time resolution of less than 10 microseconds. Neutral atomic beams, of which Lithium is a more popular choice, is usually sourced from thermal ovens since their energy requirement is normally low. But such beams suffer from large divergence, thus compromising the spatial resolution of the measurement. In order to reduce the divergence without losing much of flux, we proposed a method of laser cooling, performed only in the transverse direction. This technique reduces the transverse velocities of the atoms without disturbing the axial velocities.

We have built such a setup, which reduces the transverse velocities of the atoms. The beam was characterized using fluorescence and the transverse velocity profile was found to be a Gaussian with a FWHM of ± 5m/s. We present details of this setup, including details of the oven we designed for the Lithium source. We also present the metrics of the beam, including the transverse velocity profile of the atomic beam.

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PD-03

FPGA Based Implementation Of Adaptive Filter Algorithm For External Noise Cancellation

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Abstract

The requirement of energy is increasing exponentially due to the development of industries and population. Today's energy production plants produce some extent of the require energy but not in a safe way, like thermal power plant, where energy is produced from burning coals or fossil fuel. This causes the global warming and much other environmental harm. Moreover, these resources are limited. So, demands of clean and renewable energy sources are increases, solar and wind energy are one of the options but, due to their less efficiency of energy production, they would not suffice the energy requirements. Nuclear energy production is a clean energy source, which is capable of producing the high amount of energy by neutron chain reactions [1]. Energy produced by this method can able to suffice the energy requirements. In this method, a very high temperature is required to be produced for nuclear reactions which can be solved by Plasma Tokomak reactor where, the plasma would be produced and through which, the required temperature would be set for the nuclear reaction. The temperature generated by plasma is very high which cannot be measured through the conventional temperature measurement technique. A laser-based technique is one the method to measure the temperature of plasma [2]. During the measurement of the plasma temperature, various noise gets generated because of different noise sources. To remove the noise generated due to different sources, the research has been carried out and different noise removing techniques have been proposed. For radio frequency noise gradient-based method has been proposed, for Laser and the magnetic noise source, the moving average algorithm has been used. Also, a new adaptive filter has been proposed, which can remove the atmospheric noise like, Gaussian noise and impulsive noise. Moreover, Hardware architecture of all the proposed algorithms have been implemented on FPGA board and GUI application has been developed to set the parameters of the filters and visualize the real-time received signal.

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PD-04

Thin Films Of Heavy Elements *via* Pulsed Laser Ablation Technique As Mirrors For Tokamak Diagnostics

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Abstract

The optimization of the deposition parameters for mirror-like thin films of Mo, W and Rh on polished SS substrate by pulsed laser deposition (PLD) technique, suitable for first mirror (FM) for tokamak and fusion devices, is reported. The UV-visible-FTIR reflectivity of these thin film based mirrors was comparable to that of their respective bulk counterpart. The W and Rh thin film mirrors were exposed to H and D ion beams. The degradation was more pronounced for the UV and visible spectral range where as that of for FTIR it was marginal.

The quality and sustainability of single element W and Rh thin film mirrors, for the long term exposure of fusion plasma, can be enhanced by making multilayer thin film of more than one element. A three-layer composite thin film, Rh/W/Cu on SS, was designed and fabricated for FM application. The degradation in the reflectivity after the exposure to the D ions beam of this multilayer thin film mirror was observed to be reduced indicating the improved quality.

In order to collect large amount of plasma radiation for better reliability of spectroscopic signals, the size of Rh and Rh/W/Cu PLD thin film FMs were increased to 50 mm diameter by modifying conventional PLD technique with substrate rastering stage. The uniformity of deposition was confirmed by distinct, straight and parallel interference fringes from Rh single layer as well as Rh/W/Cu multilayer thin films.

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PD-05

FPGA Implementation Of Fuzzy Logic Controller For Laser Beam Pointing Stability Correction

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Abstract

Stability of high-power laser used as a diagnostic tool in plasma experiments (such as Thomson scattering, laser-induced fluorescence, laser blow-off etc.) is of major concern. Laser beams travel long path from source to reach the experimental setup. Mechanical vibrations of optical devices, air convection in the beam path and instabilities in the laser cavity adds to the instability of beam. Deviation of the beam in lateral or angular position may cause undesirable distortion in the experimental data. Different methods to correct the spatial deviation of the beam includes performing time series analysis, artificial neural networks using high-end workstations [1] and using Proportional-Integral-Derivative (PID) feedback control in both horizontal and vertical directions [2]. These traditional methods for compensating drift effects suffer from problems such as the need for the accurate modeling of the phenomenon, a long learning process, the linearity of the control parameters etc.

