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Deuterium Results at ELISE

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The ITER neutral beam system will be equipped with large RF driven negative ion sources, with a cross section of 0.9 m x 1.9 m which have to deliver a D^- current of 40 A accelerated to 1 MeV. The negative ions are produced by surface conversion of hydrogen atoms and ions on caesium layers. These giant sources will be tested from 2018 onwards at the neutral beam test facilities SPIDER and MITICA at RFX in Padua.

A source of half of this size is being operational since 2013 on the test facility ELISE (Extraction from a large Ion Source Experiment) at the Max-Planck-Institut für Plasmaphysik (IPP). The source plasma is generated in four (eight for ITER) "drivers", which are currently supplied by two 150 kW/1 MHz solid state RF generators.

Main goals of the experiments with this source are to demonstrate a high operational reliability and to achieve the extracted current densities required for ITER (33 mA/cm^2 for H^- for 1000 s and 28.6 mA/cm^2 for D^- for one hour). Changes on the source needed to meet these requirements will be implemented in the design of the ITER sources.

This paper will describe the optimization of the set-up of source and RF power supply which enable long pulse, high power operation as well as the experiments concerning variations of the filter field and the caesium dynamics in order to achieve time-stable ion and electron currents. The emphasis is laid on the experiments in deuterium in which considerable progress has been made in pulses up one hour.

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Achievement of 1 MeV Beam Accelerations for 60 s Toward High Power NBIs

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Long pulse beam accelerations with MeV-class hydrogen negative ions have been demonstrated by using Multi-Aperture and Multi-Grid (MAMuG) accelerators toward high power neutral beam injector (NBI) required in JT-60SA and ITER. This paper reports that pulse duration of the ITER-relevant current density of hydrogen negative ion beams at 1 MeV has been successfully extended from 0.4 s to 60 s by using a prototype five-stage MAMuG accelerator for ITER. The key for this achievement is to reduce the power loadings due to a direct interception of negative ions and secondary electrons on the acceleration grid. The extraction grid has been modified to optimize the beam optics and to control the beam directions. The acceleration grid has been modified to suppress the secondary electron generations. For these modifications, three-dimensional beam analyses including the collision process and the detail configuration of the accelerator have been improved step by step with the experimental validation. Finally, the total power loading on the acceleration grids has been successfully reduced to less than 10 % of the total beam acceleration power. As the result, 0.97 MeV, 190 A/m^2 negative ion beam was achieved for 60 s without breakdown, which was comparable to the ITER requirement of 1 MeV, 200 A/m^2. This long pulse beam acceleration with the ITER-relevant beam contributes to assure the 1 MeV accelerator for the ITER NBI.

1st Session / 25, T5_CO_14

Ongoing R&D Towards a New Generation of Neutral Beam Heating Systems for Future Fusion Reactors

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Since the signature of the ITER treaty in 2006, a new research programme targeting the emergence of a new generation of Neutral Beam (NB) systems for future fusion reactors has been underway at CEA, in collaboration with several academic laboratories in France and EPFL (Switzerland). To provide plasma heating and current drive, the NB system specifications are very demanding: a very high level of neutral power (up to 150 MW) and energy (1 MeV), including high wall-plug efficiency ($> 60\%$), high availability and reliability.
To meet these specifications, a novel NB concept based on the photo-detachment of the energetic negative ion beam is under study. The keystone of this new concept is the achievement of a photo-neutralizer where a high power photon flux (˜3 MW) generated within a Fabry Perot cavity will overlap, cross and partially photo-detach a narrow and tall "blade-like" negative ion beam accelerated to high energy (1 MeV). Such photoneutralization based NB system would have the capability to provide several tens of MW of D0 per beam line with a wall-plug efficiency higher than 70%.
The talk will describe the injector concept and the main achievements in 2016; in particular, to provide a blade-like ion beam, a first Helicon plasma jet of 1.8 meter long in hydrogen with a density ne˜5 1017 m-3 has been achieved at EPFL. At the LAC laboratory, a reduced scale photoneutralization experiment has demonstrated 50% photoneutralization in continuous wave regime on a 1.2 keV H^- beam under 10 kW photon power stored in an optical cavity.

2nd Session / 296

Prospect for a Multicharged ECR Ion Source Operated at 60 GHz

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The constant need for higher beam intensity of multiply charged ion beams is a strong motivation to investigate high frequency electron cyclotron resonance ion sources. The use of NbTi superconducting coils to generate the ion source magnetic field was successfully demonstrated up to the 28 GHz ECR frequency in many laboratories. Lanzhou laboratory is developing a 45 GHz ion source requiring the use of Nb3Sn superconducting cable. Attempts to design a superconducting ion source above this frequency appear today unrealistic using the state of the art know how of Nb_3Sn wires. To cope with the present superconducting coil limitations, very high magnetic fields (e.g. up to 36.5 T in a 34 mm bore at LNCMI Grenoble) are today generated using copper coil technology. Such techniques can be adapted to design a very high frequency ECR ion source. A summary of the 60 GHz ECR R&D performed since 2007 at LPSC is proposed. The conceptual design of a 60 GHz ion source magnetic structure using copper coils to generate a radial magnetic field of 4T and superconducting axial coils to generate the axial field with a peak value of 7 T is presented. Such a system can be tested at LNCMI Grenoble using the local water-cooling and power supply infrastructure to study the far future of high intensity, high charge state ECR ion sources applied to future generation accelerators.

2nd Session / 277, T3_CO_08

The Extended EBIS Intensity Upgrade at Brookhaven National Laboratory

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The Extended EBIS will be comprised of two closely coupled RhicEBIS superconducting solenoids to provide a longer ion trap for a 40-50% intensity upgrade. The expected intensity at the Extended EBIS exit is 2.6 x 10^9 Au^{32+}/pulse and approximately 2.1 x 10^9 Au^{32+}/pulse at the Booster ring entrance. The electron optics of the gun and collector regions remains essentially the same. This is a similar approach as the previous upgrade from the TestEBIS prototype to RhicEBIS, in which the ion trap length was doubled using a longer, single solenoid. As part of the upgrade, an efficient gas injection capability will be installed to provide higher intensities of light ions. A gas injection cell will exist in the upstream solenoid with several stages of differential pumping between the adjacent trap region and the downstream solenoid. Expected intensities, based on present performance and the scaled trap length are: H^+ ~1 x10^{12} ions/pulse and $^4He^{2+}$ ~5 x 10^{11} ions/pulse. The design will include provisions for providing beams of polarized $^3He^{2+}$ during a subsequent upgrade.

2nd Session / 270, T3_CO_07

Status Report on Development and Commissioning of New Electron String Ion Source (ESIS) Krion-6T

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The new Krion-6T Electron String Ion Source (ESIS) has been recently developed at JINR as a prototype of the ion source for the Nuclotron-based Ion Collider fAcility(NICA) project [1]. The recent experiments with the Krion-6T ESIS have been done at considerably new physics conditions in continuation of a recent works of our group on basic studies of "electron strings" and its use for highly charged ion beams production [2] . Production of highly charged ion beams of Ar^{16+}, Kr^{26+}...Kr^{30+},
Xe^{30+}...Xe^{41+}, Tm^{26+}...Tm^{51+} and Au^{30+}...Au^{32+} will be discussed in details. Results of first runs of Krion-6T ESIS on JINR synchrotron "Nuclotron" injection complex will be discussed as well. New opportunities to produce intense carbon ion beams C^{4+} and C^{6+} with use of Krion-6T ESIS for cancer therapy accelerators [3] will be considered shortly.

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2nd Session / 262, T3_Mo_71

Commissioning of the AISHA (Advanced Ion Source for Hadrontherapy) Ion Source

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The new AISHa ion source has been designed to generate high brightness multiply charged ion beams for hadrontheraphy applications, with high reliability, easy operations and fast maintenance. In order to get a compact machine the radial confinement is provided by a Halbach-type permanent magnet hexapole structure, while axial confinement is allowed by four high field He^- free superconducting magnets, allowing the optimization of the magnetic field gradient at ECR resonance. The present work shows the results of ion source commissioning along with next developments. Innovative active coupling techniques are planned to be tested to optimize the first pass wave absorption, which play an important role in the coupling optimization of the new generation ECRIS. The new setup will described in details and some additional upgrades will be proposed.

3rd Session / 308

A Review of Chemically Selective Ion Sources for Radioisotope Production at ISOL Facilities

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Radioactive ion beam facilities produce radioisotopes for experiments that range from nuclear structure studies, astrophysics and medicine, to chemistry, biology or materials science. Following production, these exotic isotopes are ionized to enable acceleration into an ion beam for transportation, purification and delivery to experiments. There are some rather specific ion source requirements for radioactive ion beam production. Element selectivity is favoured over universality, efficiency typically dominates the desire to maximise ion currents and the ionization and extraction time should be minimized. Additionally, the emittance must be sufficiently low to facilitate the mass separation of the ion beam constituents and the transportation to experiments of the ions of interest.

To achieve this, multiple ion source types are employed, ranging from resonance ionization laser ion sources (RILIS) [1], to surface ion sources [2,3] and FEBIAD-type [4] arc discharge ion sources. Chemical selectivity can be achieved in FEBIAD and surface ion sources by tailoring component temperatures and/or materials [5,6]. RILIS offers chemical selectivity through ionization via sequential element unique atomic resonances. The laser atom-interaction region however, is typically a surface ion source, which can result in surface ionized isobaric contamination. To counter this, alternative laser atom interaction regions are being developed to offer enhanced chemical selectivity and experimental flexibility, these include repeller-ion guide-extraction systems [7] and coupling RILIS with FEBIAD-type ion sources [8]. The capabilities, applications and development prospects of these ion sources across ISOL-type radioactive ion beam facilities will be reviewed.

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3rd Session / 68

Recent H^- Diagnostics, Plasma Simulations and 2X Scaled Penning Ion Source Developments at the Rutherford Appleton Laboratory

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The Rutherford Appleton Laboratory (RAL) is home to the ISIS Pulsed Spallation Neutron and Muon Facility and the Front End Test Stand (FETS). Both of these operational facilities use a Penning-type surface-plasma negative hydrogen (H^-) ion source. For research and development of the Penning H^- source, a Vessel for Extraction and Source Plasma Analyses (VESPA) has been constructed. The VESPA has demonstrated excellent beam transport of up to 80 mA using a novel elliptical-aperture einzel lens. The einzel lens replaces the legacy sector dipole magnet housed inside a refrigerated box which traps cesium vapor escaping the ion source.

In parallel with the einzel lens measurements, a 2X scaled-up Penning H^- ion source has been developed. This will enable improved performance at duty factors of up to 10%, with the advantage of either higher beam currents or longer lifetime due to the reduced plasma power load on cathode surfaces.

The long-term viability of the einzel lens and 2X source is now being evaluated, so new diagnostics devices have been installed. First, a pair of electrostatic deflector plates is used to correct beam misalignment and perform fast chopping, with a rise time of 24 ns. Next, a suite of four quartz crystal microbalances (QCMs) has shown that the cesium flux in the vacuum vessel is only increased by a factor of two, despite the absence of a dedicated cold trap. Finally, an infrared camera has demonstrated good agreement with thermal simulations, but has indicated unexpected heating due to beam-loss on the downstream electrode. These types of diagnostics are suitable for monitoring all operational ion sources; as such long-term behavior will be discussed.

As well as experimental campaigns and new diagnostics tools, the high-performance VSIM software package from Tech-X has been purchased recently, as well as the COMSOL multiphysics software. These will facilitate sophisticated collisional particle-in-cell (PIC) simulations of the ion source plasma, including cesium dynamics. As a first step, VSIM and COMSOL are being used for plasma simulations of two novel ion thrusters for space propulsion applications. Preliminary results will be outlined.

3rd Session / 174, T4_CO_12

Experimental Benchmark of the EM-PIC-MCC Code NINJA and its Application for Simulating the Linac4 H^- Ion Source Plasma

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A dedicated performance optimization of negative hydrogen ion sources applied at particle accelerators is only possible by assessing the processes occurring in the plasma. However, due to the typically very compact source design, diagnostic access is very difficult and often limited to optical emission spectroscopy yielding only line-of-sight integrated results. In order to gain spatially resolved plasma parameters and therefore a detailed insight into the plasma characteristics, the electromagnetic Particle-In-Cell Mote Carlo collision (EM-PIC-MCC) code NINJA has been developed for the Linac4 H^- ion source at CERN. The code considers the RF field generated by the ICP coil and the present external static magnetic fields and calculates self-consistently the resulting discharge properties. A benchmark of the NINJA code has been carried out at the diagnostically well accessible lab experiment CHARLIE for a variation of RF power and gas pressure. This allows for a detailed comparison between simulation and experiment where a good agreement is observed in general although some slight deviations are present. They can be explained by the assumption of strong inductive coupling in the simulation, whereas loose coupling would be more appropriate for the CHARLIE discharges. Nevertheless, the Linac4 ion source plasma is strongly coupled and accordingly, the plasma parameters evaluated from optical emission spectroscopy agree very well with the NINJA simulations. The contribution covers a detailed presentation and discussion of the benchmark investigations at the CHARLIE experiment including spatial distributions of electron temperature and density as well as line-of-sight integrated plasma parameters obtained from optical emission spectroscopy. For the Linac4 ion source, the comparison of measurement and NINJA simulation will be shown for a variation of the RF power. In addition, a first assessment of the discharge properties with respect to negative ion production and destruction rates and hence to the ion source performance will be carried out.

3rd Session / 227, T4_CO_13

Status of the New SNS Injector and External Antenna Ion Source

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The U.S. Spallation Neutron Source (SNS) now operates with 1.2 MW of beam power on target with the near-term goal of delivering 1.4 MW and a longer-term goal of delivering > 2 MW required by the planned Proton Power Upgrade (PPU) and Second Target Station (STS) projects. In early of 2018 we plan to replace the entire 2.5 MeV injector configuration which includes the ion source, Low Energy Beam Transport (LEBT) and Radio Frequency Quadrupole (RFQ) accelerator with one which is currently being tested on a research accelerator called the Beam Test Facility (BTF) located in an SNS facility. This report first provides a physical description of the new injector components, external antenna ion source (latest configuration), LEBT assembly and new RFQ. Since fall of 2016, this system has been tested extensively with regard to output beam current, persistence, emittance and energy. The results of these experiments will be presented here showing the system to be capable of supporting baseline SNS 1.4 MW operations with significant margin as well as meeting facility upgrade requirements. This represents a significant performance upgrade over the current SNS front end system.

3rd Session / 50, T4_CO_11

Conditions to Minimize Co-Extracted Electron Current and Beam Quality in J-PARC Cesiated RF-Driven H Ion Source 66 mA Operation

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The beam brightness of the J-PARC (Japan Proton Accelerator Research Complex) cesiated rf-driven H ion source has been increased by using several unique measures, including low plasma electrode temperature, slight water feeding in hydrogen plasma and so on [1-3]. The J-PARC source enables high energy linear accelerators to eject a beam with 60 mA peak intensity. The conditions to minimize the co-extracted electron current lower than the H ion current of 66 mA and the beam qualities attained with the conditions are presented in this paper. The low co-extracted electron current will be necessary for a higher beam duty factor operation.

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Poster Session 1 / 294, T3_Mo_73

Simulation of an ECR Argon Plasma

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Argon plasma behavior in a 2.45 GHz electron cyclotron resonance (ECR) plasma reactor is studied by means of a finite element software "COMSOL". Using a multi-physics approach, we have simulated the magnetic field distribution, the microwave power deposition and the plasma properties such as potential, density, temperature etc. We report some results on investigation of the effects of various control parameters such as magnetic field configuration, microwave power and gas pressure on the Argon ion density distribution as an important character in ECR plasma ion sources.

Poster Session 1 / 280, T2_Mo_41

The LIPSION Upgrade: High Quality Ion Nano-Beams

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The high-energy ion nanoprobe LIPSION* of the Universität Leipzig consists of a 3 MV singletron accelerator in combination with an ion nanoprobe which presently focusses protons and helium ions to diameters in the sub-100 nm range.

The currently used RF ion source in the accelerator dominantly produces single-charged ions of a mass range of hydrogen up to xenon. Their ionic charge state 1 (at most 2) determines the maximum of the achievable kinetic energy in combination with the 3 MV platform potential of the singletron. Furthermore, the life-time of the ion source is limited to approx. 600 h (as indicated by the manufacturer). In consideration of this fact the use of a durable ion source producing projectiles with multiple charge states for significantly higher kinetic energies (scales linearly with the charge state) would be of significant advantage. An Electron Cyclotron Resonance Ion Source (ECRIS) with almost maintenance-free operation suites these requirements and is much better adapted to the conditions in the LIPSION system providing sufficiently high currents of ions with low up to medium charge states (e.g. Ar^{8+}) to compensate for beam losses by ion transport and focusing. The ECRIS allows to provide a wide range of ionic species and charge states. A downstream particle separator based on the principle of a Wien filter purifies the particle beam before it enters the accelerator beamline with accelerator voltages of 200 kV up to 3 MV.

The aim of the described upgrade is to have a new device available producing surface defects by means of ion beams and to functionalize the resulting effects as well as to have the potential for mask-free ion implantation with focussed ion beams. The refractive power depends on the charge state in quadratic way. Thus the new ion source allows focusing heavy ions. Thus, the upgrade of the existing facility leads to a substantial increase in the performance of LIPSION, in particular for materials science. In this facility, ions with higher charge states and kinetic energy can then be placed on a few nanometers with an also upgraded mask-free patterning system.

*LIPSION from Latin: LIPSia, the Italian name of the city Leipzig and ION

Poster Session 1 / 275, T1_Mo_18

Status and Perspectives of INFN Simulation Tools: from Beam-Plasma Interaction to a Self-Consistent Plasma-Target Modelling

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Since 2012, the INFN ion source group has been undertaking an intense activity on numerical modelling, started in a European context with the EMILIE Project, and presently continuing in the framework of the PANDORA project. The work mainly concerns the study of two aspects: on one hand, the interaction of an ion beam with a magnetized plasma, a topic of interest in the field of ECR-based charge breeding of radioactive ion beams, as well as Astrophysics and inertial confinement fusion. On the other hand, the energy coupling to plasma electrons by the microwave field set-up inside the plasma chamber and their consequent dynamics, under the influence of both magnetostatic and electromagnetic fields. Equations describing the particular physics case are implemented through the Langevin formalism in a Matlab environment, including a self-consistent 3D plasma modelling obtained by the interaction between COMSOL Multiphysics and Matlab. This contribution describes the state-of-the-art of the work on both fronts: it will show an overview of the beam-plasma interaction, showing the latest results about the ECR-plasma density fine structure, as well as electron spatial temperature distribution.

Poster Session 1 / 271, T1_Mo_17

Towards Better Modelling of Surface Emission in Caesiated Materials

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Models for surface interactions and emission in ion sources may be based on surface measurements taken with quite different nearby field strengths, particle spectra, charge densities, and connected to power supplies with different VI characteristics, or even different material composition to those in the device being simulated. Particularly, standard models available in many codes do not take into account the presence of Caesium, which is widely used to boost current in H^- sources. We may only expect any description of a plasma to be as good as the models of the most important sources and sinks in the plasma. This paper describes some approaches towards improving models of the surface interaction in the hybrid PIC/fluid code VSim[1] for the case of caesiated penning sources.

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Poster Session 1 / 187, T2_Mo_39

Status of a new 28 GHz CW gasdynamic ECR ion source development at IAP RAS

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A new type of ECR ion sources – a gasdynamic ECR ion source was invented recently at the Institute of Applied Physics (IAP RAS, Nizhniy Novgorod, Russia). The main advantages of such devices are extremely high ion beam current with a current density up to 600 − 700 mA/cm^2 in combination with low emittance i.e. normalized RMS emittance below 0.1 • mm • mrad. The main part of previous experiments were carried out in a pulsed operation mode. Preliminary studies of plasma parameters were performed using a CW source with 24 GHz/5 kW gyrotron heating. Obtained experimental results have demonstrated that all gasdynamic source advantages could be realized in CW operation. To continue development of a CW gasdynamic ion source a new experimental facility is under construction at the IAP RAS. Future source will utilize 28 GHz/10 kW gyrotron radiation for plasma heating. A fully permanent magnet system with magnetic field configuration close to simple mirror trap will be used for plasma confinement. Microwave radiation will be delivered from the gyrotron to a plasma chamber through a quasi-optical line equipped with 100 kV DC-break. Up to 100 kV extraction will be used for intense beams formation. Status of the new source development will be presented.

Poster Session 1 / 238, T1_Mo_14

Ar/O_2 Plasma Treatment of Cotton Fabric via Atmospheric Pressure Plasma Jet

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An atmospheric pressure plasma jet (APPJ) system was utilized to synthesize and deposit silver nanoparticles into pure cotton fabrics to test the efficiency of the novel APPJ setup for surface treatment and coating. The novel APPJ setup works by applying sufficient voltage to two silver metal electrodes separated by a certain distance for voltage breakdown to occur obeying Paschen's Law which states that breakdown voltage is a function of gas pressure and electrode distance. In the APPJ system used in this study, 15 kV was applied to two concentric silver electrodes enclosed in a glass tube while Argon and Oxygen were introduced at fixed flow rates of 15 LPM and 5 LPM, respectively. Optical Emission Spectroscopy (OES) results indicated the presence of neutral and ionized Argon, Oxygen and Silver. Using the OES results, the calculated electron temperature was 0.51 eV (5,915.3 Kelvin) which satisfied the condition of a cold plasma (electron temperature should be much greater than gas temperature of the system) suitable for materials processing. Cotton fabrics were treated at varying exposure times of 1 min, 3 minutes and 5 minutes. Scanning Electron Microscope images, supplemented by qualitative elemental analysis using a Wavelength Dispersive X-Ray Fluorescence Spectroscopy, showed silver particle coating of the fibers because of plasma sputtering. Surface reaction of cotton was also assessed using a Fourier Transform Infrared Spectroscopy-Attenuated Total Reflectance. As further application of this study, the plasma-treated and untreated (not exposed to plasma) cotton fabrics were tested for antibacterial activity. Plasma-treated cotton fabrics displayed antibacterial activity while untreated cotton exhibited no antibacterial activity at all.

Poster Session 1 / 195, T3_Mo_63

A Study on the Dielectric Design of High Voltage Platform for Developing 28 GHz ECRIS at KBSI

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Currently, the 28 GHz electron cyclotron resonance ion source (ECRIS) has been developed to produce a high current heavy ion at korea basic science institute (KBSI). The high voltage platform of 28 GHz ECRIS is essential to deliver an ion beam to the next acceleration stage. In order to ensure the electrical safety, the high voltage platform has been designed considering dielectric characteristics. In this paper, a study on the dielectric characteristics of glass fiber reinforced plastic (GFRP) is performed to determine the thickness of GFRP tube located between plasma chamber and inner bore of cryostat. The dielectric experiments on GFRP tube are conducted under DC voltage. Sphere-to-plane electrode systems are used to examine the dielectric characteristics. Also, the relationship between the dielectric characteristics of GFRP tube and the distribution of electric field intensity is calculated and analyzed by the finite elements method (FEM).

Poster Session 1 / 194, T1_Mo_12

Enhanced Production of Electron Cyclotron Resonance Plasma by Positioning Plate-Tuner

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It has been investigated how to produce various ions efficiently on the electron cyclotron resonance ion source (ECRIS) in Osaka Univ. We attach the movable reflector, like bias plate, called plate-tuner, which is inserted from the mirror end plate opposite side to the extractor in the ECRIS. Standing waves are generated by placing the plate-tuner at nodes of the microwave and the microwave can efficiently be propagated in the vacuum chamber. As a result, the net microwave power absorbed by plasma changes by moving the position of the plate-tuner, and it is suggested that the plate-tuner contributes to enhance ion beam intensity. The effect of the plate-tuner will be investigated experimentally to measure plasma parameters by Langmuir probe, and also to measure beam intensity and charge state distribution (CSD) of extracted ion beams. Now we are trying to produce Ar, Xe, and fullerene plasmas for the support gases. We obtained the result that the net microwave power and the ion saturation current periodically by moving the plate-tuner. In near future, moreover, we are planning to improve methods of launching microwave as well as the plate-tuner for production of various ion beams, e.g. multicharged ions and heavy molecular ions, like fullerene.

Poster Session 1 / 5, T4_Mo_74

Negative Ion Radio Frequency Surface Plasma Source with Solenoidal Magnetic Field

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Pulsed and CW operation of negative ion radio frequency surface plasma source (RF SPS) with a solenoidal magnetic field and external solenoidal and saddle type antennas are described. Dependence's of a beam current and extracted current on RF power, extraction voltage, solenoid and filter magnetic field, gas flow are presented. Compact design of RF SPS is presented.

Acknowledgement

The work was supported in part by US DOE Contract DE-AC05-00OR22725 and by STTR grant, DE-SC0011323.

Poster Session 1 / 149, T3_Mo_54

Studying the Double-Frequency Heating Mode in ECRIS Plasma Using K Diagnostics

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Heating the plasma of an Electron Cyclotron Resonance Ion Source (ECRIS) simultaneously with two microwave power sources operating at different frequencies has been proven to enhance the high charge state production in comparison to conventional single frequency heating. Despite the success of this technique, the underlying physics remains not well understood. A commonly applied scheme used for double-frequency heating is to heat the ECRIS plasma with a fixed frequency using a klystron or gyrotron and a variable heating frequency using a broadband microwave amplifier such as a traveling wave tube amplifier (TWTA). The described scheme allows to adjust the secondary microwave frequency thereby offering another parameter for the optimization of the ECRIS performance. High charge state production is closely linked to the inner shell ionization rate of an ion species, which in turn can be probed experimentally by measuring the volumetric K emission rate, thus enabling an indirect view into high change state production. Using K diagnostics of argon, the influence of the secondary heating frequency on the volumetric K emission rate was investigated as a function of the microwave frequency and power balance between the primary and secondary frequencies with the JYFL 14 GHz ECRIS. In addition to this, the influence of the microwave power and magnetic field on the K emission rate and high charge state argon production were also probed. Different mechanisms proposed to explain the beneficial effect of two frequency heating will be discussed and assessed against the collected data.

Poster Session 1 / 154, T3_Mo_55

Plasma Response to Amplitude and Frequency Modulation of the Microwave Power on a 14 GHz Electron Cyclotron Resonance Ion Source

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This paper reports on experiments to study the effects of sinusoidal microwave power Amplitude Modulation (AM) on the performance of Electron Cyclotron Resonance (ECR) ion sources. The study was motivated by an inherent property of high frequency power sources such as gyrotrons, which exhibit amplitude modulation of the microwave power due to the use of high frequency switching power supplies to generate the required high voltage for these devices. Intentionally perturbing the plasma with AM helps us understand where the most stable operating parameters may be found. Additionally, the well-defined cutoffs observed in beam current and bremsstrahlung signal could possibly be used to better understand the microwave heating process and ion lifetimes in the plasma. The study was conducted on the 14 GHz ECR ion source ECR2 at the University of Jyväskylä. The klystron output was intentionally perturbed by a variable frequency sinusoidal amplitude modulation. The average microwave power was 350 W modulated between 530 W and 180 W from 0.011-25 kHz. In particular, the energy integrated x-ray signal responded linearly with microwave power and the modulation was no longer observable at approximately 1.7 kHz where the signal became solely dependent on the time averaged power. Similarly, the beam current from the ECR ion source responded more strongly to low frequency modulation, but the beam current did not preserve the sinusoidal waveform as well as the x-ray signal. The highest observable AM frequency was typically around 16 kHz but could decrease by 40%. The high charge states were observed to be more impacted by the amplitude modulation and were more linear with AM than lower charge states with respect to the charge state distribution peak. The solenoidal magnetic field was found to play an important role in defining the cutoff frequency about a minimum value. Qualitatively, we found this minimum to correspond to the field often used for beam injection into the K130 cyclotron. We will present how beam current and the x-ray signal depend on AM frequency for different magnetic fields. A qualitative interpretation of the results will be given.

Poster Session 1 / 157, T3_Mo_56

Study of the Micro Oven for the Linac3 ECR Ion Source at CERN

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The GTS-LHC ECR ion source at CERN provides heavy ion beams for the chain of the accelerators from Linac3 up to the LHC. For the lead runs the solid material is evaporated in internal ovens. The processes within these ovens are not well understood and experiences during the operation suggest there is room for improvement regarding the beam stability and the time between necessary refills.

A dedicated study of the oven at a test stand and with thermal simulations will help to understand the link between the operational parameters and the performance of the oven to provide the basis for a potential oven redesign.
The test stand replicates partially the source environment and allows thermal as well as evaporation rate measurements. This contribution presents the latest results of the study.

Poster Session 1 / 159, T1_Mo_10

Radial and Azimuthal Dependence of Plasma Parameters in a Hexapole-Trapped ECR Discharge

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Compact ECR plasma device was built in the Atomki ECR Laboratory called ECR Table Plasma Generator (TPG). It consists of a large plasma chamber (ID=10 cm, L=40 cm) and of a thin NdFeB hexapole magnet with vacuum and gas dosing systems. For microwave coupling low power TWTA is applied, operating in the 6-18 GHz frequency range. There is no axial magnetic trapping and there is no ion extraction. The relatively big plasma chamber makes it an ideal device to install Langmuir-probes into it easily while the plasma is still observable with eyes or cameras.
Four cylindrical Langmuir-probes parallel to the plasma chamber axis are installed to the rotatable endplate of the TPG's plasma chamber. This experimental setup allows to measure the azimuthal and radial dependence of several plasma parameters at fix axial position. Plasma parameters like floating potential, plasma potential, electron temperature, electron density, electron energy distribution function, effective temperature are calculated from the voltage-current characteristic of the probes. The effect of TPG settings (microwave power, gas pressure) to the plasma parameters is investigated.
Details of the experimental setup, data acquisition system, data evaluation and the plasma parameter dependences will be presented.

Poster Session 1 / 6, T4_Mo_75

Efficient Method for Cold Muonium Negative Ion Production

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Charged muons as Muonium negative ions (consisting of positive Mu ¬ meson and 2 electrons) have affinity S=0.75 eV. Muonium have ionization energy I=13.6 eV. Muonium negative ions were observed in 1987 [1], [2] by interaction of muons with a foil. In this work an efficiency of transformation of Mu mesons to negative muonium ions were very low 10-4. However, with using tungsten or palladium single crystal with deposition cesium it can be improved up to 40-50%.

A new, efficient method to produce cold negative muon ions is proposed, where surface muons are focused onto a tungsten or palladium single crystal foil (with a possibility to heat up to 2000° C) and partially covered by a cesium layer up to minimal work function. The negative muon ions can be extracted by a DC electric field and further accelerated by a linac and stripped in a thin foil.

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Poster Session 1 / 7, T2_Mo_19

RF Positive Ion Source with Solenoidal Magnetic Field

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A positive ion source with RF discharge in solenoidal magnetic field is described. In this paper we present an overview of the positive ions production in saddle antenna (helicon discharge) radio frequency (SA RF) ion sources. An efficiency of H+ ion production in recently developed RF sources with solenoidal antennas was improved to 1.5-2 mA/kW. About 60 kW of RF power is typically needed for 50 mA beam current production from a 7 mm emission aperture. This efficiency is relative low because in the RF discharge with solenoidal antenna, the plasma is generated near the coil and diffuses to the axis creating a nearly uniform plasma density distribution in all cross sections of the discharge chamber, when the plasma flow is necessary only near an emission aperture. The efficiency of the extracted ion generation was improved significantly with using of the saddle antenna. In the RF discharge with the saddle antenna the plasma is generated near the axis and the magnetic field suppresses the plasma diffusion from the axis, creating a peaked plasma density distribution on the emission aperture. With the SA the efficiency of positive ion generation in the plasma has been improved up to 200 mA/cm2 per kW of RF power at 13.56 MHz. Continuous wave (CW) operation of the RF source has been tested on the small test stand. The general design of the CW RF source is based on the pulsed version. Compact design of ion source is presented. Some modifications were made to improve the cooling and simplifying design. Features of SA RF discharges and ions generation will be discussed.

Acknowledgement

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Poster Session 1 / 8, T1_Mo_01

The Formation of Metal Plasma in Duhocamis

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The dual hollow cathode ion source for metal ion beams (Duhocamis) was introduced in 2007. The Duhocamis is derived from the indirectly-heated cathode GSI-PIG ion source and more suitable for producing various metal ion beams. To understand the discharge characteristics of Duhocamis, a series of arc discharge experiments have been performed on the test bench at Peking University. The transfer process from PIG discharge to dual hollow cathode discharge (DHCD) mode in the source was observed, and the metal ion ratio more than 90% for DHCD was measured. Based on the experimental results, the formation process of metal plasma was emphasized and discussed.

Poster Session 1 / 9, T4_Mo_76

Negative Ion Source Operation with Deuterium

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The difference in negative ion source performance between hydrogen and deuterium is investigated for three types of negative ion source design: charge exchange, surface and volume sources. The early results obtained at Ecole Polytechnique (France) with volume sources operated with and without Cs are reviewed to compare the characteristics of the source charged with deuterium to those of the source charged with hydrogen. Fundamental processes causing the observed difference in negative ion density and the beam current density are discussed.

Poster Session 1 / 10, T4_Mo_77

Carbon Film in Radio Frequency Surface Plasma Sources with Cesiation

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It is very likely that a long lifetime of cesiation in SNS RF surface plasma sources (SPS) can be connected with deposition into the emitter/converter cone and to the discharge chamber some specific carbon films.
The work function dependence for graphite with alkali deposition has no minimum typical for metals and semiconductors and a final work function is higher. By this reason the probability of H- secondary emission from cesiated metal and semiconductors can be higher than from cesiated carbon films but lest can better keep the cesiation and can operate with low cesium consumption.
It is known that a two-dimensional graphite films and films of pyrolitic graphite can adsorb and trap alkali atoms with very high probability (sticking coefficient ~1) up to very high temperature and can be desorbed by heating up to high temperature, much higher than for evaporation from a metal surface. A dynamic of carbon film formation and alkali atoms trapping is well investigated in high vacuum conditions but in SPS these processes are complicated by high gas density and by gas discharge plasma. Investigation of these processes in condition of real SPS can be important to improve the SPS performances.

