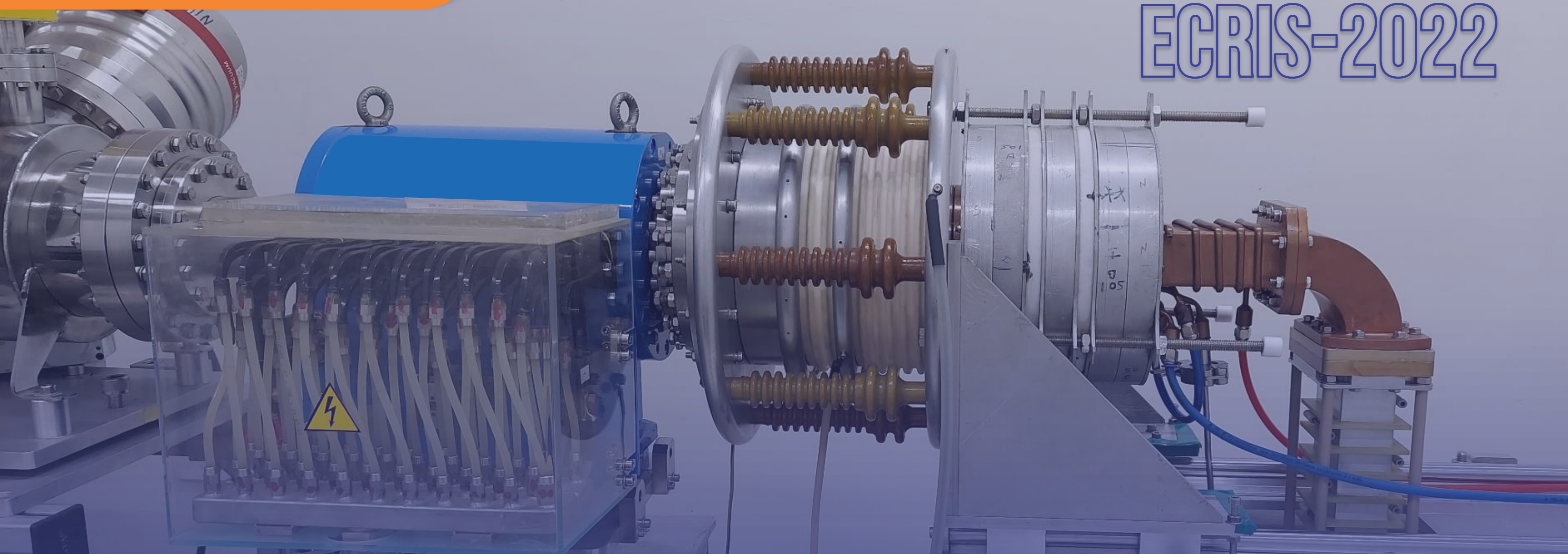
25th International Workshop on

ELECTRON CYCLOTRON RESONANCE ION SOURCES 2022

12-14 OCTOBER, 2022

ABSTRACT BOOK

ECRIS-2022



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25th International Workshop on

ELECTRON CYCLOTRON RESONANCE ION SOURCES 2022

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Book of Abstracts

Edited by

Rajesh Kumar | Mainak Bandyopadhyay

H. L. Swami | Abhishek Saxena

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First Impression: 2022

25th International Workshop on Electron Cyclotron Resonance Ion Sources 2022 (ECRIS-2022)

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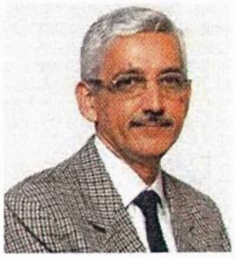

MESSAGE

I am happy to note that the Institute for Plasma Research, Gandhinagar, is organizing the 25th International Workshop on Electron Cyclotron Resonance Ion Sources (ECRIS-2022) during 12-14 October 2022, in association with the Board of Research in Nuclear Sciences (BRNS).

The Institute for Plasma Research is a premier institute in India pursuing research in Nuclear Fusion as well as Societal applications of plasmas. Electron Cyclotron Resonance based Ion Sources have great impact in these fields and a variety of other fields, such as nuclear research and accelerators.

This workshop is aimed at highlighting the state of the art in ECR Ion Source Science & Technology and to identify possible areas of collaboration and synergies among researchers in the field. I extend my hearty welcome to the delegates and wish the conference a great success.

(K. N. Vyas)

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Director, Bhabha Atomic Research Centre
सदस्य, परमाणु ऊर्जा आयोग
Member, Atomic Energy Commission

MESSAGE

I am happy to know that the Institute for Plasma Research, Gandhinagar, in association with the Board of Research in Nuclear Sciences (BRNS), is organizing the 25th International Workshop on Electron Cyclotron Resonance Ion Sources (ECRIS-2022) during 12-14 October, 2022 at Gandhinagar.

This three-day workshop will provide a platform to various research institutes/ laboratories to discuss new developments and challenges, and to identify possible solutions. It will also showcase Indian research in related areas. I hope this workshop will open up new frontiers in ECR ion source-based research and applications.

I wish the conference a great success.

Ajit Kumar Mohanty

(Dr. Ajit Kumar Mohanty)

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MESSAGE

On behalf of the Institute for Plasma Research, I would like to extend a warm welcome to all participants in the 25th International Workshop on Electron Cyclotron Resonance Ion Sources (ECRIS-2022), being held at Gandhinagar during 12-14 October 2022.

The Institute for Plasma Research is pursuing research in Nuclear Fusion Science & Technology as well as Societal/Industrial applications of plasmas. Being an active partner in the ITER project, it is also involved in technology/sub-system development for ITER. Apart from the fusion programme, IPR is also involved in an ever-growing list of plasma applications in industry, agriculture, textile processing, waste disposal, aerospace technologies, medical/health systems, etc.

ECR ion sources have wide applications in accelerator and nuclear research. A recently commissioned 14 MeV fusion neutron generator facility at IPR is a good example of ECR ion source based applications. This facility opens new opportunities in fusion and other nuclear research applications.

I believe this conference will provide many opportunities for sharing and exchanging ongoing research, inspiring young minds and broadening knowledge about various involved technologies in ECR based ion sources.

Lastly, on behalf of IPR, I thank all persons involved in conducing this workshop for their sincere efforts and BRNS for their financial support. I extend my best wishes to all the participants and hope that the workshop will achieve its desired objectives. I wish the conference great success.

(Shashank Chaturvedi)
Chairman -International Advisory Committee (IAC)
Director, Institute for Plasma Research

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Day – 1 [Wednesday, 12 October, 2022]

08:00-09:00	**Registration**
09:00-10:00	**Inaugural Function**
10:00-10:40	**Keynote Talk – 1:** *Status of technology development for pulsed ion/proton accelerators at RRCAT* **Purushottam Shrivastava,** RRCAT
10:40-11:10	**High Tea**
Technical Session – 1	
11:10-11:50	**Keynote Talk – 2:** *The never ending story of ECR Ion Sources* **Thomas Thuiller**, LPSC
11:50-12:30	**Keynote Talk – 3:** *ECR ion sources for stable and rare isotope beams - an overview* **Vaishali Naik**, VECC
12:30-13:05	**Invited Talk – 1** by **Arun Chackrabotry,** IPR
13:05-14:00	**Lunch**
Technical Session – 2	
14:00-14:20	**Oral Presentation – 1:** *Recent development of FRIB 28 GHz ECR ion source .* **Junwei Guo,** FRIB
14:20-14:40	**Oral Presentation – 2:** *A novel hybrid discharge mode of a miniaturized micro-wave ion source* **Shixiang Peng,** Peking University
14:40-15:00	**Oral Presentation – 3:** *Status of FECR Ion Source* **Liangting Sun,** IMP
15:00-15:20	**Oral Presentation – 4:** *Effect of the B-minimum field tuning on beam output and on the plasma at the Atomki 14 GHz ECR ion source* **Richard Racz,** ATOMKI
15:20-15:40	**Oral Presentation – 5:** *Overview of the latest results at GISMO facility* **Vadim Skalyga,** IAP RAS
15:40-16:00	**Tea Break**
Technical Session – 3	
16:00-16:20	**Oral Presentation – 6:** *Recent Developments in the Production of Metallic Ion Beams at GSI* **Fabio Maimone,** GSI
16:20-16:40	**Oral Presentation – 7:** *ASTERICS, a new 28 GHz electron cyclotron resonance ion source for the SPIRAL2 accelerator* **Thomas Thuillier,** LPSC
16:40-17:00	**Oral Presentation – 8:** *A compact 2.45GHz permanent magnet ECR bipolar ion source for Tandem accelerators* **Arun Annaluru,** HVE
17:00-17:20	**Oral Presentation – 9:** *Development of 2.45 GHz ECR Ion Sources at IPR* **Rajesh Kumar,** IPR
17:20-17:30	**Evening Tea**
Poster Session - 1	
17:20-19:20	**Poster Category** NDSR, FPPS & NCNG
19:20-Onwards	**Director Dinner**

Day – 2 [Thursday, 13 October, 2022]

Technical Session - 4	
09:15-09:50	**Invited Talk – 2:** *ECR/Microwave Ion Sources: Status and Developments in India* **G. Rodrigues,** IUAC
09:50-10:25	**Invited Talk – 3:** *ECR based low energy ion accelerator at TIFR and application to molecular sciences* **Lokesh Tribedi,** TIFR
10:25-10:45	**Oral Presentation – 10:** *Experimental application of a TWTA to the SPIRAL1 charge breeder* **Laurent Maunoury,** GANIL
10:45-11:05	**Oral Presentation – 11:** *Injection And Trapping of 1+ Ions In 6.4 GHz ECR Charge Breeder* **Paritosh Sing Babu**, VECC
11:05-11:20	**Tea Break**
Technical Session - 5	
11:20-11:40	**Oral Presentation – 12:** *Design of a vacuum chamber for the gasdynamic ion source with high specific energy input* **Ivan Izotov,** IAP RAS
11:40-12:00	**Oral Presentation – 13:** *High Stability and Low Emittance Microwave Discharge Ion Sources Magnetic Configuration and Ion Source Simulation Tool Development* **Lorenzo Neri,** INFN
12:00-12:20	**Oral Presentation – 14:** *Design and Development of Novel Waveguide Break for 14.45 GHz ECR Ion Source at VECC* **Anuraag Misra,** VECC
12:20-12:40	**Oral Presentation – 15:** *223Ra Ion Beam Production from ECR2 at the Argonne Tandem Linac Accelerator System* **Jake McLain,** Argonne National Laboratory
12:40-13:00	**Oral Presentation – 16:** *An experimental study of afterglow mode on SECRAL-II ion source* **Jibo Li,** IMP, CAS
13:00-14:00	**Lunch**
Technical Session – 6	
14:00-14:20	**Oral Presentation – 17:** *RF-induced losses of hot electrons from the ECR plasma* **Elena Kiseleva,** IAP RAS
14:20-14:40	**Oral Presentation – 18:** *Studies on the electron energy distributions in the 18 GHz High Temperature Superconducting ECR Ion Source* **Lakshmy PS,** IUAC
14:40-15:00	**Oral Presentation – 19:** *A multi-cusp ECR plasma source for high intensity accelerators* **Monika Phogat,** BARC
15:00-15:20	**Oral Presentation – 20:** *Interplay among cavity modes in a microwave ion source influencing the plasma dynamics and the extracted ion beam* **Chinmoy Mallick,** IPR
15:20-15:40	**Important activities of BRNS** **Hemant Prakash,** BRNS, DAE
15:40-16:00	**Tea Break**
16:00-17:20	**IPR Visit**

Day – 3 [Friday, 14 October, 2022]

Technical Session - 7	
09:15-09:35	**Oral Presentation – 21:** *Applications of an indigenously developed Compact ECR Plasma Source [CEPS] at IIT Delhi* **Ramesh Narayanan,** IIT Delhi
09:35-09:55	**Oral Presentation – 22:** *Ion-beam-induced astrochemistry: a new application of the Atomki-ECRIS* **Rahul Kumar Kushwaha,** ATOMKI
09:55-10:15	**Oral Presentation – 23:** *ECR ion Source proton fraction measurement and enhancement of it in LEHIPA* **Hitesh Kewlani,** BARC
10:15-10:35	**Oral Presentation – 24:** *Production of intense carbon beams with permanent magnet ECR ion sources* **Jiaqing Li,** IMP
10:35-10:50	**Tea Break**
Technical Session - 8	
10:50-11:10	**Oral Presentation – 25:** *First results from the gas jet coupled 2.45 GHz ECRIS for online radioactive ion beam production at VECC RIB facility* **Mahuwa Bhattacharjee,** VECC
11:10-11:30	**Oral Presentation – 26:** *Status of ECR Plasma Electron-Ion Numerical Modelling at INFN-LNS – From Space-Resolved Population Kinetics to X-Ray Emissivity Analysis* **Bharat Mishra**, INFN
11:30-11:50	**Oral Presentation – 27:** *Modelling of ECR heating in an ECRIS with axis-symmetric magnetic topology* **Arpan Khandelwal,** GANIL
Poster Session - 2	
11:50-13:20	**Poster Category** AND, SM, RIB, BET
13:20-14:20	**Lunch**
14:20-15:00	**Concluding Session**
15:00-Onwards	**Excursion**