Our work tries to eliminate such problems by using Field Programmable Gate Arrays (FPGA) based fuzzy logic feedback control design, which can inherently reduce nonlinear parameter behavior and help in robust and smart system control. Fuzzy Logic Controller (FLC) for laser beam stabilization is ideal for compensation of drift effects [3]. A Software implementation of FLC would be slow on decision making and might miss the strict timing constraints. Implementing the FLC on FPGA would result in fast, accurate and efficient system. Position Sensitive Detector (PSD) is used to provide the position of the laser to FLC and the FLC would drive the picomotors (30 nm resolution) to adjust the gimbal mirror. In the proposed system, ADC conversion takes 1 msec, FLC takes 0.5 µsec and 1 msec settling time gap is given to picomotor drivers. The FLC system will be used for Nd:YAG laser operating at 30 Hz but can be also configured to operate for 1-150 Hz lasers. The architecture uses hardware software co-design techniques, where time-critical tasks are implemented in FPGA (such as FLC and trigger circuit) and flexibility is provided using software platform. Both hardware and software are implemented on Xilinx Zynq System on Chip (SoC) XC7Z020-CLG484. The developed system can be interfaced with a Graphical user interface (GUI) to remotely configure the membership function and rule base to fine tune the FLC.

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PD-06

Simulation Of Radial Profile Of Fe^{14+} &Fe^{15+} Emissions In Aditya-U Tokamak Plasma

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Abstract

Studies of medium and high Z impurities behavior in high temperature tokamak plasmas have become important considering molybdenum, tungsten are being considered as the first wall materials due to its high melting points and capabilities to handle high heat load. Along with that Fe, Cr and Ni impurities are also present inside the tokamak plasma, due to mainly sputtering processes involving plasma facing components and the vessel wall being stainless steel. Presence of impurities leads to enhanced energy loss, fuel dilution and overall degradation of plasma properties. One of the ways to study the impurity behavior is through the monitoring of spectral emissions using spectroscopic diagnostics. Thus, the study of the radial profile of the impurities emissions are carried out in Aditya–U tokamak followed by their simulations. The VUV spectra from impurities is regularly monitored using an absolutely calibrated VUV survey spectrometer having the operation in the spectral range of 10-180 nm, which covers the important spectral lines of partially ionized low and medium *Z* impurities and also spectral emissions from higher excited states of highly ionized low-Z impurities.

The emissivity radial profiles of the VUV spectral line emission at 28.41 nm ($3p^6 3s^2\ ^1S_0$ - $3s3p\ ^1P_1$) from Fe^{14+} and, 33.54 nm ($2p^6 3s^2\ ^2S_{1/2}$ - $2p^6 3p\ ^2P_{3/2}$) and 36.08 nm ($2p^6 3s^2\ ^2S_{1/2}$ - $2p^6 3p\ ^2P_{1/2}$) from Fe^{15+} has been calculated for the typical plasma discharge of Aditya-U tokamak to study the Iron impurity behavior and transport. This has been carried out using 1-D impurity transport code, STRAHL [1]. The spectral lines from Fe^{14+} and Fe^{15+} were also simulated by changing the impurity transport parameter, such as diffusion coefficient, particle source rate, and by varying the plasma electron density n_e and temperature T_e profile. In this paper, the outcome of this study will be discussed.

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PD-07

Contrast Limited Brightness Preserving Dynamic Fuzzy Histogram Equalization Technique For Enhancement Of Steady State Tokamak Plasma Images

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Abstract

Fusion energy can be obtained by combining deuterium and tritium in the nuclear fusion reactor. Measurement and analysis of the hot plasma obtained during fusion is essential for fusion energy studies. Image processing is one of the non-invasive methods used to measure the plasma parameters. In this work a novel image processing technique, Contrast Limited Brightness Preserving Dynamic Fuzzy Histogram Equalization (CLBPDFHE), is proposed to enhance the contrast of the plasma in order to measure the plasma parameters to work on plasma confinement for a long time. Performance metrics obtained from simulation results show that the contrast of plasma is improved in the CLBPDFHE technique compared to conventional histogram equalization (HE) techniques.

PD-08

ANSYS Analysis Of CeB_6 Material Used As Laser Heated Emissive Probe Tip

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Abstract

Precise temporal and spatial behavior of Plasma potential in any plasma device has been a challenging task. Plasma potential gradient governs local electric field, which provides properties like particle drifts, transport barriers etc. In high temperature devices like tokamak plasma tends to develop edge bifurcations, therefore edge transport barriers are key tool for enhancing the plasma confinement properties in magnetic fusion devices, which in turn requires knowledge of actual potential. Hence, a Laser heated Emissive Probe has been used to measure plasma potential directly in high temperature fusion devices. However, probe tip material plays a crucial role for electron emission and collection in plasma environment. In this study CeB_6 material has been used as probe tip material. Heating dynamins of materials was considered using a continuous CO_2 laser of 10.6 micron wavelength and having maximum power 55 watt. Theoretical and simulation models using MATLAB and ANSYS have been developed to understand temperature gaining process of the probe tip. Simulation results are further validated by comparing them with experimentally measured data using an infrared camera.