Poster Session 1 / 12, T1_Mo_02

Towards Kinetic Models of Electron Transport in Negative Ion Source

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The extraction of negative ions from a plasma is necessarily accompanied by electrons, which are controlled with a transverse magnetic field. A full numerical analysis of the 3D model is hindered by the computational load and by the rapidly growing electric field towards extraction, so that we pass from quasi-neutral plasma with collisional transport to collision-less sheath to beam region.
It must be noted that ray-tracing approach can only be used in collision-less region.
Theoretical model (mostly 1D in space) can clarify the transition from collisional regime to other regions; preliminary results of simplified collision models, here discussed, show that electrons surf sideways the sheath, with a large angle (depending on collision models), with large divergence of the related transport integrals in the case of Coulomb collision. Model self consistency is also discussed. Some recommendations for numerical ray tracing methods are given.

Poster Session 1 / 24, T3_Mo_42

Conceptual Design of a Quench Protection System for a MARS Magnet

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MARS (Mixed Axial and Radial field System) is a new superconducting magnet underdevelopment with a novel coil layout for more efficiently generating high strength minimum-B fields for the next generation of Electron Cyclotron Resonance (ECR) ion source. It consists of a hexagonal closed-loop-coil and a set of auxiliary solenoids. A new quench protection system is needed for a MARS magnet to be built with NbTi conductor cooled through thermal conductions. Using the Vector Fields' 3-D QUENCH program, different scenarios were computed to investigate the key parameters in the cases with and without energy-extraction during quenches. The analyses have resulted in the design of a quench protection system for a MARS NbTi magnet with good safety margins at maximum quench voltage of ˜ 400 V and hot-spot temperature of ˜ 80 K.

Poster Session 1 / 28, T1_Mo_03

Emission Spectroscopy Diagnostics of Quartz-chamber 2.45 GHz ECR Ion Source at Peking University

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A quartz-chamber 2.45 GHz ECR ion source was designed for diagnostic purpose at Peking University [Patent Number: ZL 201110026605.4]. It can produce a maximum of 84 mA hydrogen ion beam working at pulsed mode and the root-mean-square (RMS) emittance of this proton beam is smaller than 0.2 mm mrad. In our primary work, electron temperature and electron density inside the plasma chamber have been measured with the method of line intensity ratio of noble gas. Based on these results, atomic and molecular emission spectroscopy of hydrogen are applied for the determination of hydrogen degree of dissociation and vibrational temperature in the ground state, respectively. Measurements are made at gas pressure range from 4×10^{-4} to 3×10^{-3} Pa and input RF power (peak) range from 1000 to 1800 W. Hydrogen degree of dissociation in the range of 1%-25% and vibrational temperature in the ground state in the range of 3500 K-8500 K were measured. Moreover, plasma processes inside the chamber are discussed based on these results. Details will be presented in this paper.

Poster Session 1 / 29, T3_Mo_43

Preliminary Design of a Hybrid Ion Source for 7Li^{3+} Generation

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The p(7Li,n)7Be reaction can be used to produce forward neutron beam based on the principle of inverse kinematics, which is useful to reduce the background of the measurement of prompt fission -ray emission from fast neutron induced fission of ^{235}U and 238U. A hybrid 7Li3$^+$ ion source is going to be adopted to produce 10 eA beam for this experiment. Previously a high B field 2.45 GHz ECR (Electron Cyclotron Resonance) ion source has been built at Peking University (PKU). Oxygen gas was used in the preliminary experiment. About 273 eA O3$^+$ and 446 eA O2$^+$ were produced with the high B source. This indicates the feasibility of producing high charge state ions with lower frequency and high B field. Recently, a tandem-type hybrid ion source with the combination of a 2.45 GHz ECR ion source and a hot surface ionization source was proposed for Li3$^+$ ion generation. An oven will be used to produce lithium vapor and the surface ionization source converts the lithium atoms into Li$^+$ ions. Then Li$^+$ will be striped into Li3$^+$ in ECR region. The configuration of magnetic field is min-B and the radial magnets are designed in a novel fixing structure, which effectively protect the radial magnets from heating. Details will be presented in the paper.

Poster Session 1 / 31, T4_Mo_79

Extraction of Many H^- Beamlets from Uncesiated Ion Source NIO1

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The installation of molybdenum liners in the ion source NIO1 (Negative Ion Optimization phase 1) has proven to be successful in order to largely decrease the contamination of rf window by wall sputtering; intense hydrogen plasma are thus achievable even at moderate rf power (1200 W) in a continuous regime operation (much longer than one hour), which enabled prolongated campaign at several plasma conditions; operation down to 0.5 Pa is possible, while best beam conditions were observed among 1 and 2 Pa, which is satisfying considering that NIO1 was never cesiated up to now. This has motivated a delay in the installation of the existing Cs oven, to investigate the following items: best combination of plasma grid (PG) and bias plate (BP) voltages (usually separately controllable in NIO1) in order to reduce the coextracted electrode current I_e; effect of magnetic filter; improved extraction grid EG with ion deflection compensation; correlation of EG magnetic field and discharges in the extraction gap: achieved acceleration voltage for H^- is indeed 12 kV up to now, at the relatively high pressure there (>0.2 Pa) due to the limited pumping installed.
Database of results with H is compared to previous results with Oxygen (and Oxygen/Argon mixtures), where a much larger coextracted electron current I_e was measured as expected, and ion beam current was thus limited below 3 mA. On the contrary for H, the limited rf power used resulted in a low extracted current (6 mA), consistently with the stated limitation in voltage.
Maintenance experience, concerning gasket erosion and ceramic surface alteration is discussed; the thin insulators among BP and PG and other walls show plasma related embrittlement, and are being rebuilt in a more compact BN grade.
Performance of some installed beam diagnostic (side view luminosity, Doppler-shifted emission, and carbon plate calorimetry) is critically reviewed, especially for effectiveness of beam imaging, as also compared to other beam diagnostics. As to the former method, in vertical side view projection, three columns of beamlets clearly show, while the horizontal projection is somewhat blurred by ion deflection up to now. Finally steady progress of acquisition software is noted. Related advancement of simulation tools is summarized.

Poster Session 1 / 32, T3_Mo_44

MEDeGUN Commissioning Results

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MEDeGUN [1] is an electron gun to be used in an Electron Beam Ion Source (EBIS) designed to serve as C^{6+} injector for LINAC-based 2nd generation hadron therapy facilities [2]. The latter require short pulses of at least 8 x 10^8 particles with a repetition rate of 400 Hz, which exceeds the possibilities of currently used electron cyclotron resonance ion sources (ECRIS) and EBISes.

The design of MEDeGUN is based on a combination of electrostatic and magnetic compression, which is commonly referred to as Brillouin gun. As previous devices have shown, it is very difficult to achieve the design goals in this configuration due to the high sensitivity of the electron beam to any field imperfection. Therefore the number of interfaces between the cathode, Wehnelt and anode electrodes has been limited to only two and their machining tolerances of 20 Microns have been kept during manufacturing.

In spring 2017 the MEDeGUN assembly was installed in the TWINEBIS test bench at CERN [3]. We have since then propagated the first electron beam. We will here present the commissioning results and discuss them with respect to the design goals and the possible application in the medical sector.

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Poster Session 1 / 38, T4_Mo_80

Numerical Simulation of Electromagnetic Fields and Impedance of an RF-based Negative Ion Source at HUST

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Huazhong University of Science and Technology (HUST) is developing an RF based negative ion source. Numerical simulation of the 1 MHz RF driver has been performed using a commercial high frequency FEM software. Differing from conventional inductively coupled plasma (ICP) source simulations, which exclude the effect of Faraday Screen (FS) and simplify the multi-turn helix RF antennas as independent parallel single coils, our simulation employs a complete 3D Computer Aided Design model for reproducing the realistic electromagnetic fields. Simulations with and without considering the FS have been compared. It is found that the FS suppresses effectively the axial electric field established by the turn-turn coil potential differences, furthermore, avoids the capacitive coupling between the antenna and the plasma. The simulations without and with plasma have both been performed with approximating the plasma as a homogenous electrically conducting medium. The electric and magnetic fields, RF power losses and equivalent impedance of the driver before and after the plasma ignition with different bulk conductivity are calculated. To verify the simulation validity, cold testing experiments of the driver impedance have been carried out using a network analyzer. The plasma with different conductivity is skillfully reproduced by potassium hydroxide (KOH) liquor with different density. The experimental results agree well with the simulation results.

Poster Session 1 / 43, T4_Mo_81

Contribution of Atomic Hydrogen Flux on H^- Ion Beam extracted from a Negative Hydrogen Ion Source

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Contemporary negative hydrogen (H^-) ion sources are operated with Cs ovens, and some part of the H^- ion current extracted from the source is believed produced at the surface of the biased plasma electrode. The principle mechanism of the H^- ion current production can be due to the reflection of atomic hydrogen, but this hypothesis has not been directly confirmed in the actual ion source operating condition yet. An atomic hydrogen source is attached to a multicusp type H^- ion source to see the effect upon the extracted negative ion current. The atomic beam source produces hydrogen beams of low temperature atoms by inductively exciting a plasma in a dielectric capillary tube.The source plasma parameters are measured with a Langmuir probe, and several laser based diagnostic methods. The information on Cs coverage is integrated to distinguish the role of plasma surface interaction on H^- production from the source.

Poster Session 1 / 45, T2_Mo_20

The Influence of Magnetic Field on the Ion Beam Current and Beam Oscillation of Calutron Ion Source

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Electromagnetic isotope separator is the important machine for isotope enriching of which ion source is the critical part. In China, the only one yielding-type electromagnetic isotope separator, named EMIS-170, locates in China Institute of Atomic Energy. It has been playing important role in providing highly enriched stable isotopes for many applications domestically, and the ion source used is the Calutron ion source. This paper investigates the dependence of ion beam current and beam oscillation of the Calutron ion source on the magnetic field in the EMIS-170 experimentally. It is observed that the beam current has a nonlinear relationship with the magnetic field. It significantly increases from 15 mA to 29mA with the increase of the magnetic field at the range of 170 G˜620 G and decreases slowly to 26.7 mA when the magnetic field increases to 950 G. This phenomenon is analyzed qualitatively from the view of the primary electron motions along the magnetic field and the ion diffusion across the magnetic field. It is found that the model could predict the relationship between magnetic field and ion beam. The fluctuation of the beam current is observed trivial at 340˜390 G with frequencies of about 20 kHz and 400 kHz and almost disappears at 620 G˜730 G. As the magnetic strength is larger than 730 G, the fluctuation becomes quite obvious with frequencies of about 40 kHz and 250 kHz.

Poster Session 1 / 46, T3_Mo_45

The Hybrid Electromagnetic Simulation of Ionization Characteristics in ECR Ion Source

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ECR ion source is considered to be the most efficient facility for generating highly charged ions beams, because of its board ion variety, high charge-state and beam stability, repeat-ability, etc. Compared with the intensive experiments, the study on theories and simulations of ECR ion source is more rare and immature due to its complicated physical phenomena and the huge computational cost. In this paper, an improved MAGY/PIC/MCC (MPM) model has been present for modeling ECR ion source, which can give the detailed description of ionization process in ECR discharge and save the usual computational cost by using PIC/MCC method at the same time. MPM is an hybrid electromagnetic simulation model, which includes a time-dependent description of the electromagnetic fields and a self-consistent analysis of the charged particles with collision effects. A method of the waveguide modal representation proposed by MAGY is used in the calculation of the electromagnetic fields. As the full solution of Maxwell's equations is reduced to a relatively small number of coupled partial differential equations for the amplitudes of the modes, there is a significant saving of computation time. As for the motion part, we take advantage of the PIC method in collective motions and the MCC method in collision motions. In the PIC simulation part, relativistic equations of motion are solved by the explicit leapfrog scheme using Boris's method. In the MCC simulation part, the elastic, excitation, ionizing electron-neutral collisions and the elastic, charge exchange ion-neutral collisions are taken into account. So far, we have built a self-consistent description of the interaction between the charged particles and the electromagnetic field, which has passed the numerical validation by using the commercial PIC software MAGIC. In addition, a whole time-domain simulation flow including ionization process has been established, and the generation of highly charged ion with considering the magnetic confinement, ECR heating and highly charged ionization has been studied in detail.

Poster Session 1 / 56, T2_Mo_21

Commissioning Results of the Multicusp Ion Source at MIT (MIST-1) for H_2^+

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IsoDAR is an experiment under development to search for sterile neutrinos using the isotope Decay-At-Rest (DAR) production mechanism, where protons impinging on ^{9}Be create neutrons which capture on ^{7}Li which then beta-decays producing $\bar{\nu}_e$. As this will be an isotropic source of $\bar{\nu}_e$, the primary driver current must be large (10 mA cw) for IsoDAR to have sufficient statistics to be conclusive within 5 years of running. H_2^+ was chosen as primary ion to overcome some of the space-charge limitations during low energy beam transport and injection into a compact cyclotron, to be stripped into protons before the target. At MIT, a multicusp ion source (MIST-1) was designed and built to produce a high intensity beam with a high H_2^+ fraction. I will present the latest commissioning results of MIST-1.

Poster Session 1 / 60, T3_Mo_46

Development of a New Compact ECR Ion Source with all Permanent Magnets for Carbon 5^+ Production

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A compact accelerator for high energy carbon-ion radiotherapy (C-ion RT) has been studied in Heavy Ion Medical Accelerator in Chiba (HIMAC) at National Institute of Radiological Sciences (NIRS) since 2004. Compact accelerator for Gunma University (Gunma University heavy ion medical center: GHMC), Saga C-ion RT facility (Saga Heavy Ion Medical Accelerator in Tosu: SAGA HIMAT) and Kanagawa C-ion RT facility (Ion-beam Radiation Oncology Center in Kanagawa: i-ROCK) has been operated for medical use. The Electron Cyclotron Resonance Ion Source (ECRIS) with all permanent magnets (Kei series) are used at these C-ion RT facilities. The Kei series has a magnetic field structure optimized for production of $C4^+$ ions.

It is possible to reduce operation costs by using ion sources that can supply sufficient $C5^+$ ions. Therefore, we design a new compact ECRIS with all permanent magnets to produce $C5^+$ ions. At first, we aimed to determine an optimum mirror magnetic field for production of sufficient $C5^+$ ions by using NIRS-HEC ion source, because magnetic field is the most important specification in order to develop a desirable ECRIS.

Experiments were performed to measure beam currents of $C5^+$ ions with various mirror magnetic field, microwave power and frequency. As a results, we confirmed that the beam currents of $C5^+$ ions were achieved to more than 0.3 mA with coil currents of electromagnets optimized. The magnetic field distribution was calculated from value of the coil currents with poisson/superfish. We will describe the details of the experiments and the design of the permanent magnets in this paper.

Poster Session 1 / 61, T2_Mo_22

Low Energy, High-Intensity Repetitively Pulsed Ion Beams Generation

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The paper presents the results of experimental studies of the formation of high-intensity low ion energy pulsed beams of gases, gases and metals.The generation of gas plasma was conducted by a source based on non-self-sustained arc discharge with the hot cathode. In the case of mixed ion beams of gas and metal, the plasma formation was carried out by the source with the hot cathode and vacuum arc generator. A hybrid system of the ion beams formation combines the characteristics of the traditional grided ion extractors and plasma-immersion method of ion extraction with the subsequent ballistic focusing of accelerated ions. The space charge neutralization of the focused ion beam is carried out both through the injection of plasma in the equipotential drift space in the pauses between the bias pulses, and ionization of the working gas by ion beams. The peculiarities of the formation of ion beams of nitrogen, argon, hydrogen, and hybrid ion beams of nitrogen and titanium are demonstrated. The influence of the radius and the cell size of the grid electrode, repetition rate, duration and amplitude of bias pulses and plasma parameters on the formation of high-intensity, low ion energy beams is investigated. The possibility of the ion beam formation with current density up to 1 A/cm^2 at negative bias amplitude up to 3.2 kV is shown. The presented results demonstrate the possibility of high-speed deep alloying of AISI 5140 steel by high-intensity beam of nitrogen ions.

Poster Session 1 / 63, T3_Mo_47

Status of New 18 GHz ECRIS HIISI

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The Accelerator Laboratory at the University of Jyväskylä (JYFL) has performed radiation effects testing of electronics since 1998 using a K130 cyclotron and cocktail beams produced with ECR ion sources (ECRIS). Currently most of the tests are done at 9.3 MeV/u energy which is achievable with the charge states produced by the 14 GHz ECRIS of the laboratory. The radiation effects community has shown a strong desire to reach 15 MeV/u, which is approaching the limits of achievable charge states without superconducting ECR technology using the K130 cyclotron, i.e. requiring ions with $m/q < 3$. A high-energy cocktail has been proposed to be used at JYFL with Xe^{44+} as the heaviest component. Production of such very high charge states have so far been demonstrated only with fully superconducting ECRIS, e.g. 18 GHz SUSI at MSU. The desire for the very high charge states has initiated a project to push the performance of normal conducting ECRIS by developing an 18 GHz ECRIS HIISI (Heavy Ion Ion Source Injector). The new ion source being developed features several novel ideas to reach the high magnetic fields required for the production of the highest charge states: The permanent magnet hexapole is refrigerated down to $-20°$C allowing the use of high-remanence, low-coercivity permanent magnet grade N45SH otherwise unusable in such application. The cooling also increases the remanence of the magnets by up to 5% compared to room temperature. The source has a non-cylindrical plasma chamber with 5 mm deep grooves on the magnetic poles to increase the radial mirror ratio within the plasma flux. The injection field has been optimized using a structure with magnetic steel plug with a Permendur tip and a magnetic steel bias disc. The source has three coils allowing tuning of $B_{\rm min}$ independently of $B_{\rm inj}$ and $B_{\rm ext}$. At nominal solenoid currents of $I_{\rm inj}/I_{\rm ext}/I_{\rm middle} = 1000/820/-300$ A the field values are $B_{\rm inj} = 2.80$ T, $B_{\rm ext} = 1.30$ T, $B_{\rm min} = 0.42$ T and $B_{\rm rad} = 1.32$ T. The plasma can be heated using microwaves from three separate waveguide ports for 18 GHz klystron, 14 GHz klystron and 11-18 GHz TWTA, with a total microwave power capacity of 5 kW.

The commissioning is under way. The first beam from the new ion source was extracted in May 2017. So far the source has produced 160 μA of O^{7+} beam with 600 W of 18 GHz microwave power. In this paper the design of the 18 GHz ECRIS is presented together with the most recent results producing high charge-state oxygen and xenon beams.

Poster Session 1 / 70, T2_Mo_23

Proton Beam Formation from an ECR Discharge in a Single Coil Field

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Nowadays one of widespread types of ion sources is systems with plasma heating by microwave radiation in a magnetic field under conditions of the electron cyclotron resonance (ECR). In a purpose to obtain high values of ion beam currents there is a need of high plasma density. Due to this fact one of the main directions of ECR ion sources development is to increase the frequency and power of microwave heating.
In modern ECR ion sources gyrotrons are increasingly used as a source of microwave radiation. Earlier at the Institute of Applied Physics it has been demonstrated that the use of gyrotron radiation for plasma heating in simple mirror magnetic traps allows to produce beams of light or multiply charged ions with record current.
However, the disadvantage of such systems is that they are favorable for development of magneto-hydrodynamic (MHD) instabilities, and because of that there is a need to suppress them. Due to this fact there ion source design could be complicated resulting in technological difficulties and high manufacturing costs. According to that it was proposed to explore the prospects of creating a source of hydrogen ions on the basis of ECR discharge in a single solenoid sustained by powerful gyrotron radiation. Opposed to simple mirror trap this system is MHD stable and high power of microwave radiation allows to maintain an electron temperature on a sufficient level for high ionization efficiency of light gas.
So there was proposed to explore the prospects of creating a source of hydrogen ions on the basis of ECR discharge in a single solenoid sustained by powerful gyrotron radiation. Opposed to simple mirror trap this system is MHD stable, and high power of microwave radiation allows to maintain an electron temperature on a sufficient level for high ionization efficiency of light gas.
The paper presents the first results of gas ECR breakdown studies under such conditions and analysis of the prospects for the use of such plasma for ion beam production.

Poster Session 1 / 71, T2_Mo_24

Study of Plasma Parameters in a CW Gasdynamic ECRIS

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Recent investigations of pulsed gasdynamic ECR plasma [1] resulted in development of a new type of electron cyclotron resonance ion source (ECRIS) – a so-called gasdynamic ECRIS - at the Institute of Applied Physics (IAP RAS). The main advantages of gasdynamic ECRIS are extremely high ion beam current in comparison with conventional classical ECRIS - current density up to 600 – 700 emA/cm^2 in combination with low emittance, i.e. normalized RMS emittance below 0.1 pi · mm · mrad. Previous investigations were carried out in pulsed operation mode with 37.5 and 75 GHz gyrotron radiation plasma heating with power up to 100 kW at SMIS-37 experimental facility. While the pulsed operation of gasdynamic ion source was studied in details [1, 2], CW operation of such device is not well investigated. The present work demonstrates results of the first experiments of gasdynamic ECRIS operation in CW mode. A test bench named SMIS-24 has been developed at IAP RAS. Microwave radiation of 24 GHz CW gyrotron with power up to 5 kW was used for plasma heating in a magnetic trap with simple mirror magnetic field configuration. Preliminary studies of plasma parameters were conducted using Langmuir probe and X-Ray spectrometry of Bremsstrahlung. Ion beam was successfully extracted from the CW discharge. The experiments demonstrated plasma parameters similar to those obtained in pulsed mode at SMIS 37 facility. Three electron components were observed - "cold" fraction with energies on the order of helium ionization potential, "warm" fraction with energies in the range of 30-70 eV, which is optimal for low charge states production, and "hot" fraction with spectral temperature in the range of 10-20 keV. Plasma density found to be on the cut-off level, i.e. 6 x 10^{12} cm^{-3}. A long-term reliable operation with ion current density >1 A/cm^2 (estimated) was demonstrated. Obtained experimental results demonstrate that the main advantages of the gasdynamic ECR ion source are preserved when switching to CW operation.

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Poster Session 1 / 79, T2_Mo_25

Hot Filament Performance in a Freeman Ion Source

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We are presenting the simulation results of the hot tungsten filament behavior in a Freeman ions source installed in the LANL electro-magnetic isotope separator (EMIS). The Freeman source enables us to ionize and extract high intensity single-charge ion beams from different gases as well as from various solid materials in order to purify the content of a selected isotope [1].
We have modified and adopted the LANSCE H^- Ion Source Filament Model [2] to calculate the ion source working parameters during a beam production cycle and estimate the ion source filament lifetime. Two main mass erosion processes of the hot cathode in a Freeman ion source are included: thermal evaporation and plasma sputtering. The working temperature of source filament was estimated to be in range of 2400 to 2500 K. The filament model shows that the plasma sputtering rate is several magnitude of order higher than the thermal evaporation rate.
The results of ion source modeling were compared with recorded data (LABVIEW) taken during two EMIS beam production runs using krypton noble gas.

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Poster Session 1 / 81, T2_Mo_26

Development of a Laser Ion Source for a Four-Beam Interdigital-H type Radio Frequency Quadruple Linac

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The multi-beam acceleration method is an acceleration technique for low-energy high-intensity heavy ion beams, which involves accelerating multiple beams to decrease space charge effects, and then integrating these beams by a beam funneling system. At the Tokyo Institute of Technology, in order to demonstrate that a four-beam Interdigital-H type Radio Frequency Quadruple (IH-RFQ) linear accelerator is suitable for high-intensity heavy ion beam acceleration, we have been developing a four-beam IH-RFQ linac prototype. As an injection system for a four-beam IH-RFQ linac, we developed a laser ion source using a direct plasma injection scheme (DPIS). The laser ion source is directly connected to the RFQ cavity without a low energy beam transport system, and generates four-ablation plasmas by irradiating a graphite target with four split laser. The plasmas expand through plasma transport pipes and go directly into each RFQ channel. We measured the carbon ion beam properties of the laser ion source such as the output beam current and the charge state spectrum. The details of the laser ion source test bench and the experimental results of the carbon ion beam properties will be presented

Poster Session 1 / 82, T2_Mo_27

Proton Production by a Laser Ion Source with Hydride Targets

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There has been considerable research in proton beam production with laser-produced plasma, due to its important applications in various fields, such as cancer therapy and neutron source for radiography. While the feasibility of a laser ion source as the pre-injector of cancer therapy facilities in terms of the capability of the carbon ion beam production has been demonstrated in our previous research, there are still difficulties in intense proton beam production by a laser ion source. To investigate the capability of the proton production by a laser ion source, the hydride materials were used as the targets irradiated by a Nd:YAG laser (=1064 nm, =5~10 ns) in this research. The results will be presented and discussed here, including the yields and energy distributions of the proton beams, and their dependences on the laser parameters as well.

Poster Session 1 / 83, T2_Mo_28

Multiply Charged Ion Source Based on High Current Short Pulse Duration Vacuum Arc

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Elevation of ion charge states in broad beam of vacuum arc source leads to proportional increasing of ion beam energy without elevation of accelerating voltage. The ion charge states were elevated by using of high current vacuum arc with a few microsecond pulse duration. The heavy ion (bismuth) beam of several microseconds with pulsed ion beam current of several hundreds of milliamperes and mean ion charge state about 10^+ was generated. Physics and techniques of ion source are discussed.

Acknowledgement

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Poster Session 1 / 85, T2_Mo_29

Formation of High–Intensity, Macroparticle–Free Aluminum Ion Beams

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The paper presents the results of experimental studies of the production of high intensity low ion energy repetitively pulsed beams of aluminum. The generation of metal plasma was conducted by a DC vacuum arc evaporator. The formation of ion beams was carried out using an original developed system combining plasma–immersion approach for extraction and acceleration of ions and their further ballistic focusing and transportation in an equipotential drift space formed by a partially spherical grid electrode. Design of a highly efficient system for the suppression of vacuum arc microdroplet fraction is described. The system allows to prevent the accumulation of aluminum macroparticles in the focusing area of ion beam. The main peculiarities of high intensity aluminum ion beams formation are studied. The influence of ion beam space charge neutralisation on the efficiency of its focusing and transportation, and a data on ion beam current density distribution depending on negative bias parameters (e.g. voltage amplitude, pulse duty factor) and a geometry of the grid electrode are investigated. The possibility of macroparticle–free aluminum ion beam formation with high current density up to 0.5 A/cm^2 at negative bias amplitude of 3.2 kV is shown. The experimental results demonstrate the ability of super-deep aluminum dopant penetration into Ni target under low ion energy ultra high dose implantation.

Poster Session 1 / 87, T2_Mo_30

High Intensity Proton Injector for the Fair P-Linac

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For the FAIR anti-proton research the compact proton linac will produce proton beams with energy of 70 MeV that will be injected into upgraded Heavy Ion Synchrotron (SIS 18), accelerated to 4 GeV, and further accelerated to 30 GeV in SIS 100. The commissioning of the proton injector which would serve for the injection into the proton linac is already started at CEA/Saclay. The ion source operates with a microwave frequency equal to 2.45 GHz based on electron cyclotron (ECR) plasma production with two coils each with 87.5 mT magnetic field will deliver 100 mA proton beam at 95 keV energies. The low energy beam transport (LEBT) including two short solenoids system including integrated sterrer will transport proton beam to the RFQ entrance with the expected emittance lower than 0.3π mm mrad (normalized, rms). After the LEBT electrostatic chopper will be mounted in front of RFQ to short the beam pulse to 36 µs. This paper presents the status of the commissioning phases including first results of proton injector.

Poster Session 1 / 92, T2_Mo_31

"Point-like" Neutron Source Based on a Gasdynamic High-Current ECRIS

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Neutron tomography is one of the most exciting recent achievements of nuclear physics. It opens up opportunities for a wide range of various microscopic studies of physical, chemical and biological objects. It is of note that neutron tomography requires dedicated neutron sources, i.e. paraxial sources with low angle spread. The only sources now able to deliver required neutron beams with sufficient intensity are nuclear reactors and large-scale accelerators in pair with collimators. The use of point-like neutron sources based on laser plasma induced by focusing of powerful femtosecond laser radiation onto a neutron-producing target was proposed lately. It is of note that isotropic neutron flux from a point-like source with angular spread accuracy determined by its size seems to be useful for neutron tomography. High resolution comparable to one obtained with collimated neutron beams may be derived from a source of small size.

A possibility of compact powerful point-like neutron source creation is discussed. The yield of the source based on deuterium-deuterium (D-D) reaction is estimated on the level of $10^{11}s^{-1}$ ($10^{13}s^{-1}$ for deuterium-tritium reaction). The fusion takes place while bombardment of deuterium- (or tritium) loaded target by high-current focused (about 100 micron) deuterium ion beam with energy of 100 keV. The ion beam is formed by means of high-current quasi-gasdynamic ion source of a new generation based on an electron cyclotron resonance (ECR) discharge in an open magnetic trap sustained by powerful millimeter wave radiation. The prospects of using proposed generator for neutron tomography are discussed.

Poster Session 1 / 93, T1_Mo_04

Broadband Microwave Emission and Electron Losses Associated with Kinetic Instabilities in ECR Plasmas

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Electron cyclotron resonance ion sources (ECRIS) have been essential in the research and applications of nuclear physics over the past 40 years. They are extensively used in a wide range of large-scale accelerator facilities for the production of highly charged heavy ion beams of stable and radioactive elements. Plasmas of electron cyclotron resonance ion sources (ECRISs) are prone to kinetic instabilities due to the resonant heating mechanism resulting in anisotropic electron velocity distribution. Instabilities of cyclotron type are a proven cause of frequently observed periodic bursts of "hot" electrons and bremsstrahlung, accompanied with emission of microwave radiation, and followed by a well-known and frequently observed oscillations of extracted ion beam current in the case of high plasma heating power and/or strong magnetic field, leading to a notable reduction and temporal variation of highly charged ion production. Thus, investigations of such instabilities and techniques for their suppression have become important in ECRIS research.

Data showing the presence of the microwave emission associated with the instabilities for different experimental facilities are presented. Detailed studies of the microwave radiation have been performed with a minimum-B 14 GHz ECRIS operating on helium, oxygen and argon plasmas. It is demonstrated that during the development of cyclotron instability "hot" electrons emit microwaves in sub-microsecond scale bursts at temporally descending frequencies in 6-25 GHz range and exhibit certain dominant frequencies regardless of ECRIS settings i.e. magnetic field strength, neutral gas pressure or species and microwave power. The possible energy range of the electron population amplifying the plasma waves is estimated and arguments on possible excited plasma wave modes are given.

An original method for direct measurement of the energy of electrons leaving the trap along a magnetic field using the 90 degree analyzing magnet as a spectrometer coupled to a secondary electron amplifier is developed. The measured electron energy spectra are presented and compared in stable and unstable regimes. A correlation is made between the energy of electrons leaving the trap during the development of the cyclotron instability and the spectrum of the electromagnetic radiation.

Poster Session 1 / 95, T1_Mo_05

4.0-6.0 GHz Extraordinary Mode Experiments on 2.45 GHz Electron Cyclotron Resonance Ion Source

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A new tandem type source on the basis of electron cyclotron resonance (ECR) plasma has been constructing for producing synthesized ion beams in Osaka Univ. [1] Magnetic mirror field configuration with octupole magnets can be controlled to various shape of ECR zones, namely in the second stage plasma to be available by a pair mirror and a supplemental coil. Noteworthy correlations between these magnetic configurations and production of multicharged ions are investigated in detail, as well as their optimum conditions. We have been considered accessibility condition of electromagnetic and electrostatic waves propagating in ECR ion source (ECRIS) plasma, and then investigated their correspondence relationships with production of multicharged ions. It has been clarified that there exits efficient configuration of ECR zones for producing multicharged ion beams, and then has been suggested that new resonance, i.e. upper hybrid resonances, must have occurred [2]. We have been planning new advanced experiments inducing actively these additional effects for enhanced furthermore multicharged ion beams with launching extra-ordinary (X) mode waves. Initially we have already conducted to applying 9 GHz X-mode microwaves to 2.45 GHz ECRIS, and it have been observed enhancements of higher energy tails of electron energy distributions function measured by the probe methods [3]. Next we have been try to similar experiments with 6 GHz X-mode microwaves, and in this paper we will describe the preliminary experimental results.

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Poster Session 1 / 100, T2_Mo_32

Control of a Laser-Produced Dense Plasma Flow by a Divergent Magnetic Field

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To improve the directivity of source plasma ions supplied to the extraction gap of a laser-ablation ion source (LAIS), the behavior of a laser-produced dense plasma flow modulated by a divergent magnetic field was investigated in detail. A magnetic field having a "nozzle-like" structure was induced by a pulsed solenoid near the laser target in synchronization with laser irradiation. The waveforms of plasma ions passing through the magnetic field were observed by Faraday cups located at various directions and distances from the target. From the angular dependence of the waveforms, two different mechanisms were found to cause the enhancement of the plasma ion flux independently. The core part of the laser-produced plasma plume is compressed by the magnetic pressure, leading to an increase in the plasma ion flux. The ions in the peripheral part of the plume are gathered by the collective focusing effect, which also can contribute to the flux enhancement. The results indicate that the directivity of the plasma ions can be greatly improved by optimizing the structure and strength of the magnetic nozzle. The more detailed analyses using a Hybrid Particle-In-Cell code were also performed to find the optimum magnetic nozzle parameters, which well reproduced the experimental results.

Poster Session 1 / 106, T3_Mo_49

Production of High Intensity Nickel-Ion Beams with High Isotopic Purity with the Metal Ion from Volatile Compound (MIVOC) Method

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In this paper measurements on the production of high intensity, medium charge-state Nickel-ion beams with high isotopic purity using the Metal Ion from Volatile Compound (MIVOC) Method are presented. Commercially supplied Nickelocene (Ni(C5H5)2) with natural abundance, Nickelocene with 99% enriched 60-Nickel and 98% enriched 62-Nickel were investigated with a 14.5 GHz ECRIS4. Mass over charge and intensity measurements are discussed. The procedure of the synthesis of the enriched Nickelocene was developed in the iThemba LABS target laboratory and is described in the paper as well. The in-house synthesis of metal-locenes from enriched materials allows for new ion beams with intensities is not possible so far.