• **Keynote address**	35+5 min
• **Invited talk in conference**	30+5 min
• **Oral presentation in conference**	18+2 min
• **Poster Presentation Dimension**	Portrait – A0 (84 x 119 cm) size

CONTENTS

Poster Presentations

Keynote Address

Keynote **WEIAUK01**

Status of technology development for pulsed ion/proton accelerators at RRCAT

Purushottam Shrivastava
Raja Ramanna Centre for Advanced Technology, Indore
Email: purushri@rrcat.gov.in

DAE is interested in High Intensity Superconducting Proton Accelerators (HISPA) for applications in Facility for Spallation Research, radio-isotope production, Radio-active Ion Beam (RIB) facility etc., which require high intensity proton beams in pulsed and CW operation depending on the application. RRCAT has established infrastructure facilities as well as developing the front end technologies for an envisaged 1GeV pulsed proton accelerator as a part of capacity building for spallation research. The 1GeV pulsed proton accelerator for facility for spallation research shall consist of a warm front end consisting of an ion source, LEBT, RFQ, MEBT followed by DTL. Along with an ECR ion source, several other types of ion sources have been successfully designed and developed and tested keeping in mind various applications. The warm part of the proton accelerator is followed by envisaging use of of various families of the superconducting RF cavity each housed in its cryomodule. As far as possible the superconducting RF structures and technologies which are being developed under the international collaboration will be utilized for making the 1GeV superconducting pulsed proton linac for spallation research. Apart from warm accelerator technologies, RRCAT has been pursuing a complete chain of fabrication, RF tests and characterization at various stages including the SCRF infrastructure facilities, processing, HPR, vertical test stand and Horizontal Test Stand for developing high beta Superconducting RF cavities. Several cavities have been successfully tested in the vertical test stand. Horizontal Test Stand has been commissioned and is being regularly utilized to test the dressed SCRF cavities. A strong base has been created. Present talk will cover status of the development of various technologies for pulsed proton/ion accelerator including the ion sources, RFQ, SCRF cavities, solid-state amplifiers, and infrastructure facilities etc.

Keynote **WEIAUK01**

The never ending story of ECR Ion Sources

Thomas Thuillier
Laboratoire de Physique Subatomique et Cosmologe
Email: thomas.thuillier@lpsc.in2p3.fr

Invented during the 60's, Electron Cyclotron resonance ion sources revolutionized the ion accelerator physics, allowing for important nuclear physics discoveries. The passionate work of several generation of researchers lead to incredible progresses in ion beam intensity and ion charge state. Yet, many aspects of the ECRIS plasma physics remain blur and only partially understood, calling for young talented scientist to investigate further. The past, present and future of ECRIS will be reviewed along with the main prospects and future challenges of the field.

Keynote **WEIAUK01**

ECR ion sources for stable and rare isotope beams - an overview

Vaishali Naik
Variable Energy Cyclotron Centre, Kolkata
Email: vaishali@vecc.gov.in

Electron Cyclotron Resonance Ion Sources (ECR) are very versatile and well suited for the ionization of gaseous elements with high efficiency. Beams for non-volatile elements and metals can also be produced in ECR using the oven technique or ion-induced sputtering. This along with the high-frequency operation for producing highly charged ions makes ECR the most popular choice as an injector for heavy-ion accelerators. For rare isotope beams (RIB) also, the ECR offers a viable option, particularly as a charge breeder for volatile species. Intense R&D aimed at increasing the charge breeding efficiency and overcoming limitations in terms of contaminating ions arising from plasma chamber walls is underway worldwide. Niche applications, e.g. gas-jet coupled ECR that can be used with a primary accelerator or a reactor for a standalone low-energy RIB facility are also being studied. In my talk, I will give an overview of ECR ion sources used for stable and rare isotope ion beams and will be covering research activities on the production of RIB in greater detail.

Invited Oral

Invited Oral **WET1AUIO01**

Role of Ion Sources in Fusion Devices

Arun Chakraborty
ITER-India, Institute for Plasma Research, Gandhinagar
Email: arun.chakraborty@iterindia.in

Development of high confinement plasma configurations in magnetic confinement devices forms and important objective in the study of fusion plasmas. Such high confinement modes are produced with the injection of multi-megawatts of power to the plasma in the form of RF waves and Neutral Particle Beams. Production of neutral beams for fusion grade plasmas on the other hand, are dependent on the performance of large ion sources where the requirement is for the production of high density (~10^{17} m^{-3} , uniform (within 10%), low temperature (~ few ev) plasma, typically of ~ $1m^3$ volume. Due to the specific requirements for the energy required for injection of neutral beams into the Tokamak plasma, such ion sources need to produce negative ions, which have a significantly high neutralization efficiency. Development of high current negative ion sources for the required parameters is a challenge and forms the focus of R&D activities on this front. While characterization of RF based large area ion sources have demonstrated remarkable progress, there are several open areas that require to be addressed still. In parallel, alternate modes of plasma production (including ECR based plasma production) in ion sources, are being pursued.

In another application of ion sources, ECR based sources are extensively used for the production of 14 MeV neutrons, required for preliminary studies on irradiation impacts on material.

The presentation shall provide an overview of the requirements and highlight some of the important results from the R&D activities that have been pursued over the past decade in IPR in the area of development of ion sources required for fusion devices.

Invited Oral **THT4AUIO02**

ECR/Microwave Ion Sources: Status and Developments in India

Gerard Oscar Rodrigues
Indian Institute of Technology Delhi
Email: gerosro@gmail.com

An overview of various kinds of Electron Cyclotron Resonance and Microwave Ion Sources developed in various laboratories will be discussed upon. The impact of these kind of ion sources on existing and upcoming low energy facilities and Accelerators has made tremendous progress over the past few tens of years, mainly due to its versatility, ruggedness and long lifetime. It is envisaged that in the next few tens of years or so, these ion sources will serve as the workhorse and with new emerging technologies, much higher operating frequencies will be the preferred option for new upcoming projects.

Invited Oral **THT4AUIO03**

ECR based low energy ion accelerator at TIFR and application to molecular sciences

Lokesh Tribedi
Tata Institute of Fundamental Research
Email: lokesh@tifr.res.in

With the advent of the accelerators and ion-sources many features of molecular interaction mechanisms are explored through the ion-molecule collision studies. Low energy highly charged ions can probe collision dynamics in the strong perturbation regime. An ECR based low energy highly charged ion accelerator laboratory has been developed in TIFR. The 14.5 GHz source with 200W power is mounted on a 400 kV deck. The accelerator has three beam lines equipped with experimental stations, such as, electron, recoil-ion, charge-state, x-ray spectrometers and COLTRIMS. The ECR plasma diagnosis involves measurement of hot electron temperature using bremsstrahlung x-ray technique. The ion beam current optimization has been studied using different microwave power, gas pressure and using different gas mixing. The collision physics involves the study of low energy electrons in collisions with large bio-molecules, DNA/RNA bases, water and PAH molecules; single and multiple electron capture using water as well as double or triple ionization for PAH, fragmentation dynamics of highly ionized molecular ions etc. The physics of collective excitation (giant dipole and quadrupole excitation) has been explored in the PAHs and C60 fullerenes. Some of these studies will be presented along with the results from the high energy collisions using 14MV Pelletron at TIFR

Contributed Oral

NDSR/Contributed Oral **WET2AUCO01**

Recent development of FRIB 28 GHz ECR Ion Source

Junwei Guo[1], Xing Rao[1], Guillaume Machicoane[1], Haitao Ren[1], Larry Tobos[1], Nathan Bultman[1], Philip Morrison[1], Soren Prestemon2, Diego Arbelaex[2]

[1] *Facility for Rare Isotope Beams*

[2] *Lawrence Berkeley National Laboratory*

Email: guoju@frib.msu.edu

The Facility for Rare Isotope Beams (FRIB) has been built and commissioned to become the world's most powerful rare isotope research facility. To meet a beam power requirement of 400 kW for heavy ions, a high intensity 28 GHz superconducting electron cyclotron resonance (ECR) ion source is under development at the Facility for Rare Isotope Beams (FRIB). The ion source recently achieved two major milestones: The full design field compatible with 28 GHz operation was reached; the first plasma at 18 GHz has been produced. Details of the ion source development and commissioning plan will be described.

NDSR/Contributed Oral **WET2AUCO02**

A Novel Hybrid Discharge Mode of A Miniaturized Micro-Wave Ion Source*

ShiXiang Peng[1], Jia-er Chen[1], Bujian Cui[1], Zhiyu Guo[1], Zhirong Liu[1], Yaoxiang Jiang[1], Kai Li[1], Tenghao Ma[1], Wenbin Wu[1], Ailin Zhang[2]
[1] Peking University, Beijing
[2] University of Science and Technology of China
Email: sxpeng@pku.edu.cn

At Peking University (PKU), a 2.45 GHz miniaturized microwave ion source (MMIS) was designed. In our previous work, more than 20 mA CW hydrogen ion beam at 40 keV can be obtained with microwave power of 180 W. In the pulsed mode, more than 60 mA pulsed hydrogen ion beam (10% duty factor) can be extracted with peak microwave power of 1800 W. However, the chamber diameter of the MMIS is only 30 mm, which is far less than the critical dimension (72 mm) of traditional electron cyclotron heating (ECH) mode. To understand this anomalous phenomenon, a hybrid discharge heating (HDH) mode is proposed. The HDH mode contains two parts: ignition discharge by surface wave plasma (SWP) and ionization by electron cyclotron resonance (ECR). In this work, both theoretical and experimental study are made for the comprehension of the HDH mode. On this basis, a mixed hydrogen continuous wave (CW) beam of up to 25 mA at 30 keV are extracted with a power efficiency of 25 mA/100 W.

NDSR/Contributed Oral **WET2AUCO03**

Status of FECR Ion Source

Liangting Sun[1], Yuquan Chen[1], Yucheng Feng[1], Mingzhi Guan[1], Junwei Guo[1], Jibo Li[1], Lixuan Li[1], Wang Lu[1], Jindou Ma[1], Enming Mei[1], Xianjin Ou[1], Xudong Wang[1], Beimin Wu[1], Wei Wu[1], Canjie Xin[1], Xuezhen Zhang[1], Hongwei Zhao[1], Shijun Zheng[1], Li Zhu[1]

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FECR or the First 4th generation ECR ion source is under development at the institute of Modern Physics, CAS. Aiming to be operating at the optimum operation frequency of 45 GHz, FECR is designed to be equipped with a magnet providing the optimum magnetic fields of 6.4 T and 3.4 T axial mirror maxima and 3.2 T radial peak at the plasma chamber surface, which are provided with a Nb3Sn cold mass. As a first fully Nb3Sn superconducting cold mass with a B-min configuration, it is essential to demonstrate the feasibility of such a technical approach. We have prototyped FECR magnet with a half-length sized cold mass. FECR is now on the track to the full-sized cold mass installation and magnet assembly. This talk will present the progress of the FECR ion source magnet development. Additionally, the typical foreseeing challenges such as high microwave power coupling, plasma chamber cooling challenges and similar issues will be discussed, and the recent progresses of high power high frequency operation with the third generation ECR ion source ion source will be presented.