PD-09

FBG Interrogation Using SMS Fiber And OTDR For Simultaneous Measurements Of Temperature And Strain

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Abstract

A simple and efficient method of interrogating Fiber Bragg Grating (FBG) sensor signals is proposed here using Single mode-Multimode-Single mode (SMS) fiber device and Optical Time Domain Reflectometer (OTDR). Eventually the sensor signals are analyzed for dual parameter measurement of temperature and strain. The SMS fiber device explored the multimode interference (MMI) which occurs along the length of multimode fiber (MMF) [1]. The SMS fiber structure can generate minimum and maximum interference at specific MMF length owing to mode volume mismatch. It results a precise intensity modulated spectral output. Alongside the FBG is a wavelength coded sensing device which needs an interrogation system for essential conversion of wavelength information encoded in optical power [2]. Hence combined sensing outputs from the FBG and SMS signals are monitored using OTDR. The obtained results of strain and temperature measurements from this proposed scheme perform better and enhanced sensitivity with respect to existing method [3].

A brief analysis about experimental arrangements and obtained results are given as following. The SMS fiber structure is fabricated using a commercial fusion splicer (Fujikura- 60S) by splicing a multimode fiber (50/125 µm) section between two single mode fibers (9/125 µm). The OTDR (JDSU MTS 8000 series) with an operational wavelength 1545 nm is used to detect the event induced by the temperature changes on the FBG. The OTDR measures the attenuation of reflected light or return loss and the location from where the light is being reflected within 5 km range of optical fiber network with resolution of 0.001 dB. Here, we have investigated the attenuation loss of an FBG of central wavelength 1545 nm using SMS fiber with the help of OTDR. The power loss is measured with variation of temperature and strain separately and also for the variation of temperature at discreet constant load (100 to 500 gms with an increment of 100 gms) in the range of 25^0C to 100^0C. As the FBG peak follows the linear slope region of SMS, it is expected that the response of OTDR also to be linear which is confirmed from the obtained results, that showing good linearity with adjustable R^2 =0.96. Our scheme of interrogation is expected to be robust, cheap and more efficient for simultaneous measurement of temperature and strain with good sensitivity.

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PD-10

An Experimental Setup For Studying The Fusion Edge Plasma Facing Materials Using TOF Mass Spectrometry

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Abstract

A new experimental set up is developed to study the fusion edge plasma facing materials under impact of low-energy (40–10,000eV) atomic and molecular ions [1]. The primary ions are obtained from a low-pressure D.C. gas discharge Colutron ion source. The product ions resulting from the ion–surface interactions involving different processes, for example, surface-induced dissociation (SID), surface-induced reaction (SIR), chemical- and sputtering are detected and identified by using a single-field linear time-of-flight (TOF) mass spectrometer coupled with a time- and position-sensitive dual micro-channel plate detector. The mass spectra of secondary ions are recorded by employing a pulsed extraction and acceleration technique. The experimental set up, experimental technique and data acquisition methodology are presented and discussed. A test experiment is conducted on the developed set up to demonstrate the performance and reliability of the apparatus. For this, a primary beam of 427eV N2+ ions was chosen to interact with a hydrocarbons covered surface of platinum target kept at room temperature. SID of N2+ into N+ and TOF mass spectra of sputtered, reflected and chemically formed ions from the ion–surface interaction are analyzed. A noticeable feature in the spectra is observed which shows that the odd-electron ions of sputtered hydrocarbons are preferentially produced in the interaction in addition to the other product ions. The nominal mass resolution (M/ΔM) of the present tandem mass spectrometer system is estimated to be about 600, while energy and spatial spreads of the primary ion beam are determined to be about 518meV and 2.8 ± 0.3mm respectively. The survival probability of the incident ions is found to be 6.6% suggesting that the major process of ion–surface interaction at the considered impact energy is neutralization.

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PD-11

High Resolution Spectroscopy Diagnostics For Tokamaks In IPR To Study The Ion Temperature And Plasma Toroidal Rotation

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Abstract

To study the plasma ion temperature, T_i and toroidal rotation velocity, v_t, two high resolution diagnostics have been designed for tokamaks in Institute for Plasma Research (IPR). Charge exchange recombination spectroscopy (CXRS) was conceptually designed for SST-1 tokamak to measure C VI (n = 8 → 7) transition at 529 nm for the measurement of impurity ion temperature and rotation velocity [1-4] during the operation of neutral beam injection system for the heating of SST-1 plasma. To demonstrate the capability of the diagnostics, an optical system using 1.0 m visible spectrometer plus CCD system has been utilized to measure Doppler broadened and shifted passive CX spectral line at 529 nm. The light from the plasma is collected using the combination of lenses and optical fiber from two tangential ports. The system covers the center to 15 cm of plasma with a spatial resolution of ~ 2.5 cm. Initial results shows the Ti of 110 eV and maximum v_t of 6 km/s.