Poster Session 1 / 108, T3_Mo_50

Upgrade of the GTS Electron Cyclotron Resonance Ion Source at GANIL

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The GTS (Grenoble Test Source) electron cyclotron resonance ion source, operated at 14.5 GHz, provides multiply charged heavy ion beams for the ARIBE (Accélérateurs pour les Recherches Interdisciplinaires avec les Ions de Basse Energie) facility at GANIL (Grand Accélérateur National d'Ions Lourds). In order to increase the beam currents and charge states available for experiments and to have a test bench with good performance for the R&D of new beams for GANIL users, the ion source has undergone a number of upgrades. These include the refurbishment of the extraction system and the addition of a new central coil. The injection side of the source will also be replaced in the future. A simulation approach has been used in parallel to the upgrades to identify potential performance limitations in the beam extraction and low energy beam transport sections. In addition, metal ion beam production with the MIVOC method has been tested for the first time with the GTS to expand the beam catalogue available for the ARIBE experiments. The performance of the upgraded GTS will be presented along with the results from the simulation studies and the MIVOC tests.

Poster Session 1 / 110, T2_Mo_33

Compact H^+ ECR Ion Source with Pulse Gas Valve

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Compact H^+ ECR Ion Source using permanent magnets is under development. A pulsed gas injection system, achieved by a fast piezo gas valve, can reduce the gas load to a vacuum evacuation system. This feature is suitable when the ion source is closely located to an RFQ. Use of permanent magnets reduces the size. Achieved performance will be presented.

Poster Session 1 / 112, T2_Mo_34

Low Charge State Laser Ion Source Driven by a Sub Nanosecond Laser

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We are studying possibility to use sub nanosecond lasers to deliver low charge state ion beams from various target materials. Since 2014, a laser ion source (LIS) is in operation to provide singly charged heavy ion beams to user facilities at Brookhaven National Laboratory. For the LIS, 1064 nm, 6 ns single resonator ND-YAG lasers are used. It is required to operate the LIS for more than half a year without major maintenance. Also, some materials are expensive or harmful and less consumption of the target materials would be highly benificial. In fact, most of the material consumption is due to vaporization after emitting hot ablation plasma and the vaporization is driven by heat conductivity in sub nanosecond time scale. By using a sub nanosecond laser system, we may be able to reduce the effect of heat conductivity on the target surface. This may reduce consumption of target material and improve the performance of the LIS. Using a sub nanosecond laser, the irradiation condition is being experimentally studied. In the conference, we will report the features of the new laser ion source for low charge state production using a sub nanosecond laser.

Poster Session 1 / 116, T1_Mo_06

Investigation of Laser Ablation Plasma from Thin Graphite Target

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We have tried to reveal a mechanism of laser ablation plasma generation through the developing Laser Ion Source (LIS) and confirmed that charge state distribution is forcefully affected by the laser target thickness. A LIS generates pulsed highly charged ion beams by irradiating solid material targets with high intensity pulsed laser. In the past, we examined the effect of laser target thickness on the induced plasma properties. Three different graphite sheets, 254, 70 and 25 um, were prepared and carbon beam currents were compared. We found that only 25 um target emit different ablation plasma. Although there was no distinguishable difference on highly charged states ion currents, the beam comprising only lower charge state ions from 25um graphite target was obviously weaker than that from other thicker targets. This implies that the plume of laser ablation plasma consists of highly charged C ions is generated in the region near the surface of the material and secondary plasma plume which contains lower charge state C ions is created from the deeper layers of the target. Also, the investigation of vacuum at the irradiation chamber gave us information of the laser plasma formation, since vacuum is affected mainly by un-ionized vapors from more deeper part of the target. In this presentation, we will report the latest results of the experiment using thinner range of the target thickness and more detailed plasma formation mechanism and the findings will be discussed.

Poster Session 1 / 119, T2_Mo_35

Laser Plasma Generation System with Controlled Interpulse Delay Between two Laser Shots

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The 400 kV ion implanter in TIARA facility [1] provides variety of low charge DC ion beams of C, Al, Ti, Cu, Au, Pt, etc. mainly for material sciences. Most of beams are produced from solid materials by a Freeman type ion source equipped with sample vaporization oven. In the case of high melting point materials, the beam current is insufficient (below a few microamps) and decreases with time. Additionally, conducting experiments using multiple kinds of ions is difficult because the change of ion species is difficult due to long heating time of the oven (2-3 hours).

In order to resolve above problems, we are developing a laser ion source (LIS) as a high-intensity heavy ion source for the implanter. A LIS can generate high-intensity ion beams from almost any solid material by irradiating a focused high-intensity pulsed laser onto a target. Ion species can be changed by replacing target materials or mounting multiple targets on a target holder.

To apply LIS as an ion source for the implanter, high-repetition operation is required to obtain sufficient number of particles for experiments. In order to clarify the pulse interval at which plasma is generated stably, we constructed a system that can irradiate two laser beams at the same position of the target material at an arbitrary time interval.

The details of the system and results of the plasma generation by changing irradiation time interval of two lasers will be presented.

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Poster Session 1 / 123, T3_Mo_51

Low Field Experiments with 18 GHz RF Power of the RAON ECR Ion Source

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RAON fully superconducting ECRIS which plasma chamber volume of 10 liters is adapted and uses a 28 GHz MW power as a main power source and an 18 GHz MW power as a secondary power source. We characterized our ion source at a relatively low magnetic field just with an 18 GHz MW power. A reference O^{7+} beam was monitored with the experimental parameters such as MW power, vacuum pressure, and magnetic field profile. Under some conditions, the beam current showed unstable behavior due to a plasma instability. We verified the reason of that instability and verify the characteristics of our ECRIS.

Poster Session 1 / 125, T1_Mo_07

Development of a Compact Molecular Hydrogen Ion Source for Low Energy Surface Scattering Experiments

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Fundamental data on surface reflection and adsorption/implantation are necessary for understanding edge plasma physics to design future fusion reactor components. A large divergent angle arising from low energy ion beam transport reduces signal intensity to make study on fundamental processes more difficult. A 40 mm diameter, 70 mm long compact ion source is being developed aiming at substantial reduction in beam travel distance.The source structure enables the replacement of the wall material to see the effect upon fractions of hydrogen molecular ions in the extracted beam. The ion source is attached near a rotating target in vacuum to collect data on surface reflection of hydrogen.The developed source has already produced several tens of nA of H_2^+ and H_3^+ ion beam current at energy lower than several hundred volts through a 1 mm diameter hole, while further enhancement in beam current density and reduction of beam energy are being attempted.The source material should have different recombination coefficients and changes molecular spices in the ion source plasma. The effect is being investigated for H_3^+ in the extracted beam.

Poster Session 1 / 129, T1_Mo_08

Comparison of Photometry Measurement and Numerical Analysis for Plasma Density Oscillation with Doubled Value of RF Frequency in J-PARC RF Ion Source

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A direct comparison of Balmer line emission from J-PARC RF ion source (RFIS) plasma has been made between photometry measurement and 3D3V numerical analysis.The J-PARC RFIS has internal antenna coil for injection of a few 10 kW RF power with RF frequency of 2 MHz. Negative hydrogen ion (H^-) current of 45 mA is extracted with energy of 50 keV during the user operation in present. In the photometry measurement, line intensity has been observed by high time resolution photomultiplier through collimator lens of the source chamber. Time variation of RF current is also measured to observe the relation between time structures of RF current and line intensity (plasma density) oscillation. From the comparison, we confirmed two main physical behaviors of the RFIS plasma; (i) transition between E-mode to H-mode in a few micro seconds after RF power injection and (ii) oscillation of plasma density with doubled value of RF frequency (4 MHz). From the physical model in this study, the relation between source design and plasma/H^- behaviors in the RFIS are also discussed.

Poster Session 1 / 134, T1_Mo_09

Production of Hydrogen Negative Ions in High Density Sheet Plasma.

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For development of a cesium-free negative ion source, we have carried out the experimental observation and modeling of negative ion, atomic and molecular ions in hydrogen sheet plasma. The sheet plasma is suitable to produce negative ions, because the electron temperature in the central region of the plasma is as high as 10 -15 eV, whereas in the periphery of the plasma, a low temperature of a few eV is obtained [1], [2]. Therefore, it is considered that high density production of negative ions is possible in sheet plasma. On the experiment, hydrogen plasma sheet was produced by a linear plasma device TPD-Sheet IV. Measurements were carried out in hydrogen plasma with a hydrogen gas puff. The electron density and temperature were measured by Langmuir probe. The density profiles of hydrogen negative ion and other hydrogen positive ions were measured by omegatron mass spectrometer [3]. In addition, VUV spectroscopic measurement has been carried out to obtain the vibrational temperature of hydrogen molecules [4]. To decide vibrational temperature, we fit the spectra which are obtained by spectroscopic measurements and spectra which are obtain by corona model. In the experimental result, it has been found that negative ions are produced at periphery region (14 mm from center of plasma column) of plasma sheet. When the hydrogen gas pressure was 0.2-0.3 Pa, negative ion density became maximum ($n(H^-)$ ˜10^{17} m^-3). To model the ion density in this experiment, a zero-dimensional model is developed for solving the system of rate balance equations for ion and gas species. In the calculate result, it has been found that negative ions are produced at periphery region of plasma sheet (12-16 mm from center of plasma column). When the hydrogen gas pressure was 0.2-0 Pa, negative ion density became maximum ($n(H^-)$ ˜ 10^{16} m^-3). The experiments and the model calculates results indicate that production of negative ions in sheet plasma depends on the gas pressure and location from the plasma column

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Poster Session 1 / 136, T2_Mo_36

Stability and Lifetime of Scandium Deuteride Film Cathode in a Vacuum Arc Ion Source

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The vacuum arc discharge with a deuterium impregnated metal cathode is a popular source of deuterium ions, which is widely used in neutron generators [1-3]. Recently, metal deuteride film cathode for vacuum arc discharge is studied by Efim M. Oks [1,4]. This paper reports on a study of the properties of the plasma and gas produced in a vacuum arc discharge with Scandium deuteride thin film (ScD1.8) cathode which have been deposited on Mo by sputter magnet. The ScD1.8 cathode allow the generation of multicomponent gases and ions. The stability and lifetime of the vacuum arc system to produce deuterium ions is analyzed by analyzing the gases releasing quantity, atomic fractions ratio of deuterium with metal (D:M) and neutron yield.

Fast Response Vacuum Gauge and Quadrupole Mass Spectrometer were used in the research of gases releasing quantity. The total gases releasing quantity is stability with the number of discharge. While the deuterium gas releasing quantity is fluctuation and also decrease with the number of discharge. Magnetic mass spectrometry was used in the research of atomic fractions ratio of deuterium with metal. As the number of discharge increases, the stability of atomic fractions ratio is getting worse and the ratio of deuterium ions is decreasing. Finally, nuclear analysis method was applied for studying the absolute content of deuterium ions. The result was similar to that of the magnetic mass spectrometry experiment. The stability of neutron yield is getting worse and the total amount of neutron yield is decreasing.

Key words: vacuum arc discharge, scandium deuteride film cathode, deuteride releasing, Magnetic mass spectrometry, nuclear analysis method

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Poster Session 1 / 146, T3_Mo_52

Characterization of EBIS Test Bench at KOMAC

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Electron Beam Ion Source (EBIS) has been one of the widely used table-top devices for the production of highly charged ions due to its high purity of charge states. At Korea Multipurpose Accelerator Complex (KOMAC), we have constructed a compact EBIS test bench, consisting of a EBIS-A (advanced EBIS from Dreebit GmbH, Germany), a Wien filter and a Faraday cup. The Wien filter with a permanent magnet is designed to separate charge states of ion beams produced from the EBIS-A. A fast extraction system is incorporated with the EBIS test bench to produce ion beams of a pulse width < 1 μs. We characterize the EBIS test bench with He and Ar gases. Hereinafter, results on the characterization will be discussed in detail. We also plan to install an EBIS-SC (superconducting EBIS from Dreebit GmbH, Germany) as a < 1 μs proton pulse injector to the KOMAC proton linac. Beside the commercial EBISes, a 7 Tesla EBIS is currently under development at KOMAC and will be used as an ion beam injector for a 200 MHz Radio-Frequency Quadrupole accelerator. In this paper, we briefly discuss the plans for the EBIS-SC and on-going development on the 7 T EBIS design.

Acknowledgement

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Poster Session 1 / 147, T3_Mo_53

Investigation into the Gas Mixing Effect in ECRIS Plasma Using K Diagnostics

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The volumetric K emission rate emitted from the Electron Cyclotron Resonance (ECR) heated plasma of an ECR ion source (ECRIS) can be used to estimate the inner shell ionization rate of a gas species. Additionally, the thick target radiation originating from the walls of the plasma chamber can be used to estimate the energetic electron losses from the magnetic confinement system of the ECRIS. With a previous investigation performed on the JYFL 14 GHz ECRIS and the 14.5 GHz Grenoble Test Source (GTS) at iThemba LABS, K diagnostics was used to determine the influence of the source tune parameters on the inner shell ionization rate. With this investigation it was established that the neutral gas pressure and the absorbed microwave power had the most pronounced effect on the volumetric emission rate. Specifically, it was observed that the volumetric emission rate increases with increasing neutral pressure. As an extension of this investigation, the current study probes the influence of the volumetric K emission rate of the working gas as a function of various mixing gases. By adding a lighter mixing gas to the working gas, the intensity of high charge states of the heavier element is known to increase. This effect is not completely understood but common explanations for its effectiveness include ion cooling, the dilution effect, increasing the electron density and increasing the plasma stability. With the current investigation the relative importance of all of these effects were assessed and the results will be discussed.

Poster Session 1 / 164, T2_Mo_37

Production of High Intensity ^{11}C Beams for PET-Aided Hadron Therapy

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For the production of high intensity ^{11}C beams for image-accompanied hadron therapy, we present our proposal for a radioactive ion beam production system based on the ISOL technique (Isotope Separation On-line), operated with a compact 1+ electron cyclotron resonance ion source (ECR). Carbon therapy is a very precise treatment for cancers with localized tumors. However, such treatments rely on complex treatment planning systems that simulate the dose delivery to the patient. On-line or post-treatment dose verification based on the fragmentation of ^{12}C is complex and cannot image the exact position where the energy is deposited. Therefore, we propose a carbon therapy protocol where the stable carbon beam is replaced by ^{11}C. This combines therapy with on-line PET-imaging. Thus, 3D dose distribution of the irradiation field can be measured, verifying where the energy is deposited. Since an efficient treatment requires a high intensity particle beam (˜ $4\ 10^8$ ions/s), the radioactive ion beam production system needs to be optimized, in order to deliver the beam in desirable intensity and purity to the patient. We propose a system based on the ISOL method, where ^{11}C is produced within a solid target via low-energy proton irradiation. Subsequently, the isotope has to be extracted and ionized for the mass separation. Carbon is very refractory. The atomic diffusion inside the solid and the evaporation once it reaches the surfaces are known to be difficult, which limits the isotope release out of the target. Therefore, an isotope extraction in molecular form (^{11}CO) is expected to enhance the release efficiency. Consequently, we present our studies of a target-ion source unit with a solid boron nitride target and operated with a compact 1+ ECR ion source. Plasma ion sources are appropriate for carbon oxides with their relatively high ionization potential. Particularly, ECR ion sources seem to be beneficial, due to their absence of hot metal surfaces, which would limit the ionization efficiency by long retention times of ^{11}CO. We will discuss important considerations for the target handling, and the operation of an ECR-type ion source, such as neutron fluxes and gas loads that result from the irradiation of a solid target. ECR ion sources are usually operated with permanent magnets. Therefore, high neutron fluxes are a limiting factor with respect to the stability of the plasma confinement. Simulations that have been carried out with the particle transport code FLUKA [1, 2], show that the flux resulting from low-energy proton irradiation are in an acceptable range to be managed with shielding. Furthermore, applying a controlled oxygen leak to the boron nitride target introduces the difficulty of oxidation of the target material, which could overload the ion source. First chemical equilibrium and molecular sideband calculations indicate that the resulting gas flux remains manageable for an ECR ion source. However, the extraction as ^{11}CO via external oxygen supply includes complications for the target material stability. Consequently, further investigation and experimental validation will be done in the future. This work is supported by the Marie-Skłodowska -Curie Innovative Training Fellowship of the European Commission's Horizon 2020 Program under contract number 642889 MEDICIS-Promed.

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Poster Session 1 / 165, T3_Mo_57

The Current Status of 28 GHz ECR Ion Source at KBSI

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The 28 GHz superconducting electron cyclotron resonance (ECR) ion source has been developed to produce a high current heavy ion beam for the linear accelerator at KBSI (Korea Basic Science Institute). In the last year, an ECR ion source was upgraded to improve performance. The extraction system was changed to prevent arcs which were generated between the negative electrode and ground electrode. The bias disk had a cooling system added after being damaged in the first operation. To improve the radial magnetic field, the inner-yokes were inserted inside the hexapole magnet. This report describes the results of the upgrade of the ECR ion source. Also we will announce results of ion beam extraction.

Poster Session 1 / 167, T2_Mo_38

Increasing of the Operation Duty Cycle for Heavy Elements such as Au, Pb, Bi and U from High Current Ion Sources

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The upcoming FAIR facility (Facility for Antiproton and Ion Research) will provide wide opportunities for investigation and research programs in different branches of science including antiproton physics, bio and material research, nuclear astrophysics and many others. A significant part of these programs require high intensity primary beams of heavy ions: ^{197}Au, ^{208}Pb, ^{209}Bi and especially ^{238}U with duty cycle up to 2.7 Hz.
The production of high current Au, Pb and Bi beams with vacuum arc ion sources is in developing phase. It is limited by the injection requirements into the RFQ (radio frequency quadrupole) on one hand side (the requested charge state for ions is 4+ or higher) and by physical properties of the materials on the other hand side (these metals are soft and fusible with relatively low melting point, that makes the production of 4+ ions challenging). Using composite materials, an alloy or a mixture of the desired element with a more refractory metal, instead of pure metals in the cathodes of the ion source dramatically improves the production of 4+ ions in the plasma for Au, Pb and Bi and allows providing high current ion beams for operation. Nevertheless, the operation duty cycle at the moment is limited to maximum 1 Hz. At higher duty cycles a drastic drop in the ion beam quality is observed.
In the case of uranium, the high current operation, producing U^{4+} ion beam, is well established with 1 Hz. However, by increasing the duty cycle by a factor of 2.7 notable reduction of the ion source performance and pulse-to-pulse stability are observed. Moreover, the frequency of occurrence for such disturbing effects as high voltage breakdowns in the extraction system and ignition failures in cathodes is dramatically increased.
In this work the problematic of increasing the operation duty cycle for heavy elements to 2.7 Hz is considered in details. The possible ways to reach the requirements of future FAIR experiments especially for uranium beam are discussed.

Poster Session 1 / 168, T1_Mo_11

Study of Low-Energy Electron Transport at Extraction Region in Hydrogen Negative Ion Source with an Additional Electrons Source

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Tandem type hydrogen negative ion (H^-) sources are generally designed to have two plasma regions of different average electron energies. The higher and lower electron energy regions are called "driver region" and "extraction region", respectively [1]. The driver region should contain electrons with energy high enough to produce excited hydrogen molecules for H^- production. On the other hand, the extraction region is generally located in the vicinity of a beam extraction hole in order to enhance H^- beam current, while avoiding the H^- destruction due to the higher energy electrons over 1 eV. The separation of the two plasma regions is realized with the filter magnetic field which is introduced to the extraction region. Therefore, the low-energy electron transport in the filter field determines the plasma parameters at the extraction region which decides the performance of H^- sources.
In this study, we aim to understand mechanism of the low-energy electron transport at the extraction region through experiments, especially transport across the filter magnetic field, using numerical simulations in order to obtain basic knowledge for development of more efficient H^- sources.

In the experiment, we use a test stand with a small cylindrical-shape ion source whose diameter and length are 9 cm and 11 cm, respectively [2]. The ion source generates a DC hydrogen plasma with a pair of tungsten filament installed at the driver region. Here, to study the low-energy electron transport, we introduced another filament system [3] inside the extraction region. The additional filament system enhances density of low-energy electrons in the extraction region. The injected electrons diffuse around the filament and the electron density increases locally. The transport of these low-energy electrons in the extraction region can be studied through an analysis of the local change on the density profile. Thus, we measured the spatial distribution of electron density with a Langmuir probe under different experimental conditions. The experimental results were analyzed with two-dimensional position and three-dimensional velocity Particle-In-Cell (2D3V PIC) simulations to understand the low-energy electron transport.
In our early experiments, we have already confirmed the local-density enhancement in electron density profiles. In a poster, we will report the results of experiment and analysis with the PIC simulation.

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Poster Session 1 / 172, T3_Mo_58

The Effect of ECRIS Tuning Parameters on the Intensity of the Ar^{9+} Optical Emission and Ion Beam Current

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The intensity of the ion beam extracted from an electron cyclotron resonance ion source (ECRIS) depends on the production rate of ions and the efficiency of the ion beam formation and transport. The production of Ar^{9+} ions in an ECRIS plasma and the beam formation of the resulting Ar^{9+} ion beam have been studied with the JYFL 14 GHz ECRIS by using optical emission spectroscopy and measuring the m/q analyzed beam current. The parametric dependence of the intensity of the 553.32650 nm optical emission line resulting from a magnetic dipole transition between the metastable excited state $2s^2 2p^5\ ^2P^{\circ}_{1/2}$ and the ground state $2s^2 2p^5\ ^2P^{\circ}_{3/2}$ of Ar^{9+} has been measured from a radial diagnostics port of the JYFL 14 GHz ECRIS and compared to the intensity of extracted Ar^{9+} ion beam current as a function of microwave power and neutral gas feed. The optical measurements have been done with high resolution (31 pm at FWHM) and high throughput Fastie-Ebert monochromator coupled with a photomultiplier tube detector with a phase-sensitive lock-in detection setup. The relative changes in both the optical emission and the beam have been compared and will be discussed. Microwave power dependency was confirmed with the transient measurements where the microwave power was adjusted rapidly. The results suggest that in case of Ar^{9+} the production rate does not constrict the performance of the ECRIS at high microwave power but instead the beam formation could limit the extracted current.

Poster Session 1 / 177, T3_Mo_59

Characteristics of a Heavy Ion Injector z/A 1/3 based on Laser-Plasma Ion Source

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Design of the high-current ion injector for ions with z/A 1/3 is described. The system consists of a laser-plasma generator based on a repetition rate CO_2 laser, a vacuum target chamber with optical focusing system, a beam extraction and transport system, and RFQ accelerator with z/A 1/3. The goal of the work is to optimize parameters of all of the above components for maximum ion beam current at the output. Carbon ion energy spectra of CO_2 laser produced plasma at radiation power density of $8 \cdot 10^{11} W/cm^2$ were studied. Conditions for generating $^{4+} \div$ $^{6+}$ ions in the vacuum chamber in use were found. The $^{4+}$ ion beam produced by the source was matched into the RFQ and measurements of its emittance and current are being performed.

Poster Session 1 / 182, T3_Mo_60

The Preliminary Tests of the High Charge State All-Permanent Magnet ECR Ion Source DECRIS-PM

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Super-heavy-element factory is under development at the Flerov Laboratory for Nuclear Reactions, JINR, Dubna. The factory will include DC-280 cyclotron, which will be equipped with two 100 kV high voltage platforms. A high charge state all-permanent magnet 14 GHz ECRIS – DECRIS-PM has been designed and fabricated to provide intense multiple charge state ion beams. The request for the source is a production of medium mass ions with A/q=4÷7.5 such as $^{48}Ca^{8+}$. The conceptual design of DECRIS-PM is presented. During the first tests, the source shows a good enough performance for the production of medium charge state ions (such as 900 eμA Ar^{8+}, 550 eμA Ar^{9+}, 200 eμA Ar^{11+}, 160 eμA Kr^{15+}, etc.).

Poster Session 1 / 184, T3_Mo_61

Upgrading of the CAPRICE Type ECR Ion Source

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The CAPRICE-type ECR ion source mVINIS has been upgraded by increasing its magnetic field to improve a plasma confinement and thereby enhance the source performance. This modification made it also possible to increase the internal diameter of the plasma chamber and to replace the coaxial microwave input on the waveguide. Some major subsystems such as: the vacuum system, the microwave system, the gas inlet system, the solid substance inlet system, and the control system have been also refurbished. All these improvements have resulted in a substantial increase of ion beam currents, especially in the case of high charge states, with the operation of the ion source proven to be stable and reproducible. This modification can be applied to other CAPRICE-type ion sources.

Poster Session 1 / 186, T3_Mo_62

Intense, Pure and Stable Highly Charged Ion Beams from the AECR Ion Source at KVI-CART.

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At KVI-CART, an upgrade of the AECR ion source is in preparation, with the main objective to increase the intensity, stability and purity of the highly charged ion beams. To increase the intensity a new hexapole will be installed with stronger Nd-Fe-B magnets. To further increase the magnetization, the temperature of the hexapole bars will be lowered, making use of the temperature dependence of the coercivity of the Nd-Fe-B material. The stability of the highly charged ion beams will be improved by changing the cooling sequence of the hexapole from an on-off sequence to a proportionally controlled system. Regarding the purity of the highly charged xenon beams, the choice of the enriched xenon isotope with respect to the possible contaminants originating from the material of the plasma chamber (Si, S, Mg), determines the purity of the 30 MeV/u highly charged xenon beams at KVI-CART.

Poster Session 1 / 197, T1_Mo_13

Production of Oxygen Ions through the Laser Ablation of Alumina

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Laser ablation of a solid oxide compound material makes the ion production of gaseous elements possible. Using an aluminum and alumina for the target in the laser ion source, the plasma characteristics in a low laser energy scheme was investigated to understand the difference in ion production of oxygen from the aluminum oxide material. The Faraday cup measurements of the laser produced plasma were measured using the laser power densities of 2.0, 2.9, 3.5 and 4.3 $\times$ 10^8 W/ cm^2 and the ions examined through an electrostatic ion analyzer identified the ion species in the plasma pulse. The mass separated ion signals for a range of deflection voltages were analyzed to give a temporal distribution of ion species as an approximation of the ion composition in a single plasma pulse. Faraday cup measurements revealed that the alumina target produces a lower acceleration potential than an aluminum material for a laser power density of 2.0 $\times$ 10^8 W/cm^2 but the disparity became less apparent as the laser energy was increased. Mass separated ion signals show the presence of mainly Al, O and C with charge states of up to +3 for both the aluminum and alumina laser targets. Large amounts of singly charged oxygen and aluminum ions were detected for the alumina target taking up half of the ion population whereas the higher charge state ions and other ion species were kept below 10%. However, for the aluminum target, singly charged aluminum ions dominate the ion population in the plasma pulse for all laser power densities with other ions and higher charge state aluminum ions stay below 30%. The ratio of the produced oxygen ions in the plasma pulse for the alumina target attest to the possibility of alumina as a solid source of oxygen.

Poster Session 1 / 198, T3_Mo_64

Operation of a Double Frequency Heated ECRIS in cw and Pulsed Mode

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The FAIR facility will require low duty cycle intense heavy ion beams which cannot be produced by the CAPRICE Electron Cyclotron Resonance Ion Source (ECRIS) installed at GSI. In order to fulfill this requirement an upgrade of the high charge state injector is mandatory. An experimental investigation at the ECRIS testbench was carried out with the aim to enhance the extracted ion currents in pulsed mode.
An increase of current of the highly charged extracted ions, on a short time scale, is obtained by pulsing the microwaves feeding the plasma, according to the so called afterglow mode.
It was also demonstrated that the current of the highly charged ions can be significantly improved by applying microwave based techniques like the frequency tuning or the double frequency heating.
Recent experimental results proved that the microwave frequency tuning and afterglow operation mode combined together allow to further enhance the intensity of pulsed highly charged ion beams in comparison with modes where these two techniques are applied separately.
In order to analyze the effect of the superposition of different frequencies in pulsed and cw mode on the ion source performance, several experiments were carried out on the CAPRICE-type ECRIS. Different combinations of frequencies and operation modes have been investigated under different settings of the ion source. The results of this investigation are reported here.

Poster Session 1 / 207, T3_Mo_66

Effect of the Plasma Chamber Radius on the High Charge State Production in an ECR Ion Source

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The version 2 and 3 of the 18 GHz PHOENIX ECR ion source have been developed in the framework of the SPIRAL2 project. The former V2 design focused on maximizing the radial magnetic confinement at the plasma chamber wall, resulting in a compact chamber volume of 0.6 liter with a diameter of 62 mm. The new V3 design focused on a larger diameter of 89 mm (chamber volume 1.4 liter) keeping the radial field intensity as high as possible and enhanced pumping features. The two versions having nearly the same axial mirror structure and the same radial magnetic field intensity at wall, it is of interest to compare their performance as a function of the plasma chamber radius. Preliminary experiments have shown an improvement of high charge state production of Argon up to 120% in the V3 source with respect to the V2, delivering 120 µA of Ar^{14+} beam for instance. The V3 results will be presented, compared with the V2 and possible physics explanation for such an effect reviewed.

Poster Session 1 / 219, T2_Mo_40

A Compact 2.45 GHz Microwave Ion Source and Associated Wien Filter Based Analyzing System for Low Energy Ion Beam Facility

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A high flux, low energy ion beam facility has been designed, developed and commissioned at the Inter University Accelerator Centre (IUAC), New Delhi. [1, 2]. It mainly consists of a 2.45 GHz microwave ion source, a compact multi-electrode extraction system and an experimental chamber for performing experiments using intense ion beams in the energy range of a few keV to a few tens of keV. Various kinds of experiments have been carried out related to studies in materials sciences and plasma physics. The facility is planned to be upgraded using a compact Wien filter with a mass resolving power (m/m) of ˜ 200, assuming slits are positioned at a distance of 100 mm from the exit of the filter. The Wien filter will transmit ions with velocities ranging from 0.97 x 10^5 m/sec to 13.83 x 10^5 m/sec. The results of beam optics simulations, the detailed design of the Wien filter and beam transport system will be presented.

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Poster Session 1 / 236, T3_Mo_67

PKGANESA: an ECRIS for Testing the Axisymmetric Magnetic Structure for the Production of Multicharged Ion Beams

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After the development in the 90's of the mono-charged ion source [1] based on a axisymmetric magnetic structure, the next step towards multicharged ion source has been undertaken with the Multigan ion source [2]. The preliminary results did not fully demonstrate the ability of this source to produce high charge states. Therefore, GANIL and Pantechnik got both involved in a collaboration to develop an ECRIS prototype using an optimized axisymmetric magnetic structure devoted to the production of high charge state ions at 10 GHz of RF frequency.

Magnetic structure has been designed, mechanic parts have been machined and assembled before setting this ion source called PKGANESA on a dedicated test bench at the Pantechnik company.

This contribution shall present the PKGANESA characteristics: magnetic structure, mechanical design, RF design as well as measurements done at Pantechnik on the charge states distributions obtained with Ar and the evolutions of CSD regarding RF power, bias electrodes and buffer gases.

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Poster Session 1 / 237, T3_Mo_68

Technical Approaches towards Intense High Charge State Ion Beam Production with Superconducting ECR Ion Sources

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Superconducting ECR ion source incorporated with the cutting edge techniques provides the ultimate conditions for highly charged ion beam production. In the last 12 years (since ICIS 2005 in Caen, France), ECR ion source performance has got remarkable improvement, most of the typical ion beam intensity records have been renewed almost every year, with the great efforts in superconducting ECR ion source development. SECRAL and recently built SECRAL-II ion sources are both high performance 3rd generation ECR ion sources developed at IMP. Technical advancement has obviously helped boost the yield of high charge state ion beams. For instance, only 8.5 e A Ar^{17+} has been produced in 2007 with SECRAL, while 10 years later, SECRAL-II delivered up to 130 e A Ar^{17+} during a high microwave power test. Similar improvement also applies to many other highly charged heavy ion beams. These promising results owe to the continuous technical modification and optimization for dense hot plasma buildup, highly charged ion production, intense beam extraction and high efficiency transmission with reasonable beam quality. This paper will summarize the achievements performed with both SECRAL and SECRAL-II. The technical solutions to produce very intense highly charged ion beams will be discussed and presented.

Poster Session 1 / 242, T3_Mo_69

Recent Developement of RIKEN 28 GHz SC-ECRIS

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To further increase the beam intensity of highly charged U ion beam for RIKEN radio-isotope (RI) beam factory project and to produce the intense beam of medium mass heavy ions, such as Ti, V and Cr ions, for super-heavy element (Z = 119 and 120) search experiments, we tried to improve the performance of the RIKEN 28 GHz SC-ECRIS in last two years.
In the test experiment, we successfully produced ˜ 300 eμA of V^{13+} at low field ($B_{\mathrm{ext}} \sim 1.4$ T) and low RF power ($\sim$ 1.3 kW of 28 GHz). It is significantly low magnetic field compared to that for so called "high B mode" operation ($B_{\mathrm{ext}} \sim 2B_{\mathrm{ecr}}$ ($\sim$ 2T) with 28 GHz). We also produced ˜ 150 eμA of U^{33+} at $B_{\mathrm{ext}} \sim 1.55$ T and RF power of $\sim$1.5 kW.
In this contribution, we presented how to produce these beams in detail.

Poster Session 1 / 246, T1_Mo_15

Non-Conventional Microwave Coupling of RF Power in ECRIS Plasmas

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X-ray imaging and numerical simulations demonstrate that the RF power deposition in ECRIS plasmas is not concentrated in the near-axis region, as it would be desirable in order to maximize the ion beam brilliance. There are different arguments to explain this occurrence as due to the symmetry of the plasma chamber. In this "aperture coupled" cylindrical cavity resonator, in fact, any eigenmode solution of Maxwell equations prefers off-axial concentration of the electromagnetic field. The "aperture-coupling" of the rectangular waveguides with the cylindrical chambers (as it is normally for ECRIS) also suffers of an intrinsic, geometrical impedance mismatch. Both these issues suggest that a major optimization of RF coupling efficiency to ECRIS plasmas is still possible, provided that the overall geometry is changed. A reshaping of both the plasma chamber and related RF launching system - in a plasma microwave absorption oriented scenario - is considered as a possible solution, as well as the design of optimized launchers (taking inspiration from tools adopted in the thermonuclear-fusion) enabling "single-pass" power deposition, i.e. not being affected by cavity walls effects.