NDSR/Contributed Oral **WET2AUCO04**

Effect of the B-minimum field tuning on beam output and on the plasma at the Atomki 14 GHz ECR ion source

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A room-temperature, second generation, homemade ECR Ion Source operates at Atomki. It serves to provide variously charged atomic plasmas for plasma diagnostics research and low energy ion beams for atomic physics and also for some medical/industrial applications. The source can produce acceptable ion beam currents for low charged ions, and in more modest intensities for highly charged ions (HCI). At HCI production the maximal (and typical) B_{min}/B_{ecr} ratio at 14.25 GHz is 0.75. During the numerous beam-tests in recent years, it was always clear that even a slight decrease of Bmin destroys the beam intensity a lot. This fact suggesting that the fine tuning of Bmin (e.g. to reach B_{min}/B_{ecr} 0.8 or higher) would be desirable to get much higher beam intensities. From the other side, it was shown by several groups that plasma instabilities limiting the performance of the ECR ion sources occur at certain conditions, i.e. at B_{min}/B_{ecr} ratio around 0.8. Instabilities events are always followed by sudden RF and X-ray emission from the plasma. Thus, the detection and analysis of RF and/or X-ray emission is a way to understand more details on the nature of the instabilities furthermore gives chance to find ways to suppress them. This way an ECR ion source having the possibility to vary B_{min}/B_{ecr} between 0.7-0.9 would be a very useful tool to study plasma instabilities. These two different promising goals (1: to increase HCI intensities and 2: to study plasma) led our team to the decision to modify the magnetic structure of the Atomki-ECRIS in order to get higher and variable B_{min}/B_{ecr} value. This paper shows the steps of the modification and its effect on the HCI production. The first plasma studies (by means of varying B_{min}/B_{ecr}) in this ECRIS via volumetric soft X-ray detection will be also shown.

NDSR/Contributed Oral **WET2AUCO05**

Overview of the latest results at GISMO facility

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Gasdynamic Ion Source for Multipurpose Operation (GISMO) is a CW high-current quasi-gasdynamic ECR ion source at the IAP RAS. The quasi-gasdynamic confinement regime, featuring high plasma density (up to 10^{13} cm^{-3}) and moderate electron temperature (~100 eV), allows to produce hydrogen plasma fluxes with equivalent density above 1 A/cm2. It has been already demonstrated that major benefits of quasi-gasdynamic confinement, previously tested in pulsed mode at SMIS37 facility, are scalable to the CW operational mode. In recent experiments at GISMO facility, the high-current CW hydrogen beams were produced in long-term routine operation. A new unique extraction system especially effective for the formation of high current density ion beams was developed and tested. The first experiments with heavier gasses were performed showing good prospects for production of high-current multicharged ion beams. A possibility of 30 mA He^{2+} beams formation was demonstrated. Latest results of beam current, emittance and charge state distribution measurements are presented.

This work is supported by Ministry of Science and Higher Education of the Russian Federation grant # 075-15-2021-1361 from 07.10.2021.

NDSR/Contributed Oral **WET3AUCO06**

Recent Developments in the Production of Metallic Ion Beams at GSI

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At GSI different ion sources produce ion beams from gaseous and metallic elements and to fulfill the demand for metallic ion beams, the two injectors are involved and different production techniques are used. The CAPRICE ECRIS installed at the High Charge States Injector (HLI) delivers CW metallic ion beams with the method of thermal evaporation using the resistively heated ovens for metals and solid compounds. The most requested element, 48Ca, is evaporated with the Standard Temperature Oven (STO) for nuclear physics, material research, and super heavy element groups. To guarantee a stable operation with chemical reactive materials like 48Ca, an optical emission spectrometer has been included as real-time monitoring and diagnostic device and a tungsten grid has been mounted at the oven head to reduce the parasitic heating. The results in terms of higher intensity and stability obtained in the last beam run are reported here. The achieved results together with the ion source settings and parameters have been used to train a machine learning tool based on neural networks. The goal is to program a system able to prevent instabilities and to find stable operating settings for metallic ion beams when the oven the response time of the ECRIS is relatively slow. An overview of the metal ion beams provided by High Current Injector (HSI) from various ion sources at two operation terminals (Terminal North and Terminal South) is given. At the Terminal North, the ion source VARIS (Vacuum ARc Ion Source) provides to the RFQ up to 15 emA metallic ion beams with a typical duty cycle of 1 Hz / 0.5 ms (pulse length). The recent development on the new metal ion species for operation as well as on the special operation mode for uranium beams is presented. The Penning Ion Gauge (PIG) ion source inside the Terminal South produces metallic ion beams with high intensity at a high duty cycle and the main results in terms of ion beam variety and performance are presented as well.

NDSR/Contributed Oral **WET3AUCO07**

ASTERICS, a new 28 GHz electron cyclotron resonance ion source for the SPIRAL2 accelerator

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A new 28 GHz superconducting electron cyclotron resonance ion source named ASTERICS(1) is under design for the NEWGAIN(2) project, which consists in developing a new M/Q=7 heavy ion injector for the SPIRAL2 linear accelerator at GANIL, Caen. After an introduction to the new injector, the specifications of the ion source and the status of its preliminary design are presented: superconducting magnet, ion source and microwave hardware, ion beam extraction and transport on the high voltage platform.

(1) ASTERICS is the acronym for Advanced Spiral Two Electron cyclotron Resonance Ion source at Caen with Superconducting magnets

(2) NEWGAIN is the acronym for NEW GAnil INjector

NDSR/Contributed Oral **WET3AUCO08**

A compact 2.45GHz permanent magnet ECR bipolar ion source for Tandem accelerators

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To serve light ion (H and He) irradiation and implantation using a tandem accelerator, HVE has developed a dedicated negative ion injector using a 2.45 GHz ECR ion source. For the extraction of negative hydrogen, the source is equipped with a transverse magnetic (filter) field in the plasma chamber to allow direct negative extraction, whereas for helium, the source operates in positive mode and negative helium is formed by directing the positive helium beam through a sodium charge-exchange medium. The development aims at >1000 uA analyzed H- and > 50 uA analyzed He-. The novelty of this injector is to be able to switch from positive ion extraction for He to a direct negative ion extraction for H without any hardware interventions, making it suitable for full computer control. The injector extraction system consists of a vacuum chamber that accommodates a puller electrode movable in X, Y, and Z directions, a fixed grounded electrode, and a Na charge exchange canal for He-. The shapes of extraction electrodes were optimized using IBSimu to transport He+ and H- beams within the low acceptance of the charge exchange canal. Differentially pumped vacuum sections are considered for space charge compensation for He+ transport section and also to limit He neutralization after the charge exchange canal.

NDSR/Contributed Oral **WET3AUCO09**

Development of 2.45 GHz ECR Ion Sources at IPR

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Institute for Plasma Research (IPR) has developed an indigenous 2.45 GHz Electron Cyclotron Resonance (ECR) ion source. It is being used for applications like accelerator-based neutron source, Spacecraft Plasma Interaction eXperiment (SPIX), Chemical Vapor Deposition (CVD), RFQ accelerator, and material applications. The 2.45 GHz ECRIS mainly consists of the microwave system, plasma cavity, and NdFeB permanent magnets-based magnetics system. A three-electrode accel–deccel type extraction system has been developed to extract 20 mA D+/H+ beam at 40 keV in CW mode and coupled with the 2.45 GHz ECRIS. The ECRIS has been set up and commissioned. The Beam Diagnostic System (BDS) has been installed in the ECRIS to measure the beam diameter, emittance, and beam current. The 2.45 GHz ECR ion source is also used in the Spacecraft Plasma Interaction eXperiment (SPIX) facility. The main application of the SPIX facility is to study the interaction of the spacecraft with the ionospheric plasmas and its impact on its health, particularly on the solar panel. The 2.45GHz ECR ion source has been integrated with the SPIX vacuum vessel to produce the argon plasma of required plasma density and temperature in the order of 1-5 x 10^{12} m^3 and 1 eV- 10 eV, respectively. The Argon plasma has been produced as a function of microwave power and gas pressure. The plasma density and plasma temperature inside the SPIX vacuum vessel have been measured with an indigenously developed low-density Langmuir probe. This paper present the detailed design of the 2.45 GHz ECRIS ion source and the latest result of its plasma and beam parameter measurement.

EBCB/Contributed Oral **THT4AUCO10**

Experimental application of a TWTA to the SPIRAL1 charge breeder

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The SPIRAL1 charge breeder (SP1CB) at GANIL is an ECR-type ion source used either for producing multi-charged ion beams from stable gases or for increasing the charge state of a 1+ radioactive ion beam for subsequent acceleration. Thus, the shape of the Charge State Distribution (CSD) at the extraction of SP1CB constrains the energy and intensity of the post-accelerated beams at GANIL. A new TWT-type HF amplifier has been installed on the SP1CB, to be used alone (variable single frequency heating) or in addition to a fixed-frequency Klystron amplifier (double frequency heating), with promising test results. The variable single frequency mode allowed us to lower the mean charge state of noble gases without losing total ionization efficiency, leading to a certain control over the CSD. The double frequency mode has been successfully used to push the CSD towards higher Q for both noble gases and injected 1+ beams. Measurements of the charge breeding time in this mode have shown that, the second frequency can increase the efficiency for high charge states without slowing the charge breeding process. This is important in the case of SPIRAL1, where short-lived radioactive ions with half-lives below 100ms can be produced. Finally, the second frequency heating helps cancel instabilities at high HF power.

EBCB/Contributed Oral **THT4AUCO11**

Injection and Trapping of 1+ Ions in 6.4 Ghz Ecr Charge Breeder

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ECR ion source based charge breeders are used in isotope separator on line facilities for efficient acceleration of rare isotope beams. In ECRIS charge breeder system, the injected low charge state beam ions are stopped within the plasma and their charge state is increased by electron impact ionization. In an ECR based charged breeder system, 1+ ion beam with longitudinal kinetic energy E = eVb enters the charge breeder held at a potential Vs=Vb+ΔV, and │ΔV│<< Vb. The plasma potential of the charge breeder is ~10 to 20V and, therefore, ΔV must be negative to prevent reflection of the 1+ ions prior to their entrance into the plasma of the charge breeder. The capture process is a consequence of cumulative small-angle scatterings of the 1+ ions in ion-ion Coulomb collisions with the plasma. As a result beam ions slow down and diffuse in velocity space. For efficient capture of the 1+ ions, the beam parameters at the injection is very crucial for overlapping between the plasma volume and ion beams. In this paper we have studied the trapping of externally injected 1+ ions into 6.4 GHz ECR charge breeder. The minimum-B magnetic field generated by solenoid fields and a haxapole field in radial directions is used for the plasma confinement. The 1+ ion beams produced from the 2.45 GHz ECR ion source and their transport into the entrance of the charge breeder is controlled with a double einzel lens. The injection kinetic energy, beam size and orientation of the beam phase space are optimised by changing voltage of the charge breeder and the voltages of the einzel lens respectively. The optimised parameters of the beam and the experimentally measured plasma parameters of the charge breeder have been used for the simulation of beam slowing down process into the plasma.

NDSR/Contributed Oral **THT5AUCO12**

Design of a vacuum chamber for the gasdynamic ion source with high specific energy input

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A gasdynamic ECR ion source, which utilizes a so-called quasi-gasdynamic or collisional plasma confinement, is characterized by the high plasma density, the low electron lifetime and, therefore, the large extracted beam current (on the order of several hundreds of mA), with a drawback of the low average ion charge in the beam when compared to a conventional (classical) ECRIS. However, such devices are of great interest for modern powerful proton accelerators, being capable of delivering hundreds of mA of light ion beams of superior quality. In a gasdynamic confinement mode, plasma losses are great, therefore the power needed for sustaining the discharge is orders of magnitude higher than that in conventional ion sources. At GISMO facility, which is described in the present work, the total heating power is up to 10 kW at 28 GHz, and the plasma volume is ~40 cm3. A specific input energy per plasma unit volume is usually on the order of 100 W/cm3 during normal operation, and may possibly reach the value of 250 W/cm3. In conventional ion sources the specific energy input is on the order of several W/cm3. The plasma chamber has an inner diameter of 32 mm and a length of 120 mm, which makes the cooling very challenging. The present work describes the plasma chamber design being in successful operation for 2 years, and discusses the future upgrade of the chamber, based on electromagnetic, heat transfer and CFD (computational fluid dynamics) calculations. A particular attention is brought to the design of microwave-to-plasma coupling device.

Funding Agency: This work was supported by the grant of Russian Science Foundation (project number 19-12-00377).