A tangential X-ray Crystal Spectrometer is designed and under fabrication for ADITYA-U Tokamak [5] to measure ion temperature and plasma rotation velocity using Doppler broadening and Doppler shift of spectral line radiations emitted from tokamak plasma respectively. The spectrometer consists of a cylindrically bent Si crystal and two dimension CCD detector to measure Ar XVII line emission at 3.9494 Å viewing the plasma tangentially in the toroidal plane of the vacuum vessel. A very thin Beryllium foil is used to avoid radiations in other wavelengths. The diagnostic has a tangential angle of 26˚ with respect to the toroidal direction in the magnetic axis and will be directly mounted on one of the radial ports of ADITYA-U as it has to be operated under ultra-high vacuum to detect X-ray radiation from the plasma. Due to the very complex geometry of the tokamak system and space limitation, the spectrometer system was subjected to stringent design restrictions. The spectrometer contains three major parts, the collection arm, crystal housing and detection arm. The engineering design has been optimized after adequately addressing issues related to port geometry, machine accessibility etc.

In this poster, the details of the both diagnostics will be discussed and initial results will be presented.

PD-12

Design And Development Of Reflectometry Diagnostic System For Aditya-U Tokamak

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Abstract

Conventional reflectometry is used to measure electron density profile, by probing the plasma and detecting the reflected signal from the density cut-off surfaces. To measure the density profile the probing frequency must be swept in time or multiple frequencies must be used to cover the whole density range [1-2]. In paper [3], Clairet et al has reported measurement of density profiles with excellent time resolution and the dynamics of the plasma turbulence from the plasma edge to the core using ultra-fast frequency sweeping reflectometry systems. Here, reflectometery diagnostic system is proposed for ADITYA-U machine. It is based on fast (100µsec) frequency sweeping reflectometry system which sweeps the frequency from 26 to 36 GHz, and would measure a density profile from edge to $5x10^{18}$ m^{-3} for an operational magnetic field up to 1.5 Tesla. Microwave electronics components have been developed for the reflectometery system like Voltage controlled oscillator (VCO) board (6.5 to 9 GHz), power divider (6.5 to 9 GHz), frequency multiplier (13 to 18 GHz), mixer (13 to 18 GHz), Temperature Compensated Crystal Oscillators (TCXO) board (100 MHz) and IQ demodulator board (DC- 400MHz). The E-plane sectorial horn antenna and kapton based vacuum window is designed using Ansoft HFSS (high frequency structure simulator) software, which is based on the finite element method. Horn antenna meets the system requirements with the high gain (14dB) and low VSWR (1.1). Kapton based vacuum window shows good agreement with the requirements like low insertion loss (0.05 dB) and return loss is more than 44 dB. The detailed design and development of the system would be described and discussed in detail along with results.

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PD-13

4-Channel Wireless Data Acquisition System For Magnetic Diagnostics Of Aditya-U Tokamak

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Abstract

We have designed and developed a prototype model of a Multichannel wireless digitizer for Aditya-U Tokomak to replace the long cable and to solve the isolation problem during the frequency measurement. The wireless digitizer utilizes the integrated ADC and the SRAM of microcontrollers to transfer the data wirelessly. The device consists of simple circuits and a transceiver, which performs in 10-12 bit resolution and trans receive data in 2.4GHz ISM band frequency. The harsh magnetic environment of the tokomak is one of the major challenge of this wireless digitizer. To find the sustainability of the device in harsh magnetic condition of the tokamak we conducted different experiments and we find out the device is very suitable in tokamak environment. Also we have developed a Graphical User Interface for this device in LabVIEW to control it from control room.