Poster Session 1 / 247, T1_Mo_16

Microwave Emission from ECR Plasmas Under Conditions of Two-Frequency Heating Induced by Kinetic Instabilities.

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Multiple frequency heating is one of the most effective techniques to improve the performances of ECR ion sources. It has been demonstrated that the appearance of the periodic ion beam current oscillations in ECRIS at high heating power and low magnetic field gradient is associated with kinetic plasma instabilities. Recently it was proven that one of the main features of multiple frequency heating is connected with stabilizing effect, namely the suppression of electron cyclotron instability in ECRIS plasmas. Due to this kind of stabilization it is possible to run the ion source in stable mode using higher total microwave power and thus to obtain better ion beam parameters. Unfortunately, even with using of such technique at some threshold level the plasma becomes unstable. This work is devoted to experimental investigations of the peculiarities of cyclotron instability in the case of two-frequency heating. It was found out that the plasma microwave emission spectrum connected with the instability is affected by the division of injected power shared between the frequencies. The frequency with higher power was found to determine the microwave emission spectrum, which correlated fully with the spectrum obtained in single frequency operation with the given injected frequency.

Poster Session 1 / 260, T3_Mo_70

The Effect of Frequency Tuning in the 10 GHz NANOGAN ECR Ion Source

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Earlier studies [1] on the frequency tuning effect in the 10 GHz NANOGAN ECR ion source have shown that larger intensities of medium and highly charged ions were extracted as compared to the source operation at 10 GHz and that the beam quality obtained was even better. In the present study we have tried to systematically correlate the x-ray intensities of the warm electrons measured at the injection side, along with the production of the medium and highly charged ions. 3D Simulations of the structure of the emerging beam at the extraction side support the beam digitized measurements and depict a non-hollow beam formation. The detailed experimental measurements together with the simulations will be presented.

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Poster Session 1 / 269, T3_Mo_72

Main Magnetic Focus Ion Source for Ionization of L- and M-Shell Electrons of Heavy Elements

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Novel device based on the technology of Main Magnetic Focus Ions Source [1] has been developed recently at JINR. The electron beam characterized by the current of 50 mA and the energy exceeding 30 keV is focused by the magnetic system consisting of the radial permanent magnets. Highly charged ions are produced in the main focus of magnetic lens, where the electron current density exceeds 10 kA/cm^2. The computer simulations of the charge-state distributions for Xe, Au and Bi ions are presented. A comparison with first experimental results is also made.

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Plasma-Surface Interaction in Negative Hydrogen Ion Sources

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Fundamental data are indispensable to set up a numerical simulation model to predict the amount of current extracted from an ion source. Surface recombination process plays a decisive role for determining the proton ratio in hydrogen plasma ion species, and the data on recombination coefficients have been accumulated for elements used for ion source wall materials [1]. The surface conditions of ion sources, however, are usually far from ideal ones composed of pure metals with hydrogen in ultra-high vacuum environment in which most of the plasma-surface interaction data are collected. For example, a plasma grid of a negative hydrogen (H^-) ion source adsorbs Cs and hydrogen, but the co-adsorption process data obtained in ultra-high vacuum environment [2] cannot be utilized as plasma wall interaction can contaminate the plasma grid surface.

This study aims at finding the plasma-surface interaction process influential on H^- ion source performance. A small ion source sealed with copper gaskets was designed and assembled to study plasma-surface interaction in a H^- ion source. Ports for residual gas analysis, optical emission spectroscopy, Langmuir probe measurement, and laser injection for photodetachment together with adsorbate material ablation are integrated into the source. A high temperature tungsten capillary tube forms a directed beam of atomic hydrogen to see the contribution to the extracted H^- ion current. Effect on Cs accumulation on the plasma grid due to temperature distribution over the inner wall of the ion source is estimated with an infrared thermography.
Addition of foreign materials into the source will alter plasma-surface interaction in the vicinity of the plasma grid. Oxygen or water injection into the test ion source should form oxides on the surface of the plasma grid and may decrease H^- ion emission. Carbon coating on a pure metal substrate can increase/decrease surface work function and sticking probabilities of the grid surface against hydrogen atoms and molecules. Resulting change in extracted H^- ion current together with co-extracted electron current are discussed.

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4th Session / 255

Flow Patterns of H^- Ions Measured with Directional Photodetachment Langmuir Probe

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Tiny amounts of caesium (Cs) injection into negative ion sources enhances the density of hydrogen/deuterium negative ions (H^-/ D^- ions) drastically. Sequential processes through the production to extraction of negative ion is essential to understand the negative-ion dynamics from physics point of view and to improve the performance of negative ion source from engineering point of view. Our primary result obtained by means of a directional photodetachment Langmuir probe (DPLP) shows that the flow of H^- ions comes from metal part of the plasma grid to the bulk plasma region, turned the direction at a certain distance from the grid and moves back to aperture direction where the H^- ions flow due to beam extraction. In order to improve the spatial resolution and expand the region of the flow measurement, a new DPLP whose probe tip aligned along the centre of the probe stem; the probe equips a flow mask plate on the edge of a rotatable tube coaxial to the stem.

In this presentation, changes of the flow patterns of H^- ions with respect to the difference between plasma potential and bias potential, filling H_2 gas pressure and work function, which is measured with newly installed work function detector, together with the combined date obtained with cavity ringdown measurement and Cs laser absorption spectroscopy.

4th Session / 214, T3_CO_06

Plasma Diagnostics Update and Consequences on the Upgrade of Existing Sources

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The development and upgrade of ion sources for accelerators depends more and more on the optimization of the microwave-to-plasma coupling. Proton sources require to optimize the electron energy distribution function (EEDF) in the range of a few tens of eV. Multicharged ions sources require the optimization of EEDF in the keV scale depending on the needed charge state. The energy tail of EEDF must be damped since hot electrons are detrimental for the source performances.

Last but not the least, also the spatial distribution of the EEDF within the plasma chamber should be known since RF power have to be deposited mainly in the regions of the plasma core near to the extraction hole and around the axis. In a few words, plasma parameters diagnostics will play a fundamental role for next developments and upgrade of existing sources, as well as for the design of new ones.

This work presents the set of plasma diagnostics (including interferometer, polarimeter, optical emission spectroscopy, Langmuir probe, pin-hole camera and X rays detectors) already installed at the INFN-LNS testbenchs, the characterization of the EEDF as a function on the source parameters (magnetic field profile, microwave power and frequency and neutral pressure) and the expected consequences on the future design of ion sources.

4th Session / 188, T1_CO_02

Photoelectron Emission Induced by Low Temperature Hydrogen Plasmas

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Low temperature hydrogen plasmas of positive (H^+, H^{2+}, D^+) and negative (H^-, D^-) ion sources are strong sources of vacuum ultraviolet (VUV) radiation. Theoretical calculations based on fundamental conservation laws and reaction cross sections show that at least 10 % of the applied plasma heating power is dissipated via photon emission. The theoretical result is supported by experimental evidence showing that, depending on the plasma heating mechanism, 8-30 % of the discharge power is radiated at VUV wavelength range. The VUV photons (wavelength < 150 nm) carry enough energy to induce a significant emission of photoelectrons when they impinge on a metal surface (typical work function 4-5 eV) on the plasma chamber wall. The emitted photoelectrons might have a considerable effect on plasma properties and especially on the formation of the plasma sheath. We have compared the low temperature hydrogen plasma induced photoelectron emission from molybdenum, aluminium, copper, tantalum, yttrium, nickel, and stainless steel (SAE304) surfaces with different plasma heating methods. For example, in a filament-driven hydrogen arc discharge the total estimated photoelectron current from the plasma chamber walls is on the order of 1 A per kW of discharge power, which corresponds to almost 10 % of typical arc current. Photoelectron emission studies also include low work function cesium and rubidium covered surfaces, which are essential for surface production of negative ions. This work summarizes the photoelectron emission experiments and discusses plausible photoelectron induced effects on plasma properties and plasma sheath structure.

4th Session / 107, T8_CO_25

45 GHz Microwave Power Transmission and Coupling Scheme Study with Superconducting ECR Ion Source at IMP

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A versatile platform for basic researches LEAF or Low Energy Accelerator Facility has been launched at IMP. In order to meet the beam intensity requirements of highly charged heavy ions, a 45 GHz superconducting ECR ion source FECR (a Fourth generation ECR ion source) is under intense R&D at IMP. Therefore, we introduced a 45 GHz gyrotron system which is capable of providing output power up to 20 kW in both CW and pulse modes as a microwave power source for FECR. Other than the gyrotron oscillator, the microwave power transmission, coupling and ECR heating are critical issues for FECR. Since the wavelength of 45 GHz microwave is about 6.67 mm and the maximum power level is 20 kW, the quasi-optical transmission scheme is utilized for high power transmission. This scheme has already been widely utilized in fusion devices, while to accommodate with an ECRIS, the outcome yet remains to be evidenced. The design and technical details of transmission line and coupling system will be presented in this paper. After off-line tests of microwave transmission efficiency and mode purity, 45 GHz gyrotron microwave source will be commissioned with SECRAL II (a superconducting ECR ion source optimized for 28 GHz operation), and some preliminary results of ECR heating and intense beam production will be discussed in this paper.

5th Session / 240

Review of PIC Modelling for the Extraction Region of Large Negative Hydrogen Ion Sources

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Particle-in-cell (PIC) codes are used since the early 1960s for calculating self-consistently the motion of charged particles in plasmas, taking into account external electric and magnetic fields as well as the fields created by the particles itself. One main feature of PIC codes is that they resolve the Debye length, i.e. they can calculate the transition between the quasi-neutral plasma and a wall (the plasma sheath) or – in the case of extraction of charged particles – the transition between the plasma and one or more extracted beamlets (the extraction surface).

Due to the used very small time steps (in the order of the inverse plasma frequency) and mesh size the computational requirements can be very high and they drastically increase with increasing plasma density and size of the calculation domain. Thus, usually small computational domains and/or reduced dimensionality are used. In the last years the available CPU power strongly increased. Together with a massive parallelization of the codes it is now possible to describe in 3D the extraction of charged particles from a plasma, using calculation domains with an edge length of several centimetres, consisting of one extraction aperture, the plasma in direct vicinity of the aperture and a part of the extraction system.

Large negative hydrogen or deuterium ion sources are essential parts of the neutral beam injection (NBI) system in future fusion devices like ITER and the demonstration reactor DEMO. For ITER NBI RF driven sources with a source area of 1.9×0.9 m^2 (1280 extraction apertures) will be used. Extraction of negative ions is accompanied by co-extraction of electrons which are deflected onto an electron dump. Typically, the maximum negative extracted ion current is limited by the amount and the temporal instability of the co-extracted electrons, especially for operation in deuterium.

Although the general effectivity of measures decreasing and stabilizing the co-extracted electron current (for example the magnetic filter field, B_{max} several mT) can be easily demonstrated in the experiment, a thorough optimization (for example finding the optimum filter field topology) can be done only by applying models. Different PIC codes are available for the extraction region of these large RF driven negative ion sources. Additionally, some effort is ongoing in developing codes that describe in a simplified manner (coarser mesh or reduced dimensionality) the plasma of the whole ion source.

The presentation first gives a brief overview of the current status of the ion source development for ITER NBI. Different PIC codes for the extraction region are introduced as well as the coupling to codes describing the whole source (PIC codes or fluid codes). Presented and discussed are measures used in the experiment for reducing the co-extracted electrons as well as recent results of the 3D PIC code ONIX (calculation domain: one extraction aperture and its vicinity) for the ITER prototype source (1/8 size of the ITER NBI source) and the ELISE source (0.9×1 m^2, equal to the same width but only half the height of the ITER source). Finally, an outlook to the future of both the experiments and the code development is given.

5th Session / 130, T7_CO_21

RF driven Multiaperture Surface-Plasma Negative Ion Source: Beam Formation and Transport through LEBT

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High-voltage negative-ion based injector is under development at Budker Institute of Nuclear Physics. Its essential feature is beam transport from the multiaperture source to a single-aperture accelerating tube through a low energy beam transport line (LEBT). This scheme permits to purify the beam from the co-streaming fluxes of fast hydrogen atoms, gas molecules, cesium vapor. As a result, the loading on the accelerating tube by harmful co-streaming and secondary particles is considerably reduced. It will enable more stable operation of the negative ion beam accelerator.
Experimental study of long-pulsed 0.8 -1.2 A, 85-100 keV negative ion beam formation and transport through the LEBT to the distant calorimeter is described. The parameters of the transported beam were measured in the LEBT center at distance 1.6 m by the movable Faraday cup and at the LEBT exit (at distance 3.5 m from the source) - by the multisection beam calorimeter. The efficiency of beam transport vs various beam and LEBT parameters will be presented and discussed.

5th Session / 215, T7_CO_22

First Measurements of Beam Plasma in NIFS Test Stand

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We report on the characteristics of the beam-generated plasma in the multibeamlet case of a large hydrogen negative ion (H^-) beam at NIFS. The plasma potential, and the energy of secondary particles in the drift region of an ion beam, offer an insight into the mechanisms that allow beam transport in low pressure gasses.
The first measurements reported here were made by means of a four-gridded retarding field energy analyzer, combined with the measurement of the drain current at the beam dump, and with infrared beamlet monitoring technique. The retarding field analyzer measures the energy distributions of particles emitted radially from the beam-generated plasma [1]. The beam is dumped onto a graphite calorimeter, which is electrically insulated, so that it can be electrically biased and the collected current can be measured. The thermal image of the calorimeter is acquired during the beam pulse, thus offering a quantitative estimation of the single beamlet optics and multibeamlet focusing [2].
The influence of the neutral gas density is studied by puffing hydrogen gas in this drift region. Neither the ion nor electron saturation current are stable in low pressure regime, while above 10 mPa the characteristics can be obtained for a ~50 keV, 300 mA beam. The measured ion and electron energy distribution functions are strongly affected by the electric bias of the calorimeter, giving indications on the plasma potential profile in the diffusion region. In the compensation region, the beam potential is set by the calorimeter potential. The measured ion distribution functions suggest the possible presence of two populations with different temperatures. The collected data will be used to improve and validate numerical models of beam-plasma formation [3].

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5th Session / 244, T5_CO_17

First Results of Deuterium Beam Operation on Neutral Beam Injectors in the Large Helical Device

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Deuterium beam operation on neutral beam injectors (NBI) have been carried out successfully in the Large Helical Device (LHD) in 2017. We had operated three hydrogen negative-ion and two positive-ion based NBI's since 1998 and 2005, respectively. In 2017, the injection beam power has reached 31 MW used five beam lines, which gave us a new operation region for high ion temperature plasma. Upgrading the beam energy from 40 keV to 60 keV and from 40 keV to 80 keV for deuterium operation in the positive ion based NBI of BL4 and BL5, respectively, we have achieved over 9 MW beam injection which is exceeded designed values. We have shown high-arc efficiency (extracted beam current/arc power) with 83% high deuteron ratio in the positive source measured by Doppler spectroscopy. We also extracted deuterium negative ion beam from three tangential NBI's (BL1, BL2, and BL3) without increase beam energy, although the injection power decreased by half. There was almost no contamination of hydrogen due to the switching to the deuterium beam. The arc efficiency of the deuterium negative ion is 60 - 70 % of the hydrogen case, and the current density of the accelerated current reached 190 A/m^2, which is comparable with the designed value of deuterium beam current for ITER-NBI. Since the deuterium beam width observed on the calorimeter is widened by 1.2 times, it might be considered that the geometric focusing condition of the beam is not optimum for deuterium. The beam injection efficiency decreased by 15 % caused by several factors. Certainly, the extracted electron current increased in deuterium operation, however, we have any trouble on the beam line components.

6th Session / 241

Charge Breeding of Radioactive Isotopes at the CARIBU Facility

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An Electron Beam Ion Source Charge Breeder (EBIS-CB) has been developed at Argonne National Laboratory as part of the CAlifornium Rare Ion Breeder Upgrade (CARIBU). For the past year, the EBIS has been undergoing commissioning as part of the ATLAS accelerator complex. It has delivered both stable and radioactive beams with $A/Q < 6$, breeding times < 30 ms, low background contamination, and charge breeding efficiencies $> 18\%$ into a single charge state. The operation of this device, challenges during the commissioning phase, and future improvements will be discussed.

Acknowledgement

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6th Session / 298

New Challenges in Ion Beam Extraction Modelling

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The classic sheath model for unmagnetized positive ion extraction codes was developed in the seventies. It assumes that the extracted ions originate from a positive plasma potential and experience a monotonic acceleration through the plasma sheath towards the extraction at negative potential. The model assumes that the compensating electron density can be stated as an analytic function of the potential. The classic model has been shown to predict the properties of extracted beams well.

Later, the use of the successful model extended to negative ion extraction systems, especially H^-, by changing the assumed potential distribution and by adding e^-, H^+, H_2^+, H_3^+ and possibly other particle populations in addition to the H^- either by tracking the particles through the E-field and the geometry or by assuming that the particle densities are analytic functions of the potential. This type of codes have shown decent accuracy predicting the extracted H^- and e^- properties despite the fact that the effect of the filter magnetic field on the electrons in the plasma is not taken in account properly and that the particle flux emitted by the plasma is assumed to be uniform. Especially in the case of surface-enhanced production of H^- it is believed that the
particle fluxes near the plasma electrode aperture are not uniform. In these cases methods are needed to model such cases as it is of importance to understand the effect of the nonuniformity on the beam properties.

Similar situation exists also in electron cyclotron resonance ion source (ECRIS) beam formation. The magnetic trap consisting of an axial magnetic mirror and a hexapole component is used to provide the resonance condition for heating the plasma and the confinement necessary for the creation of the high charge states.The beam is formed from the particle flux escaping the trap through the extraction aperture and due to the fact that electrons are trapped to the magnetic field lines the particle flux has a nonuniform triangular shape. Cylindrically symmetric uniform emission extraction simulations are often used to model ECRIS beam formation as sufficient information is not often available for use in more detailed simulations.

This paper describes the consequences of the approximations made by the extraction models and presents methods for modelling the formation of nonuniform beams.

6th Session / 234, T5_CO_16

Improved Understanding of the Caesium Dynamics in Large H^- Sources by Combining TDLAS Measurements and Modelling

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The ITER Neutral Beam Injection (NBI) relies on sources of negative hydrogen and deuterium ions which deliver a homogeneous and temporally stable extracted negative hydrogen ion beam for up to one hour (57 A extracted D^- current from an extraction area of 2000 cm^2), at which the co-extracted electron current has to be lower than the extracted negative ion current. The large ELISE (Extraction from a Large Ion Source Experiment, first plasma in 2013) test facility with an ion source size of 0.9 x 1 m^2 is equipped with a ½ ITER-NBI scale H^- source. Negative hydrogen ions are created by conversion of hydrogen atoms and positive ions on a surface with low work function. In order to reach the ITER requirements, a stable and homogeneous coverage of caesium has to be maintained on the plasma grid, which is the first grid of the extraction system. The dynamics of the highly-reactive Cs in the source is complex due to the vacuum conditions (10^{-7} mbar) as well as the plasma-enabled redistribution of Cs.

The Monte-Carlo test particle transport code CsFlow3d has been developed in order to simulate fluxes of Cs and Cs^+ as well as the Cs coverage on the surfaces of the ion source during vacuum and plasma phases of the pulsed-driven sources. A successfully applied benchmark of the code at the small size prototype ion source (ITER source size) allows now for giving predictions also for the larger ion sources. For the ELISE source, the code revealed for the Cs dynamics a high relevance of backstreaming positive ions created in the extraction system, which has to be taken into account since due to the available HV power supply ELISE is presently only able to extract a beam for 10 s each three minutes in long (up to one hour) plasma pulses. The installed Tunable Diode Laser Absorption Spectroscopy (TDLAS) diagnostic at the Cs 852 nm resonance line allows for measuring the neutral Cs density averaged along two horizontal lines-of-sight close to the plasma grid, giving additionally insight into the vertical asymmetry of neutral Cs. As a new feature, the temperature of Cs is evaluated from the Doppler broadening. Predictive results of the code, as the role of backstreaming ions and the temporal behavior of the Cs density in short (20 s) and long pulses could be experimentally verified. A comparison between measurement (Cs density) and modelling (Cs density, fluxes and coverage) is presented for long and short pulses at ELISE.

6th Session / 39, T4_CO_10

The RAID Experiment for the Investigation of Negative Ion Physics for Fusion Applications

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The Neutral Beam (NB) system for ITER will deliver an ion beam with energy of 1 MeV and current of 40 A. Only NB systems based on negative ions can attain the neutralization efficiency required for the NB system in ITER. Helicon plasmas are a promising candidate for the production of negative ions. The RAID (Resonant Antenna Ion Device) at the Swiss Plasma Center represents a crucial step in understanding helicon plasma physics and negative ions production through volume processes. In this talk the last advances on RAID will be presented including the preliminary measurements of H^- density by means of Cavity Ring-Down Spectroscopy and microwave interferometry measurements.

6th Session / 73, T1_CO_01

Particle-Based Model of Plasmadynamics in ITER-Prototype Negative Ion Source

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This work represents a detailed numerical simulation of the ITER-prototype negative ion source. The numerical model is based on Particle-in-Cell / Monte Carlo Collision (PIC-MCC) methodology to study production, transport and extraction of all charged particles (electron, positive and negative ions) in a self-consistent electric field (magnetostatic approximation). The effect of grid biasing and gas isotope (hydrogen/deuterium) have been investigated.

Poster Session 2 / 283, T5_Tu_59

Neutral Beam Injection System for the C-2W Field Reversed Configuration Experiment

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C-2U Field-Reversed Configuration (FRC) experiment proved substantial reduction in turbulence-driven losses via tangential neutral beam injection (NBI) coupled with electrically biased plasma guns at the plasma ends.[1, 2] Highly reproducible FRCs with a significant fast-ion population [3] and total plasma temperature of ~ 1 keV were produced and sustained for times significantly longer (more than 5 ms) than all characteristic plasma decay times without beams. [4]

Last year, the C-2U experimental device underwent a major upgrade in order to to further improve the FRC sustainment and demonstrate the FRC ramp-up. The new C-2W machine is equipped with a new NBI system producing a record total hydrogen beam power of 13+ MW in a 30 ms pulse. The NBI system consists of eight positive-ion based injectors featuring flexible, modular design based on a triode ion optical system with slitted multi-aperture inertially cooled grids and ballistic beam focusing. The cold-cathode arc discharge plasma sources [5] generate up to 180 Amps of extracted ion current.

This presentation provides an overview of the C-2W NBI system, including the design of the injectors, layout of the power supply system, and first experimental results.

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126, T4_Tu_07

Diagnostics of Ta deposited Plasma Electrode for Negative Hydrogen Ion Production with DC Laser Photodetachment Method

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The difference in material that covers the plasma electrode surface can affect the production and destruction processes of negative hydrogen ions (H^-). Tantalum adsorption on the plasma electrode is believed to reduce negative ion destruction by capturing hydrogen atoms, and the same effect is expected for caesium adsorption.

In this experiment, tantalum and tungsten filaments produce a hot cathode discharge plasma in a cylindrical ion source filled with hydrogen gas. The filaments evaporate the material to form a layer of each element on the plasma electrode surface. These filaments are 0.35 mm in diameter and the ends are fixed to the current feed through ports with screw to make their length to be about 90 mm. The ion source has 150 mm inner diameter and 200 mm height. A 350 l/s turbo molecular pump coupled to an oil rotary pump evacuate the apparatus to reach the ultimate pressure down to 3.0×10^{-5} Pa. Electron temperature and electron density are measured with a Langmuir probe immersed in the plasma. Irradiation of an 808 nm semiconductor laser yields photon induced signal corresponding to the H^- density by photodetachment reaction near the plasma electrode. The characteristics of photodetachment signal against plasma electrode bias are being investigated for different coverage of Ta.

Poster Session 2 / 281, T6_Tu_81

REGLIS3 at S3 for the Production of High Purity Refractory RIBs

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Rare Elements in-Gas Laser Ion Source and Spectroscopy at S3 (REGLIS3) is the new set-up currently under construction at the SPIRAL2/GANIL facility for the production of high-intensity radioactive ion beams, preselected by the Super Separator Spectrometer (S3). REGLIS3 will be a source for the production of low-energy, high-purity isotopic and isomeric ion beams and at the same time a tool for high-precision laser spectroscopy and mass spectrometric measurements [1], amongst others. It is based on the 'In-Gas Laser Ionization and Spectroscopy' (IGLIS) technique, which has been pioneered at KU Leuven in Belgium. In the most recent variant of this technique, a radioactive ion beam is thermalized and neutralized in a gas cell. A continuous flow of gas leads the atoms to the exit of the gas cell, where a de Laval nozzle produces a quasi-parallel supersonic gas jet in which the resonant laser ionization takes place. The selectively-ionized atoms of interest are then efficiently transported and bunched by a system of segmented Radio-Frequency Quadrupole (RFQ) ion guides, accelerated and mass separated. The low temperature, small velocity spread and low pressure in the jet, enable the different spectroscopic broadening mechanisms to be significantly reduced in comparison to in-gas-cell laser ionization spectroscopy, where the ionization region was placed within the gas cell, rather than in the gas jet [2]. The first on-line demonstration of this new technique has been recently performed at the LISOL facility, Louvain La Neuve, Belgium, with 214-215Ac isotopes [3]. A strong improvement in spectral resolution was obtained compared to the standard in-gas cell technique. A gain in efficiency and selectivity of about a factor ~20 was also achieved. With these new results, the selective production of isomer ions can be investigated. These results and the status of the REGLIS3 setup will be presented at the conference.

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Poster Session 2 / 268, T6_Tu_80

Development of an Off-Line Negative Ion Source for the Characterization of the Photodetachment Detector GANDALPH

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The Gothenburg ANion Detector for Affinity measurements by Laser PHoto-detachment (GANDALPH) has recently been built to determine the electron affinity (EA) of radioisotopes by laser photodetachment spectroscopy. As a proof-of-principle, the EA of the 128-iodine negative ion, produced at the CERN-ISOLDE radioactive ion beam facility, was measured with GANDALPH – representing the first ever photodetachment measurement of a radioactive isotope. This is a milestone towards the determination of the EA of the radioactive halogen astatine (At), the rarest naturally occurring element on Earth. The EA of astatine, together with the previously measured first ionization potential (IP) gives valuable benchmarks for quantum chemical calculations predicting the chemical properties of this element and its compounds.

GANDALPH is undergoing several upgrades in order to improve its suitability for the study of low intensity beams (<1 pA) of negative radioactive astatine ions that may be expected at ISOLDE. To facilitate offline testing and fine-tuning of the neutral atom detector, as well as to test electrostatic elements in the beam-line, a dedicated off-line negative ion source has been conceived.

We will introduce the general concept of the GANDALPH experimental beam line and the envisioned measurements at ISOLDE. A detailed description of the ion source and its parameters will be given in addition to a summary of the first results obtained from off-line experiments.

Poster Session 2 / 266, T5_Tu_58

Particle Model of the Driver of the Negative Ion Source for ITER Neutral Beam Injection System

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The Neutral Beam Injection (NBI) heating system of ITER is a key stage for the yield of the full tokamak machine. The performance of the NBI system in turn strongly depends on the yield of the first component of the system, the negative ion source of D^- (or H^-) ions.
The plasma is inductively created, by means of a RF discharge in the deuterium or hydrogen gas, in the so-called "driver". This kind of source is therefore referred as Inductively Coupled Plasma – Radio Frequency (ICP-RF) source. The formed plasma expands in a larger chamber and is then extracted.
While several simulation tools have been developed for the expansion and extraction regions, a full self-consistent particle simulation of the driver region is still lacking, because of the difficulties created by the inclusion of the inductive coupling in the computational codes.
For this reason we developed a 2.5D Particle-In-Cell Monte-Carlo-Collision (PIC-MCC) model of a cylindrically symmetrical ICP-RF source with the dimensions and the parameters of the driver of ITER NBI negative ion source, with hydrogen as filling gas, keeping the grid spacing and time step of the simulation small enough to respectively resolve the Debye length and the plasma frequency scales. We report the results of these simulations, which require a massive parallelization, and give some details about the computational side.

Poster Session 2 / 76, T4_Tu_01

Work Function of Caesiated and Cs-Free Materials for Enhanced H^- Surface Production

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Sources for negative hydrogen ions for accelerator front-ends or neutral beam injection systems of fusion experiments use the surface conversion mechanism to convert hydrogen atoms and positive ions from a low temperature hydrogen plasma to negative ions. The efficiency of the underlying conversion mechanism is dominantly determined by the work function of the surface, which is the reason for using low-work-function materials. These materials, e.g. caesiated surfaces or materials with inherently low work function, typically show also a high chemical reactivity and are thus easily affected by impurities from background gases. In H^- sources background pressures are typically in the range of $10^{-7} - 10^{-6}$ mbar and furthermore the surface is recurring in contact with a hydrogen plasma. On the contrary, work function values of low-work-function materials found in the literature are mostly measured in ultra-high vacuum (below 10^{-9} mbar) and can consequently not be applied to the conditions present in negative ion sources. Hence, dedicated fundamental investigations are performed under ion source conditions at a flexible laboratory experiment aiming at the parameters influencing the surface work function. Absolute work function values are determined via the Fowler method [1,2]. Investigated materials include caesiated and Cs-doped surfaces as well as lanthanated (MoLa, WL10, LaB_6) and bariated (tungsten dispenser cathode) materials.

It is shown, that with caesiated surfaces the lowest work function of all so far investigated materials can be achieved (measured down to ≈ 2 eV). However, this value is highly dependent on Cs influx, plasma surface interaction and impurity incorporation. Cs-free materials do not exhibit such a distinct dynamical behavior, while their nominal work function values taken from the literature are expected in the range of 2.1−3.0 eV. Measurements of the negative ion density above such surfaces have, however, already shown [3] that the enhancing effect on n_{H^-} is much less pronounced than for caesium, which is attributed to surface work functions higher than the nominal values. In order to obtain the envisaged low work function, several of these materials require specific activation procedures at temperatures up to 1500 °C. At conditions closer to typical ion source operation, i.e. surface temperature of below 250 °C in a H_2 plasma, lanthanated tungsten (WL10) for instance showed a decrease of the work function of only down to about 4 eV.

Hence, ways of optimizing the work function of Cs-free as well as caesiated surfaces are investigated by a wide-ranging variation of the surface temperature, inducing plasma surface interaction with and without biasing the sample surface as well as combinations of it. Furthermore, the stability and/or degradation behavior of the work function with and without plasma exposure is of major interest.

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Poster Session 2 / 80, T4_Tu_02

Recent Results in Modeling of LANSCE H^- Surface Converter Ion Source

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Models of the hot cathode performance and thermal arc discharge were used to estimate main plasma parameters and the sputtering rate of tungsten atoms. The hot filaments in H- surface converter ion source suffer from non-uniform mass loss that limits its operational lifetime. The dominant mass loss mechanisms used in the new filament model are: the thermal evaporation and plasma sputtering caused by heavy ions (Cs^+ and W^+). Light hydrogen ions (H^+, $H2^+$, $H3^+$) do not have an influence on the tungsten filament erosion in our ions source. Their maximal kinetic energies gained in near cathode region (up to 180 eV) are below the ion sputtering threshold energies. In several hot wire resistance measurements during the LANSCE beam production cycles, we have observed an increase of the filament mass erosion rates after the cesium transfer, following a change in cesium oven temperature or following a change to the arc discharge voltage. The filament lifetime analysis based solely on the simplified thermal evaporation was no longer applicable [1, 2]. We will discuss a set of experiments to separate and measure the different mass erosion contributions caused by the thermal evaporation and the heavy ion plasma sputtering.

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Poster Session 2 / 103, T4_Tu_04

Numerical Analysis of Negative Hydrogen Ion Beam Optics by Using 3D3V PIC Simulation

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In order to clarify the physics of the H^- ion extraction and beam optics such as the beam halo formation, and contribute to the design of a negative ion source, the integrated model of negative ion beam from plasma meniscus formation to the beam acceleration is developed by using the 3D3V PIC (three dimensions in real space and three dimensions in velocity space particle in cell) model combined with a Monte Carlo calculation. In this study, the beam optics including the beam halo is estimated quantitatively from the viewpoints of the heat loads in the accelerator and the emittance of the negative ion beam.

The JT-60U negative ion source is modeled in the present study. The accelerator is the multi-stage type, which consists of the first acceleration grid (A1G), the second acceleration grid (A2G), and the grounded grid (GRG). Each voltage is taken to be 120 kV, 240 kV, and 355 kV, respectively.
The present 3D3V PIC model is summarized as follows:

1) The electron temperature and the electron density are taken to be 1 eV and 1 x 10^{18} m^{-3}, respectively. The ion temperatures in the source plasma are taken to be 0.25 eV for the H^+ ions and the volume produced H^- ions.

2) Electron-neutral and Coulomb collisions are taken into account through the electron diffusion across the magnetic fields. Since the electrons lost along the magnetic field line cannot contribute to the diffusion across the magnetic field, we take into account the electron loss along the field line as " /// " model, where / and are the characteristic time of the electron loss along the magnetic field line and the characteristic time of the electron diffusion across the magnetic field, respectively.

3) The surface produced negative ions are modelled to be launched from the surface of PG uniformly. The initial velocity distribution is assumed to be the half-Maxwellian with the initial temperature of 1 eV.

4) From the measured emittance of the H^- ion beam, one can estimate the H^- ion temperature to be 0.1 eV of the order of magnitude. Therefore, the energy relaxation processes of H^- ions due to the Coulomb collision and charge exchange with the H atoms are taken into account.