NCNG/Contributed Oral **THT5AUCO13**

High Stability and Low Emittance Microwave Discharge Ion Sources Magnetic Configuration and Ion Source Simulation Tool Development

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High stability magnetic configuration, never used before, was selected and exploited during the commissioning of the Proton Source for the European Spallation Source (PS-ESS). Region of unprecedented beam stability was found between several thousand source configurations tested with a custom control system able to operate on the source without humans’ interaction. The stability shown in this new configuration, denominated High Stability Microwave Discharge Ion Source (HSMDIS)[1], is excellent (±1.5% flat-top stability, ±3% pulse-to-pulse stability) and the emittance of the produced beam (0.1769 π.mm.mrad RMS normalized) is lower than produced by standard MDIS configuration. High linearity between power and extracted beam current was observed making easier the use of the source. This new mode of operation can be easily implemented in all existing sources. Plasma simulation revealed that the new behaviour is generated by a new plasma heating paradigm activated by a precise magnetic configuration peculiarity. Detailed analysis will be presented thanks to the recent upgrades of our ion source simulation tool, now able to simulate from the plasma formation to the beam extraction.

[1] Neri L., Celona L., High stability microwave discharge ion sources, Scientific Reports 12, 3064 (2022). https://doi.org/10.1038/s41598-022-06937-7

NCNG/Contributed Oral **THT5AUCO14**

Design and Development of Novel Waveguide Break for 14.45 GHz ECR Ion Source at VECC.

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An indigenously developed 14.45 GHz ECR ion source is injecting heavy ion beams into K-130 cyclotron at VECC. Waveguide break is required to provide the isolation between the microwave system and plasma chamber. The waveguide break is constituted by two waveguides interrupted by an insulator. It should withstand the applied high voltage between the plasma chamber and microwave system. However, due to the presence of insulator the surface current on the wall of rectangular waveguide becomes discontinuous leading to a potential drop across the insulator resulting into a reasonable amount of microwave radiation leakage from the waveguide break. In order to achieve low microwave leakage, a rectangular waveguide with a choke flange in combination with another rectangular waveguide with a cover flange separated by an insulator is generally used. The design objective of the waveguide break is to achieve adequate high voltage isolation with low reflection and low microwave radiation leakage to environment. The design of the choke flange requires that the thickness of the insulator, radius and depth of the groove in choke flange along with the radius of the choke flange, must be optimized to achieve the design objective. However, the published works in the literature discusses the design of the waveguide break with single choke, which is optimized for a specific frequency. It is often required to feed two frequencies in the ECR ion source for its better performance. For this purpose, conventionally two separate waveguide breaks tuned to specific frequencies are utilized. In this paper we propose a novel double choke waveguide break which is optimized for simultaneous operation at 14.45 GHz and 18 GHz. In addition, a generalized equivalent circuit model for single and double choke waveguide break will also be discussed [2-5]. Simulation and measurement results of the different single choke and double choke waveguide break will be compared and discussed.

* M.Cavenago and C.T.Iatrou, Rev. Sci. Instrum., 65, 1122, 1994. * G.L.Ragan, McGraw Hill, 1948.* D.M.Pozar, 4th Edition, Wiley * N.Marcuvitz, McGraw Hill, 1951 * J.Helszajn, IET press, 2000.

Funding Agency: Government of India

RIB/Contributed Oral **THT5AUCO15**

223Ra Ion Beam Production from ECR2 at the Argonne Tandem Linac Accelerator System

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A beam of radium-223 has been produced from the Argonne Tandem Linac Accelerator System (ATLAS) ECR2 ion source and delivered to target. To achieve the experiment objectives of 1.07 GeV and 1E6 particles/s on target, an ion beam of 223Ra34+ was required. Sample preparation and loading techniques were developed in concert with ATLAS target makers and health physicists. Approximately 400 nanograms of material was available for the experiment, warranting the use of accelerator mass spectrometry (AMS) techniques for machine tuning [*]. Following the removal of the Ra-223 sample, contamination has been a constant challenge while the residual material in the plasma chamber decays. Lessons learned and best practices are included with an emphasis on health physics strategies used to keep radiation levels as low as reasonably achievable and contamination minimized before, during, and following the experiment.

[*] R. Scott, W. Bauder, T. Palchan-Hazan, R. Pardo, and R. Vondrasek, Review of Scientific Instruments 87, 02A732 (2016).

Funding Agency: This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357.

FPPS/Contributed Oral **THT5AUCO16**

An experimental study of afterglow mode on SECRAL-II ion source

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As the HIAF (High Intensity Heavy Ion Accelerator Facility) project requires intense pulsed beams of highly charged ions produced by the ECR ion source with ≥ 2 ms peak duration and 1–3 Hz repetition rate, neither the peak beam intensity nor the reported afterglow peak duration (typically less than 1 ms) with today's ECR ion sources can meet the HIAF requirement. In this talk, we carried out an experimental study of the afterglow mode with a third generation electron cyclotron resonance ion source, SECRAL-II (Superconducting ECR ion source with Advanced design in Lanzhou No. II), at high frequency (24 & 18 GHz) and high power (~8 kW). The experimental results show that intense pulsed beams of highly charged ions with long peak duration (greater than 2 ms) could be produced by operating a third generation ECR ion source in afterglow mode with double frequency heating. Meanwhile, the influences of main source parameters, such as the microwave power, microwave pulse width, and microwave frequency, on the afterglow characteristic are systemically investigated.

FPPS/Contributed Oral **THT6AUCO17**

RF-induced Losses of Hot Electrons from the ECR Plasma

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Physics of the processes occurring in the ECR plasma still requires a lot of research. In particular, electron energy distribution function (EEDF) in such plasma, which depends on plenty of parameters, is one of the most topical questions posed for the deeper understanding of the plasma confinement and its stability. Even these days, no method has been proposed to directly measure the exact EEDF in the ECR plasma. However, an alternative was presented to measure the hot fractions of electrons escaping from the discharge chamber*. It has given the possibility to estimate the characteristics of the plasma along with the other diagnostics. The experiments on various facilities have shown the existence of a hump on the distribution that barely depends on parameters, such as pressure and magnetic field. In the previous works**, it has been proposed and shown experimentally that such humps can be associated with the modes somehow occurring and distributing in the chamber. The idea is based on a quasi-linear diffusion concept***, in particular, on the assumption of the cavity mode excitation by the hot plasma. The excited mode then scatters energetic electrons to the loss-cone, forming the hump. In this work, the lost electron energy distributions (LEED) were measured along with the microwave emission from the ECR plasma to prove the described hypothesis. A series of experiments was performed on the newly constructed Gasdynamic Ion Source for Multipurpose Operation (GISMO) facility with high energy input.

* S.V. Golubev, I. V. Izotov et al., RSI 83, 2 (2012).

** V. Izotov, A. G. Shalashov et al., PPCF 63, 4 (2021).

*** A.G. Shalashov, E. D. Gospodchikov, I. V. Izotov, PPCF 62, 6 (2020).

The work was supported by the Russian Science Foundation, grant #21-12-00262.

FPPS/Contributed Oral **THT6AUCO18**

Studies on electron energy distributions in High Temperature Superconducting ECR Ion Source, PKDELIS at IUAC

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The 18 GHz, High Temperature Superconducting Electron Cyclotron Resonance Ion Source [1] is a part of High Current Injector which is being commissioned at IUAC. X-ray Bremsstrahlung measurements have been used to study the energy distributions of electrons in gaseous as well as metal ECR plasma. In a previous study [2], X-ray Bremsstrahlung measurements have been carried out to understand the effect of negative DC bias voltage on the high temperature component of the electrons. In the present study, the Bremsstrahlung experimental set up and the effect of axial magnetic field on electron energy distribution will be discussed in detail.

[1] D.Kanjilal et al., Review of Scientific Instruments, Vol.77 , 03A317 (2006).

[2] G.Rodrgues et al., Review of Scientific Instruments, Vol. 81, 02A323 (2010).

FPPS/Contributed Oral **THT6AUCO19**

A multi-cusp ECR plasma source for high intensity accelerators

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Plasma based ion sources have become an important tool in recent decade for various scientific and societal benefitted applications in accelerator technology such as nuclear waste transmutation, radio-isotope production, ion therapy etc. Due to the stability, reliability, lower emittance and higher beam currents offered by ECR- based plasma ion sources have gained significance in high intensity ion accelerators. A compact 2.45 GHz ECR plasma source has been developed in-house to study the microwave power coupling to ECR plasma source. An optimized one step ridge coupler has been used to improve the microwave coupling to the source thereby enhancing the electric field amplitude at the center of cylindrical resonator cavity (acting as a plasma source) operating at TE111 mode. A 14-pole permanent magnet multi-cusp has been used for the radial confinement of the plasma. Preliminary studies have been done with the Argon plasma. A novel wave cut-off probe and a Langmuir probe has been indigenously developed for plasma diagnosis. In this paper we will present a comparative study of plasma parameter measurements using the indigenously developed cutoff probe and the Langmuir probe.

FPPS/Contributed Oral **THT6AUCO20**

Interplay among cavity modes in a microwave ion source influencing the plasma dynamics and the extracted ion beam

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Generation and excitation of multiple cavity modes in an experimental microwave ion source chamber are reported. The frequencies of those cavity modes are close to the operating microwave frequency, 2.45 GHz. Their interactions with each other inside plasma control the microwave (MW) coupling, the plasma dynamics and influence the ion beam quality. The linear superposition of those close frequency cavity modes, recognized as phase modulation generates a new range of plasma oscillations with the same modulation frequency. Newly generated phase-modulated waves are verified from the signatures of experimentally measured frequency emission from the plasma and the hot electron population build-up. The increase of the hot-electron population is caused by the plasma resonance with the modulated waves. Furthermore, few cavity modes are having more power than the threshold value required for nonlinear superposition and causes parametric decay phenomenon (PD).PD is also responsible for generating the ion waves in the over-dense plasma condition and thus causes additional plasma fluctuations of the corresponding frequencies. These above-mentioned phenomena influence the plasma dynamics and its ion beam stability. The present work reports the experimental observations of the phase modulation and the parametric decay due to the interplay of multiple cavity modes and the corresponding ion beam oscillations. The experimental results are supported by analytical calculation and finite element method (FEM) simulation. The influence of above mentioned self-excited plasma oscillations of a microwave ion source on its beam property is reported in the present study.

AND/Contributed Oral **FRT7AUCO21**

Applications of an Indigenously Developed Compact ECR Plasma Source [CEPS] at IIT Delhi

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Plasma Lab at IIT Delhi has developed an indigenous lightweight Compact ECR Plasma Source (CEPS) [1, 2] which can be easily mounted on to any plasma chamber. This generic source has been found useful for various applications, one of which could be a plasma thruster for deep-space plasma propulsion. In this study, the CEPS was mounted onto one end of a cylindrical SS chamber (50 cm ID and 75 cm long). Experiments were undertaken with 2.45 GHz, 200-600 W CW microwave input and Ar gas filling pressures of 0.3 mTorr to 10 mTorr [3]. Recent investigations [4, 5], have also revealed that the CEPS source could be developed into a potential electrodeless plasma thruster for deep space plasma propulsion. Based on the plasma parameter measurements using a specially designed capped axial Langmuir probe and a theoretical model, the thrust was estimated to be of the order of a few tens of milliNewton (≈45 mN @ 600 W microwave power for Ar plasmas). However, before one can consider to develop a prototype model, it is necessary to measure the thrust using a thrust balance system to validate the above results. This paper will report the design of an indigenously developed thrust balance measurement system based on the principle of the lever effect with the thrust of the thruster to be transferred directly to a load cell after the thrust is amplified by the lever effect. In order to see the working and feasibility, simulations will be performed before fabrication of the final prototype which would be tested under the above mentioned plasma conditions. Details of the design and results of this thrust diagnostic system will be discussed in this paper.

References:

[1] Ganguli A and Tarey R D 2006 Indian Patent #301583 Patentee: IIT Delhi [

2] Ganguli A, et al 2016 Plasma Sources Sci. Technol. 25 025026

[3] Verma A, et al 2019 Plasma Res. Exp. 1 035012

[4] Ganguli A, et al 2019 Plasma Sources Sci. Technol. 28 035014

[5] Verma A et al 2020 Plasma Sources Sci. Technol. 29, 085007

AND/Contributed Oral **FRT7AUCO22**

Ion-beam-induced astrochemistry: a new application of the Atomki-ECRIS

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An electron cyclotron resonance ion source (ECRIS) has been operating at Atomki for over 20 years. This second generation 14 GHz source is a stand-alone device that is used to provide versatile low-energy ion beams and plasmas for atomic physics research, plasma investigations and for material science. One of specialties of this ECRIS is that it is able to produce not only positive but also single-charged negative ions and certain molecular beams, as well. The Atomki-ECRIS originally was equipped with one 90Â° beamline, however a second 55Â° beamline was installed recently to host and serve a special astrochemistry chamber. The field of astrochemistry has been the recipient of continuously increasing interest in the last few decades. A large number of molecules have been detected in the ISM, from diatomic ones to complex organics/PAHs. The physical conditions; temperature, density, UV radiation and energetic charged particles determine reaction paths followed and the complexity of molecules. Many laboratory experiments have been performed utilizing light sources (synchrotron, UV lamp) and high energy ion accelerator facilities to study the chemistry taking place in the ISM. However, only limited types of positive ion species (with high energy) have been used to irradiate astrochemical ices despite the presence of many distinct types of ions in the ISM or surrounding planetary bodies. Our plan is to overcome this limitation and understand the interaction of many types of singly and multiply charged ions having wide energy ranges with astrochemical ices. The ice-layers/mixtures are formed on infrared transparent substrates cooled to 11 K and are to be irradiated with different positive/negative ions produced by the ECRIS at (0.5-30)*Q keV beam energy (Q: ion charge). The projectiles planned for studies are H+ and H- to heavy ions (C, O, N, S). The chemical evolution of ice will be monitored using an IR spectrometer and a QMS attached to the UHV chamber.