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CONTRIBUTED PAPERS

THEORY & SIMULATION

SIM-01

Computational Studies Of Plasma Transport Across Magnetic Filter For ROBIN Negative Ion Source Using PIC-MCC Simulation

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Abstract

The physics of plasma transport across strong magnetic field is a complex phenomenon and plays an important role in many applications including fusion reactors, thruster and also in negative ion sources. Kinetic modeling, such as PIC method, is one of the most appropriate one to study this phenomena. We have developed in-house (1D-3V and 2D-3V) Particle in Cell Monte Carlo Collisional (PIC-MCC) codes to study the effects of a filter field on plasma transport [1]. The PIC-MCC model used for this study uses a simple, purely electro-static and explicit model which can be used to understand the collisional transport across magnetic filters under conditions similar to real ROBIN negative ion source (magnetic field, pressure, density etc.). ROBIN (RF operated Beam source in India for Negative ion research) has been setup at IPR, Gandhinagar to understand and investigate the different issues related to production, transport and extraction of negative hydrogen ions in negative ion sources for fusion applications [2]. The source consists of a driver, an expansion chamber, a transverse magnetic filter field (TMF) and extraction grids. Using these codes (1D and 2D), we have investigated different plasma characteristics such as plasma potential, electron temperature, electron and ion density profiles, electric field, current etc. in the case of a Gaussian shaped magnetic filter, as a case. Simulation results show similar qualitative and quantitative behaviors as observed during the first phase of ROBIN experiments. We have also parallelized the code using OpenMP which can run efficiently on multi-core and many-core architectures. The 1D analysis clearly shows the requirement of higher dimensional model for such studies which can take into account real source geometry, plasma instabilities and wall effects to get better match with experimental results. Our 2D-3v PIC-MCC code can be used to simulate a 2D rectangular computational domain with periodic boundary conditions perpendicular to the magnetic filter and discharge axis, however this does not take into account the actual geometry of the source. We find that qualitatively plasma transport is similar in both the cases, but there are quantitative differences. Unlike 1D, in case of 2D simulations we also observe appearance of instabilities particularly in the magnetic filter region under certain conditions. The role of these instabilities towards the plasma transport across the filter requires further investigation. We have also performed several studies to understand the effect of numerical parameters on the model results.

SIM-02

Validating Virtual Models of Industrial Robotics Using Game Engines

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Abstract

In this lecture we are describing a method for rapid testing and validation of industrial robot designs using *virtual reality* and *game engines* traditionally developed for entertainment purposes. We leverage the speed of these tools to simulate environments using the industry's approach to optimise for performance rather than accuracy.

We identified Unity 3D game engine to experiment and to validate a standard arm robot, the ABB 1410. We have developed a prototype for a robotic arm to perform in-vessel operations in a tokamak. We experimented with UI/UX and standard physics by developing custom inverse kinematic solver to validate the arm movement in VR space. We describe the process we followed, the tools we used and developed in order to complete the prototype.

The development of better gaming engines and the advent of new technologies such as virtual reality been hailed as new means to explore better industrial design. In the following lecture we are presenting our work on using these technologies for the design of remotely operated robotics in a hazardous environment. Our objective was to build a prototype of a robotic arm, to model its kinematics and deploy the virtual model in an off-the-shelf gaming engine. We then proceeded to test the ability of the prototype to help the system designers to get feedback on their current modifications to robotics and to understand the limitations under which this system would operate. The main contribution of this effort is to provide a methodology to build a verified and validated virtual tool for industrial robotics, using off-the-shelf tools, which are originally designed for entertainment purposes. We present our approach, results and shortcomings during the process of building the prototype.

In this lecture we present the design problem for using a virtual model of the ABB IRB 1410 robotic arm for maintenance and training operations in a tokamak. We then outline the procedure we followed to generate the kinematics required to move the arm and log the values for various parameters of movement. These parameters were then compared with standard kinematic simulation tools for verification and validation. The model was then deployed with a Virtual Reality (VR) headset to allow designers and system engineers to test the arm in an immersive virtual environment. We conclude with a discussion of the experience of the system engineers and a plan for future work and deployment for design of newer models of the robotic arm.

SIM-03

Classification And Prediction Of Disruptions In Tokamak Using Deep Learning Techniques

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Abstract

Classification of favourable and non-favourable discharges is very important for plasma operation point of view. Non-favourable discharges are mainly disruptive in nature as they are responsible for the sudden loss of confinement and transfer of plasma energy to the surrounding structure. During a disruption, the plasma current and the thermal energy content of a Tokamak plasma discharge collapse in an uncontrollable way, thereby generating mechanical forces and heat loads that would in turn destroy the structural integrity of surrounding structures and vacuum vessel components. The basic aim of the research work is prediction of disruption as well as classification - the former relevant during operation of the Tokamak, the latter during selecting disruptive and / or non-disruptive shots from a shots database.

Deep Learning is a part of machine learning techniques for more human-like learning, based on data representations. Convolutional Neural Network (CNN), a technique that falls under deep learning was used with image representation of 10 input diagnostics for various plasma shots. Recurrent Neural Network (RNN) [2] mainly with Long Short Term Memory (LSTM) has been considered due to its suitability to prediction of time series data. As cited in [1], in the past machine learning techniques like Artificial Neural Network(ANN) has been used to predict the occurrences of plasma discharges.