In the present PIC simulations, the stripping loss of H^- ions via the collision of H^- ion and the residual H^2 gas molecules is not taken into account. Thus, the heat loads in the experimental result by extrapolating the source gas pressure to 0 Pa, in which there is no contribution from the stripped electrons, is compared with the simulation result. From the experimental results, the fractions of heat loads to the total beam power at 0 Pa are evaluated to be 2.4 % (A1G), 3.0 % (A2G), and 5.0 % (GRG), respectively. On the other, hand, in the simulation result, the fractions of heat loads due to the intercepted negative ions to the total beam power are evaluated to be 0.9 % (A1G), 2.4 % (A2G), and 3.7 % (GRG), respectively. As for the A2G and the GRG, the simulation result almost agrees with the experimental result.

However, there is a difference for the heat load of the A1G between the simulation result and the experimental result. The heat loads in the experimental result include the secondary electrons from the extractor and so on although the effect of the secondary electrons is not taken into account in the present 3D PIC simulation. Thus, the contribution of the secondary electrons will be one of the reasons for the difference of the heat load of the A1G between the 3D PIC simulation and the experimental result.

Moreover, the emittance of the normalized emittance of the negative ion beam after the exit of the GRG is estimated to be 0.18 mm mrad, which agrees with the typical value of the negative ion beam emittance.

Poster Session 2 / 109, T4_Tu_05

System for Voltage Control and for Data Acquisition of Retarding Field Energy Analyzer

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One of the main concerns when working with negative ion sources is beam collimation during propagation. All the particles that make up the beam have the same electric charge, therefore they tend to repel each other: this causes the beam to widen after being accelerated. In environments where the beam needs to travel long distances before reaching its target, the compensation of its space charge is necessary; the most straightforward way of achieving this is the creation of a plasma around the beam, created by ionization of the background gas by the beam itself. This effect, called space charge compensation, plays therefore a key role in the beam propagation and a deep understanding of phenomenon is fundamental when operating negative ion sources. In order to perform measurements of the particles forming such beam, a retarding field energy analyzer (RFEA) is suitable. RFEAs are indirect non perturbing instruments, which analyse the particles emitted radially from the beam plasma, and allows to estimate the plasma parameters from the energy distribution function of ions and electrons. This diagnostic system consists of a conductive case located perpendicularly to the beam. It mainly acts as a repeller for electrons; thus the remaining positive ions expelled from the beam due to the slightly positive potential can enter the analyzer and reach the collector at the opposite end. Inside the analyzer, four grids are biased with variable voltages to select the particles according to their energy and to measure the relative collected currents. To this purpose a polarization and acquisition system was designed and developed suitable to the RFEA. In this paper the circuitry of such system is presented, showing its main features and discussing the performances. The system is designed so as to bias the grids and the metal case itself, and to investigate the corresponding collected currents. The system has been developed starting from a Raspberry_PI single-board computer and the printed circuit board called R_Adapt. The latter one is a multi-channel card for ADC-DAC general purpose, with the possibility of expansion, having the integrated ADC and DAC channels electrically isolated and managed via Raspberry_PI. The system comprises: 4 amplifiers (made with the components Apex PA85) with output voltage of ±120 V at 100 kHz; 4 acquisition channels for the voltage of the grids with 12 bits resolution at 100 kHz. The settings of the amplifiers and the data acquisition are managed by three Raspberry_PI cards and the custom card R_Adapt developed at Consorzio RFX. This one guarantees the electrical insulation of the measurements with respect to the electrical reference of the Raspberry_PI cards to carry out measurements at different potential without affecting the output signals. The acquisition system setup is based on the C.A.R.S. (Control and Acquisition on RaspberryPi Systems) solution, using WebSocket and a webserver present on the Raspberry_PI. With this configuration the client PC does not need any particular configuration to use the device. Data is stored locally and can be accessed via web browser, ssh or ftp.

Poster Session 2 / 124, T4_Tu_06

Numerical Analysis of Ion Dynamics in RF ICP Discharge

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Radio Frequency (RF) Inductively Coupled Plasmas (ICPs) have been utilized in the wide variety of fields, e.g., material processing [1], accelerator [2], fusion [3]. Although such RF-ICPs play important roles in their fields, the operation of the RF-ICPs is difficult to control because of the complexity of their discharge process. In the previous work, an ElectroMagnetic Particle in Cell Monte Carlo Collision (EM PIC-MCC) code has been developed to obtain the insight of such complex discharge process of RF-ICP. The code is able to track the dynamics of the charged particles (e^-, H^+, H_2^+) in the RF ICP discharge. We have worked on the step-by-step upgrade of the simulation code to make the more detailed physics analyzable.[4,5,6,7] The work presented in [7] enables the code to reproduce the discharge mode transition (E-to-H) in a self-consistent manner. The results indicate that the dynamics of the positive ion may affect the discharge process especially during/after the mode transition.

Acknowledgement

The present study investigates the dynamics of ions in the RF-ICP discharge with some upgrades, e.g., H_3^+ will newly be taken into account, more consistent determination of the initial condition. Using the upgraded simulation code, we discuss the relation between the dynamics of the ions and the typical discharge parameters such as plasma density/temperature, spatial profile of each particle species and the power deposition inside the plasma, etc.

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Poster Session 2 / 127, T4_Tu_08

Development of Cesium-Free Negative Ion Source by Using High Density Sheet Plasma

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This study relates to the negative ion source for Neutral Beam Injection (N-NBI [1]). Production of negative ions plays an essential role in N-NBI. A negative ion beam with an energy of 1 MeV and a current of 40 A (a negative ion current density of 20 mA/cm^2) is required for 3600 s to produce 16.5 MW of power. Conventional negative ion sources require cesium seeding to obtain high negative ion density by surface production. However, cesium seeded surface production of negative hydrogen ions is not desirable from the point of view of operating steady state ion sources. On the other hand, our experimental setup (sheet plasma device TPD-Sheet IV [2]) can product high density negative hydrogen ion in cesium-free discharge by using the magnetized sheet plasma. We observed that there is negative hydrogen ions by mass spectrometry and performed an experiment of negative hydrogen ion extraction. Under a secondary hydrogen gas entering the hydrogen plasma, the peak position of the negative hydrogen ion density (nH^-) is localized in the periphery of the sheet plasma.[3,4] It is found that negative hydrogen ions are formed by the dissociative attachment of low energy electrons (Te = 1-2 eV) to highly vibrationally excited molecules, which are attributed to the electron-impact excitation of molecules by high energy electrons (Te > 10 eV) in the plasma column, and they are transported to the periphery of the sheet plasma. The negative hydrogen ion density were detected using an Omegatron mass analyzer, while the electron density and temperature were measured using a Langmuir probe. We carried out current measurement at collector and calorimetry using the calorimetry method with a thermocouple by single aperture extract device. As a result, when the extraction voltage was 3.0 kV and the discharge current was 50 A, a negative hydrogen ion current density of 7.0 mA/cm^2 was obtained by current measurement at collector. Also, in the calorimetry method using thermocouples measured at the same time, a negative hydrogen ion current density of 5.5 mA/cm^2 was obtained.

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Poster Session 2 / 128, T4_Tu_09

The Effect of Transport and Extraction of Non-Uniform Surface Produced H^- in Large Multi-Aperture Negative Ion Sources

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Spatial non-uniformity of the surface produced negative ions (H^-) has been one of the causes of non-uniform beam and the resultant short pulse duration time and insufficient power for QST's (former JAEA) JT-60SA Negative Ion Source (NIS) [1]. Since the asymmetric feature of the high-energy electrons causes the spatial non-uniformity of the H^- on the Plasma Grid (PG) surface [2], a numerical analysis of the electrons inside the JT-60SA NIS has been conducted with the KEIO-MARC [3] (**K**inetic **E**lectron transport simulation of **IO**n source plasmas in the **M**ulti-cusp **ARC** discharge) code [4]. By modification of the filter magnet configuration in the JT-60SA NIS, the numerical results of negative ion production rate agrees reasonably with the extracted beam intensity in the experiment, and the improvement of the spatial uniformity has been observed [1, 2, 4]. However, we still see both qualitative and quantitative disagreements to some extent. This could be attributed to the fact that we have not compared the two results directly, i.e. the surface produced negative ions are not extracted directly but, once transported inside the NIS and then extracted as beams.

Therefore, the purpose of this study is to compare the calculated and the experimented beams directly by taking H^- transport and extraction into account. In order to do so, a 3D H^- trajectory calculation has been developed which is similar to the model developed by Sakurabayashi [5]. By comparing the numerical results with the experimental results [1, 2], the macroscopic features of the H^- transport and extraction will be discussed.

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Poster Session 2 / 131, T4_Tu_10

Numerical Simulation of the EEDF and the Neutral Transport in the DC Arc-Discharge Hydrogen Negative Ion Source for Medical Use

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Multi cusp DC arc-discharge hydrogen negative ion (H^-) source has been developed for proton cyclotron, which is used for Boron Neutron Capture Therapy (BNCT) [1, 2]. In order to shorten the treatment time for BNCT, it is required to get high extracted beam current from the source.
The final goal of this study is to understand the dependency of the H^- production on the following operation parameters and optimize the H^- production in the source. 1) geometry of the source chamber and location of filaments, 2) 3D magnetic configuration, 3) the position of H_2 gas injection and 4) arc-discharge power.
In this study, we focus on H^- surface production. It is pointed out that H atom flux onto the plasma grid (PG), especially Franck Condon H atom with first flight, plays a key role for the H^- surface production [3]. Therefore, it is necessary to evaluate the spatial distribution of H atom production due to the H_2 dissociation and the H atom flux onto the PG. In this study, these important parameters have been numerically calculated. The numerical model consists of two parts. Firstly, the electron energy distribution function (EEDF) in the source has been calculated by KEIO-MARC code [4,5,6]. Secondly, neutrals (H_2 ,H) transport has been simulated by Monte Carlo method with the EEDF by KEIO-MARC code being fixed.
Based on the above model, we are now performing a series of numerical simulations. These simulation results will be useful to understand the dependency of the parameters noted above on the (H^-) production and optimize the (H^-) production in the source.

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Poster Session 2 / 132, T4_Tu_11

Present Status of the J-PARC Cesiated RF-Driven H^- Ion Source

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Operation of a cesiated rf-driven negative hydrogen ion source was initiated in September 2014 in response to the requirements of beam current upgrade in J-PARC linac. Delivery of the required beam current from the ion source to the J-PARC accelerators has been successfully performed. In 2016-2017 campaign, continuous operation of the ion source for approximately 1450 hours (from January to March 2017) was achieved with beam current, macro pulse width and repetition of 45 mA, 500 μs and 25 Hz, respectively. We present the operation status of the ion source as well as R&D activities at a new test stand [1] equipped with a set of an H^- ion source and an LEBT which is almost the same configuration as the J-PARC linac.

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Poster Session 2 / 133, T4_Tu_12

Development of the Plasma Impedance Prediction Model in Radio Frequency Negative Ion Sources

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A new linear accelerator Linac4 is under development at CERN as a part of the upgrade of their accelerator chain. A radio frequency (RF) driven type negative hydrogen (H^-) source is used as an injector of Linac4. The Linac4 H^- source must deliver 40-50mA, 45 keV H^- beam. The power transfer efficiency between the RF generator and the ion source plasma is one of the important parameters that determines the extracted H^- beam current. In order to achieve efficient power supply, it is required to match the impedance between the RF-system and plasma loading. In the previous study [1], it has been shown that the frequency tuning during the plasma pulse is useful to cope with the variation of the load impedance.

Aiming to investigate the optimum frequency tuning, we have developed a plasma impedance prediction model. The model consists of mainly two parts: 1) the global particle/energy balance of plasma, and 2) the equivalent circuit model of the RF plasma and surrounding antenna [2, 3]. The characteristics of the load can be calculated in the time domain by using this model.

We have calculated the optimum frequency tuning during the plasma pulse using the model described above. The results indicate that the amount of the power supplied to the plasma increases by a few tens percent by tuning the frequency adequately. The calculated optimum waveform of the frequency agrees qualitatively with the frequency waveform used for the experiments at CERN [4]. The model developed in the present study is useful to investigate the optimization of power supply by the dynamic frequency tuning and can also be used for the analysis of other inductively coupled plasma (ICP) reactors.

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Poster Session 2 / 140, T4_Tu_13

Development of an Electron Attachment Type Negative Fullerene Ion Source

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Intensification of negative fullerene (C60) ion beam current from an ion source is indispensable for research and developments using a MeV energy C60 ion beam with a tandem accelerator. Generally, a cesium sputtering type ion source has been used to generate a negative C60 ion beam. An average current of the negative C60 ion beam is about 50 pA, and the current goes down to 1/100 within an hour or less because the C60 molecules in a sputter cathode were broken by the impact of cesium ion [1]. Therefore, we are developing an electron attachment type C60 negative ion source alternative to the cesium sputtering type ion source. A C60 has a high electron affinity of 2.65 eV, and the electron attachment cross section is high when the electron energy ranges from 0.2 to 12 eV. In this method, the sublimed C60 is negatively ionized by capturing a low energy electron. A new ion source which is composed of an ion generation chamber, a sample vaporization oven, and a filament as an electron supplying source has been made. The negative ion generation test with the ion source is performed in off-line test stand equipped with an analyzing magnet. As a result, the C60- beam current of 600 nA is able to extract at the beam energy of 3 keV. In addition to the thermal electrons emitted from the filament, low energy electrons emitted by ionization of C60 might be contributing to the generation of negative C60 ions, because the positive C60 ions are generated at the same time. The current can be kept constant more than 10 hours by gradually increasing the oven temperature and the filament current. Details of the ion source and the results of negative C60 ion generation test will be reported at the conference.

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Poster Session 2 / 144, T4_Tu_14

Long-Term Performance of CW Negative Hydrogen Ion Source at BINP Tandem Accelerator

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An 8 mA CW surface-plasma negative hydrogen ion source [1] has been routinely used during last decade for proton beam production at 2 MeV vacuum insulation tandem accelerator at the Budker Institute of Nuclear Physics. Continuous 4–6 hours dc runs of the source were regularly produced, and proton beam with current > 5 mA was accelerated [2].
The source uses the hydrogen-cesium Penning discharge with plasma injection from hollow cathodes. The negative hydrogen ions are produced due to surface-plasma mechanism on the anode electrode, covered by cesium, and are accelerated with the triode ion-optical system. It is important to note, that the only one source unit was used during the indicated ten-year period, and only a few upgrades of the source construction with replacement of the worn elements were made. Data on source performance, upgrades and maintenance statistics during long term exploitation will be presented and discussed.

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Poster Session 2 / 148, T4_Tu_15

The Improvement of CSNS Ion Source

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CSNS ion source, similar to ISIS ion source is a type of penning surface plasma ion source, which can produce 50 mA H^- beam. The commissioning of CSNS front end including ion, LEBT and RFQ has been finished. Above 15 mA H^- beam is obtained at the exit of RFQ, which meets the requirement of CSNS phase I. However, the improvement of both, beam performance and operation stability, is desirable to be studied further. Some modifications have been performed, including penning field, extraction optics, post acceleration, and power supply. A new ceramic insulator is designed. A cap is added into the end of insulator, which increase insulated distance in vacuum side with no influence on beam optics. The permanent magnet is tried to produce penning field instead of pole tip mounted on the analyzing magnet top surface. Some simulations are done using PBGUNS and CST. Various extracted structure are simulated aiming to make the beam through the extracted electrode without loss. Furthermore, a new extraction power supply is designed, which can offer associate pulse power supply. During non-pulse extraction, this associate power supply is created to extract negative beam, which will loss on the surface of extraction electrode largely. In this case, the surface temperature of extraction electrode will be heated to over a hundred degree. And the cesium vapor from the discharge chamber will and not deposit on this surface. The stability of ion source thus is improved further. The commissioning of ion source shows a good result within 48 hours. The plasma emission spectrum is also applied to diagnose the plasma discharge.

Poster Session 2 / 150, T4_Tu_16

First Experimental Results of the Helicon Driver on Cybele

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Cybele machine which is directed to development of the future NBI system SIPHORE for the reactor DEMO [1] is assembled and operated at the IRFM in CEA Cadarache. The main purpose is to create a tall and narrow (blade-like) negative ion beam (H^-, D^-), for further neutralisation by laser photodetachment. The source has a high aspect ratio (1.2 m $\times$ 0.15 m), which is particularly relevant to the SIPHORE concept and creation of the blade-like beam. In the top of the source a Helicon driver is installed, which currently operates with a 13.56 MHz 10 kW generator. A magnetic field parallel to the source vertical axis is generated by two lateral electric coils sitting on opposite sides of an iron rectangular frame which surrounds the source, to provide homogeneous vertical magnetic field.

The Cybele ion source has been tested with the Helicon driver to inject plasma particles in the direction parallel to $\vec{\mathbf{B}}$. The first experiments were carried out with 3 kW of RF power, in pure Argon or mixture of Argon and Hydrogen at the gas pressure ˜0.3 Pa (ITER and DEMO relevant).

Plasma propagates well in the source volume over 1 to 1.2 m. The Langmuir probe diagnostics measured plasma density up to $4x10^{17}\,m^{-3}$ and temperature around 3-5 eV (pure Argon) at a distance of 10 cm from the center of plasma column and at a vertical position 60 cm from the output of the driver.

The experiments revealed a significant deviation of the plasma column from the vertical axis.

Modelling activities dedicated to the optimization of the Cybele source were performed. The simulation of 3D electron trajectories explained the reason of plasma deviation. The non-symmetrical magnetic field coils with respect to the Helicon driver cause plasma particle deflection from the main central axis of the NI source.

Further investigation and construction modification will be done in next few months, to make the plasma column well centered in the vertical direction. For this purpose a new flange is under manufacturing now. Also new extraction and acceleration grids in front of plasma source are manufactured in order to extract the negative ions from the plasma edge.

Finally, in this contribution we will present the first results obtained on the optimized Cybele machine. Also, the plans for the future are acceleration grids construction and negative ions extraction from the plasma.

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Poster Session 2 / 162, T4_Tu_17

Performance of PKU H^- Source with Liners of Different Materials

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A new microwave driven Cs-free H^- ion source was designed at Peking University for the mechanism research of H^- source. To understand the influence of liner material to the performance of this ion source, a series of experiments with different materials of liners of Ta, Au, Be, Al, Cu have been carried out recently. In our experiment, H^- beam was extracted with negative voltage of 35 kV and ion species of H^+, H^{2+} and H^{3+} were extracted from plasma with positive voltage of 35 kV. All of these experiments were performed in vacuum pressure of 7×10^{-3} Pa with RF power of 2800 W (100 Hz/0.5 ms). The experiment results show that the liners of Ta, Ni, Au are much better than Al, Cu. This phenomenon will be explained based on the difference of second electron emission coefficient and work function of each material. The results will benefit us to better understand the physical principle of H^- source and help us to figure out a better performance. Details will be presented in the article.

Poster Session 2 / 173, T4_Tu_18

Parametric Dependence of Hydrogen Plasma Lyman-Band Emission and H^- Ion Beam Intensity in LIISA Ion Source

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Electronic ground state hydrogen molecules at high vibrational states, $\mathrm{H_2}(\mathrm{X}^1\Sigma_g^+, \nu \geq 5)$, have large cross sections for dissociative electron attachment, $\mathrm{H_2}(X^1\Sigma_g^+, \nu) + \mathrm{e} \rightarrow \mathrm{H_2^-}(^2\Sigma_g^+) \rightarrow \mathrm{H^-} + \mathrm{H}$, at low electron energies.
Thus, their production through electron impact excitation to electronic singlet states, i.e. $\mathrm{H_2}(\mathrm{X}^1\Sigma_g^+, \nu) + \mathrm{e} \rightarrow \mathrm{H_2}(\mathrm{B}^1\Sigma_u^+, \mathrm{C}^1\Pi_u) \rightarrow \mathrm{H_2}(\mathrm{X}^1\Sigma_g^+, \nu \geq 5) + hf$, is an integral step of $\mathrm{H^-}$ volume production in negative hydrogen ion sources.
The $\mathrm{H^-}$ ion beam intensity and vacuum ultraviolet (VUV) emission within the higher order Lyman-band corresponding to $\mathrm{H_2}(\mathrm{B}^1\Sigma_u^+, \nu) \rightarrow \mathrm{H_2}(\mathrm{X}^1\Sigma_g^+, \nu)$ transitions were measured from the LIISA $\mathrm{H^-}$ ion source at JYFL with varying source pressure and heating power.
It was observed that certain Lyman-band emission lines react differently to the variations of the given operational parameters.
The origin of the observed behavior was studied by comparing the experimental Lyman-band spectra to synthetic spectra produced by taking the ground state vibrational distribution from the literature and modeling the electronic excitation and subsequent decay processes with two deviant assumptions.
According to the first model, the $\mathrm{H_2}(\mathrm{B}^1\Sigma_u^+, \nu)$ vibronic state has a long lifetime, therefore allowing vibronic oscillations resulting to relaxation of the quantum mechanical wave function. The second model postulates that the electronic excited state decays immediately i.e. the internuclear distance remains constant between the excitation and de-excitation events.
It was found that the relaxed model correlates better to the acquired experimental results when compared to the prompt decay model.
A relation between the extracted ion beam intensity and the specific Lyman-band emission lines reflecting the production rate of certain vibrational states will be discussed.

Poster Session 2 / 175, T4_Tu_19

Modification of a classical Penning Ion Source operating mode for Sub-Femtoampere Beams at the U-120M Cyclotron

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Detector R&D projects in particle physics and experiments in radio-biology require often very low intensity, stable beams with well controlled flux. Usual method to decrease beam intensity by collimators is usually not suitable since background radiation has to be kept as low as possible. This paper describes internal cyclotron Penning ion source (PIG) modification which allowed to achieve sub-femtoampere beam intensities. Upgrade of the the PIG source power supply at the U-120M cyclotron allowed to move to new working regime of the ion source and achieve proton fluxes as low as 25 p/s.cm^2 well on the edge of the common beam monitoring systems.

Poster Session 2 / 185, T4_Tu_20

Effect of Filter Field and Biased Double-Bias Plate on Volume Process in Negative Ion Sources

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The RF negative ion source NIO1, built at Consorzio RFX in Padua (Italy), is aimed to investigate general issues on ion source physics, as well as innovative solutions for electrical efficiency, in view of their use as sources of neutral beam injectors (NBIs) in future fusion experiments, like MITICA, the ITER NBI prototype.
NIO1 has been designed to produce 9 H^- beamlets (in a 3x3 pattern) of each (when using cesium) and 60 keV, using a three-electrode system (plasma grid, extraction grid and post accelerated grid) downstream the plasma source. Since no cesium has been used yet in NIO1, the negative ion production relies on the volume process only. In order to maximize its efficiency, some solutions have been proposed.
Inside the source chamber, in front of the plasma grid, an electrically insulated bias plate has been located, which can be independently biased with respect to the plasma grid or, in turn, with respect to the source walls. The original design solution for the filter field (generated by current flowing through the plasma grid and external return coil), was modified in order to increase its absolute value inside the source chamber, by a different configuration of the cusp field magnets. The aim of this contribution is to show the beneficial effect of these two design solutions in improving negative ion current in NIO1.

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Poster Session 2 / 192, T4_Tu_21

Construction of External Antenna RF H^- Source in CSNS

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A RF H^- source with external antenna is under construction for China Spallation Neutron Source (CSNS) project Phase-II, which requires a H^- beam of 40 mA peak current, 25 Hz repetition rate, and 1 ms pulse length. The plasma chamber is made of Si_3N_4 ceramic to endure high thermal shock. The water-cooled antenna is brazed on the outer wall of the plasma chamber to enhance heat dissipation of the chamber. The antenna is powered with a solid-state amplifier of maximum 80 kW via an isolation transformer and an impedance transformer. To produce a flat-top H^- current, we aim to program the amplitude of RF input signal, so that the fluctuation of the beam current is compensated with the change of the RF power within a pulse. An online plasma cleaning technique is also under development to clean the electrodes with Helium plasma. The work principle of the cleaning technique is simulated with SRIM program (http://www.srim.org), which is to calculate the sputter rate of ions on different surfaces. Up to now the mechanical construction of the source is finished, and the RF match network is still under test. The source is expected to produce H^- current at the end of 2017.

Poster Session 2 / 221, T4_Tu_23

Global Model of a Negative Hydrogen Ion Source with Caesiated Plasma Grid

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A global model is applied to investigate the complex chemistry in a negative hydrogen ion source with caesiated plasma grid. This global model includes electrons, neutral hydrogen molecules with all vibrational states ($H_2(v)$), hydrogen atoms in the first 3 electronic states ($H(n)$), and ground state ions (H^+ , H_2^+ , H_3^+ and H^-). It uses a comprehensive set of surface and volume chemical reactions including a model for negative hydrogen ion production from caesiated surfaces. In the global model, steady state species continuity equations, electron energy and total energy equations, heat transfer to walls, and quasineutrality are solved simultaneously in order to calculate number densities and temperatures of plasma components in the discharge over a wide range of pressures and absorbed powers. We present preliminary global model results for a plasma composition and species temperatures in a caesiated plasma grid extraction chamber of a negative hydrogen ion source. These results are used to extract the most important plasma species and chemical reactions for use in 2-Dimensional fluid simulations of plasma evolution in a cesiated plasma grid extraction chamber by the multi-species fluid code USim.

Poster Session 2 / 223, T4_Tu_24

Optimization of the Cesiation Process for the SNS H^- Ion Sources

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Cs-enhanced, RF-driven (internal or external antenna) H^- ion sources are used to produce high current (>60 mA), high duty-factor (1 ms, 60 Hz) H^- beams for the accelerators at the Spallation Neutron Source (SNS) facility. A solid reaction Cs dispenser system placed near the ion source outlet, the Cs collar embedded with cartridges containing a mixture of Cs chromate and St101 getter material, is used to cesiate the ion source. When the Cs collar is heated to ~550 °C, the chromate reacts with the getter and releases elemental Cs. A newly installed ion source undergoes a plasma conditioning process, which is to outgas and sputter clean the chamber and internal components. To effectively outgas the Cs collar, the collar temperature is kept at ~250 °C (higher than typical operation temperature of ~200 °C but far below the cesiation temperature) during the plasma conditioning. After fully conditioning the chamber, a cesiation at ~550 °C is conducted to ready the ion source for beam delivery. While every ion source startup follows the same conditioning and cesiation procedure, variations in the amount of released Cs observed with plasma emission spectroscopy are often recorded. In some cases, a significant amount of Cs release was observed even during the plasma conditioning phase. Excessive Cs can cause severe sparking in the extraction region and the electrostatic beam transport section. This paper will present the optimization studies of the ion source conditioning and cesiation process guided by the Cs signal in the plasma emission spectroscopy. The studies include reducing the Cs collar temperature during the plasma conditioning, skipping the step of cesiation at ~550 °C if the Cs presence is significant during the plasma conditioning, and experimenting with the temperature and duration of cesiation.

Poster Session 2 / 225, T4_Tu_25

Record Performance of the Spallation Neutron Source H^- Injector

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In July 2017 SNS will resume 1.2 MW proton beam operations to produce world record beams for neutron scattering experiments. This is enabled by the excellent performance of the SNS H^- ion source and the compact electrostatic LEBT that inject up to 60 mA into the RFQ. To reduce inefficiencies and downtime the source service cycle periods have been increased and up to 96 days have been demonstrated. During the long service cycles up to 7 Amp-hours of H^- ions are injected into the RFQ, which is at least 10 times more H^- ions than are produced with other pulsed H^- sources for accelerators during a single service cycle.
The high user demand at SNS no longer allows for risking downtime. Increasing the SNS H^- source service cycle only became possible after careful wear measurements showed that sputtering reduces the porcelain coating of the antenna at the most exposed location by less than 1% per week. That means that during a ˜20 week target cycle, only ˜20 % of the insulation would be lost. This is not a problem because the 0.5 mm coating is much thicker than what is needed to hold off the typical voltages generated in high power plasma operations. Running a single H^- source per target service cycle yields the absolute minimum of source related unavailability.

Poster Session 2 / 226, T6_Tu_72

Resonant Ionization of Atomic Te with Ti:Sapphire Lasers

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Resonance ionization laser ion source has become an essential tool for the production of isobarically pure radioactive ion beams for nuclear research [1]. Efficient resonant ionization of beams of atomic tellurium using a combination of Ti:Sapphire and dye lasers has been recently reported [2]. Development of suitable ionization schemes is important for the laser ion sources equipped with all Ti:Sapphire lasers. We have conducted photoionization studies of tellurium in a hot-cavity laser ion source with three Ti:Sapphire lasers. In the ion source Te atoms are resonantly excited by two lasers from the ground state to an excited state and then ionized by the third laser. Photoionization spectra are obtained by scanning the third laser wavelength. A number of autoionizing states and a series of autoionizing Rydberg states have been observed, some of which could lead to efficient three-step resonant ionization of Te.

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Poster Session 2 / 276, T4_Tu_26

Response of Negative-Ion Beamlet by Insulation Tip in the Vicinity of Plasma Grid

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Negative ion transport from metal surface to meniscus of plasma grid in negative ion source with cesium seeding is useful to design high performance ion sources and has been reported in previous works, most of which are simulation studies. Some of experimental studies estimated the main transport route of negative ion by comparing ion beam currents with the several shapes of negative-ion production surfaces. Experimentally to perform the transport analysis in further detail, we introduced a beamlet monitor in a beam line and insulation tip in the vicinity of the plasma grid to the NIFS-RNIS (Research and development Negative Ion Source of National Institute for Fusion Science) which is a large-scaled multi-apertures negative-hydrogen ion source with cesium seeding. The plasma grid metal surface is the main production area of the negative hydrogen ion forming beam. The beamlet monitor can observe the each beamlet intensity and shape of multi beamlets. The insulation tip can move in three dimensions. The beamlet intensity decreased when the insulation tip was put not only on the plasma grid aperture but also above the plasma grid aperture at least several mm from the plasma grid surface. The beamlet intensity does not much change when the insulation tip was put on the metal surface near the plasma grid aperture. The main transport route can be interpreted as negative-hydrogen-ions once spread to the space in the vicinity of plasma grid and is extracted as beam from the space. In this article, we report the transport of the negative-hydrogen ion through the response of the beamlet by the insulation tip three dimensionally positioned in the vicinity of the plasma grid.

Poster Session 2 / 285, T4_Tu_27

Scaled Penning Source Developments

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A new Penning surface plasma source has been developed with a larger plasma volume with double the linear dimensions of the standard ISIS source. The standard ISIS source has successfully delivered beam for ISIS operations for over 30 years. A variation of this source [1], with the same plasma dimensions is currently being used for the Front End Test Stand (FETS) at RAL. However it has been demonstrated that the existing design cannot deliver the full 2 ms 50 Hz 60 mA beam requirements [2].

The new scaled source was developed to: deliver the full duty cycle requirements for FETS; produce higher beam currents; and yield longer lifetimes for ISIS operations when run at lower discharge currents. This paper covers the development work through preliminary tests and two prototypes. The current performance of the latest source is detailed.

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Poster Session 2 / 297, T4_Tu_29

Production of Ruthenium-96 Ions for RHIC*

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The 2018 heavy ion experimental program for the Relativistic Heavy Ion Collider (RHIC) requires the collisions of Ruthenium-96 (Ru-96) ions. The production of Ru-96 ions is challenging due to the low abundance of the 96 isotope in natural Ruthenium (5.52%) and the small quantity of isotopically enriched material available. To best meet the needs of the experimental program, the BNL Tandem Van de Graaff and a cesium sputter ion source will be used as the injector for the RHIC acceleration chain. A research program was started to minimize the amount of enriched material required while still satisfy the experimental requirements for intensity. The lifetime of the Ruthenium cathodes were also studied.

Acknowledgment

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Poster Session 2 / 99, T4_Tu_03

Langmuir Probe Characterization of the NIO1 Ion Source Plasma

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In view of the future experiments on the large ion sources used for the neutral beam injection system of ITER and DEMO reactor, a small scale negative ions source called NIO1 (Negative Ion Optimization, phase 1) is operated at Consorzio RFX since 2014 [1], [2]. At this stage H^- are mainly formed by volume processes, while the use of cesium vapour to enhance the surface production is forseen in a second stage. The plasma is sustained by a 2.5 kW RF generator, inductively coupled via a seven turn coil surrounding the plasma chamber. The production and survival of negative ions stronlgy depends on the plasma properties in the vicinity of the apertures from which particles are extracted and a beam is formed. In order to characterize these properties against the variable pressures, power electric and magnetic field strenght in the source a dedicated campaign with a movable Langmuir probe immersed in the plasma was carried out. This paper firstly reports on the installation of such probe on NIO1 and on the development of its control and acquisition system. The data aquired in different source conditions are then presented and discussed.

Acknowledgement

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Poster Session 2 / 303, T4_Tu_30

Diagnostics and Improvements for the LANSCE H^- Ion Source

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Several diagnostic studies are planned for the H^- Ion source at LANSCE. Studies related to the tungsten filament quality and lifetime, cesium saturation of the converter, and of the plasma in the ion source. Diagnostics will be done using thermal imaging and laser spectroscopy. These studies will help improve the quality performance of the H^- ion source at LANSCE.

Poster Session 2 / 306, T4_Tu_31

Improvements to a 13.56 MHz RF Powered H^- Ion Source

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D-Pace's new 13.56 MHz RF powered H^- ion source, a hybrid design between the TRIUMF licensed filament powered ion source [1] and the University of Jyväskylä licensed RF ion source [2], has been shown to be less efficient than the filament powered ion source, even though both sources use the same body and extraction system [3]. The difference is thought to be due to RF power losses to the outside of the ion source, to the lack of plasma confinement on the back plate of the ion source, and to the absence of a sputtered tantalum coating on the plasma chamber walls. We believe that the lack of confinement on the back plate also causes the RF window to get hot, with a maximum temperature measured at 450 °C at 3.5 kW of RF power. We are investigating the use of a solenoid and permanent magnets behind the antenna and the back plate of the ion source to create a magnetic field that further confines the plasma by preventing the electrons from striking the RF window. Electron tracking simulations show that both methods can reduce the electron density on the RF window in similar proportions as with the filament ion source. Furthermore, we present the effect of sputtering a tantalum coating on the plasma chamber of the ion source on the production of H^- ions in the RF powered source. Our results show an increase in H^- beam current at higher RF powers with a fresh coat, and a subsequent decrease in beam current over time.