AND/Contributed Oral **FRT7AUCO23**

ECR ion Source proton fraction measurement and enhancement of it in LEHIPA

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The 50 keV, 10 mA ECR ion source is design, developed and commissioned at LEHIPA[1]. The LEHIPA is 20 MeV proton accelerator in which ion source is the front end of it. Presently LEHIPA is commissioned up to 11 MeV. The key requirements for ion source beam are stable, repeatable, reliable, tunable beam current with higher proton fraction (~80% and above). The ion beam extracted from the source contains H+, H2+ and H3+ ion. We are interested only in the 50 keV H+ ion for further acceleration. In this paper the proton fraction measurement experiment using bending magnet and enhancement of it is discussed. The optimization of proton fraction is done by adding the alumina cylinder and boron nitride plates in the plasma chamber. The experimental results for proton fraction measurement by varying applied microwave power and operating gas pressure are discussed. The proton fraction of the ion source is improved from 64% to 83% by optimizing and adding alumina cylinder and boron nitride plate in the plasma chamber.

[1] S V L S Rao et al., Commissioning of the LEHIPA 3 MeV RFQ, in Proceedings of the Indian Particle Accelerator Conference 2019 (InPAC-2019), IUSC, DELHI, INDIA, (2019).

Funding Agency: BARC

AND/Contributed Oral **FRT7AUCO24**

Production of intense carbon beams with permanent magnet ECR ion sources

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Since Lanzhou first all-permanent magnet ECR ion source (LAPECR1) was developed successfully at Institute of Modern Physics (IMP) in China. It has been applied in many accelerators with excellent characteristics. For the purpose of yielding various ion beams including low and high charged states ions, more than three types of all-permanent ECR ion source were developed at IMP up to now. In recent years, carbon beams were widely applied in some leading research fields, such as carbon therapy, nuclear astrophysics and so on. In order to investigate the production of intense carbon beams, LAPECR series ion sources were employed to optimized the beam intensity and the beam quality. Additionally, some techniques were employed to optimize source performance and avoid the breakdown of key equipment. This paper will introduce LAPECR series ion sources and present the latest results of carbon beams production.

RIB/Contributed Oral **FRT8AUCO25**

First results from the gas jet coupled 2.45 GHz ECRIS for online radioactive ion beam production at VECC RIB facility

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In the Radioactive Ion Beam (RIB) facility at VECC, radioactive recoils are transported from the production chamber to a remotely located 6.4 GHz Electron Cyclotron Resonance ion source (ECRIS) using the Gas-jet Recoil Transport (GJRT) technique. The radioactive atoms are online ionized in the ECRIS and the RIB of interest selected in the downstream isotope separator is accelerated to higher energies in a radio frequency quadrupole (RFQ) and Heavy-Ion Linac modules. Due to high dynamic gas load from the production chamber, the ECRIS vacuum is often not better than few times 10-5 mbar, resulting in the difficulty in obtaining multiply charged ion beams. As an alternative, a charge breeder line consisting of two ECR ion sources in tandem is being developed. Under this scheme, the gas jet-transported radioactive recoils are injected in a 2.45 GHz ECRIS optimized for 1+ RIB production. The 1+ beams extracted from the first ECRIS are mass separated, decelerated and axially injected in the 6.4 GHz ECRIS for charge breeding to multiple charge states matching with the required A/q for the RFQ and Linac modules. In this contribution, we discuss the design and recent beam commissioning results of the gas-jet coupled 2.45 GHz ECRIS. Apart from beams of stable isotopes, the ECRIS has been tested for online measurement of RIB of 11C ($T_{1/2}$ = 20.36 min) that was produced using primary proton beam from k130 cyclotron at VECC. The details of the gas-jet ECRIS and the RIB production experiments will be presented.

SM/Contributed Oral **FRT8AUCO26**

Status of ECR Plasma Electron-Ion Numerical Modelling at INFN ¿ From Space-Resolved Population Kinetics to X-Ray Emissivity Analysis

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While ECR ion sources have been in use for many years as reliable devices for supplying accelerators with ion beams tuned according to experimental needs, their fundamental physical mechanisms remain a topic of study. The interplay between quantities like RF power and frequency, gas pressure, type of ion and chamber geometry strongly influences the microscopic variation in plasma properties and consequently, the properties of extracted ion beams. Developing robust simulation toolkits to study the correlation between output beams and internal plasma dynamics is essential not only for fundamental ECRIS research but for applications making use of magnetised plasmas as well. One such application is the PANDORA facility under construction at INFN-LNS, which aims to exploit the charge state distribution (CSD) of ECR ions to measure in-plasma beta-decay rates of radioisotopes as in stellar environments. The underlying theory for the process requires detailed inputs on the ion population kinetics* as a function of their position in plasma. The plasma physics groups at INFN-LNS and LNL have developed a 3D particle-in-cell (PIC) code suite aimed at modelling electron and ion dynamics in a self-consistent manner, capturing the most relevant physics for each (EM wave propagation and damping, stepwise ionization and excitation, self-generated potential dip etc.) and capable of furnishing space-resolved information on density, energy, CSD and atomic level populations. The simulation schemes are robust, comprehensive, make few assumptions about the state of the plasma and can be extended to include more detailed physics. We present here an overview of the status of these numerical models as well as the comparison of simulation results with experimental data for benchmarking. By combining the outputs from the ion and electron models, space-resolved X-ray emissivity calculations have also been performed which can pave the way for potential use as a diagnostic tool**,***.

* K. Takahashi and K. Yokoi, Nucl. Phys. A 404, 3 (1983).

** B. Mishra et al, Condens. Matter. 6, 41 (2021).

*** B. Mishra et al, Phys. Plasmas, 28, 102509 (2021).

The support of the 3rd National Commission of INFN through the PANDORA_Gr3 project is gratefully acknowledged.

SM/Contributed Oral **FRT8AUCO27**

Modelling of ECR heating in an ECRIS with axis-symmetric magnetic topology

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A new 10 GHz ECR ions source (PK-GANESA) with an axis-symmetric magnetic topology has been developed in a GANIL-Pantechnik collaboration [1]. Preliminary experimental results lacked the evidence of production of high charge state ions from the source. A description of the electron transport thanks to a Monte Carlo approach has been implemented for typical conditions of the PK-GANESA source. The gain of energy is modeled through the introduction of stochastic heating during the stay of the electrons in the ECR heating zone, while energy losses are the result of electron-heavy species collisions. This contribution deals with the simulation methodology, results, and implications.

References:

[1] P. Salou et al., AIP Conf. Proc. 2011, 040021 (2018)

Poster Presentations

Fluctuations in an ECR produced Hydrogen plasma in diverging Magnetic fields in a Large Volume Plasma System

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An indigenously developed lightweight, Compact ECR Plasma Source (CEPS) developed at Plasma Lab, IIT Delhi has been utilized for the production of a uniform, large area, high density hydrogen plasma in a coaxially attached large volume expansion chamber. The CEPS comprises primarily of a magnetron, triple stub tuner, mode convertor and a portable cylindrical SS plasma section (dia: 9.0 cm, length: 11.5 cm) placed coaxially within a set of NdFeB ring magnets. The CEPS is highly portable and can be easily mounted onto any plasma chamber. The ring magnet assembly is axially magnetized, which produces a magnetic null point a few mm outside the magnet assembly on its axis. The magnetic field beyond the null point is a converging-diverging field that penetrates into the attached target chamber as an exponentially falling field with scale length, ~ 9.3 cm.

For this work, the CEPS is mounted at one end of a large cylindrical expansion chamber having dia ~ 100 cm & height ~ 100 cm. A Langmuir probe, wth a capped tip, was used for axial scans from the source to far downstream along with radial scans at different axial planes. Initial experiments performed with CW microwave power, ≈ 400W, at pressures, ≈ 1 and ≈ 2 mTorr demonstrated high plasma density, (ne) ≈ 10^11 cm-3, with electron temperature (Te) ≈ 4 - 8 eV and plasma potentials (Vp) ≈ 30 - 40 V, close to the source mouth. The density and temperature drops initially becoming nearly constant in the downstream region (from z = 15 cm-50 cm) of the large volume chamber. Radial scans at different z-planes showed uniformity in both ne and Te profiles for all the pressures.

With increase in microwave power (> 600 W) one observes a very unique feature wherein a strong filament-like structure is observed emanating from within the source surrounded by diffuse plasma into the large volume chamber undergoing pulsations at a few Hz frequency. It is believed that this phenomenon could be due to instabilities linked to highly energetic ion beams ejected from within the CEPS into the expansion chamber. Initial investigation to confirm the presence of ion beams would be carried out in this paper using a retarding field energy analyser (RFEA) and correlating the beams with the associated pulsating plasma column along with fluctuation measurements.

FPPS/Poster **WEP1PG002**

The Effect of Magnetized Quantum Plasma on Jeans Instability

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The influence of quantum plasma on Jeans instability is investigated in the presence of magnetic fields, the dispersion relation considering with parallel and perpendicular direction has shown the stabilizing effect on the growth rate of Jeans instability with moderate temperature high density regime. The graphical illustration is depicted to see the influence of magnetic field on Jeans criteria. The inclusion of magnetic fields with quantum effect on the motion of a charged particle involves the essential properties of acceleration and the transport of highly ionized particles is important in connection with a well-known application of the confinement of magnetized plasma. This framework has the potential in astronomical condition to shape the fusion research in shape science plasma such as neutron star, magnetars, white dwarfs which are formed from the collapse of low mass star, less than about 10 time the mass of the Sun.

FPPS/Poster **WEP1PG003**

Production of intense pulsed highly charged ions beams with high performance superconducting ECR ion source

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An experimental study of the afterglow mode was performed with a third generation electron cyclotron resonance (ECR) ion source, SECRAL-II (Superconducting ECR ion source with Advanced design in Lanzhou No. II), under double frequency heating. The experimental results show that intense pulsed beams of highly charged ions (e.g., 266 eμA of 129Xe34+, 169 eμA of 129Xe38+) could be produced at high frequency (24+18 GHz) and high power (~8 kW). Compared with the beam intensity records obtained in CW (Continuous Wave) mode, the gain factor is up to ~3. Meanwhile, it is found that the required optimum microwave pulse time and decay time of highly charged ions in the afterglow mode are much longer than those for the second generation ECR ion sources typically operating at 10-18 GHz. This study provides a viable solution for heavy ion synchrotron accelerator complex such as HIAF (High Intensity heavy ion Accelerator Facility) project that requires intense pulsed beams of highly charged ions with 1~2 ms peak pulse duration. Moreover, this work also indicates that it is most likely to further improve the afterglow performance by operating a fourth generation ECR ion source operating at higher frequency (≥45 GHz) and higher power (≥20 kW).

FPPS/Poster **WEP1PG004**

Effects of Magnetic Field Configuration on Hydrogen Plasma in a Miniatured 2.45 GHz ECR Ion Source

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2.45 GHz electron cyclotron resonance ion source (ECRIS) is widely used to produce H+, H2+, and H3+ for the demands of accelerator facilities. A study on the effects of four different magnetic field configurations (MFCs) to produce CW hydrogen plasma with a miniatured 2.45 GHz ECRIS is launched at Peking University(PKU). The contour plots of H+, H2+, and H3+ ion beam intensities and fractions on the gas pressure and microwave power are presented with different MFCs. The proton fraction of 33% is obtained within resonance MFC whose resonance area is larger than other MFCs. Beams with H2+, and H3+ ion fractions greater than 80% are produced under optimized working parameters. By optimizing gas pressure and microwave power with different MFC, the maximum beam intensities of H+, H2+, and H3+ could reach 6.2 mA, 13.5 mA, and 6.5mA, respectively.