In the present work, data from 100 plasma shots with 10 different diagnostics of ADITYA Tokamak has been used for training the RNN – LSTM model after certain preprocessing and normalization. A correlation matrix of the inputs was calculated to understand the similarity between the behaviour of certain diagnostics based on pattern of the inputs. The network contains one LSTM neuron, which was run for 730 time step periods. The output of the trained model was provided as an array of shape, with an information, whether the disruption occurred at that time step or not. For each input output of 60 time steps was provided, to predict 60/5 = 12 msec ahead. The RNN model has the potential to reveal latent relationships among the experimental variables of a complex dataset. Presently, the results are being analyzed and training and testing with more data is awaited to further fine tune the result and conclusions.

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SIM-04

Effect Of Spin Polarization On Electron Acceleration In Quantum Magnetoplasma

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Abstract

The evolution of intrinsic spin effect of electrons are one of the most important aspect of quantum plasma. Plasma can be regarded as quantum when the quantum nature of its particle significantly affect its microscopic properties and varations occurs on scale larger than the thermal de-Broglie wavelength. Spin evaluation in quantum plasma leads to existence of new waves [1-2]. For high tempreature plasma, quantum feature due to intrinsic magnetic moment of electron becomes noticeable and their spin effect [3-4] in plasma are found to be somewhat different from those of non-spin [5-6] quantum effect in plasma. Over last few decades, there have been many papers devoted to influence of spin -1/2 effect on dynamics of plasma [7-8]. The growing interest in investigating new aspects of dense quantum plasmas is motivated due to its applications in industry and in space. Till now palsma electron has been considred as single fluid. Here, two different spin state (spin-up and spin–down) of electrons has been assumed relative to background magnetic field as the spin state of particles will be also perturbed by the presence of electromagnetic waves.

The present paper studied ponderomotive electron acceleration by an intense circularly polarized laser pulse in high density magnetized quantum plasma with spin-up and spin-down exchange interaction using QHD models. Such a study has not been reported in the literatures so far. The effects of quantum Bohm potential, fermi statical pressure and difference in spin-up and spin-down concentration of electron caused by external magnetic field have been taken into account. The magnetization effects and spin polarization plays a crucial role in case of spin-up and spin-down exchange interaction. A simple solution for ponderomotive electron acceleration and effect of spin polarization on it is presented.

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SIM-05

Simulation Of Plasma Transferred Arc Characteristics During Plasma Material Processing

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Abstract

Plasma transferred arc technique has been used for heating, melting, welding and vaporizing the materials. During these processes, metal vapour generated from electrodes / job pollutes the plasma. The mixing of vapours with plasma changes characteristics of the arc and affects the heat transfer from the plasma to material / job. To control and improve efficiency of the plasma material processing, it is important to understand the effect of mixing of metal vapour with plasma on characteristics of the plasma arc. In this regard, a 2D axis-symmetric numerical model is developed to simulate the arc plasma in between rod type cathode and disc type anode. Assumptions and computational domain used in this model are similar to the same used in the previous studies [1, 2]. A set of governing equations, such as energy, momentum, vector potential and scalar potential equations, are solved simultaneously by finite volume method with appropriated boundary conditions [1].

Argon arc in argon atmosphere and argon arc in air atmosphere are simulated for different arc currents. As expected, the temperature, velocity and power increase with increase in arc current. At 100 A, argon arc in air atmosphere forms constructive arc whereas, in the case of argon arc in argon atmosphere, there is a formation of diffusive arc due to the thin cold boundary layer near the anode region. The arc heating efficiency decreases with increasing arc current in the case of argon arc in argon atmosphere whereas, in case of argon arc in an air atmosphere, the same increases with increasing arc current. To validate the developed model, temperature and velocity of the argon plasma arc are compared with that of previously published results [3]. Modelling of material evaporation from the anode is being developed to study the effect of evaporated metal vapour on the arc characteristics.

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SIM-06

Characterization Of Force Networks In Mono And Polydisperse Pebble Assemblies Under Compaction

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Abstract

Forces in granular assembly are transmitted from one particle to another contacting particle, forming a set of force networks consisting of particles. Due to the discrete nature of granular assemblies, these forces, most of times are not uniformly distributed among all the particles. Some particles may end up carrying larger loads then the remaining. The force networks thus formed can be classified into strong and weak force networks based on the magnitude of force transmitted. From previous studies, it is observed that the majority of particles carry less than the average load applied in the system. The particles carrying higher loads forms a strong network of forces and these particles are more prone to failure. Objective and quantitative analysis of these force chains is essential in understanding the micromechanics of the pebble beds and prediction of onset of pebble failure.