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Poster Session 2 / 307, T5_Tu_60

Alternative New Concept of an Efficient Negative Ion Source for Neutral Beams

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Negative ion sources are a key component of neutral beam Injection systems, which are used in fusion experiments to raise the plasma parameters close to start ignition. A novel concept for a negative ion source based on existing well tested Hall thrusters (HT) is presented. The thruster scheme is modified in order to maximize the hydrogen dissociation so as to produce an atom flux at an energy optimized to maximize the yield of negative ions when impinging on a low work function surface. The novel concept can in principle offer several advantages among which a limited amount of co-extracted electrons, a more uniform generation of negative ions and a lower rate of destruction of negative ions. In this contribution the numerical simulations aimed to identify the optimum geometry, magnetic field map and operational parameters of the source are presented discussing the effect of the HT working point on the dissociation rate. A preliminary design of the experimental equipment is also presented including the ion source and the vacuum chamber, focusing on the aspects related to the gas injection and the operational pressure and describing the main diagnostics.

Poster Session 2 / 11, T7_Tu_82

Isotope Separator for External Ion Injection into EBIS

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An advanced Electron Beam Ion Source (EBIS) was successfully used over the last several years at Brookhaven National Laboratory to supply highly charged ion beams of different elements to the Relativistic Heavy Ion Collider (RHIC) and to the NASA Space Radiation Laboratory (NSRL). In many cases there is an advantage to inject isotopically pure beams of singly charged ions into EBIS to enhance RHIC luminosity. For this purpose we are developing isotope separator based on 90° double-focusing dipole magnet coupled to a hollow cathode ion source. This source is capable to generate 1+ ion beams of different elements for external injection into EBIS with intensity high enough to completely fill capacity of EBIS ion trap. Quadruplet of electrostatic quadrupole lenses has been installed in front of the magnet to separate different isotopes in the plane of output slit. CsI (Tl) scintillator placed at this plane has been used to optimize mass resolution of the separator. The main challenge was to achieve simultaneously both required resolution and about 100% transmission from ion source to the output of the separator. The results of measurements for krypton, xenon and zirconium isotopes with natural abundance will be presented and discussed.

Acknowledgement

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Poster Session 2 / 15, T5_Tu_32

Advanced Filter Structures for NIO1 and other Negative Ion Sources

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The magnetic filter is an outmost important part of a H^- plasma ion source since it must reduce electron transport, density, and temperature, apparently with no clear physical indication of a saturation criteria. In the early 2016 configuration of NIO1 (Negative Ion Optimization phase 1), an average of B_x=30 G dipole field was obtained in the extraction region with a current I_{PG} of 400 A (circulating in suitable conductors, placed near or inside the ion source plasma chamber), with a striking linearly improvement of beam ion current with field strength. By a simple alteration of NIO1 front Halbach-type multipole (with 2*m=14 poles), a B_y >100 G dipole field was obtained, far beyond capability of current conductors, but without any tunability, so that interpretation of experiments is now difficult.
Here it is speculated to alter this multipole in a different way (with a very laborious rebuild of some of the multipole bars and their enclosures) so that a B_x about 80 G is produced (tunable by ± 30 G by adding the B_x term produced by current as before) and a general theory of perturbation of multipole fields with dipole fields is presented, with comments on stagnation points and plasma confinement. The example and the measurement for the Electron Cyclotron Resonance Ion Source Alice where m=3 (since multipole is there a hexapole) are also briefly recalled.
A 2D simulation tools for a rapid selection of useful configurations was developed. Extensive 3D numerical simulation are presented for NIO1, to better describe fringe field effects and to attempt some predictions of the filter effectiveness. Comparison of numerical results show the importance of detailed 3D modeling, and prompted for innovative assembly methods of the multipoles and their enclosures.

Poster Session 2 / 17, T7_Tu_83

Comparison of Ion Beam Profile Measuring Methods

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Typically, measure of the current distribution (or current density) at the target surface can be performed by using different probes, or Faraday cups, or systems of the rotating disk collector, or systems of scintillation plates and the secondary electron multipliers. However, in those cases, the target and the measuring system should be located under a ground potential. Thus, such measurement methods are not applicable in studies of the current distribution at the surface of miniature linear accelerators targets [1], to which mostly is applied high negative potential relative to the ground. In this way the current distribution can be estimated by the indirect measurements of either the visible column of the output ion beam or the distribution of the sputtered material on surface of the target by a profilometer [2].
In this paper methodology for direct measurement of current distribution on a target surface biased to the negative potential by the 6 channel profile monitor is described. This device has been used to obtain current distribution on the target. This distribution depends on geometrical and physical parameters of the ion–optical system miniature linear accelerator (based on Penning ion source). It is shown that the visible accelerated beam trace, in the accelerating gap and in the plane of the target along with direct measurement are two complementary methods of ion-optical systems studies, where high negative potential is applied to targets.

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Poster Session 2 / 34, T5_Tu_33

Beam Energy Recovery for Fusion: Secondary Electrons Problem Study and Experimental Tests

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The Experimental Fusion Reactor ITER will use fast Neutral Beam (NB) injectors to increase the plasma temperature in order to drive the plasma current necessary for stability. The NB are produced by a D^- beam generated by a negative ion source which is neutralized by a gas cell with an efficiency of 60%. In order to improve the electrical efficiency of the NB production, a beam energy recovery system of the residual charged particles could be foreseen. In particular, we have already proposed an energy recovery device with an axisymmetric cylindrical ion collector. The scaled ITER type negative ion source, NIO1, has been developed at RFX (Padua) for studying and improving the ion extraction efficiency. An experimental test on beam energy recovery by using the NIO1 ion beam has been recently proposed. However, one important issue related to the beam energy recovery are the secondary electrons generated by the interaction of the ions with the collector walls which may escape from the device, reducing energy recovery efficiency and cause damages. In this contribution the problem of minimizing the secondary electrons production in the beam energy recovery device has been studied and simulated. Although the secondary electrons escape from the ion collector is greatly stopped by the cup axisymmetric geometry, a small fraction emitted with higher energy (200 eV) could exit from the collector and be reaccelerated back. A reduction of this effect can be obtained by adding a new electrode in front of the collector. Simulations have been carried out to optimize the shape and the voltage of that electrode. A simple test bench for secondary electron emission, to verify simulation tools and reliability of existing data, is being completed at INFN-BA laboratory.

Poster Session 2 / 36, T6_Tu_61

Simulation of Charge-Breeding Processes in ECRIS

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Charge-breeding processes in Electron Cyclotron Resonance Ion Sources are numerically simulated by using the target helium plasma parameters obtained with NAM-ECRIS code. Breeding efficiency is obtained as a function of 1^+ ion injection energy for some alkali ion beams.Time dependencies of extracted ions are calculated; typical times for reaching saturation in currents are in the range of few tens of milliseconds. Role of charge-exchange processes in breeding of ions is discussed. Recycling of ions on the source walls is shown to be important.

Poster Session 2 / 47, T6_Tu_62

A Prototype Target-Ion Source for RIB Production in a Reactor

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A project to produce RIB in a reactor has been proposed in China Institute of Atomic Energy, China. A target-ion source with about 5g ^{235}U will be installed in one of the reactor neutron ducts with inner diameter 170 mm. To verify the feasibility of RIB production, an off-line prototype target-ion source has been designed and fabricated. The design details will be described.

Poster Session 2 / 48, T5_Tu_34

R&D of Radio Frequency Ion Source for Neutral Beam Injector in ASIPP

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The radio frequency (RF) ion source has many merits compared to the traditional arc based ion source because of it has long lifetime due to no filaments. It has the potential to be operated in steady-state. In order to meet future development needs of neutral beam injectors, a radio frequency ion source was designed and developed in Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP). So far, the RF ion source with single driver (diameter of 20 mm and depth of 12 cm) and with two drivers were developed. The drivers have the same structure, a turns coil, Faraday shield with water cooling and quartz insulator.
A radio frequency ion source test bed was also developed for the ion source performance tests. It contains a 50 kW RF generator with 1 MHz frequency, a matching network, a RF power dummy, a water flow calorimeter (WFC) system, a control system and gas pumping system. The RF plasma can be generated with higher gas pressure or start filament. High power of 50 kW was coupled into the ion source using the matching network. The RF power deposited in the RF driver was estimated by the WFC system leading to the optimization of driver for long pulse operation. More RF ion source design details and tests results will be presented in this paper.

Poster Session 2 / 49, T5_Tu_35

Status of Arc Based High Power Ion Source for EAST Neutral Beam Injector

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A beam line with 4 MW beam power and 80 keV beam energy was designed and developed on the Experimental Advanced Superconducting Tokamak (EAST). A hot cathode high power ion source was employed for a neutral beam injector (NBI) on EAST. The ion source contains a hot cathode plasma generator and a tetrode accelerator. The beam cross section is 10 cm × 48 cm which depends on the beam injection window on EAST. A bucket plasma generator was designed. 32 filaments were installed in the top of plasma box, and were installed in two lines with the longest side. The accelerator is slot type and has four layers, which forms the extraction-acceleration-deceleration electrostatic structure.
The deuterium was used on the EAST ion source. The performance of ion source was investigated, including the effects of filament voltage and arc voltage on the arc current, beam current and arc efficiency. The characteristic of deuterium beam was also studied, which included the beam species, beam profiles and beam transmission efficiency.The beam energy needs matching the plasma density in the EAST and the highest injected beam energy reaches 70 keV and the total beam power is 1.8 MW for one source. The details of achievements of ion source with deuterium beam will be presented in the paper.

Poster Session 2 / 51, T6_Tu_63

Towards Direct High-Resolution Laser Spectroscopy on Exotic Isotopes at Hot Cavity Ion Sources: Crossed Laser - Atom Beam Interaction in the Laser Ion Source Trap LIST

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Today ion sources based on laser resonance ionization are well-established core techniques at the worldwide leading radioactive ion beam facilities such as CERN-ISOLDE or ISAC-TRIUMF. Ensuring both, highly efficient and element-selective ion beam production to the users, these devices in addition allow for direct laser spectroscopic investigations on exotic nuclei far off stability with lowest production yields. Recent developments comprise preeminent suppression of isobaric contaminants by spatially separating the hot atomization cavity from a clean laser – atom interaction volume. This Laser Ion Source and Trap (LIST) design permits experimental access to nuclides such as neutron-rich Po, which were formerly inaccessible due to overwhelming contamination by easily surface ionized alkaline elements [1, 2].

Yet, spectral resolution as well as the ability of isotope- or even isomer-selective ionization in these sources is limited by the Doppler broadening of atomic resonances of typically a few GHz within the hot atomic vapor. This has so far limited the possibilities for direct in-source hyperfine structure (HFS) spectroscopy to heavy elements, such as Hg, Au, Bi etc. [3]. We present an upgrade of the LIST with a perpendicular laser - atom beam interaction geometry in the RFQ structure based on robust metal mirrors, reducing the spectral linewidth far below 100 MHz FWHM. This novel PI-LIST (Perpendicular Illumination) unit was installed and tested at the RISIKO off-line mass separator at Mainz University, which, due to its resemblance in the front-end design, acts as an ISOLDE development facility. In the framework of the ECHo project [4], direct in-source high resolution studies on the HFS of the long-lived radioactive isotopes ^{163}Ho and ^{166m}Ho were performed, using a frequency-doubled injection-locked narrow bandwidth Ti:sapphire laser [5]. These first-time laser spectroscopic investigations on the high-spin isomer ^{166m}Ho evidentiary demonstrate the applicability of the technique. The nuclear parameters µ and Qs were derived from very dense and highly complex HFS spectra, which up to now was solely object of dedicated collinear laser spectroscopic experimental beam lines like Collaps or CRIS at ISOLDE.

The novel measurement technique, its operation characteristics and the evaluation of the spectra are presented, covering also preparatory experiments on radioactive isotopes of Tc and Ac [6]. In addition, opportunities and constraints for spectroscopic on-line experiments as well as isomer-selective ion beam production under on-line conditions are derived.

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Poster Session 2 / 64, T5_Tu_36

Effect of Plasma Grid Bias on Negative Ion Beam Optics

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The plasma discharge power acts as a control parameter for the plasma density, and the beam optics can be optimized by properly controlling it. In negative ion sources for fusion, a plasma grid (PG) is positively biased with respect to an ion source chamber in order to control the ratio of negative ions to electrons in the extracted beam. In our recent studies, it was confirmed that the negative ion and electron densities near the PG decrease with increasing the bias voltage. Hence, the bias voltage is expected to be one of the other key parameters to determine the beam optics, and we have examined a relation of the beam optics to the bias voltage thoroughly.

Systematic scan of the bias voltage was carried out for different discharge powers with fixed extraction and acceleration voltages. It was observed that the beam optics sensitively changes with the bias voltage. This indicates that the bias voltage plays an important role for production of a high energy and high current beam.

In the paper, we will compare dependences of the beam optics on the bias voltage and the discharge power for hydrogen and deuterium plasmas in detail. Moreover, we will discuss the effect of the plasma grid bias on the meniscus formation.

Poster Session 2 / 67, T5_Tu_37

Experimental Realization of Non Resonant Photon Neutralizer for Negative Ion Beams. Concept of Neutralizer for Big NBI Systems

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Currently few doubt that a common approach with a gas target for a negative ion beam neutralization in large NB-heating systems is not enough promising. Photon neutralization is considered as main alternative to gas target for injection efficiency enhancement. Significant power density of photons in steady state is needed for this purpose. This requires certain radiation storage. Generally, authors propose different variations of Fabry-Perot cell (see for example [1]), which have sufficiently strong limitations such as a laser beam quality, optic elements stabilization and other. In [2] a new concept of open adiabatic photon trap has been suggested. First successful results on quasi-stationary neutralization of negative ion beams were presented in [3]. This paper contains additional studying process of photoneutralization and more accurate efficiency measurement of hydrogen and deuterium negative ions beams.
Photon storage trap is designed as a system of parallel placed mirrors 25 cm long, consisting of individual cylindrical and spherical mirrors with a dimension of 30mmx50 mm and a radius of curvature of 250 mm. The effectiveness of this approach is mainly determined by the quality of the reflecting surface. It is practically independent from the quality of the injected radiation and does not require high precision alignment of optical elements. In such a system, the photons undergo multiple reflections. Experiments were carried out using an injector with a beam energy 6-12 keV and a current of 1 uA, the laser power up to 2 kW. Neutralization coefficient obtained for negative hydrogen ions is ~90% and ~98% for deuterium.
Based on the obtained results, the concept of a neutralizer for large neutral injection systems was proposed. It contains estimates for the parameters of the required non-resonance adiabatic storage of photons, a laser source, and protection from particle fluxes to mirrors.

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Poster Session 2 / 72, T5_Tu_38

Modelling of Negative Ion Extraction from a Magnetized Plasma Source

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Negative ion sources are used in a variety of research fields and applications such as in tandem type electrostatic accelerators, cyclotrons, storage rings in synchrotrons, nuclear and particle physics and in magnetic fusion devices. In magnetic fusion applications, negative ion sources are a subset of a Neutral Beam Injector (NBI) producing high power neutral beams which are injected into the Tokamak plasma. These fusion type negative ion sources are large volume, tandem type (i.e., a discharge and an expansion chamber) and work at low pressure (0.3 Pa). The plasma is generated typically by hot cathodes (heated filaments) or Radio-Frequency (RF) antennas (Inductively-Coupled-Plasma discharges) standing either inside or outside the discharge. Negative ions are generated on a cesiated grid (which is called "plasma grid" in contact with the plasma) as a byproduct of the bombardment of fast hydrogen or deuterium atoms. The negative atomic hydrogen (deuterium) ions are extracted through the plasma grid (PG) apertures by the high potential of an extraction grid (first grid of the NBI's electrostic accelerator), respectively. The negative ion current produced on the PG is typically space charge saturated and a virtual cathode forms in front of the grid surface (the plasma potential presents a minimum in front of the electrode, which limits the extracted negative ion current). The flux of plasma particles (positive ions and electrons) impacting the PG controls both the shape and the magnitude of the cathode potential. More negative ions may hence escape the PG surface in a plasma compared to an hypothetical situation where the PG surface would be in vacuum. In this work, we simulate the extraction of a negative ions beam from a magnetized ion source [1, 2, 3]. The model is a Particle-In-Cell algorithm with Monte-Carlo Collisions (PIC-MCC). We show that the negative ion beam perveance P=I/V^3/2 is practically invariant with respect to the simulated plasma density and as a result a given value of the perveance corresponds qualitatively to a similar negative ion beam profile on the extraction grid (and shape of the plasma meniscus, respectively). Furthermore, the extracted beam current may be scaled to any associated value of the plasma density. Aberrations appear for a meniscus curvature radius of the order of the radius of the grid aperture. These aberrations cannot be cancelled out by switching to a chamfered grid aperture (as in the case of positive ions).

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Poster Session 2 / 77, T5_Tu_39

Laboratory Experiments for Developments in View of DEMO NNBI

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DEMO will be the first fusion plant to produce electricity and has to demonstrate the capability of fusion technology to be used in a power plant environment. Reliability and high wall-plug efficiency are the key requirements for any system to be used on DEMO. In case of neutral beam injection (NBI) – one of the heating and current drive systems currently under discussion for DEMO – upgrades to several components are presently investigated within the EUROfusion activities, such as the ion source or the neutralizer. In order to maintain experimental flexibility, related fundamental investigations are performed at small-scale laboratory experiments under ion source conditions.

ITER's NBI system is based on negative ions (NNBI) produced by surface conversion of hydrogen particles at a low work function converter surface. This surface is therefore covered with caesium. However, Cs is very reactive and thus the converter is easily affected by impurities. Furthermore, the interaction with the ion source hydrogen plasma leads to complex redistribution dynamics of the volatile Cs coating. Thus, in view of DEMO NNBI investigations are performed aiming either at reliable and reproducible Cs dynamics together with reduced Cs consumption, i.e. improved Cs management, or at identification of alternative materials for efficient negative ion production. Specific investigations are performed using several materials known from the literature, like boron-doped diamond, tantalum or LaB_6.

Secondly, the total RF power required for generating the hydrogen plasma for an ITER-like NNBI system is in the range of several hundred kilowatts. In order to relax the demands on the RF components in view of DEMO, several alternative RF coupling schemes are investigated in small-scale setups: magnetically enhanced ICP coupling, helicon wave heating as well as planar ICP coupling. The power transfer efficiency as well as the achievable plasma parameters are investigated depending of several external parameters like RF frequency or design of the plasma vessel.

Thirdly, the efficiency of the entire beam line of ITER NNBI is only in the range of about 25 %. The main limitation is the neutralization efficiency of the accelerated negative ion beam by a gas target, which is around 60 % in maximum at the required beam energy of 1 MeV. Here the concept of laser neutralization with theoretical efficiencies of up to 100 % is suggested as alternative. Together with less gas consumption and reduced pumping requirements the wall-plug efficiency could be increased to about 60 %. Such a drastically new concept requires feasibility studies, from which fundamental investigations on the coupling of a laser cavity with a negative ion beam are performed in a laboratory experiment.

Poster Session 2 / 84, T5_Tu_40

Development of helium ion source for NPA system in ITER

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Calibration of energy channels and control of stripping foil quality in neutral particle analyzers designed for international tokamak reactor ITER will be carried out using a specialized source of helium ions. The ion beam should have a uniform current density in entrance aperture of the analyzer with a diameter of 2 cm. The total intensity of the beam entering the analyzer should be adjusted in the range (0.1-1) pA. Within 30 minutes, the beam energy stability should not be worse than ± 0.25 %, and the intensity should not vary by more than ± 10%. The source should provide trouble-free operation for four years of operation with a frequency of switching on once a month for four hours. To manufacture the source, the radiation-resistant materials, which are allowed by ITER, should be used.

The paper presents a developed and successfully tested mock-up of a source of helium ions with the energy of 40 keV. The ionization of the helium fed by mass-flow controller is carried out in a high-vacuum Bayard-Alpert ionization gauge. The Bayard-Alpert gauge efficiently ionizes the gas due to oscillations of electrons emitted from the cathode of electrons inside the cylinder from a grid with high transparency. The Bayard-Alpert lamp is a completely standard, widely used reliable device with a sufficiently long operational life. To monitor the production of ions, a collector of the gauge is used. The beam of helium ions with an angular divergence of 40 mrad is formed by a diode ion-optical system with round apertures 1 cm in diameter covered with a fine-structure molybdenum mesh. The source is shifted from the analyzer observation channel and located at a distance of 70 cm from the entrance of analyzer. The formed beam starts at angle of 5 degrees to the axis and after deflection by an electrostatic condenser is directed along the axis to the analyzer.

The energy of the beam ions from the source was experimentally optimized to allow measurements of the ion energy spectrum by a channel detector prototype of the analyzer. The detector prototype was based on a photomultiplier tube with a CsI(Tl) scintillation crystal. Spectrometric measurements have shown that the energy of 15 keV of the helium ions is high enough to separate the ion pulses from the detector noise. Beam ions energy reduction simplifies the design and minimizes size of the helium ion source.

Poster Session 2 / 86, T5_Tu_41

Update on the Negative Ion Based Neutral Beam Injectors for ITER

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The ITER baseline foresees 2 Heating and Current Drive Neutral Beam Injectors, HNB's, operating at 1 MeV 40 A D^0, each capable of delivering 16.5 MW of deuterium ions to the plasma, with a 3rd HNB injector foreseen as an upgrade option that would bring up the total neutral beam power to 50MW [1]. In addition a dedicated Diagnostic Neutral Beam Injector, DNB, will be injecting a modulated 100 keV 60 A of H^0 for charge exchange recombination spectroscopy (CXRS) [2]. The R&D effort for the negative ion source for the neutral beam injectors of the International Tokamak Experimental Reactor (ITER) is well underway and results and achievements are reported by the collaborating laboratories in many contributions to this conference. This contribution reports the status of the integration of the HNB and the DNB systems into the ITER plant, the adopted design refinements and the new installation strategy.

As the ITER buildings construction is advancing and services are being installed, the interfaces between the different plant systems are frozen. Design improvements have been made to the duct liner however the asymmetric configuration required the preclusion of counter injection. At the preliminary design review of the absolute valve the panel requested a design modification to improve the manufacturability. The sealing solution of the beam line vessels has been reviewed and a double metallic seal solution developed. The magnetic field compensation system has also been reviewed using the construction design of the tokamak building and the manufacturing design of the ITER tokamak magnets.

In 2016 the ITER Council has approved the Overall ITER Project Schedule and − ad referendum − the Overall Project Cost: the schedule foresees First Plasma in 2025, followed by a staged approach to Deuterium / Tritium operation with full fusion power capability foreseen in 2035. Therefore, the Neutral Beam installation scenario has been reviewed and will now be performed in three stages: in the Phase I only captive services pipes will be installed, in Phase II the captive NB components and the power supplies and in Phase III the beam line components and Front-End-Components. This makes the Neutral Beams available on ITER for the pre-Fusion Operation, though currently exploration into possible advancement proposals is ongoing.

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Poster Session 2 / 105, T5_Tu_42

Power Transfer Efficiency in Inductively Coupled Radio-Frequency Ion Source: Case Study for the NIO1

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An ion source called NIO1 (Negative Ion Optimization, phase 1) has been developed by Consorzio RFX and INFN-LNL and is currently in operation in the Consorzio RFX premises in Padova. NIO1 has a radio frequency (RF) inductively coupled (IC) ion source designed to produce a total of 130 mA H^- current and to accelerate the ions up to energy of 60 keV; it operates at a frequency of 2 ± 0.2 MHz with maximum RF power of 2.5 kW.

In the IC RF ion source, plasma is generated and heated in a component called driver by the RF field induced by a coil. In a preliminary work, a methodology was developed to evaluate the equivalent electrical parameters for IC RF ion sources and power transfer efficiency to the plasma. This methodology takes into account various relevant mechanisms of plasma particle dynamics like ohmic heating, stochastic heating and classical skin depth, which are modelled based on the available literature. These formulations are then integrated with a simplified scheme describing the magnetic coupling between plasma and the RF coil (2-windings transformer model).

In order to develop the methodology further, this work provides an improved equivalent electrical model of the driver based on a multiple winding transformer scheme accounting for the mutual coupling between the RF coil, plasma and the surrounding metallic structures. The developed methodology is then applied to NIO1 ion source. The results in terms of equivalent electrical parameters and power transfer efficiency will be presented based on both the simplified and the improved approach.

Acknowledgements:

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Poster Session 2 / 120, T6_Tu_64

Investigate the Characteristics of Oxide of ^{96}Zr

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In Brookhaven National Laboratory (BNL), a collider experiment having same mass number and different charge number atoms is planned at RHIC (Relativistic Heavy Ion Collider). Specifically, it is planned to investigate the influence due to the difference in charge number by comparing ^{96}Zr atoms and ^{96}Ru atoms and one of the isobars, ^{96}Zr beam will be provided by the laser ion source (LIS).
To provide ^{96}Zr beam from laser ion source, we are investigating the characteristics of oxide of enriched ^{96}Zr powder. The reason for using oxides as a laser target is that ^{96}Zr occupies only about 2 - 3 % in the natural abundance of Zr. Therefore, solid metal of ^{96}Zr is very expensive and oxide materials, which may be easily obtained in the market, are being tested. We believe this study is useful for applying the rare materials in other ion sources including ECR.
As a method of forming an oxide laser target, sintering is being tested. The compressed oxide powder is heated for several hours at a high temperature more than 1000 °C. In the laser plasma from the oxide target, many impurities are expected. For this reason, atoms for each mass-to-charge ratio are investigated using EIA (Electrostatic Ion Analyzer), and performance of the oxide targets are evaluated. We will present the latest experimental results.

Poster Session 2 / 139, T5_Tu_44

Upgrade of the Low Energy, High Power Neutral Beam System

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The upgraded version of the neutral beam injector is described, which provide 1.7 MW power and 15 keV atom energy in injected beam. The nominal extracted proton beam current is 150 A, while the ion source provide the maximal current up to 180 A. The beam duration increased to 30 ms after upgrade in comparison with 8 ms for previous version [1]. The multy-slit 3-grid ion-optical system demonstrate quite good angular divergence about 10 mrad in parallel the slit direction, while the transversal angular divergence is turned out to be ˜3 times larger. The beam integral transversal divergence exceeds both calculated value and measured one for single-slit ion optical system. The possible causes are analyzed in the paper. The results of numerical simulation to optimize the ion-optical system on order to minimize the transversal divergence and the results of experimental tests are given.
The eight neutral beams with the total injection power of 14 MW are installed and tested successfully as the injection system for plasma heating in the open magnetic trap.

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Poster Session 2 / 145, T5_Tu_45

Experimental Study of Matching Network with Different Frequency for RF Ion Source

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The radio frequency (RF) ion source has the potential of steady-state operation which due to it has no filament. Compares to the traditional arc based ion source, the RF power should couples into the plasma through the matching network. So, the matching network is much important for the RF ion source. Due to the plasma impedance will be changed before and after the plasma generation, the impedance characteristic is not easy to be calculated and measured. In order to get higher RF power couple efficiency, the matching network was studied through the experimental on the RF ion source test stand.
The matching network was designed with different frequency (1 MHz and 2 MHz) on the RF ion source test bed. The key parameters of capacitances on matching network were calculated. Two adjustable capacitances were used on the matching network due to the change of plasma impedance in the driver. The matching characteristic was investigated with the 50kW RF generator with 1 MHz and 10 kW RF generator with 2 MHz. It will be helpful for the design and operation of matching network of RF ion source with different RF frequency. The long pulse RF discharge was also tested with the best matching status. The details of the results will be presented in this paper.

Poster Session 2 / 153, T5_Tu_46

Benchmark of 3D Multi-Beamlet Numerical Models for the Optics Design of Negative Ion Accelerators

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Beam optics is a key requirement in multi-stage multi-beamlet negative ion accelerator for fusion applications, such as the high power Heating Neutral Beam injectors for ITER and JT-60SA. In particular, the efficiency of beam neutralization and transport to the tokamak plasma to be heated is crucially dependent on the divergence and deflection angle of the single beamlets with respect to their ideal trajectories.
In 2016 an extensive collaboration between Consorzio RFX (Padova, Italy) and QST (Naka, Japan) was established in order to experimentally test some ITER-like multi-beamlet configurations on the Negative Ion Test Stand (NITS) in Naka. This campaign allowed a detailed comparison of the experimental results with respect to the estimations obtained by numerical models during the design phase.
Although the numerical models were based on well-established commercial codes (OPERA-3D and COMSOL), some discrepancies were evidenced both between the two numerical models and between the models and the experimental results.
A detailed benchmark has therefore been carried out in order to better identify the origin of these discrepancies, so as to obtain a fully reliable numerical description of the experiments. The present contribution describes the results of such an extensive comparison.

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Poster Session 2 / 155, T5_Tu_47

Conceptual Design of an Ion Source for the DAMAVAND Neutral Beam Injection

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Among the tokamaks in the world, DAMAVAND is one of the small ones and, regarding the features of its plasma, offers useful and important research fields among which the plasma heating injector design is one of the most conspicuous ones. The heart of any neutral beam injector is the ion source in which ions are produced for the first time. In this paper, conceptual design of an ion source for plasma heating in DAMAVAND tokamak is presented. The machine is based on positive ion injection. Compelling reasons for the selection of this type of source are mentioned. Further, in this paper, we investigated different types of suitable ion sources for plasma heating in tokamaks. Therefore the bucket ion source is selected. Then, the conceptual design of a bucket ion source used in DAMAVAND-NBI has been elaborated upon. It is shown that taking the tokamak parameters and the amount of beam absorption into consideration, the bucket ion source must deliver a beam with 4.5 keV, 30.15 kW and 6.7 A, which are critical energy, neutral beam power, and neutral beam current respectively, required for DAMAVAND tokamak plasma heating.

Poster Session 2 / 156, T6_Tu_65

Recent improvements of the LPSC Charge Breeder

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The LPSC ion sources team develops the Phoenix Charge Breeder since 2000. The performances have been improved over time acting on the 1^+ and N^+ beam optics, the base vacuum and the 1^+ beam injection. A new objective is to increase significantly the plasma chamber volume to improve the plasma confinement, enhance the higher charge state production and the 1^+, N^+efficiencies, and improve the ion source tunability. A development plan has been defined to modify the ion source magnetic structure accordingly with several steps in the period 2017 - 2020. The first iteration consists in increasing the axial magnetic field at injection from 1.2 T to 1.6 T by adding a plug under vacuum. It has been implemented in April 2017 and the efficiencies have been measured for gaseous and alkalis 1^+ beams. The results together with the foreseen evolution of the source will be presented.

Poster Session 2 / 158, T6_Tu_66

The Effect of Plasma Instabilities on the Background Impurities in Charge Breeder ECRIS

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Experimental observation of plasma instabilities in 14.5 GHz PHOENIX charge breeder ECRIS is reported. It is demonstrated with ^{133}Cs and ^{85}Rb that the injection of the 1+ ion beam into oxygen (^{16}O) discharge of the CB-ECRIS can trigger electron cyclotron instabilities, which restricts the parameter space available for the optimization of the charge breeding efficiency. It is concluded that the transition from stable to unstable plasma regime is caused by gradual accumulation and ionization of Cs/Rb and simultaneous change of the discharge parameters in 10 - 100 ms time scale, not by a prompt interaction between the incident ion beam and the ECRIS plasma. The delayed appearance of instabilities is presumably due to the variation of the electron energy distribution in a time scale similar to the reported breeding times of the high charge states of the injected ions. Since the commonly applied method of measuring the breeding time, i.e. pulsing the 1+ injection, clearly affects the charge state distribution of the buffer gas discharge and its electron energy distribution, it is argued that the actual breeding times in continuous operation can differ significantly from those obtained by studying the injection transient. Even more importantly, the instabilities lead to loss of ion confinement, which results to sputtering of the surfaces exposed to the plasma, followed by up to an order of magnitude increase of impurity currents in the extracted n+ ion beam. The data demonstrating the instability-induced sputtering is supported by time-resolved measurements of the biased disc current and ion beam energy spread conducted with the conventional JYFL 14 GHz ECRIS.

Poster Session 2 / 163, T6_Tu_67

Charge Breeding Technique at GANIL: Commissioning of the SPIRAL1 Charge Breeder and New 1+/n+ Test Bench

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The 1+/n+ method, early developed at the LPSC laboratory, is implemented at GANIL for the production of radioactive ion beams as well as for studying the production of intense stable metallic beams.

Regarding radioactive ion beam production, the SPIRAL1 charge breeder has been installed in the midst of the SPIRAL1 LEBT. Many modifications of the beam line and the ancillaries have been done to host the charge breeder. The first beam of ^{40}Ar was extracted during May demonstrating a distribution peaked on the 9+ charge state with 16% in particle of ionization efficiency.

Concerning stable ion beam production, the GTS ion source, providing stable ion beam for the ARIBE facility, is under modification to include a charge breeding capability. The idea is to test the 1+/n+ method as an additional particle injection technique to produce high intensity metallic beam. Due to its high global efficiency (around 50%) and narrower charge state distribution, this technique has to be investigated to compete in numerous cases with the conventional methods: oven – sputtering – MIVOC.

This contribution will present preliminary results of the SPIRAL1 charge breeder set in its final location (SPIRAL1 facility) as well as the description of the 1+/n+ test bench for the production of intense metallic ion beam.

Poster Session 2 / 170, T5_Tu_48

High Power and Long Pulse Negative Ion Production by Suppressing of Arcing for JT-60SA

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Reliable and stable operation of a hydrogen negative ion source to produce 500 keV, 22 A for 100 s is required for a neutral beam injector (NBI) for plasma heating and current drive of JT-60 Super Advanced (JT-60SA). The chamber to produce the negative ions is a semi-cylindrical multi-cusp source, so-called KAMABOKO source. Though 100 s long pulse operation was already performed, many anomalous and local discharges, i.e., arcing, limited the input power, and consequently, beam current was limited up to 15 A in long pulse operation. The arc power of this shot was about 160 kW, however the arc power of 200 kW is required to achieve beam current of 22 A. To achieve higher current without arcing, we have investigated causes of the arcing in the several aspects. In the past study, it was clarified that impurities in plasmas or excess cesium induce the arcing. On the other hand, it looks that the arcing positions were influenced the magnetic field configuration, which passes over the filament cathodes. In this study, the filament positions were changed to make clear the influence of the magnetic field to the arcing at the filaments using a small KAMABOKO source. As the result, the better filament position was clarified in this study, which can increase the discharge power to 40 % without arcing. It means this improvement may increase achievable arc power to 220 kW from 160 kW. Applying this better filament position, over 100 s long pulse operation with 30 kW could be achieved at MTF in QST Naka.