This work was supported by the National Natural Science Foundation of China (Grant Nos. 11975036, 11775007) and the State Key Laboratory of Nuclear Physics and Technology, Peking University.

FPPS/Poster **WEP1PG005**

Effect of Length of ECR Region on Electron Temperature and Density in a Multi Charged Ion Source

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The need for an ion source has been mainly driven by accelerators. It demands high reliability, stability and a maintenance-free source, which is capable of not only producing multi-charged ion species (like Ar, He, O, N etc..) but can be easily switched between elements. The ECR-based ion source is the prominent candidate for this requirement. An all permanent magnet, 14.5 GHz ECR base ion source is being indigenously developed at IPR. In the ion source, the length of the region of ECR resonance (B=f/28) can be changed and optimized depending on the RF frequency f (in range of 12.75 to 14.5 GHz), which in turn improves the ECR plasma parameters like electron density and temperature. These parameters are critical for the high current and charge state of ions. The measurement of these parameters gives a good indication of the performance of the ion source. This paper present the detailed design of the multicharge ion source and the latest result of plasma parameters measurement.

FPPS/Poster **WEP1PG006**

ECR Discharge Plasma VUV Emission from CW Tandem Negative Hydrogen Ion Source

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Electron cyclotron resonance (ECR) discharge sustained by high-power millimeter-wave gyrotron radiation in open magnetic systems is one of the promising high-current CW negative hydrogen ions (H-) sources [1]. Plasma was confined in a double-trap magnetic system, consisting of a simple mirror trap and a cusp. The microwave radiation was launched into the first trap where the plasma is produced and sustained under the ECR condition. Dense plasma flux flew into the second trap through a perforated plate, preventing the microwave propagation, where H- ions are generated. This approach allows to produce plasma with high density and energy deposition beneficial for effective hydrogen excitation and therefore negative ions generation. H- current density up to j ≈ 80 mA/cm2 had been obtained earlier from the tandem negative hydrogen ion source based on pulsed ECR discharge [2]. The vacuum ultraviolet (VUV) plasma emission of the ECR discharge could strongly influence on plasma-chemical processes in the H- generation area, requiring the necessity to investigate its characteristics.

This work is devoted to the experimental study of VUV emission generation in the H- tandem source based on CW ECR discharge sustained by 28 GHz/5 kW gyrotron radiation. Plasma VUV emission was studied in three wavelengths: the atomic Lyα line (122 ± 10 nm), molecular radiation in the Lyman band (160 ± 10 nm), and the molecular continuum (180 ± 20 nm). The VUV emission optimization by tuning heating power and neutral gas pressure was shown.

FPPS/Poster **WEP1PG007**

Trajectory Simulations of an Expanding Plasma generated from an ECR Plasma Source

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For deep space missions, the electrode-less plasma thruster (EPT) is a novel electric propulsion (EP) concept, in which a magnetic nozzle (MN) helps to accelerate the plasma ions [1]. The convergent-divergent magnetic field lines of the magnetic nozzle convert the thermal energy of electrons into the directed kinetic energy of ions by guiding the plasma expansion and producing a significant amount of thrust. The idea is to get a better understanding of the expanding plasma generated by an ECR source for thrust measurement. Using classical trajectory simulations we model the collision-less plasma expansion generated from a Compact ECR Plasma Source (CEPS) [2] developed by Plasma Physics Laboratory (PPL), IIT Delhi. Our simulations incorporate the experimental magnetic field configurations and attempt to develop an understanding of the overall thrust generation mechanism in order to support experimental findings [3].

[1] Merino M and Ahedo E 2016 Magnetic nozzles for space plasma thrusters Encyclopedia of Plasma Technology vol 2 ed J Leon Shohet (London: Taylor and Francis) pp 1329-51

[2] Ganguli, A., et al. "Development of compact electron cyclotron resonance plasma source." 2013 19th IEEE Pulsed Power Conference (PPC). IEEE, 2013.

[3] Ganguli, A., et al. "Evaluation of compact ECR plasma source for thruster applications." Plasma Sources Science and Technology 28.3 (2019): 035014.

FPPS/Poster **WEP1PG008**

Experimental Studies on ECR Produced Hydrogen Plasma Ion Beams

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ECR hydrogen plasma sources have a wide range of applications in the industry and research. The Plasma Lab at IIT Delhi has recently developed ECR sources which are able to produce highly energetic (~ 40 - 100 eV) hydrogen ion beams. The hydrogen plasma was produced inside an ECR plasma source in the pressure range 1 - 8 mTorr and 650W, CW microwave power which was allowed to expand into a larger cylindrical chamber (ID=48.2 cm, length=75 cm). Two magnetic field configurations (Setup I and II) were used in the present work.

In Setup I, the NdFeB ring magnets of a Compact ECR Plasma Source (CEPS) [1] were mounted coaxially on the plasma source section attached to the expansion chamber, while for Setup II, a combination of a solenoid and permanent ring magnets were used. The magnetic field of each Setup extends into the attached expansion chamber.

The plasma was characterized using a specially designed Langmuir probe (LP), with an on-axis Retarding Field Energy Analyzer (RFEA) being used for beam measurements. In Setup I, the LP measurements reveal a high-density hydrogen plasma at 1 mTorr pressure with plasma density (ne) ≈ 2 x 10^{11} cm-3, electron temperature (Te) ≈ 8 eV and plasma potential (Vp) ≈ 50 V near the source mouth with ne decreasing to ≈ 5 x 10^{10} cm-3 away from the source mouth, where, Te ≈ 3 eV and Vp ≈ 10 V. At higher pressures (p ≈ 8 mTorr), ne ≈ 4 x 10^{11} cm-3, with Te ≈ 4 eV and Vp ≈ 14 V, near to the source and decreasing to ne ≈ 9 x 10^{10} cm-3, Te ≈ 0.62 eV and Vp ~ 3 V away from the source. In Setup II ne decreases from ≈ 1 x 10^{11} cm-3, with Te ≈ 6 eV and Vp ≈ 30 V to ne ≈ 5 x 10^{10} cm-3, Te ≈ 2 eV and Vp ≈ 11 V moving away from the source. On the other hand, at higher pressures, at p = 8 mTorr for instance, ne decreases from near to the source ≈ 2 x 10^{11} cm-3, with Te ≈ 3 eV and Vp ≈ 9 V to ≈ 9 x 10^{10} cm-3, Te ≈ 0.78 eV and Vp ~ 4 V away from the source.

From these observations it may be inferred that there is a significant drop in the plasma potential from within the source into the expansion chamber. This ambipolar field would be ideal for ion acceleration. Hence, an axial RFEA [2] was used to measure ion energies close to the mouth of the plasma source section for both Setups. In Setup I, ion energy analysis using RFEA shows highly energetic ions with energy ≈ 97 eV and ≈ 68 eV, (5 cm and 10 cm away from the source) respectively at 1mTorr pressure. At 8mTorr the ion beam energy is ≈ 18 eV and ≈ 14 eV respectively.

[1] A. Ganguli, R. Tarey, N. Arora and R. Narayanan. Plasma Sources Sci. Technol. 25 025026 (2016).

[2] A. Verma, A. Ganguli, D. Sahu, R. Narayanan and R. Tarey. Plasma Sources Sci. Technol. 29 085007 (2020).

FPPS/Poster **WEP1PG009**

Observation of Shear Alfven waves for molecular ion beams in a magnetically confined plasma

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Electron cyclotron resonance (ECR) ion sources are one of the main injector to heavy-ion accelerators and are capable of producing highly charge state intense ions. The mechanism of ionization inside ECR source involves the plasma undergoing many impacts of successive collisions by the stray electrons which get energized by the injected radio waves as per the resonance condition. The ECR plasma has to undergo various kinds of instabilities under different operating conditions of the source. From ideal operating conditions to over-driven conditions of the ECR source, the plasma instabilities are observed in the form of extracted beam current oscillations. They are studied experimentally from the beam current fluctuations of Nitrogen molecular ion beams from ECR source. They are produced at driven frequency (2.23 GHz) as well as in kHz regimes (tunable) and are mostly present near the optimized parameters of ECR source. They exist for every ion beam extracted from the ECR source and also exist in every ECR ion source under certain operating conditions as per detailed study over 10 GHz Nanogan ECR source and 2.45 GHz Monogan (M-100) source. The experimental results are explained using the basic theory of instabilities in magnetically confined plasma via dispersion relations of Shear Alfven waves.

The primary author is presently working at CERN, Geneva.

FPPS/Poster **WEP1PG010**

Studies of pure and mixed ECR plasma - an effort in understanding the gas mixing and isotope anomaly

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The high-energy experiments demand new classes of charged particle accelerators for recording low cross-section events and hence the need for developing high intensities of highly charged ions. The state-of-art Electron Cyclotron Resonance Ion Sources (ECRIS) [1] are well known for producing high intensities of multiply charged ions and are very suitable for such applications. The performance of 4th generation Superconducing ECRIS is many orders of magnitude higher than that of any conventional ion source. The high intensities of highly charged ions are further improved by employing the gas-mixing experiments in ECRIS and consequently, the isotope anomaly in the plasma was observed [2, 3]. The Low Energy Ion Beam Facility (LEIBF) equipped with 10 GHz all- permanent-magnet Nanogan ECRIS has been operational since 2000 for delivering varieties of ion beams for conducting experiments in materials science, atomic and molecular physics. For this purpose, in the course of developing beams with improved intensities, the gas mixing studies have been taken up with ECR plasma of inert gases (Ne, Kr, and Xe). Further, the intensities of naturally abundant isotopes in these plasmas have been recorded to shed more light on the isotope anomalous effect. The interesting experimental results on the gas-mixing and isotope anomaly in Ne, Kr, and Xe plasmas will be presented in detail and the possible physical mechanism of these processes will be discussed.

[1] R. Geller, IOP, Bristol (1996)

[2] A. G. Drentje, Rev. Sci. Instrum. 63 (1992) 2875

[3] A. G. Drentje, A. Girard, D. Hitz, and G. Melin, Review of Scientific Instrum. 67 (1996) 953

FPPS/Poster **WEP1PG011**

Compact 2.45 GHz ECR ion source with coaxial coupling system

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A very compact permanent magnet 2.45 GHz electron cyclotron resonance (ECR) ion source has been designed and developed for various purposes. The microwave power is coupled into the plasma chamber by the coaxial antenna instead of the waveguide, the magnetic field is produced by a single NdFeB permanent magnet ring and the diameter of the source body is only 5 cm. A 300 μA H+/H2+/H3+ mixed beam could be extracted from a 1.0 mm diameter extraction aperture with beam energy of 10 keV. And the extraction beam energy spread of the ion source also was measured by a retarding field energy analyzer (RFEA), the results shown that the extraction beam energy spread could be lower than 5 eV.

FPPS/Poster **WEP1PG012**

Ion Beam Driven Lower Hybrid Wave Instability in a Magnetized Plasma Containing Two Ion Species

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In the present manuscript, we have developed a theoretical model of a plasma cylinder consisting of electrons, light positive & heavy positive ion species. An ion beam is propagated through the plasma cylinder parallel to the applied static magnetic field. Numerical calculations of unstable frequency and the growth rate for both the light and heavy ion modes are carried out using fluid theory for the existing typical plasma parameters. The growth rate versus relative concentration of positive ions is drawn and it is observed that the growth rate increases with the relative concentration of positive ions and scales as cube root of the ion beam density. However, the growth rate increases more rapidly for the light positive ion mode as compared to the heavy ion mode. Moreover, the unstable wave frequency is much larger for the light positive mode as compared to the heavy positive ions mode and measured as one half power of ion beam energy.

Growth rate, unstable frequency, Cerenkov interaction, beam energy.

This work has been partially supported by SERB-DST, Government of India (EMR/2016/002699).

Design and Modelling of a Superconducting Magnet System for an Ecris Using Cable-in-Conduit

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SECRAL (Superconducting ECR ion source with Advanced design at Lanzhou) is a superconducting ECRIS able to produce intense highly charged ion beams, that has achieved record beam currents for very high charge states. In this work, the Applied Superconductivity Research Group at Universidad AutÃ³noma de Zacatecas (UAZ) presents a design of a superconducting magnetic system for an ECRIS that shares some characteristics with SECRAL. Cable-In-Conduit technology was implemented to reduce the amount of superconducting cable, reduce helium consumption, and increase the magnetic field operational range within the chamber without compromising its design. Finite element analysis simulations were carried out to optimize the magnetic field distribution within a plasma chamber of similar dimensions as SECRAL. The proposed design is capable of producing a maximum axial magnetic field of 4 T using two solenoids formed with 4 layers of CIC, each layer having 20 turns around the plasma chamber. Radial confinement of plasma is achieved by means of a magnetic sextupole at the center of the plasma chamber. Furthermore, we present a mechanical analysis of the force distribution within the superconducting coil, and its effect on current degradation.