Present study focuses on the characterisation of these force chains in mono-sized and polydisperse pebble assemblies under compaction. Compaction of Lithium metatitanate and Lithium orthosilicate are simulated using discrete element method (DEM). Evolution of force networks with respect to applied stress are analysed through DEM simulations. Along with force networks, coordination number, contact radius and particle stored energy are also studied with application of stress. Influence of particle size distribution on the force networks is also studied. The present study helps in understanding the micromechanics and force network evolution in deforming granular assembly.

SIM-07

Deep Q-Learning For Navigation Of Robotic Arm For Tokamak Inspection

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Abstract

In Tokamak computerized human-machine interfaces are used to control the manipulators and robots for inspection and maintenance activities. These activities include routine and critical activities such as tile inspection, dust cleaning, equipment handling and replacement tasks. The inspection tasks can be carried out by cameras moving with a deployed robotic arm inside the tokamak chamber. Inverse kinematic solution is required for navigating the robotic arm to the desired position. Such closed form inverse kinematic solutions become complex in the case of dexterous hyper-redundant robotic arms that have high degrees of freedom and can be used for inspections in narrow gaps. Reinforcement learning technique can be used to develop real time inverse kinematic solver for hyper-redundant robots.

The theory of reinforcement learning is inspired by the psychological and neuroscientific perspectives of human behavior [1], concerned with the problem of selecting an appropriate action from a set of actions in an environment, to maximize some cumulative reward. Reinforcement Learning are not given explicit path, instead it uses trial and error to reach the goal initially, but later uses its past experience to take the optimal path, in the problem an agent decides the best action only on the basis of its current state, this is best described by Markov Decision Process.

There are various strategies to solve Reinforcement problem in polynomial time, one of them is Q-Learning. Q-Learning can handle problems with stochastic transitions and rewards, without requiring adaption or probabilities of actions to be taken at a certain point; therefore, it is also called as "model free" strategy. Though Reinforcement Learning has positively achieved success in variety of domains, like Game Playing, it is “previously” limited to low dimensional state space or domains in which features can be assigned manually. In our approach we use Deep Neural network with Q-Learning - so called Deep Q Network (DQN). We created a visualization of a two link robotic arm with 4 Degree of Freedom (DOF) with the Deep Q-Learning concept that initially explores each and every possible way to reach the destination which is called training. Number of experiences are gathered in a fixed memory and trained in the random batches of fixed size. During testing, the robotic arm reaches the destination without any flickering in the defined space. It is observed that DQN successfully learned optimal policies from high dimension sensory inputs using Reinforcement Learning [1].

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SIM-08

Sound Velocity In Liquid Pb-Li Eutectic: A Theoretical Study

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Abstract

Lead-Lithium alloy (Pb-Li) in its eutectic composition i.e. $Pb_{83}Li_{17}$ is one of the most promising candidate for its application as liquid blanket. It has been tested in Helium Cooled Lead Lithium (EU-HCLL), Dual Cooled Lead Lithium (US-HCLL) and Indian LLCB [1, 2]. In the present work, we report the results of our theoretical study of phonon frequencies and sound velocity in liquid Pb-Li eutectic. Second order perturbation theory is used to compute the effective pair potential using Wills-Harrison form including Born-Mayer term. Further, phonon frequencies are calculated using phenomenological approach of Hubbard and Beeby [3]. Sound velocities are determined from the long wavelength limit of phonon frequencies at four temperatures. The computed values obtained from the present work are in very good agreement with the experimental results [4]. It is observed that volume effects play an important role in case of Pb-Li eutectic.

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SIM-09

Numerical Investigation Of 3-D Fluid Flow And Conjugate Heat Transfer Characteristics In A Wavy Channel Based PCHE Model

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Abstract

Computational fluid dynamics is used as a design and analysis tool to propose an efficient PCHE (Printed Circuit Heat Exchanger) model. 3D conjugate heat transfer numerical simulations are done, considering the variation of thermo-physical properties as a function of temperature and using Helium as a working fluid and alloy 617 as solid substrate. In this regard, three different CFD studies are presented. The first CFD study [1] is on *straight channel based PCHE*, and the effect of variation of thermo-physical properties, operating conditions and three different design modifications are studied. Thermal hydraulic performance is found better for single as compared to double banking and is same for aligned as compared to the staggered arrangement of the hot and cold channels. PCHE models with hemispherical dimples are found to give better thermal hydraulic performance. The performance is presented for the variation of the heat transfer density (for a PCHE model) and the pressure drop (in the hot and cold channel). The second CFD study [2] in on *triangular wavy-channel based PCHE,* and the effect of various angle of bend θ (0^o(straight), 5^o,10^o and 15^o) and Reynolds number (Re=350, 700, 1400 and 2100). Heat transfer enhancement as compared to pressure penalty is higher for the wavy channel; and increases with increasing Re and θ. The third CFD study [3] is on the effect of three wavy-channel configurations (triangular, sinusoidal and trapezoidal) in a single banked PCHE. Trapezoidal channel based PCHE models is found to offer highest heat transfer with the largest pressure drop. The optimal thermo-hydraulic performance is also assessed, considering the thermal performance factor (TPF) obtained for all the three channels. The highest values of TPF are predicted for trapezoidal wavy channels (3.5) which is followed by sinusoidal (2.5) and triangular (1.5) wavy channels. *The present work will lead to optimal usage of space available for Helium Cooling System (HCS) of Test Blanket Module (TBM) in International Thermonuclear Experimental Reactor (ITER).*