The arcing positions on the filaments were located not only in the hottest region on the filament but also in the region inside the multi-cusp magnetic field near the chamber wall. In a three-dimensional electron trajectory analysis, there is a direct path of electrons from the filament to the chamber wall along the multi-cusp magnetic field and there is a localization of electrons in this region. When the filament is inserted deeply to the chamber to avoid the electron emission inside the multi cusp, the electron localization is suppressed. To confirm whether this direct path to the chamber wall is one of causes of arcing, the filament positions were varied by changing the insert depth of filaments in the experiment. As the result, it has been found that changing the insert depth of filaments could improve the arc power without arcing from 30 kW to 40 kW (30 % improvement) in the small KAMABOKO source. In addition, it was also found from simulation that electron localization is suppressed by changing insert direction of filaments from equatorial direction to obliquely upward direction because of difference of the magnetic field distribution around filaments. Changing the insert direction of filaments in addition to changing the insert depth of them could cause another 10 % increase in the arc power without arcing: from 40 kW to 44 kW. At the same time, it is also found in a Langmuir-probe measurement that electrons nearby the chamber wall was decreased to a half with the insert depth of filaments from 10 mm to 50 mm as expected in the simulation. The demonstration test of this improvement was performed at MTF in QST Naka. In this test, we could achieve the long pulse plasma generation of 30 kW and 300 s, which is enough long compared with required value, 100 s, for JT60SA ion source. This result will be applied for JT-60SA ion source to achieve stable high power and long pulse operation.

Poster Session 2 / 171, T5_Tu_49

Design Study of 200 keV H^- Accelerator for CFETR Neutral Beam Test Facility

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To bridge the gap between ITER and fusion demonstration reactor (DEMO) and to realize the fusion power in China, a new fusion facility named the China Fusion Engineering Test Reactor (CFETR) is under conceptual design. Neutral beam injection (NBI) is one of the proposed auxiliary heating system to bring the CFETR plasma to the ignition temperature. A steady-state neutral beam with the power larger than 20 MW at 0.8 MeV is demanded for CFETR. As the most critical step towards the CFETR-NBI system, a research project of the CFETR neutral beam test facility (CFETR-NBTF) will be started in China over the next 5 years. The CFETR-NBTF will be equipped a negative ion source with multi RF drivers and a single stage accelerator of 200 keV.

The objective of this study is to identify a single stage accelerator to produce 200 keV H^- ion beam through the physics design based on beam optics, stripping loss of negative ions, and thermo-mechanical performance of the grids. In the beam optics study, a single-beamlet analysis is applied to evaluate the geometry of the grid apertures, the ratio of acceleration and extraction voltage, and the related beam divergence and clearance. Through a multi-beamlets analysis, magnetic configuration is designed to deflect electrons in the accelerator, and to minimize the effect of magnetic field on the beamlet. Besides, electrical field shaping plates (also named kerbs) are designed to compensate the repulsion between beamlets and to steer the beamlets to a focal point. Utilizing a 3D gas flow analysis to calculate the gas flow in the accelerator and to estimate the relevant the stripping loss of negative ions. The design of each grid segment is described in detail. The thermos-mechanical performance of the girds is evaluated by means of 3D fluid-thermal-structural models, in terms of cooling water velocity, pressure drop, grid temperature, stress, and deformation.

Poster Session 2 / 178, T5_Tu_50

Experimental Validation of Grid Heat Loadings in the Five-Stage Accelerator with the ITER-Relevant Gap Lengths

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The ITER neutral beam injector (NBI) is required to inject 1 MeV, 16.5 MW neutral beams for 3600 seconds converted from 1 MeV, 40 A (200A/m^2) deuterium negative ion (D$^-$) beams. In order to realize the system, a five-stage multi-aperture multi-grid (MAMuG) accelerator, so-called MeV accelerator designed with the same concept as the ITER accelerator, has been developed in the MeV test facility in the National Institute for Quantum and Radiological Science and Technology (QST) in Japan. A key subject for acceleration of the powerful beam is optimization of beam optics in the accelerator. To test beam optics on the same conditions of the ITER accelerator, the acceleration grids have 4 apertures with several diagnostics.

For long pulse acceleration of such high power beams, the design values of the ITER accelerator are $<$ 7 mrad in divergence angle and $<$ 5 % in a ratio of heat loading on each acceleration grid to the total electrical input power. However, in the design code, there are several assumptions to calculate the negative ion trajectory because physics of the negative ion extraction is under studying. Therefore, the experimental validation is essential to realize the ITER accelerator. The MeV accelerator has already demonstrated the acceleration of 1 MeV, 200A/m^2 hydrogen negative ion (H$^-$) beams for 60 seconds successfully [1]. In this time, to simulate the equivalent perveance of the ITER accelerator, which is 1MeV, 280A/m^2 in the H$^-$ beams, the accelerator configuration was modified to optimize for this beams. Beam profiles and grid heat loadings have been investigated experimentally.

The acceleration gap length was modified by using a two dimensional simulation code. Practically, the gap length has been changed from 109 mm to 88 mm. To achieve the voltage holding capability of 1 MV in this modified gap configuration, the accelerator structure was redesigned based on the empirical scaling law obtained from voltage holding experiments [2]. As a result, a stable 1 MV holding has been achieved in this modified configuration.

To measure the beam distribution on the acceleration grid, a specially developed grid was installed. The grid has apertures with precise heat load profile measurement sensors. The accelerated beam profile was measured at a one-dimensional CFC (Carbon-fiber-composite) target.

Beam acceleration test up to 0.7 MeV has been performed at present. The heat loading on each acceleration grid was lower than 5 % of the electrical input power, which satisfied with the ITER requirement. The beam divergence angle was less than 5.6 mrad, which also satisfied with the ITER requirement. In this paper, the detailed comparisons between the beam acceleration test and the analysis are described in the beam optics and the grid heat loadings.

This is the first demonstration of MeV-class negative ion beam acceleration with the ITER-relevant acceleration gap lengths. These results can contribute to the direct prediction of the performance of the ITER accelerator.

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Poster Session 2 / 179, T5_Tu_51

Overview of the Beam Physics Investigation at the ELISE Test Facility

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Each beam line of the ITER Neutral Beam Injection (NBI) system is designed to deliver 16.5 MW into the plasma, thus providing heating and current drive by means of 40 A of negative ion current accelerated up to 1 MeV for 1 hour. Strict requirements are foreseen for these negative hydrogen ion sources: high extracted current density (33 mA/cm^2 for H^- and 28.6 mA/cm^2 for D^-), very small beam core divergence (< 7 mrad) and a beam uniformity of better than 90%, for a large beam extracted from 1280 apertures. The ion source filling pressure has been set < 0.3 Pa, in order to keep the stripping losses in the accelerator to a tolerable level, and the ratio of co-extracted electrons to ions should be less than one. These high-demanding requirements are necessary to minimize the overall beam losses (and therefore to maximize the efficiency), and minimize the heat loads on the components along the beam line.

The ELISE test facility operating at IPP is an intermediate step in the design and assessment of the NBI system for ITER, providing the earliest experiences on the operation and performance of a large RF-driven negative hydrogen ion source, with half the size of the ITER source (extraction system with 640 apertures for a beam size of almost 1 m $\times$ 1 m). In ELISE, both hydrogen and deuterium RF-induced plasmas at 0.3 Pa can be run for up to 1 hour, extracting a negative ion beam for 10 s every 150 s, due to limitations in the HV power supply; the negative ions can be accelerated up to 60 keV. A beam divergence of 17 mrad can be achieved, limited only by the HV and the accelerator system. At ELISE, it is possible to have an insight into the beam physics of the large beam by means of several diagnostics with a high spatial resolution. The Beam Emission Spectroscopy (BES) diagnostic can provide information on the beam uniformity as well as on the divergence along a vertical (resolution of 5 cm) and a horizontal profile; the Infra-Red (IR) data evaluation of the beam hitting the diagnostic calorimeter provide a 2D map (resolution of 4 cm) of the beam power density.

Three main topics will be reported: studies on the vertical beam homogeneity (in terms of both intensity and divergence) in correlation with source operational settings and performances; the investigation of the presence of a beam broad component (i.e. a small fraction of the accelerated ions with a significantly higher divergence than the majority of the beam); the investigation of the stripping losses inside the extraction system.

Poster Session 2 / 193, T6_Tu_68

Laser Ion Source for High Resolution Doppler-Free Resonance Ionization Spectroscopy of Radioisotopes and Enhanced Isomer Selectivity

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The Resonance Ionization Laser Ion Source (RILIS) is the most extensively used ion-source at the CERN-ISOLDE on-line radioactive ion beam facility. It provides not only high efficiencies but also offers element and, in some cases even isomer selective ionization. The ionization method itself, based on stepwise resonance excitation and ionization of atoms using tunable lasers, offers the opportunity of performing so-called in-source spectroscopy studies of radioactive isotopes, to reveal nuclear ground-state properties such as charge radii or moments via measurements of isotopic shifts and hyperfine structure of atomic transitions [1].

Doppler broadening of the atomic lines in the high temperature ion source environment limits the achievable resolution of this method. Consequently, its application has been focused on the heavier elements. Furthermore, the feasibility of nuclear isomer selective ionization is restricted to the few cases for which the differences in the hyperfine structure splitting for different nuclear states are resolvable. Nevertheless, the sensitivity of in-source spectroscopy remains unrivaled and therefore a means of eradicating the Doppler-dominated resolution limitation whilst maintaining the sensitivity is a highly desirable goal. By introducing a mirrored surface at the rear of the ion source, and reflecting the incident laser beams back upon themselves, Doppler-free 2-photon excitation and subsequent ionization of the atom becomes feasible. Different methods and materials for achieving this laser beam reflection inside the ISOLDE target/ion source assembly are under investigation. For effective use of the 2-photon excitation, the laser line width has to be reduced as much as possible. For the pulsed RILIS lasers the line width of < 100 MHz could be reached as defined by the Fourier transformation. A bow-tie, seeded and injection locked titanium:sapphire (Ti:Sa) laser is being developed for covering the red-near IR range, whilst a seeded dye amplification stage will be used for covering the yellow – red spectral range.

Here we summarize these ISOLDE-based developments and also present the results of the first successful demonstration of Doppler-free in-source resonance ionization spectroscopy, conducted at the RISIKO mass separator at Mainz University.

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Poster Session 2 / 199, T5_Tu_52

Commissioning and First Results of the ASIPP RF-Driven Negative Ion Source

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Considered the lack of research on the negative ion source for NBI application in China, the Hefei utility negative ions test equipment with RF source has been developed at ASIPP. It will work as a satellite for CFETR Neutral Beam Test Facility. The rf power of negative ion source is up to 50 kW. The size of the plasma chamber is 65 cm(L) ×26 cm(W) × 19 cm(H). An enhanced filter field was adpoted by combining the filter magnets and confined magnets. The negative ion accelerator consists of plasma grid, extraction grid and ground grid, which can extracted 120 beamlet in total. The mission of the test equipment is to understand the characteristics of RF operation and negative ion generation and extraction, and to improve the RF efficiency and beam quality. Moreover, it's a flexible test equipment equipped with kinds of diagnostic techniques. Thus, it can be used to test and compare exciting and new concepts. The first negative ion beam extraction experiments have been carried out. The compositions of the test equipment and the experimental results are presented in this paper.

Poster Session 2 / 202, T5_Tu_53

Distributions of Primary-Electron Populations in Different Magnetic Filter Configurations

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The magnetic filter is essential in all current negative ion sources for neutral beam injectors. The negative ions produced are easily destroyed by collisions with fast electrons (>2 eV). While the fast electrons are necessary to produce the plasma (e, H+, H2+, H3+, H) through ionizing collisions with the gas. To resolve this conflict, the magnetic filter is applied to form a negative ion extraction region in front of the plasma grid, where the electron temperature is cooled down through the filter field. Combined with the confined magnetic field, there are several filter field configurations. Because the plasma generation has a strong relation with the primary electrons in the filament-arc negative ion source. Hence, the influence of the magnetic filter field on the plasma has been studied through the distribution of primary electrons in this paper.

Poster Session 2 / 203, T6_Tu_69

Electron and Ion Beam Simulations for the BNL Extended EBIS at Brookhaven National Laboratory

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The Electron Beam Ion Source (RHICEBIS) provides various types of ions with the Relativistic Heavy Ion Collider and the NASA Space Radiation Laboratory at Brookhaven National Laboratory. RHICEBIS will be extended in length to provide a factor of 1.4 increase in the extracted Au^{32+} ion beam as well as internal gas injection capability for light ions. Two unshielded 5T superconducting solenoids, similar to the existing RHICEBIS solenoid, but reinforced to withstand the forces of close axial proximity, will be used to provide the magnetic field necessary for foring the EBIS electron beam with current density ˜600 A/cm^2. The axial spacing between the solenoid coils will be $\geq$ 45 cm, resulting in an dip in the magnetic field to less than 1T and a corresponding increase in the electron beam diameter in that region. The drift tube structure throughout the Extended EBIS must be designed to allow for transport and trapping of ions, accounting for the variation of electric potential along axis of the varying diameter electron beam. To investigate the processes of ion injection, trapping, and extraction, we calculated the electric potential for several electrode configurations between the solenoids, and study the influence on ion beam trajectories by computer simulation. Estimates of radial offsets of the electron and ion beams at the electron collector due to misalignments of magnetic system will also be presented.

Poster Session 2 / 205, T6_Tu_70

Slow Extraction of Charged Ion Pulses from the REX-EBIS

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The Isotope Separator On-Line DEvice (ISOLDE) facility located at CERN, produces and transports radioactive ion beams at low or high energy through the REX/HIE-ISOLDE linear accelerator, for nuclear physics, astrophysics, solid-state physics and applied-physics purposes. Enhancing the charge state of the ions is a prerequisite for efficient acceleration and is accomplished by an Electron Beam Ion Source (REX-EBIS). In conjuction, for effective event discrimination at the experimental detectors, a requirement is to spread the time distribution of extracted ion pulses from this EBIS. A Slow Extraction scheme is presented to determine a step function in time for the extraction potential of the REX-EBIS which demonstrates a lenghtening of the time structure of both stable and radioactive ion beams, with different mass-to-charge ratios and for time structure lengths in the millisecond range. Key operational parameters of the EBIS impacting the average ionic temperature and its axial energy spread are discussed in order to anticipate subsequent changes in the resulting pulse time structure during experimental runs.

Poster Session 2 / 216, T5_Tu_54

Numerical Investigation of the Early Operational Phase of the Negative Ion Test Facility SPIDER: Beam Features and Diagnostics

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The ITER project requires additional heating provided by two injectors of neutral beams (NB) resulting from the neutralisation of accelerated negative ions. To study and optimise negative ion production, the SPIDER (Source for Production of Ions of Deuterium Extracted from an Rf plasma) test facility is now in the assembly phase in Padova, with the aim of testing beam characteristics, verifying the source proper operation and providing a test bench for the diagnostic systems to be operated in the full-energy prototype of ITER NB injectors.
The target of the SPIDER facility is to produce a focussed H^- or D^- ion beam, having particle energy of 100 keV and beam current of 58 A in H^- or 45 A in D^-. The beam particles will be produced in a radiofrequency-driven plasma source having a power up to 800 kW. During the first operational stage, negative ions will be generated in the plasma volume whereas, later on, negative ion production will be substantially increased by a thin layer of caesium evaporated onto the source surfaces. SPIDER experiments will start at the beginning of 2018.
The present contribution briefly describes the specific features of the SPIDER accelerator and concentrates on the preliminary phases of SPIDER operations, dedicated to source and accelerator commissioning with the goal of increasing SPIDER performances, voltage holding conditioning of the accelerator, caesium conditioning of the source; beam extraction will be carried out.
The expected beam features are analysed by means of numerical simulations, considering the detailed magnetic and electrostatic configuration of the accelerator, the various operational phases, the corresponding expected source and beam parameters. These results are most useful to prepare for the earliest experimental campaigns. Correspondingly the expected results of the beam diagnostic techniques, like beam emission spectroscopy, beam dump calorimetry and the instrumented calorimeter STRIKE, are computed in cases with optimal beam optics as well as far from the optimum conditions.

Acknowledgement

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Poster Session 2 / 218, T6_Tu_71

The CANREB Project for Charge State Breeding at TRIUMF

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The goal of the CANREB (CANadian Rare isotope facility with Electron Beam ion source) project at TRIUMF is to deliver pure highly charged radioactive ion beams suitable for acceleration and performing experiments to investigate nuclear reactions. Radioactive isotopes at an ISOL facility like ISAC and ARIEL at TRIUMF are produced by bombarding solid targets with high energy particle beams. Singly charged ions can be extracted from an ion source immediately coupled to the target. At present an ECRIS charge state breeding system is used to prepare the ions for further acceleration. CANREB will complement this by providing higher purity of the beams and extending the available mass range. To accomplish this ions are first sent through a high resolution mass separator, where most of the isobaric contaminations can be removed. After this the ions are injected into an RFQ cooler buncher and finally bunches are injected into an EBIS for charge state breeding. In order to meet the acceptance of the following accelerator chain a mass to charge ratio of less than 7 amu/e has to be reached. The bunch repetition time is set to 10 ms. This will allow operation also with short lived isotopes. To guarantee the short breeding time for the entire mass range and to have a high injection efficiency the EBIS is designed to operate at an electron beam density of up to 20 000 A/cm^2 with a magnetic field of 6 T. With the EBIS being operated at ultra-high vacuum and no plasma wall interactions additional contaminations induced by the charge state breeding process are expected to be significantly reduced compared with the ECRIS. A drawback is the pulsed operation mode, which can cause pile up in some experiments, and the limitation in total beam intensity given by the buncher, which is at about 10^7 ions per bunch.
The system is presently being set-up. First charge state breeding tests with the EBIS have been performed and the results will be reported on.

Poster Session 2 / 228, T6_Tu_73

Effects of the CARIBU EBIS Trap Configuration on Extracted Ion Beam Characteristics

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Recently the CAlifornium Rare Isotope Breeder Upgrade (CARIBU) Electron Beam Ion Source (EBIS) charge breeder was commissioned at the ATLAS accelerator facility. Different EBIS trap configurations were used in order to investigate the effects on the extracted beam. Extracted beam intensities, timing, and energy spread were measured using a fast-counting ionization chamber. Results of the commissioning runs will be presented, and implications regarding optimization of the charge breeder configuration will be discussed.

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Poster Session 2 / 229, T6_Tu_74

Charge Breeding of CO^{+} Beams at REX-ISOLDE

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In a theranostic approach in hadron therapy, the β^{+} emitter ^{11}C can be used as the therapeutic beam and for range verification via PET imaging at the same time. Within the MEDICIS-PROMED project we study a possible injection scheme of the radioactive beam into the synchrotron-based medical accelerator. In this approach, ^{11}CO is produced with the on-line isotope mass separation technique followed by a beam preparation stage based on an Electron Beam Ion Source (EBIS).
Through tests at REX-ISOLDE with REXEBIS and the cooler/buncher REXTRAP the limitations of CO charge breeding can be explored with stable, high-intensity $^{13}CO^{+}$ ion beams. Possible charge breeding schemes and recent measurement results concerning beam transmission, charge breeding efficiencies and studies of molecular break-up in REXEBIS and REXTRAP are presented.

Poster Session 2 / 235, T6_Tu_75

Towards Ga^+ and Au^+ Ion Injection into ESIS: Mock-Setup Experiments and Ion Beam Profiling.

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A singly charged ion delivery system has been designed and constructed for the purpose of charged ion injection into the Electron String Ion Source (ESIS) at JINR, Dubna, Russia. [1], [2]. A Liquid Metal Ion Source (LMIS) is used to produce Ga^+ and Au^+ ions which are transported through a beam-line system consisting of charged particle optics [3]: Focusing Einzel-lenses, an electrical quadrupole switchyard for 90° beam bending and subsequent correction and focusing lenses before the entry port into the ESIS. Up to date, a mock-up of the full system has been created and used to study the injection process and ion transport efficiency, as well as the subsequent extraction of ions using reflected singly charged ions from the mock-up ESIS entry port. A multi-wire "Harp" beam profilometer has been used to study ion beam profiles and to obtain beam parameters of an injected and extracted Ga^+ ion beam. The results are summarized within this poster report.

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Poster Session 2 / 245, T6_Tu_76

Status and Development of the MARA Low-Energy Branch

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The MARA low-energy branch (MARA-LEB) is currently under development at the Univ. of Jyväskylä. The facility will be focused on the study of ground-state properties of exotic proton-rich nuclei employing in-gas-cell and in-gas-jet resonance ionisation spectroscopy, and will provide mass measurements of nuclei at the N=Z line of particular interest to the astrophysical rp process.

MARA-LEB will couple the recently commissioned MARA vacuum-mode mass separator [1] with a gas cell combined with an ion guide system for stopping, thermalising and transporting reaction products to the experimental stations. The mass selectivity of MARA, combined with the elemental selectivity achieved through laser ionisation within the gas cell, will open the way to the study of nuclei with production cross-sections several orders of magnitude smaller than isobars produced in the same nuclear reaction. Isotopes at or close to the N=Z line, for example light Ag and Sn isotopes, are of key interest. However, reliable experimental data on their ground-state properties are not available due to the absence of a technique which can be used for their efficient production and separation.

The gas cell is based on the concept developed at KU Leuven [2] and designed for the S3-LEB facility, GANIL. It will be able to use both Ar and He buffer gases to allow for more efficient neutralisation or faster extraction times respectively. Laser ionisation will be possible using a dedicated Ti:Sapphire laser system either in the gas cell or in the gas jet. Following extraction from the cell the ions will be transferred by radiofrequency ion guides and accelerated towards a magnetic dipole for further mass separation before transportation to the experimental setups.

In the first phase of the project a detector setup will be used for the characterisation and commissioning of the gas cell. Important information related to ionisation density in the gas and the effect on neutralisation will be studied, of direct interest to S3-LEB. In the second phase the gas cell will be combined with a laser ionisation spectroscopy setup and in the third phase with an MR-TOF-MS [3] which is currently being designed at IGISOL.

This presentation will focus on the status of the design and development of the facility.

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Poster Session 2 / 248, T6_Tu_77

The First Radioactive Ion Beam at the Beijing Radioactive Ion-Beam Facility

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Beijing Radioactive Ion-beam Facility (BRIF) at China Institute of Atom Energy (CIAE) utilizes the high intensity proton beam extracted from a 100 MeV cyclotron to produce the radioactive ion beams (RIB) by the isotope separation on-line method. A positive surface ionization source has been developed to produce the first radioactive ion beam. The modulation design was under development to fullfill the strict requirements of high voltage insulation, radioactive damage, vacuum and cooling water seal, and so on. The ion source was tested with $^{7}Li^{+}$ and $^{39}K^{+}$ stable beams. Also $^{38}K^{+}$ radioactive beam was produced by bombarding CaO target by 100 MeV proton beam. The designing and the current status of the target/ion source will be presented.

Poster Session 2 / 250, T5_Tu_55

Development of High Current Density Helicon Ion Source for DNB in VEST

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The combined system of Charge Exchange Spectroscopy (CES) and Beam Emission Spectroscopy (BES) will be developed in Versatile Experimental Spherical Torus (VEST) to measure ion temperature and rotation velocity by not using impurity but main hydrogen ion emission line directly. Diagnostic Neutral Beam (DNB) system is needed to supply high energy neutral particles for charge exchange reaction in this system.

A 9 kW compact high-current density helicon ion source has been developed for DNB. The target beam current is set to be ~300 mA at 30 kV to get a sufficient light intensity for CES. The Helicon ion source system consists of three parts: plasma source, extraction system, and power systems. Plasma density of the plasma source is measured to be as high as ~5 x $10^{18}/m^3$, indicating maximum extractable beam current density of 600 mA/cm^2. In order to extract ~300 mA beam current, circular hole with 8 mm diameter is chosen as extraction hole. Triode extraction system to maximize beam current density at low energy is designed. Marx modulator is developed for extraction power system. In this paper, detailed design of the hellion ion source system will be presented with initial performance data such as beam power from calorimeter measurement.

Poster Session 2 / 251, T5_Tu_56

Study of Isotope Effects in Hydrogen Negative Ion Sources

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One of the typical "isotope effects" in negative ion sources for fusion is that the amount of co-extracted electrons is increased for the deuterium plasmas compared to the hydrogen plasmas. With respect to this phenomenon, the experimental result was reported, in which dependence of the co-extracted electron current on the bias voltage changed with plasma species [1]. In Ref. [1], the authors suggested that the plasma potential may become higher in the deuterium plasmas because of the smaller ion loss rate, and that this may cause the co-extracted electron current to increase at same bias voltage. In order to examine this hypothesis and give deeper knowledges on the isotope effects in hydrogen negative ion sources, we have carried out the probe measurements in the extraction and driver regions with different gases (H_2, He, Ar).

We observed the mass dependence of the plasma potential. In addition, it was found that difference of the electron density in the extraction and driver regions becomes smaller with the heavier gas. In the paper, we will show dependence of the plasma parameters on the plasma species in different discharge conditions and will discuss roles of the magnetic filter and the grid bias on the isotope effects.

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Poster Session 2 / 253, T5_Tu_57

Comparison of Beam to Arc Discharge Current Ratio Between Hydrogen and Deuterium Operations in LHD-NBI Ion Sources

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One of the indexes of ion source performances is a ratio of beam current to discharge power (discharge power efficiency). In some cases, one ion source is utilized for several kinds of ion beams depending on the application. The discharge power efficiency can change by ion species. In particular, hydrogen and deuterium ion beams are utilized in the ion source of a Neutral Beam Injector (NBI) for nuclear fusion experiments. In the NBIs on the Large Helical Device (LHD) project, both of hydrogen and deuterium ion beam operations started in positive and negative ion sources. Ion source plasmas are generated by filament arc discharge in these ion sources. The same discharge power efficiencies were observed in hydrogen and deuterium operation in the positive ion source, while the discharge power efficiency in the deuterium operation was 50 - 70 % of that in the hydrogen operation in the negative ion source. In positive ion source, positive hydrogen and deuterium ion fluxes to the plasma grid correspond while ion density and velocity increases and decreases by a factor of square root, respectively. In the negative ion source, the extracted negative ions as the beam are mainly produced on the cesium covered plasma grid surface from parent particles which are atoms and/or positive ions. A negative ion production yield on the plasma grid depends on the parent particle speed perpendicular to the plasma grid surface. Slower parent particle speed by a factor of square root induces lower negative ion production yield in deuterium operation comparing with hydrogen. A ratio of beam current to arc discharge current (arc current efficiency) related to the discharge power efficiency is useful to connect ion source plasma parameters to extracted beam current. We discuss causes of similarity and difference of the discharge power and arc current efficiencies of hydrogen and deuterium operations in positive and negative ion sources. Additionally, from the causes, we estimate how much electron current increases in negative-deuterium-ion beam extraction comparing with hydrogen.

Poster Session 2 / 265, T6_Tu_79

Ion Sources for New Radioactive Refractory Element Beams at CERN-ISOLDE

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Despite the manifold new developments introduced to ISOL (Isotope Separation Online) target units within the last 60 years, the beam extraction of elements with very high boiling points (refractory elements) remains a very challenging topic. Due to their vanishingly low volatility, radionuclides of these elements generated by the driver beam are captured within the target and suffer from hampered release [1].
A common method to create beams of less volatile elements is the extraction as molecular sidebands. Just recently exotic boron beams could be produced as BFx+ molecular ions by ionization with an arc-discharge type VADIS ion source [2, 3], which is typically operated at temperatures of about 2000 °C. Taking into account the typical target temperature in the same range, only compounds exhibiting a certain stability at high temperatures were considered at the CERN-ISOLDE facility so far.
However, following new developments, which came up in the field of superheavy element chemistry within the last years [4], a new compound class might open up new perspectives for the extraction of the most refractory elements. Highly volatile carbonyl complexes M(CO)x, x=5-6 of suitable elements were found to form already at ambient temperature and pressure upon thermalizing fission fragments in a carbon monoxide-containing atmosphere. The fact, that nine out of fifteen transition metals, which are not yet available as beam, form volatile carbonyl compounds demonstrates the potential of the "carbonyl method".
While carbonyl compounds have proven to be suitable means of transportation, they are delicate compounds. Decomposition on hot surfaces, by electron beams, in plasmas and upon exposure to UV-light is expected, which provides new challenges for the ionization of the compound. This is especially the case for radioactive beam ion sources. Here the ion source is included in a robot-swappable combined target and ion source assembly and must therefore be compact. At the same time, the limited production rate of radionuclides demands a high efficiency of the source.
Within this work, different types of ion sources were systematically investigated with respect to their applicability for carbonyl complex ionization. To account for the thermal fragility, a VADIS ion source was modified to allow the injection of carbonyl complexes along a colder path directly into the anode body of the source. Moreover, two RF cold plasma sources were tested. These were the 2.45 GHz microwave driven COMIC source equipped with a quartz chamber [5], and the HELICON source [6], which is typically operated in the region between 170 and 180 MHz.

Finally, the laser-induced break-up of carbonyl complexes as essential preparatory step to resonant laser ionization was also experimentally addressed. As next steps, we plan to conduct on-line experiments to investigate the carbonyl-based beam production at ISOLDE as well as further ionization tests with a mono charge ECR ion source.

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Direct Laser Ionization and Acceleration using PW Lasers

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The potential of high intensity laser acceleration with petawatt PW-class laser systems such as the BELLA laser at LBNL are reviewed. Several mechanisms will be discussed as well as limits to the maximum ion energies, required targetry and diagnostics in order to utilize the capabilities of PW laser operation (and ion beam generation). Further, transport of such ion beams to an EMP-free environment, application of novel, high-gradient plasma optics [1] is proposed.
Benchmarked by first experimental results, we will present end-to-end simulations at the ion source and transport that lay out the achievable parameters of such a beam line and indicate that these ion beams can isochorically heat a 1 mm^3 gold target to the Warm Dense Matter state.

Acknowledgement

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Superconducting ECR Ion Source: from 24-28 GHz SECRAL to 45 GHz FECR

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Superconducting ECR source with higher magnetic fields and higher microwave frequency is the most straightforward path to achieve high beam intensity and high charge state in the past years. SECRAL, a superconducting third generation ECR ion source, is designed for 24-28 GHz microwave frequency operation with an innovative magnet configuration of sextupole coils located outside the three solenoids. SECRAL at 24 GHz has already produced a number of record beam intensities, such as Ar^{12+} 1.4 emA, Xe^{26+} 1.1 emA, Xe^{30+} 0.32 emA, and Bi^{31+} 0.68 emA. SECRAL II, an upgraded version of SECRAL, was built successfully in less than 3 years, and has recently been commissioned at full power of a 28 GHz gyrotron. Quite good results for highly charged ion beam production have been achieved, such as more than 600 e A Ar^{16+}, 10 e A Ar^{18+}, 140 e A Kr^{28+} and 0.5 e A Kr^{33+}. To produce more intense highly charged heavy ion beams, following the frequency scaling law of ECR ion source, a 45 GHz superconducting ECR ion source FECR (a first Fourth generation ECR ion source) is being built at IMP. FECR will be worldwide the first Nb3Sn superconducting-magnet-based ECR ion source with 6.5 Tesla axial mirror field, 3.5 Tesla sextupole field on the plasma chamber inner wall and 20 kW@45 GHz microwave coupling system. This talk will focus on SECRAL performance comparison at 24 GHz and 28 GHz, and technical design and challenges of 45 GHz FECR as well, which demonstrates a technical path for highly charged ion beam production from 24-28 GHz SECRAL to 45 GHz FECR.

7th Session / 94, T2_CO_03

Status of New Developments in the Field of High-Current Gasdynamic ECR Ion Sources at the IAP RAS

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The experimental and theoretical research carried out in the past at the Institute of Applied Physics (IAP RAS) resulted in development of a new type of electron cyclotron resonance ion source (ECRIS) – the gasdynamic ECRIS. The gasdynamic ECRIS features a confinement mechanism in a magnetic trap that is different from Geller's classical ECRIS confinement i.e. the quasi-gasdynamic one similar to that in fusion mirror traps. Such ion source type has demonstrated good performance producing high current (100-300 mA) multi-charged ion beams with moderate average charge (Z=4-5 for argon) and especially high efficiency for low emittance hydrogen and deuterium beam formation (500 emA current, current density up to 700 emA/cm^2 and RMS emittance below 0.07 • mm • mrad). Experimental studies of gasdynamic ECRIS in a pulsed mode were performed at SMIS 37 facility.
The obtained high-level results have stimulated a wide spectrum of research activities devoted to further extension of the gasdynamic ECR source principles to related fields of research and applications. The present report overviews recent investigations at the Ion Sources Laboratory connected with ECR plasma heating by powerful millimeter wave gyrotron radiation. Novel ideas such as using a magnetic field generated by a single coil for plasma quasigasdynamic confinement for proton beams production, applications of a dense ECR plasma for H^- generation, development of a new CW gasdynamic ECR source with 28 GHz gyrotron heating among others are discussed.

7th Session / 264, T2_CO_04

High Intensity Proton Source and LEBT for the European Spallation Source

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At the Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud (INFN-LNS) the beam commissioning of the high intensity Proton Source (PS-ESS) and the Low Energy Beam Transport line for the European Spallation Source (ESS) has been completed. The official project schedule was satisfied and the packaging for the shipment to Lund is under way. Due to the high flexibility of the magnetic system, and to the innovative approach developed for the commissioning, we were able to test a huge amount of configurations (more than 500 thousands). According to the last update, the source is able to produce stable total current between 40 and 125 mA (90 mA requested), with a proton fraction of up to 87% (75% requested), 99% normalized beam emittance of 1.06 .mm.mrad at 82 mA (1.8 .mm.mrad at 90 mA requested), intrapulse current fluctuation below ±1.5% (<±2% requested), long term current fluctuation below ±3% (<±3.5% requested). The optimum source configuration that satisfy all requirements at the same time was identified. The LEBT parameter optimization was focused on the reduction of emittance growth and the satisfaction of nominal Twiss parameters at the RFQ beam interface. Results and used strategy will be shown in details.