NCNG/Poster **WEP1PG014**

Progress of ITRIP System

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A new conceptual design and prototype ITRIP (Ion TRap for high Intensity Pulsed beams) for the production of high-intensity pulsed ion beams based on ion trap is proposed. After compression and accumulation of the extracted ions from an ECR ion source, the ions from the ion trap will be extracted in a short time. The peak intensity of the extracted ion beams is expected to be several times higher. This paper shows the recent experimental results of ITRIP system. The prototype of PoP (Proof of Principle) is designed and set up. The primary tests have been done. Precise timing of the pulsed power supplies is achieved with the PoP platform and the experimental results show the feasibility of the bunching section. The experiments of accumulation and extraction of O and Ar ions show that the designed ion trap can effectively make the ion confinement and accumulation.

NCNG/Poster **WEP1PG015**

Design study of lithium vapor feeding system for ECRIS

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At Brookhaven National Laboratory (BNL), we plan to develop an ECRIS for lithium beam production. The high-intensity, high-duty lithium beam is useful for applying medical isotope production and the inverse kinematic neutron generator. The most challenging component of Li3+ ECRIS is the lithium vapor supplier into the plasma chamber. A high-temperature oven inserted into the chamber is widely used. Since a reliable lithium supply subsystem is crucial for project success, we investigate the external system, which consists of the lithium evaporation chamber, the lithium vapor transfer line, and a special leak valve for precise control of the lithium vapor pressure in the plasma chamber at the level 10-8 Torr. All parts of the subsystem should be kept at above 200 ºC. Also, we will study laser ablation of lithium in the chamber. This may simplify the lithium supply system. The design of these external vapor supplying systems will be discussed and compared with standard oven

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NDSR/Poster **WEP1PG016**

Production of intense ion beams from DECRIS-2M and ECR4M ECR ion sources

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Intense and stable beams of the metal ions are requested in a variety of applications. The article reports the results of production of ions of gaseous and solid substances from two ECR ion sources - DECRIS-2M and ECR4M. DECRIS-2M is modernized version of CAPRICE type ECR ion source. During the tests at the test bench the intense ion beams of Ar, Kr, Xe, Bi, Pb and Al were produced. The results demonstrate substantial increase of the ion beams intensity in comparison with the original source, especially in the case of high charge states. The article also presents the results of production of Zr ion beam at the U-400 cyclotron from the ECR-4M ion source. Two methods Â¿ sputtering and MIVOC - were employed for production of Zr ion beam. The produced ion beams were successfully accelerated and delivered for physical experiment.

Development of a new 18 GHz ECR type ion source for the DC-140 Cyclotron Complex

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The new DC-140 cyclotron complex is under development in the Flerov Laboratory of Nuclear Reactions (JINR). The complex is designed for production of heavy ion beams with mass-to-charge ratio A/Z from 5 to 8 (Ne4+, Ar8+, Kr16+, etc.) up to the fixed energies 2.1 and 4.8 MeV per nucleon. These beams will be used for wide range of applied research, such as the production of the heterogeneous micro – and nano-structured materials, testing of electronic components (avionics and space electronics) for radiation hardness, ion-implantation nanotechnology and radiation materials science.

To ensure the required ion intensities and charges, a new 18 GHz ECR ion source DECRIS-5M is under development. The ion source of the DC-110 cyclotron complex (DECRIS-5) is taken as a prototype with some modifications. The article includes the results of calculation of modified magnetic structure, and description of the source design.

NDSR/Poster **WEP1PG018**

Upgrade of the ECR Ion Source DECRIS-2m

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Upgrade of the CARICE-type ECR ion source DECRIS-2m is made to improve its operation capabilities by increasing both the source magnetic fields and the plasma chamber length and radius. This modification made it possible to replace the coaxial microwave input to the rectangular waveguide. These improvements result in a substantial increase of the extracted ion beam currents. During the first tests, the source shows a good performance for the production of the medium charged ions such as 750 eμA Ar8+, 120 eμA Xe20+, 40 eμA Bi27+.

Automated Gyrotron Setups and Components Designed by IAP RAS/GYCOM for Modern ECR Ion Sources

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The report presents brief review of unique automated gyrotron setups and its separate components developed and made by Institute of Applied Physics of the Russian Academy of Sciences (IAP RAS) jointly with GYCOM Ltd. [1-6] intended for use in particular as a radiation sources in modern ECRIS facilities. Typical microwave power of these setups is several tens kW with efficiency up to 0.4 [1] (0.65 in case of depressed collector and magnetic field profile optimization [2]) at the frequency range 18 – 45 GHz. The output power of gyrotrons can be smoothly regulated from about 0.5% to 100% of the full power. Typical operating voltage is in the range of 15–30 kV, and the electron beam current is 1 – 2.5 A. All gyrotrons can operate in both CW and pulsed modes.

Most of the gyrotrons with the electromagnets (oil or water cooling) operate at the 2nd cyclotron harmonic to reduce the main coil energy consumption. The use of novel magnetically shielded solenoids provides a magnetic field strength of more than 1.5 T [3], which makes it possible, when operating at the 2nd cyclotron harmonic, to provide an output frequency of more than 40 GHz. The setups with an operating frequency above 40 GHz, for example, 45 GHz/20 kW [4], built on the basis of liquid helium free cryomagnets. Different varieties of broadband frequency gyro devices – multi-frequency or fast-swept in time operation – are under investigation for ECRIS purposes. The double-frequency CW 10 kW second harmonic gyrotron with 2% fast frequency sweep and a frequency-tunable gyro-BWO operating at center frequency of 60 GHz with CW output power about 10 kW has been developed. Achievement of such parameters of gyrotron setups is possible due to using of unique high voltage power supplies and electrodynamic components of transmission lines developed and manufactured in IAP RAS and GYCOM Ltd. The gyrotron setups described in the report are equipped with a computer control system, which provides control of the microwave power delivered to the consumer and trouble-free operation.

NDSR/Poster **WEP1PG020**

Status of Hybrid Superconducting Ecr Ion Source Development at Imp

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A Hybrid superconducting Electron Cyclotron Resonance ion source in Lanzhou (HECRAL) has been designed and constructed at the Institute of Modern Physics. HECRAL is designed to operate at 24 GHz. The magnetic confinement of the ion source is realized by the axial mirror field provided by four superconducting solenoids while the radial hexapole field supplied by permanent magnet hexapole. The maximum axial magnetic fields are 3.4 T at source injection and 1.7 T at source extraction respectively, and the radial field at the plasma chamber wall of a 100 mm inner diameter is above 1.4 T. Detailed magnet design and force analysis will be discussed. HECRAL has been successfully assembled and tested. Some preliminary highly charged ion beam production results will be presented.

AND/Poster **FRP2PG022**

Analysis of the electrostatic potential field of an open-endcap, cylindrical Penning Trap

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The Delhi Penning Trap (DPT) is designed to study and measure the radiative lifetime of a broad range of metastable ion species. DPT consists of a compact, mechanically compensated open-endcap, cylindrical Penning trap with permanent magnets. It is being developed as a tool which would enable us to isolate and manipulate the charged particles from an ECR ion source in a well- controlled environment in order to study the life time of the transitions from metastable states in highly charged atomic ions. In this abstract, we describe how the harmonicity of the trapping potential depends on the geometry of the trap electrode. We give the comparison between the expansion coefficients from analytical calculations [1] and the coefficients obtained from SIMION simulation. We also demonstrate that the introduction of the two diametrically opposite holes (as shown in figure 1) in the ring electrode does not affect the harmonicity of the confining field near the trap center under the same geometrical conditions. The operation of the trap also depends on the homogeneity of the magnetic field. The NdFeB permanent-magnet [2] provides the field strength of 1 Tesla. We present the magnetic field profile of the permanent- magnet (REM NdFeB) using CST studio suite. Measurements show that the homogeneity of the magnetic field in the region of Â± 2.5mm near the trap center is better than 1%.

AND/Poster **FRP2PG023**

Charge State Stripping and Stopping Power Analysis of Lead Ions in Carbon Foils

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The charge state stripping of ion beams in particle accelerators is crucial for securing high energy gains. Fully stripped ions are always desirable as they not only give maximum energy gain from subsequent accelerators but also have properties of Hydrogen like ions with extended potential barrier. The accurate prediction of charge state of ion beams emerging out of a thin foil require precise optimization of the incident ion beam energy, beam emittance etc. Similarly, the choice of foil material, its thickness and purity govern the desirable outcome of the final charge state. Thereby, optimizing both of the parts i.e., incident beam and foil properties, is highly desirable for not only obtaining maximum charge state but also its significant proportion in overall charge state distribution. Here, we have studied the interaction of 208Pb56+ ions with Carbon foils of different thickness at an incident beam energy of 28.9 MeV/u using ETACHA4 code 1]. We observed that the charge state distribution curve for 208Pb56+ in C foils are found in accordance with the experimental data of Leon et al. [2]. So, the optimization for different combinations of carbon foil thickness and beam energies in the range 1.0 MeV/u to 28.9 MeV/u are performed using ETACHA4 code and the combinations resulting in maximum charge state are reported. Since the experimental cost is huge for such experiments, therefore, our theoretical study provides a cost-effective alternate of experimental study in this area. The stopping power of these ions in C foils are also verified simultaneously using SRIM and TRIM along with study of charge state stripping.

AND/Poster **FRP2PG024**

High reliability chopper system for HIAF project

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Due to the demand for pulsed beam time structure modulation and fast machine system protection for the Heavy Ion Accelerator Facility (HIAF) project at Institute of Modern Physics, a high reliable chopper system is designed to install on the low energy beam transport line. It contains a pulsed high voltage power supply which rising and falling edge is less than 25ns, a characteristic feature is that a backup high voltage module is added, then it can provide additional secondary protection when the main high voltage module is out of work. Furthermore, the input timing signal with 8ns time accuracy is provided by a white rabbit type system. Two kinds of machine system protection signal called single and global fault are connected to this chopper system, when one of these protection signals change from 10MHz to low level, the high voltage power supply will immediately output maximum voltage to deflect ion beam, in order to avoid beam energy decay on the accelerator. The experimental results show that its total response time is less than 2µs. The long-time performance test has been certified that this chopper system presents high reliability and stability so that it can suit HIAF project acquirement.

AND/Poster **FRP2PG025**

Functional Characterisation of ECR Ion Source based 14 MeV neutron generator

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Institute for Plasma Research, India has developed an Electron Cyclotron Resonance Ion Source (ECRIS) based high yield 14 MeV neutron generator for fusion related benchmark experiments. The 2.45 GHz ECRIS is used to produce deuterium beam which is bombarded on solid tritium target to generate neutrons. This neutron generator is designed to produce 1012 neutrons per second in continuous mode as well as pulse mode. The neutron yield depends on the ECRIS parameters. The parameters such as current, diameter and energy of beam, directly impacts on neutron productions. In order to gain the stability and optimum performance of neutron generator for various kind of experiments, it is very essential to establish the relation between these beam parameters and neutron yield. In this present work, the rigorous study has been performed to measure the dependency of neutron yield on ECRIS beam current, diameter and energy. In addition to this, variation in the neutron yield has also been studied by varying acceleration voltage. During the experiments, beam current and beam diameter were monitored using New Parametric Current Transformer (NPCT) and Beam Profile Monitor (BPM) respectively. The neutron yield was measured using three different diagnostic methods. An Associated Alpha particle Diagnostic (AAD) technique was used to measure the absolute yield of neutron generator. Well calibrated single crystal diamond detector and He-3 proportional counter were also used to monitor the yield. This paper discusses the methodology adopted during the experiments and its results. The outcome of this work will support the neutron generator facility for futuristic experiments.