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SIM-10

3D-DNS Simulations Of Helically Forced Magnetohydrodynamic Turbulence With Varying Magnetic Prandtl Number & Data Analysis

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Abstract

Magnetohydrodynamic (MHD) Turbulence plays an important role in various astrophysical phenomenon such as generation and sustaining of magnetic fields, large-scale magnetic structure formation, to name a few. It also plays an important role in the confinement of Plasma in fusion devices like tokamaks and stellarators. Three dimensional direct numerical simulations (3D-DNS) are one important way of studying MHD turbulence [1,2,3,4]. We, in our project proposal proposed helically forced 3D-DNS of MHD turbulence with varying magnetic Prandtl number (Pr_m), in both low (<1) and high (>1) Pr_m ranges. We also propose to analyze the data using spectral, statistical and topological methods [5,6]. This proposal stems from our previous experience of studying spectral and statistical analysis along with visualization of the data (for understanding magnetic reconnection process) [7,8,9,10]. We also include for the first time topological analysis, which involves analysing of the data using Morse-Smale Complex and Covariance Tensor methods. This kind of studies is being proposed for the first time in the world [11,12]. The expected outcome of this proposal is (a) better understanding of spectral transport of magnetic helicity in various regimes, (b) statistical interpretation of the data to understand some magnetic phenomenon in astrophysical scenarios and (c) understanding inverse cascade of magnetic helicity and magnetic reconnection both are topological properties of turbulent magnetic fields. Further, the topological analysis may also enhance our understanding of interactions among various physical phenomena like magnetic energy, kinetic energy, kinetic helicity and magnetic helicity. The learning from these studies will be used in understanding confinement of Plasma in tokamaks, especially in low ß plasmas. Such an understanding may help us improve technologies that can keep at bay large-scale magnetic structure formation, which is harmful for plasma confinement in tokamaks and stellarators. Currently the project is in the Code-development and testing phase.

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SIM-11

Numerical And Experimental Characterization Of DC Non-Transferred Arc Plasma Torch With Shroud Gas Injection And Prediction Of Heat Flux From Plasma Jet To Plasma Facing Material

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Abstract

In this work, a special type of DC non-transferred arc plasma torch is characterized both numerically and experimentally and heat flux from the plasma jet emerged from the torch to the plasma facing material is predicted. A 3D computational fluid dynamic model of the plasma torch with shroud gas injection is developed to characterize the plasma torch and to obtain nozzle exit profiles of plasma temperature and velocity. Equations that govern the plasma flow inside the torch are energy, momentum, electric and magnetic vector potential equations. A set of these equations are solved using finite volume method. The assumption and boundary conditions used to simulate the plasma torch are similar to that used in previously published report [1]. Heat flux from the plasma jet to plasma facing material is predicted by solving energy equation with phase change. Temperature, electric potential and velocity distributions inside the torch are predicted from different arc currents and axial gas flow rates. Predicted velocity and temperature fields inside the torch without application of the external magnetic field reflect the experimental observation. Heat flux from the plasma jet to plasma facing materials is predicted for different stand-off distances. It is observed that copper transfers the heat load of 2.74 kW with lesser temperature gradient along the heat transfer direction than steel and copper needs much higher heat load for melting compared to steel.

The influence of shroud gas injection configuration on the I-V characteristics and electro-thermal efficiency of a dc non-transferred plasma torch operated in nitrogen at atmospheric pressure is investigated experimentally. At higher axial gas flow rate, the I-V characteristics of the plasma torch are similar irrespective of the shroud gas injection nozzle used. The variation of electro-thermal efficiency with arc current is almost similar to that of arc voltage with arc current. The operational characteristics of a dc non-transferred arc plasma torch are predicted using the techniques of dynamic similarity. The voltage and operational characteristics are predicted using these numbers for a number of experimental conditions, which are in good agreement with actual experimental results. Predictions are made on the limits of operational characteristics of this torch and class of torches at higher powers.

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