AND/Poster **FRP2PG026**

Ion Sources at Hit and Results of Test Bench Runs

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The Heidelberg Ion Beam Therapy Center (HIT) is a hospital-based treatment facility in Germany. Since the first treatment in 2009 more than 7500 patients have been irradiated with protons or carbon ions and, since July 2021, also with helium ions. At HIT three Supernanogan ion sources supplied by Pantechnik are operated 24/7 for up to 335 days per year. Presently HITÂ¿s injector test bench is used to optimize the injector components and to prepare an upgrade of the RFQ. Aiming at prolonged service intervals of the ion sources newly developed solid-state amplifiers shall replace the 14.5 GHz tube amps routinely used for the clinical operation. Offering similar properties solid-state amplifiers have the potential to significantly increase the technical lifetime. At the testbench the ion beam was analyzed in order to rule out unwanted influences from this new amplifier type. HIT aims at higher beam intensities in order to increase the patient throughput. Among other optimizations a new RFQ-design will be needed to enhance the transmission of this linac-section and to optimally match the ion-optical properties to the existing low-energy beam transport line. The pepperpot measuring system being used to analyze the beam characteristics upstream to the RFQ was redesigned. The newly designed mask-target assembly allowed for an increase of the active detection area and an accurate pixel calibration scheme based on a specific mask. We measured a complete set of 4D-emittances for the ion species 12C4+, H3+, 4He2+ and 16O6+. The results will serve as references for the upcoming RFQ-Design. This paper will give an overview of the developments at the test bench and the innovations around the ion sources at HIT.

AND/Poster **FRP2PG027**

The Design of a High Current 2.45 GHz Microwave Ion Source for an Electromagnetic Isotope Separator

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Stable isotopes are utilized widely in energy sources, military industry, semiconductor, agriculture, medicine, pharmacology, biology, food industry and chemistry field. Due to the rapid development of applications of nuclear science and technology in China, the production capacity of isotopes cannot meet the growing demands. Therefore, the development of electromagnetic isotope separators with high yields and high isotopic purity is needed. An electromagnetic isotope separator based on a 2.45 GHz microwave ion source and isotopic magnet has been developed to study a number of important heavy isotopes, such as Xenon and molybdenum isotopes. The ion source is expected to produce 20 emA Xe+ ,5 emA Sr+ and 5 emA Mo+ respectively. To achieve this goal, series of technical difficulties need resolving, such as metal vapor damage of the microwave window, beam quality, the special-shaped discharge chamber and precise control of the oven temperature. The trajectory plot of 20 emA Xe+ was simulated with the IBSIMU code using the extracted slit geometry. In order to obtain high density plasma, the distribution of the magnetic field along the chamber was optimized by CST software. Simulation results show that when the coils current is 90 A, the density of Xenon plasma can reach up to 10^{11} cm3.

AND/Poster **FRP2PG028**

Theoretical Investigation of Interaction of Kr and Xe Ions with Al Foils

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The performance and overall energy gain of the particle accelerators involving stripper foils are highly dependent on the overall charge state distributions, the mean charge state, and the output beam emittances after the stripping. The determination of accurate charge state is quite complex process because of the multiple collisions that the ions suffer in target foil, resulting in stripping of the ions. The key parameters which affect the overall distribution of the charge states are incident beam energy, foil thickness and its purity. ETACHA4 code was developed over the years which determines the charge state distributions of fast ions. We have studied the interaction of 84Kr36+ and 129Xe44+ ions of energy ranging from 26.44 MeV/u and 43.9 MeV/u with various Al foils of thickness lying in between 1.60 mg/cm^2 – 20.15 mg/cm^2. The results are found in accordance with the experimental data of Leon et al. Further, the optimization for obtaining maximum charge state in the broad energy range i.e. 1.0 MeV/u - 10.0 MeV/u has also been performed. The present theoretical analysis provides information about the capabilities of Al foil as effective and efficient stripper in the particle accelerators.

AND/Poster **FRP2PG029**

Status of a compact 39Ar Enrichment System for Argon Dating

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The low abundance of 39Ar extremely limits 39Ar-ATTA's (39Ar Atom Trap Trace Analysis) dating efficiency with 39Ar radioactive isotope. Aimed at improving the ATTA's efficiency, an isotope enrichment system has been developed at IMP (Institute of Modern Physics) to increase the abundance of 39Ar in the incident sample gas. In this enrichment system, a 2.45 GHz ECR ion source was designed to ionize sample gas and produce isotopes beams with several mA, and the isotopes beam is transported and separated in the separation beam line, which is consisted of two quadrupoles and an analysis magnet. The separated isotopes are collected by a rotated aluminum foil target. According to the recent cross-checked results with 39Ar-ATTA, high enrichment factor of 39Ar isotope has been successfully reached and the enrichment process can preserve sample's dating information well. Now, this system is being arranged to enrich samples of ocean water or glaciers. This paper will give a general introduction to the platform setup and the latest experiment results.

AND/Poster **FRP2PG030**

Antenna Array Influence on the Surface Wave Plasma Source

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In a modern ion implanter, plasma flood gun (PFG) is used to neutralize wafer charge during doping process, preventing the breakdown of floating wafers caused by the space charge accumulation. In order to obtain the PFG which can produce ribbon electron beams with the characteristics of high stability, high plasma density, no metal pollution and long life, studies at PKU are focused on surface wave plasma(SWP) source recently. A 2.45 GHz microwave driven planar SWP source with a quartz plate and a series of metal slotted antenna arrays was designed and tested. The size of the plasma chamber is 280 mmÃ—150 mmÃ—40 mm with a 280 mmÃ—2 mm extraction slit. Theoretical and experimental studies are carried out on the influence of different shape array antennas on SWP. Through the selection and optimization of antenna structure, a relatively uniform argon plasma with density of 1.7Ã—1017/m3 is obtained under the condition of gas flow rate of 2 sccm and input power of 500 W. In this case, the plasma distribution is studied by emission spectrum diagnosis and 22 mA ribbon electron beam is measured.

AND/Poster **FRP2PG031**

Synthesis of High Quality Diamond Seed Substrate by Plasma Enhanced Chemical Vapor Deposition Method

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India Plasma Enhanced Chemical Vapor Deposition (PECVD) is a prominent method to grow qualitative diamond crystal at very low temperature and low pressure. PECVD method was implemented to guide the optimization of synthesis parameters including substrate temperature (800-900), gas pressure (6-7 kpa) and volume concentration of CH4 and H2 for deposition. The simultaneously changes of growth parameters and its analysis, the growth quality of the obtained sample was improved. The substrate temperature measured by infrared pyrometer while the flow rate of ach gas was regulated mass flow controller. Raman Spectroscopy was carried out in order to confirm diamond phase of grown sample. The obtained diamond crystal has outstanding material properties that can enable exceptional performance in applications such as medical diagnostic, radiation detectors, optical component for laser, window for RF and microwave transmission, a cutting tools, electrodes as electrochemical sensing etc. The new applications including high power electronics, quantum properties and erosion resistance coating in nuclear fusion reactors can also in focus for high quality single crystal diamonds.

Keywords: Diamond Seed Crystal, Plasma Enhanced Chemical Vapor Deposition (PECVD)
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SM/Poster **FRP2PG032**

Modelling of a Resonant Cavity based on a 2.45 GHz Microwave Ion Source

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The Central University of Punjab Bathinda (CUPB) had taken an initiative in the past couple of years to establish its first plasma diagnostic facility based on the indigenous development of a 2.45 GHz Microwave Ion Source [1], considering similar developments reported elsewhere [2]. In the early stages of development, studies on 3D modeling of the microwave plasma cavity and its optimization were carried out. Its optimization process involved finalizing the dimensions of the microwave plasma cavity, in addition to making the cavity a resonant cavity when the waveguide circuit is coupled with the cavity. A numerical and simulated approach had been used to design the sections of the ridge inside the waveguide so that the cavity could possibly sustain high electric fields. A numerical approach was designed for a varying number of ridge sections so that the plasma impedance condition could be satisfied by the microwave plasma cavity. Modeling was carried out using COMSOL Multiphysics and CST, Microwave Studio codes. The high electric fields achieved inside the microwave plasma cavity had been verified by igniting the plasma even in the absence of a confining magnetic field. Details of the design and developments and further studies will be discussed.

Funding Agency: SERB India

SM/Poster **FRP2PG033**

Toward A High-Temperature Surface Microwave Source for Ion Implantation

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To generate high-current B+ ion beams for ion implantation, a hybrid ion source that combines electron cyclotron resonance and thermal surface ionization, called a high-temperature surface microwave source (HSMS), is under development. A combination of a high-temperature hot surface (2000°C) and microwave heating are the essential components of an HSMS to produce high-energy electrons for B+ generation. A helical tungsten filament will be used in the HSMS source to obtain a high temperature and to provide an axial configuration with a magnetic field of approximately 875 Gs for 2.45 GHz electron cyclotron resonance. During the design process of the magnetic system, heating system and mechanical structure of the source body, heat transfer, electron bombardment, the heat insulation structure and the thermal stress have been calculated and verified carefully. Numerical simulations will be adopted to study the transient thermal behaviours of the source to investigate the coupled thermal effect of the microwave window and the ion source chamber.

This work is supported by the National Natural Science Foundation of China (Grant Nos. 12105278) and the Fundamental Research Funds for the Central Universities.

SM/Poster **FRP2PG035**

Investigation of Argon plasma in the presence & absence of magnetic fields

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Microwave-based electron cyclotron resonance cavity has been designed at the Central University of Punjab, Bathinda. In our previous work, analytical and modeling approaches were adopted to render a plasma cavity resonant microwave based on the 2.45 GHz microwave frequency. Here in the present work, a four-stage ridge waveguide (using COMSOL Multiphysics) is investigated for the high electric field criterion. Argon gas plasma modeling has been carried out inside the microwave plasma cavity to investigate the high electric field. To achieve this the modeling has been carried out in a 2D plane as well as in a 2D axis-symmetric case. Also, the problem with the 2D plane background is discussed in the present work and rectified in the 2D axis workaround. Finally, an observable change in the presence and absence of a magnetic field profile is modeled and discussed.

SM/Poster **FRP2PG036**

Development and Validation of the Numerical Model of Electron Cyclotron Resonance Ion Sources

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Processes of the secondary electron emission (SEE) from the walls are included into the Numerical Advanced Model of Electron Cyclotron Resonance Ion Sources (NAM-ECRIS). It is found that SEE strongly influences electron confinement time and ion production. With the modified model, we observe reactions of the source to changes in a gas flow into the source and in an injected microwave power. The source performance with scaling the hexapole magnetic field is investigated. The calculated tendencies are close to the experimental observations.

BET/Poster **FRP2PG038**

Model analysis of the dynamics of elliptical beam in solenoids

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The behavior of a beam with elliptical cross-section and arbitrary partial emittances in longitudinal magnetic field is studied analytically. Such analysis is important for the task of the formation of the beam extracted from the ion source and passed the non-ideal ion-optical system as well as for the LEBT design. The peculiarities of the coupling of the beam oscillations in solenoids are investigated depending on the input parameters of the beam and the characteristics of the solenoidal field. Beam dynamics is analyzed using the modified KV-model. The results of the calculations are presented describing the evolution of the beam parameters.

BET/Poster **FRP2PG039**

The Beam Space Charge Compensation Study at Gismo Facility

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It is well-known that the quality of intense ion beams suffers from its space charge. The proper reduction of this effect can lead to an effective beam transport. The most common technique of achieving a high space charge compensation degree is adding a gas on the beam line. The beam space charge compensation research has a long history* but the problem is still relevant. In particular, the transition process of compensation is still not studied experimentally. The space charge compensation process study was carried out using a Gasdynamic Ion Source for Multipurpose Operation (GISMO) at IAP RAS** with high power (up to 10 kW) and high frequency (28 GHz) heating. The ion source operated in several modes: CW, pulsed and CW with pulsed ion beam extraction. The plasma is confined in quasi-gasdynamic mode which allows the formation of dense plasma fluxes (up to 1.5 A/cm2). In order to operate with intense ion beams effectively, it is necessary to study the space charge compensation aspects regarding the facility. The beam transversal profile was filmed on a CCD camera. The ion beam formation was modeled using IBSimu. The space charge compensation degree was estimated using the beam width comparison between the experimental results and the simulation. A two-electrode extraction system was used. Also it was possible to inject the gas in the diagnostic chamber and change its type. The beam space charge compensation degree evolution in time was studied using a pulsed mode of plasma heating. The experimentally obtained space charge compensation degree was about 80%.

*) I. A. Soloshenko, DOI: 10.1109/DEIV.1998.738839

**) V. A. Skalyga, A. F. Bokhanov, S. V. Golubev, et al., DOI: 10.1063/1.5128489

The work was supported by the project of the Russian Science Foundation Grant No. 21-19-00844.

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