7th Session / 111, T7_CO_20

Investigation of Laser Energy Absorption by Ablation Plasmas

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Laser energy absorption is being studied by measuring reflected laser beam in Brookhaven National Laboratory. To provide highly charged heavy ion beams using laser ion source (LIS), efficient laser energy absorption to the plasma is important. In the plasma heating stage, laser beam penetrates outer layer of induced plasma. When the laser beam reaches a cutoff electron density of the plasma, the beam is reflected. If the absorption layer of the plasma plume is not thick enough, a considerable fraction of the laser energy is just bounced back and heating efficiency is low. In the plasma heating process, not like other ion sources, magnetic field confinement is not used and the induced plasma keeps expanding. Therefore, the plasma expansion velocity influences the laser energy absorption process. By changing the laser irradiation properties, efficient laser energy absorption condition is explored. In the conference, the measured latest results will be discussed.

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Innovative RF-driven ion source thruster for space applications

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Invited Talk

8th Session / 222, T8_CO_26

Status of Ion Sources at the National Institutes for Quantum and Radiological Science and Technology (QST)

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The National Institutes for Quantum and Radiological Science and Technology (QST) was established in April 2016 based on the merger of several institutes, the National Institute of Radiological Sciences (NIRS), and Takasaki Advanced Radiation Research Institute, Kansai Photon Science Institute, Naka Fusion Institute, Rokkasho Fusion institute formerly affiliated to the Japan Atomic Energy Agency (JAEA). The aims of QST cover a broad range of research and development for the applications of radiation, laser, and plasma.
Now QST maintains various ion sources and these ion sources are specialized in various applications through a long history of research and development, such as, heavy-ion radiotherapy, a production of radiopharmaceuticals, life-science studies and industrial applications with ion beam technology, highly-charged heavy ion acceleration from the laser system, neutral beam injectors for fusion plasmas based on negative ion sources, an irradiation tool dedicated to high neutron flux production based on an ECR ion source.
We report the status of our facilities and show considerable scope for expansion of quantum science and technology.

8th Session / 272, T8_CO_27

Ion Sources for Medical Radioisotopes Produced by Electromagnetic Mass Separation at CERN-MEDICIS

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MEDICIS is a starting facility dedicated to the production at CERN of medical radioisotope batches my electromagnetic mass-separation [1]. Ever more specific and efficient ion sources have been developped along the years across the different operating ISOL radioactive ion beam facilites and projects. Some examples can be found in ref. [2]. During the past few years, new insights were gained in the physical processes driving these delicate devices, very often submitted to harsh chemical, thermal or radiological conditions [3].
The requirements for a dedicated facility like CERN-MEDICIS are different, notably because high efficiencies, moderate chemical selectivity, high reliability with large isotope beam currents is more particularly required. Investigations in some cases have been done to develop specific ion source devices for medical radioisotope electromagnetic mass separation [4]. However the large spectrum of separation conditions require more dedicated developments to reach separation yields that are commensurate with more traditional radiochemistry separation processes used in conventional medical isotope production methods.
In this contribution, we will report on the large spectrum of separation processes intended at CERN-MEDICIS, together with information already available from recent ion source developments at Isolde and at other isotope mass separation facilities. In particular, large separation process yields can already be obtained for medically important radionuclides such as ^{225}Ra and ^{225}Fr, generators of one of the few alpha-emitting ^{225}Ac medical radioisotopes, or for more prospective Hg Auger electron emitting radioisotopes. Developments for the separation of cyclotron-produced ^{149}Tb, only available up until now at spallation ISOL facilities, is ongoing.
Part of these investigations are done with collaborating institutes of MEDICIS and in the European program MEDICIS-Promed [5].

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8th Session / 263, T6_CO_15

Study and Optimization of the VADLIS Ion Source for the Production of Radioactive Beams at ISOLDE

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The development of the Versatile Arc Discharge and Laser Ion Source (VADLIS) has been crucial to the success of several experiments at ISOLDE, CERN's radioactive ion beam facility, since it was used online for the first time in 2015 [1]. The VADLIS is a result of the combination of the Resonance Ionization Laser Ion Source (RILIS), used for 25 years at ISOL facilities to achieve element and isomeric selectivity, and the Versatile Arc Discharge Ion Source (VADIS), a variant of the ISOLDE FEBIAD successfully operated online at ISOLDE since 2008 [2].

As demonstrated by Day Goodacre et al [1], the VADIS cavity can become an effective laser-atom interaction region provided that the lasers can be transmitted through the 1.5 mm diameter exit aperture, and the cavity is operated in so-called 'RILIS-mode', whereby the anode voltage and source magnet are optimized for laser-ion extraction below the voltage required for significant electron impact ionization. This method enabled the first RILIS operation with molten targets for the study of mercury isotopes by in-source laser spectroscopy [3]. The efficiency of RILIS mode and VADIS mode operation was found to be comparable under standard on-line operating conditions for Hg, Cd and Mg [3]. An additional advantage is the possibility of choosing between different modes of ionization depending on how the source is operated, providing access to a greater variety of elements within the allocated beam time.

The electrostatic potential in the cavity has a strong impact on the time structure of the laser-ion beam, as well as the ion survival and extraction probability. These factors have an influence on both the efficiency and the achievable selectivity of the ion source. To better understand the experimental results, a Particle-in-Source (PIC) software [4,5] was used to simulate the electrostatic plasma conditions and time structures. A good agreement between the simulations and the earlier experimental results, reported in [1] has been obtained, validating the model that has been implemented.

The simulations provide a means of visualising the distribution of the electrical potential within the cavity, and to perform ion tracking, leading to the identification of regions where ions were slowly extracted or even trapped. With an optimised electrical configuration, the simulations indicate an improvement in the ion extraction conditions, theoretically increasing the efficiency and allowing a shorter extraction time. A first prototype with improved cavity characteristics was built and tested at the ISOLDE offline laboratory; the extraction efficiency was shown to increase by up to a factor 5 with this prototype. Ongoing developments that involve geometrical modifications for better extraction will be discussed as well in this work.

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9th Session / 292

Progress on the MEVVA Source VARIS at GSI

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The vacuum arc ion source VARIS, based on the MEVVA IV (MEtal Vapor Vacuum Arc) ion source, has been developed at GSI in 2004 especially for production of high current $^{238}U^{4+}$ ion beams for synchrotron operation. Compared to the MEVVA IV ion source the VARIS has a number of improved characteristics: higher emission current density, better vacuum conditions, better pulse-to-pulse stability, reduced intensity fluctuations during the beam pulse, higher fraction of fourfold uranium ions in the plasma, reduced power consumption and therefore higher efficiency.

For the last few years the development of the VARIS was concentrated on several aspects. One of them was the production of high current ion beams of heavy metals such as Au, Pb and Bi. Particular difficulties with these elements are caused by their physical properties, these are soft and fusible metals with relatively low melting point and high vapour pressure at operating temperature. This makes the production of fourfold ions (injection requirements into the radio frequency quadrupole RFQ) in a vacuum arc generated plasma quite challenging. However, the solution is found. The situation can be dramatically improved by using the composite materials or alloys with enhanced physical properties for the cathodes.

Another aspect is an increasing of the beam brilliance for intense U^{4+} beam by optimization the geometry of the electrodes in the extraction system. A new 7-holes triode extraction system allows an increase of the extraction voltage from 30 kV to 40 kV and reduces at the same time the outer aperture of the extracted ion beam. Thus, the record beam brilliance for U^{4+} beam in front of the RFQ has been achieved, exceeding the RFQ space charge limit for ion current of 15 mA.

Several new projectiles in middle-heavy region have been successfully developed from VARIS ion source to fulfill the requirements of the future FAIR (Facility for Antiproton and Ion Research) research programs. Influence of an auxiliary gas on the production performance of certain ion charge states as well as on operation stability has been investigated. Optimization of the ion source parameters for a maximum production efficiency and highest particle current in front of the RFQ has been performed.

The next important aspect of the development will be the increasing the operation duty cycle of VARIS ion source for all elements especially for uranium to 2.7 Hz in order to provide the maximum availability of high current ion beams for future FAIR experiments. The possible strategy to reach this goal is discussed.

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Commissioning of the ECR Ion Source of the High Intensity Proton Injector of the Facility for Anti Proton and Ion Research at CEA-Saclay

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The Irfu/SACM at Saclay is in charge of developing and building the ion source and the low energy line or the proton linac of the FAIR accelerator complex (Facility for Antiproton and Ion Research) located at GSI (Darmstadt) in Germany. The FAIR Facility will deliver stable and rare isotope beams covering a huge range of intensities and beam energies for experiments in the fields of atomic physics, plasma physics, nuclear physics, hadron physics, nuclear matter physics, material physics and biophysics. A significant part of the experimental program at FAIR is dedicated to antiproton physics that requires an ultimate number 7×10^{10} cooled pbar/h.

The high-intensity proton beam that is necessary for antiproton production will be delivered by a dedicated 75 mA/70 MeV proton linac. A 2.45 GHz microwave ion source will deliver a 100 mA H^+ beam pulsed at 4 Hz with an energy of 95 keV. A dual solenoids Low Energy Beam Transport line (LEBT) allows the injection of the proton beam into the radio frequency quadrupole (RFQ) within an acceptance of 0.3 mm.mrad (norm. rms). An electrostatic chopper system located between the second solenoid and the RFQ is used to cut the beam macro pulse from the source to inject 36 s long beam pulses into the RFQ. At present time, a Ladder-RFQ are under construction at the University of Frankfurt.

This article reports the first beam measurements obtained since mid of 2016. Proton beams have been extracted from the ECR ion source and analyzed just after the extraction column on a dedicated diagnostic chamber. Emittance measurements, as well as extracted current and beam proportion analysis have been performed in different configurations of ion source parameters, such as magnetic field profile, RF power, gas injection or extraction voltage.

9th Session / 13, T4_CO_09

Implementation of Design Changes Towards a More Reliable, Hands-off Magnetron Ion Source

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As the main H^- ion source for the accelerator complex, magnetron ion sources have been used at Fermilab since the 1970's. At the offline test stand, new R&D is carried out to develop and upgrade the present magnetron-type sources of H^- ions of up to 80 mA and 35 keV beam energy in the context of the Proton Improvement Plan. The aim of this plan is to provide high-power proton beams for the experiments at FNAL. In order to reduce the amount of tuning and monitoring of these ion sources, a new electronic system consisting of a current-regulated arc discharge modulator allow the ion source to run at a constant arc current for improved beam output and operation. A solenoid-type gas valve feeds H_2 gas into the source precisely and independently of ambient temperature. This summary will cover several studies and design changes that have been tested and will eventually be implemented on the operational magnetron sources at Fermilab. Innovative results for this type of ion source include cathode geometries, solenoid gas valves, current controlled arc pulser, cesium boiler redesign, gas mixtures of hydrogen and nitrogen, and duty factor reduction, with the aim to improve source lifetime, stability, and reducing the amount of tuning needed. In this summary, I will highlight the advances made in ion sources at Fermilab and will outline the directions of the continuing R&D effort.

9th Session / 232, T7_CO_23

Residual Gas Effect in LEBT on Transverse Emittance of Multiply-Charged Heavy Ion Beams Extracted from ECR Ion Source

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Emittance of multiply-charged heavy ion beam extracted from ECR ion source should be matched with the acceptance of the following low energy beam transport (LEBT) and accelerator in order to improve transport efficiency. The more beam brightness increases, the more important space-charge effect is because it induces the spatial aberration of beam optics components, e.g. dipole magnets and quadrupole and solenoidal lenses, especially for LEBT. The aberration causes the beam emittance enhancement and degrades the emittance matching condition. Electrons generated from the collisions between the ion beam and residual gas of the LEBT are considered to partially neutralize the space-charge effect. Thus, we intend to confirm the residual gas effect on space-charge effect of heavy ion beam through the measurement of the transverse four-dimension (4-D) phase-space distribution by controlling the residual gas pressure of LEBT with neutral gas (Ar, Kr and so on) through a variable leak valve.

To observe of the transverse 4-D phase-space distribution, namely transverse emittance, we have developed an on-line pepper-pot emittance meter, which is a suitable device because we can obtain the transverse emittance from only one picture of beamlets passing through the well-aligned pinholes. The emittance meter consists of a plate with 24 × 24 pinholes (0.1 mm diameter each), which are aligned in a grating pattern with 2 mm pitch. The pinhole plate is mounted on the movable holder along the beam axis in front of an imaging screen (P46) with a MCP. By adjustment of the drift distance between pinhole plate and MCP, the angular resolution is able to be optimized with in the limit of separation of the neighboring beamlets.

By using the pepper-pot emittance meter, we have measured the transverse emittances of multiply charged ^{18}O and ^{40}Ar beams with changing the residual gas pressure in the LEBT by injecting neutral gas. We used O_2, Ar and Kr gases as injection gases as a systematic investigation of the residual gas effect. The 4-D distribution is sensitive to the spatial aberration caused by the higher order harmonics of magnetic field of beam optics component. We will discuss about how the residual gas affects the transverse emittance taking the beam optics components of the LEBT into account.

9th Session / 37, T6_CO_18

The RHIC Polarized H^- Ion Source

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A novel polarization technique had been successfully implemented for the RHIC polarized H^- ion source upgrade to higher intensity and polarization. In this technique a proton beam inside the high magnetic field solenoid is produced by ionization of the atomic hydrogen beam (from external source) in the He-gas ionizer cell. Further proton polarization is produced in the process of polarized electron capture from the optically-pumped Rb vapor. The use of high-brightness primary beams and large cross-sections for charge-exchange resulted in production of high intensity H^- ion beam with 85% polarization. High beam brightness and polarization resulted in 75% polarization at 23 GeV out of the (Alternating Gradient Synchronisation) AGS and 60-65% beam polarization at 100-250 GeV colliding beams in RHIC.

Poster Session 3 / 137, T8_We_61

A Photoconductive Semiconductor Switch Driven Ion Beam Injector for Radiobiological Experiments

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We have been developing a compact ion accelerator system for evaluating potential health risks of radiation exposure against ion beams. In order to realize the compact ion accelerator, we adopted a dielectric wall accelerator (DWA) concept for beam acceleration. The DWA system uses photoconductive semiconductor switch (PCSS) driven high voltage transmission lines to generate pulsed electric fields on the inside of a high gradient insulating (HGI) acceleration tube. A prototype of a carbon ion injector using a laser ion source and a DWA type accelerating module has been developing at KEK. At the conference, we will report the design of this system and the latest experimental results of the performance tests of PCSS and high voltage generation.

Poster Session 3 / 135, T7_We_16

Observation of Beam Current Fluctuation Extracted from an Rf-Driven H^- Ion Source

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In J-PARC, peak H^- current of several tens mA is produced from a cesiated hydrogen plasma ignited by a solid-state rf amplifier with the frequency of 2 MHz [1-3]. In case of the high-intensity H^- beam extracted from the ion source, the plasma density in the source chamber is so high that the ion sheath around the beam extraction area follows the rf oscillation. The reason is that the ion plasma frequency defined by the ion density is approximately 100 times higher than the driving frequency [4]. The potential fluctuation of the plasma is combined with the driving rf electric field and causes motion of charged particles in the plasma some changes. As a result, the H^- beam extracted from the source plasma also fluctuates. The beam current signal from a Faraday cup was measured by a spectrum analyzer. A powerful frequency spectrum at 2 MHz which is as same as that of the rf amplifier was observed. At the conference, we present results of the beam current fluctuation. It is thought that the beam particles have some fluctuation to the transverse motion perpendicular to the beam axis as well. Thus, we also propose a measurement system using a time-resolved and highly-sensitive emittance monitor in order to observe the beam fluctuation in the phase space.

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Poster Session 3 / 138, T7_We_17

Integrated Modeling of the Beam Formation and Extraction in the Linac4 Hydrogen Negative Ion Source

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Linac4 H^- ion source is required to deliver 50 mA of H^- ions within a transverse rms emittance of 0.25 mm mrad[1, 2]. In order to meet these requirements, it is indispensable to clarify the H^- ion extraction and beam formation process in the vicinity of the beam extraction hole i.e. extraction region in the H^- ion source. In the previous works, the extraction region in the Linac4 H^- ion source has been modeled by the 2D Particle in Cell (PIC) [3] method and 3D PIC method [4]. In the Ref. [4], the extracted H^- ion beam current and co-extracted electron current by the 3D PIC simulation has been compared with the experiments. However, the beam emittance calculated by the simulation model has not been directly compared with the experiments.

In order to compare the beam emittance with the experiments, we are now developing the integrated model of the source plasma, extraction region and acceleration region. As for the source plasma, the NINJA [5], which is 2D Electro-Magnetic-PIC (EM-PIC) code for the RF inductively coupled plasma has been applied. In the extraction region, 3D KEIO-Beam Formation and eXtraction (BFX) code has been applied to calculate the plasma meniscus and H^- ion beam formation process. Finally, the IBSIMU and the TRAVEL-3D have been applied in the beam transport in the acceleration region to obtain the beam emittance.

We have performed the case of the positive ion extraction for the validation of the integrated model. It has been shown that the extracted positive ion current by the integrated model reasonably agrees with the experiment. In the presentation, we will show the case of the negative ion extraction, and the H^- beam emittance and extracted beam current will be compared with the experiments.

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Poster Session 3 / 141, T7_We_18

Extraction of an Aluminum-Nitride Ion Beam from a Planar Magnetron Sputter Type Ion Source

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Ion beam based processes to prepare semiconductor components open possibilities to further down size electronic appliances in future. Aluminum-nitride (AlN) has potential applications in many fields of electronics such as ultra-violet light-emitting diodes and highly thermal conductivity dielectric materials. Direct implantation of AlN molecular ions into base materials may realize a new semiconductor fabrication process, and the possibility of realizing a pencil beam of AlN molecular ions has been started investigated.

A capacitively coupled 13.56 MHz RF magnetron sputter type ion source produces a beam of AlN^+. The source contains an aluminum target immersed in nitrogen containing plasma. Introduction of Ar gas into N_2 discharge plasma enhanced target sputtering, and beam current characteristics against the gas ratio of Ar to N_2 were measured for fixed gas pressure and RF power. The result showed beam current ratio of AlN^+ to Ar^+ increased with the increasing amount of Ar gas injected into N_2 plasma. The observed maximum ratio of AlN^+ to Ar^+ reached to about 1.5%, while the ratio of Al^+ to Ar^+ was about 24% at the corresponding discharge condition. The operating condition of the source was affected by formation of AlN layer, and the time dependent behavior of the AlN^+ beam is discussed in relation to the formation of AlN layer on the ion source wall.

Poster Session 3 / 142, T7_We_19

Development of a Carbon Cluster Ion Source with a Hollow Cathode

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Shallow carbon implantation by low energy carbon cluster ions can be an effective method to reduce heavy metal contamination of Si wafer for semiconductor industry. An ion source utilizing high voltage hollow cathode discharge is designed and being tested in order to examine the capability to generate carbon cluster ions. A 35.5 mm inner diameter, 40 mm long glass made ion source has a carbon hollow cathode electrode, a carbon anode electrode and an electrically floated carbon intermediate electrode. The hollow cathode has a 22 mm inner diameter, 30 mm outer diameter and 30 mm height. The composition of the extracted beam is analyzed with a magnetic deflection type mass analyzer of 285 mm Larmor radius. The ions travel about 800 mm to reach the entrance to come into the field region of the mass analyzer, change the direction by 90 degree and further travel another 800 mm distance to reach the Faraday cup. Typical mass spectrum taken at about 40 Pa estimated Ar gas pressure in the ion source, 8 mA discharge current, 485 V discharge voltage and 4 kV extraction voltage shows that carbon clusters are generated with the ratios: 0.012 [C^+/Ar^+], 0.071 [C_2^+/Ar^+], 0.55 [C_3^+/Ar^+], 0.00091 [C_4^+/Ar^+], 0.00055 [C_5^+/Ar^+] 0.0016 [C_6^+/Ar^+], and 0.0053 [C_7^+/Ar^+]. Carbon cluster ion production is being investigated for different discharge conditions.

Poster Session 3 / 143, T7_We_20

Analysis of the H^- Extraction in the Linac4 Negative Ion Source by 2.5D Particle Simulation

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Linac4 cesiated surface negative ion source is required to produce 50 mA of H^- ions within a transverse rms emittance of 0.25 mm mrad [1,2]. In order to achieve the requirements, it is necessary to optimize the H^- beam extraction from the Linac4 negative ion source. Recently, the extraction region of the Linac4 ion source has been modeled by three- Dimensional Particle in Cell (3D-PIC) method in Ref. [3] to analyze the effects of the operation parameters (e.g. magnetic filter strength) on the H^- extraction. However, the effects of the operation parameters have not yet been completely understood. The final goal of this study is to make clear the effects of the operation parameters on the H^- extraction. For this purpose, it is necessary to carry out the numerical simulations for a wide range of the parameter space.
Several 2D-PIC and 3D-PIC models for the H^- extraction have been developed up to now [4-7]. Such 2D models are very useful to understand the basic physics of the H^- extraction [4-6]. And they are suitable for the wide range of the parameter survey of the operation parameters because their computational costs are very small. However, the 2D models are not suitable to evaluate the effects above in the quantitative sense. For example, the beam halo ratio calculated by 2D model is significantly larger than that in the experiments. On the other hand, 3D models give a quantitatively reasonable result. However, 3D models are too massive to perform a wide range of the parameter survey.
In this study we have developed a new 2.5D PIC model, in which particle losses perpendicular to the calculation plane are taken into account. The 2.5D model gives good agreements with the experiments on the H^- beam current and the e/ H^- ratio. Now we are validating the beam divergence obtained by the 2.5D model. After that verification, the effects of the operation parameters (e.g. extraction voltage and plasma electrode shape) will be studied. In addition, the transport of the surface produced H^- ions which is deeply related to the H^- beam current and emittance will be also analyzed.

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Poster Session 3 / 151, T8_We_62

Development of 1 MV Electrostatic Accelerator with Compact RF Ion Source at KOMAC

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1 MV electrostatic accelerator is being developed in the KOrea Multipurpose Accelerator Complex (KOMAC), and has specifications of the 1 MV of maximum accelerating voltage and more than 1 mA of beam current to meet the needs from the users with a MeV range ion beam implantation. The accelerator consists of ion source, accelerating tube, beam transport system, switching magnets and target chamber. For the high-voltage power supply, ELV type was chosen due to its robustness and capability of high current. Because of the limited space and limited electrical power inside the pressure vessel, a compact RF ion source driven at 200 MHz was chosen. Before installation of the accelerator, we carried out several tests including high voltage and beam extraction at the 300 kV test-stand, test of strength and vacuum tightness of quartz tube used as plasma chamber under 0.53 MPa SF6 environment, reliability test of electronics for RF ion source controlled by optical fiber. In this paper, the tests and installations for 1 MV electrostatic accelerator are described and the results of beam extraction measurement are presented.

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Poster Session 3 / 152, T7_We_21

Performance and First Data Analysis of the ESS Emittance Measurement Unit

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For the ESS project, an Emittance Measurement Unit (EMU) was developed by CEA Saclay. This EMU, based on Allison scanner design, was installed in a LEBT for the ion source commissioning at INFN-LNS at the beginning of the year 2017. Transverse emittance is one of the key measurements to be performed during the commissioning of the low energy sections of a hadron linac.The good knowledge of the beam transverse phase space allows a safe and efficient operation of the machines by using the results of the measurement for beam dynamic simulations.
For a linear accelerator with high beam power operating in pulsed mode, it is mandatory to have a high-resolution emittance measurement as well as a time resolve measurement. To achieve this, a high dynamic range acquisition chain is needed. During the first measurement campaign, a dynamic range above 103 was demonstrated, showing unexpected background signals that the authors will discuss in this paper. The paper also describes the performance of the EMU, and the results of simulations performed to estimate the effective length of the electrostatic field needed for the particle deflection in the Allison scanner based EMU.

Poster Session 3 / 160, T8_We_63

Characterization of 1 MHz Solid State High Frequency Power Supply with Inductively Coupled Plasma

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A program to develop 200 kW, 1 MHz solid state high frequency power supply is initiated in a phased manner with industry. High frequency power supply is intended for plasma formation in neutral beam source or similar applications, providing high efficiency. The present high frequency power supply is configured with multiple modules of Class-D H-Bridge inverters, magnetic combiners, tuning and matching network to provide 1 MHz sinusoidal output at 50 Ω load. A prototype 5 kW power was developed and coupled with plasma to characterize the solid state concept.

Recent experimental campaign has established matching network parameters to strike and sustain hydrogen plasma with a density in the range of 10^{15} to 10^{17} m^{-3} at 2-3 Pa and forward power of 1.2 kW @ 1 MHz. Practical result shows that the solid state design produces plasma with an optimum power factor of 0.8-0.9 over a pulse length of 60s and beyond. It has also been observed that a power factor of 0.7-0.8 is achievable without isolation transformer in the matching circuit. Experiments are useful to study the behavior of power supply in scenarios of dynamic (plasma) conditions or sudden load/off load conditions.

This paper describes the behavior of prototype 5 kW, 1 Mhz solid state power supply during the experiment. It also gives the conceptual design of a 200 kW high frequency power supply based on the inputs learned from the prototype experiment.

Poster Session 3 / 161, T8_We_64

On the Formation Mechanism of Modified Fullerenes in the Two-Chamber Configuration of the Bio-Nano ECRIS

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Recently, we reported the fullerene modification using neutral-neutral or neutral-ion collision reactions in the two-chamber configuration of the Bio-Nano electron cyclotron resonance ion source (ECRIS) [1]. In our methodology, modified fullerenes can be synthesised in vapor-phase in an ECR plasma, or on a surface of a plasma chamber, and can be characterised by on-line mass spectrometric analysis of the ECRIS beam, or by off-line analyses (e.g. time-of-flight mass spectrometry, liquid chromatography mass spectrometry, etc.). So far, we have successfully synthesised a modified C70 with iron (Fe) and chlorine (Cl) atoms using two individual plasmas: Fe-Cl plasma and C70 plasma.
In a subsequent experiment, shown in this study, we investigated the ion/electron density distributions in the plasma chamber by using electrostatic probe method. We correlated these results with the off-line synthesised material investigations and also with plasma electron simulations in order to collect more information on the mechanism of the synthesis process.

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Poster Session 3 / 166, T8_We_65

The First Test of the Ion Implantation Beamline at VIBA

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VIBA (Versatile Ion Beam Accelerator) is a compact linear accelerator facility using 28 GHz ECR ion source at KBSI (Korea Basic Science Institute). The goal of VIBA is to support various researchers using low-energy ion beams. During the year, diagnosis system of VIBA was changed for ion implantation. Ion implantation chamber was separated from the conventional diagnostic chamber for improving ion implantation. We performed ion implantation on silicon wafers with several ions and energies, and measured the depth profile of each sample using a surface analysis instrument. Experimental results were compared with simulations performed using SRIM 2013 code. Characteristics of ion implantation using ECRIS will be reported.

Poster Session 3 / 169, T8_We_66

Analysis of the Superconducting Magnet Performance for RAON 28 GHz ECR Ion Source

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The superconducting magnet for RAON 28 GHz ECR ion source has been designed. The designed magnetic field distributions for the 28 GHz ECR ion source were 3.5 T at the injection side, 2 T at the extraction side and 2 T on the inner surface of the plasma chamber, respectively. The magnets using NbTi wires were composed of the four solenoid magnets for axial magnetic field and one saddle type hexapole magnet for radial field. The experiments were conducted at 4.2 K conditions using liquid helium. In this paper, magnet performance results were analyzed based on the balance of the magnetic force. The results showed that the difference in magnet performance was 10 ~ 20 %, according to magnetic force balance affected by the sequence exiting the magnets. Thus, the sequence has an effect on the magnet performance. This results are expected to help in finding the optimal sequences.

Poster Session 3 / 180, T7_We_22

Ion Beam and Discharge Characteristics of a Multi-Cusp Ion Source with Various Magnetic Field Configurations

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Magnetic confinement of plasma is of importance for improving the ionization efficiency particularly for hot cathode discharge plasma [1]. In this contribution, we present an investigation on the effects of varying multicusp configuration of annular SmCo magnets on plasma confinement for hot cathode plasma and its consequences on ion beam generation. Hot cathode plasma was subjected to a magnetic field via an adjustable multicusp configuration of permanent magnets creating an axial magnetic field with a maximum surface flux density of 3660 Gauss. This configuration consequentially confines and creates a virtually magnetic field-free area for the bulk plasma [1]. For broad ion beam extraction, the ion beam density as well as beam uniformity becomes important for various applications such as thin film deposition. Thus, tuning the magnetic field configuration is crucial in the ion source chamber.

Argon (Ar) plasma was excited using two 0.3mm diameter tungsten wires as hot-cathodes. Langmuir probe measurement via a cylindrical wire probe was employed to determine the effect of varying the magnetic field configuration of the upstream chamber. This was correlated to the discharge characteristics in terms of electron temperature, plasma potential, and plasma density. In this work, low pressures are utilized to yield high degree of ionization and reduce the energy spread of incident ions [2]. Moreover, plasma density is significantly influenced by varying working pressures, especially when interacting with an external magnetic field. The plasma was also operated at low discharge currents for a homogeneous plasma discharge [3,4]. A retarding potential analyzer was used to correlate the extracted ion beams with the upstream discharge characteristics and magnetic field configuration.

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Poster Session 3 / 181, T8_We_68

Development of 2.45 GHz ECR Proton Source for Compact Accelerator-Driven Neutron Source System

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In order to spread neutron use in industrial field, it is important to provide a compact semi-ready-made neutron source that a company and a factory can easily introduce. Therefore we have studied a compact accelerator-driven neutron source system, which consists of a 2.45 GHz simple-mirror electron cyclotron resonance (ECR) proton source, a four-vane RFQ linac and a lithium target for neutrons production by the Li(p,n)Be reaction. The operating frequency of the proton RFQ linac is 650 MHz and is adopted for downsizing. We designed its specifications through beam trajectory and electromagnetic simulations and fabricated the 2.45 GHz simple-mirror ECR proton source. The details of the neutron source system and the experimental results of the proton source will be presented.

Poster Session 3 / 183, T7_We_23

Particle Dynamic Simulations of the GSI Test Injector Facility HOSTI

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At GSI a high current test injector (HOSTI) is in operation since 2009. It has been designed for the experimental investigation of high brilliance low charge states ion beams and for the injection optimization of high current ion beams into the existing and future LINAC.
The ion beam from HOSTI is extracted with a three-electrode system and post-accelerated to match the longitudinal input energy of 2.2 keV/u of the RFQ.
In order to improve the understanding of the effect on the ion beam dynamic of the main components of the post acceleration system, the electric field has been simulated for different configurations. The simulated potential lines have been used to analyze the ion trajectories downstream the extraction system and through the post-acceleration system and the simulated emittances are in very good agreement with the measurement results.
Different settings of ion beam have been investigated and several parameters have been tuned to find the optimized configuration determining the highest brilliance of the extracted ion beam and the results of these particle dynamics simulations are described here.

Poster Session 3 / 176, T8_We_67

Electron Beam-Mediated Reduction of Silver Ions Impregnated in a Natural Zeolite Framework

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Zeolites have been heavily utilized for different industrial applications that include catalysis, ion exchangers, and adsorbents. Due to the stability and rigidity of the zeolite framework, it has been investigated recently as a template to hold nanoparticles in its matrix [1]. This would allow the framework to immobilize nanoparticles without the need for a polymeric stabilizer that prevents agglomeration.

Silver (Ag) embedded in a zeolite matrix is one of the heavily studied nanocomposites because of its properties that may find applications in biomedicine and sewage disposal systems. Ag is a potent antibacterial material with a broad antibacterial spectrum and considered to be relatively safe [2]. The usual route for the synthesis of these composites is via impregnation through ion-exchange of the solid support then reduction to their metallic states [3]. However, conventional techniques for the reduction process involve the use of harsh chemicals detrimental to health and environment.

Recently, reduction via radio frequency plasma treatment has been conducted [4] to reduce Ag ions to its metallic form embedded in a natural zeolite framework. In this work, electron beams were utilized to reduce Ag in the zeolite matrix. A multi-cusp ion source with a tungsten hot-cathode as filament was employed in the process. Extraction of charged particles was achieved using a ˜90% transparent dual-electrode extraction system made of tungsten wire mesh capable of producing low-energy beams [5]. Ag-impregnated zeolite powders were mounted and exposed to ˜100 eV electron beams at different exposure times ranging from 15 min to 60 min. Results indicated the successful reduction of Ag upon irradiation of electron beams. This confirmed that the composites acted as "electron sinks" [6] and promote the reduction of Ag and eventual growth of nanoparticles embedded in the matrix. The present scheme allows the use of sub-keV electron beams for the reduction process and does not need additional potential acceleration compared to previous works [7,8].

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Poster Session 3 / 65, T7_We_10

Spectral Modelling of Neutral Beam for Doppler Shift Spectroscopy Diagnostics of INTF

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A 100 keV, negative hydrogen ion based neutral beam system is at the developmental stage in INTF at Institute for Plasma Research (IPR), India. This test facility is used for characterising the large beam source which is to be used in the Diagnostic Neutral Beam (DNB) for ITER. A large number of diagnostics are also at the developmental stage for measuring and monitoring the beam performance. The Doppler Shift Spectroscopy (DSS) diagnostics is a beam emission spectroscopy (BES) system chosen for characterizing the beam by evaluating the beam divergence, stripping losses and the beam uniformity from the observed. INTF beam source is designed to deliver 60 A of negative hydrogen ion current through its 1280 apertures arranged in a 4 x 4 beam groups having each a matrix of 5 $\times$ 16 beamlet resulting a beam cross section of 0.6m (h) x 1.6m (v). It is proposed that the beam properties on the entire cross section of the beam can be studied using 36 lines of sight (LOS) at different ports on the vacuum vessel. The LOS are deployed at 12 horizontal from the left side, 12 horizontal from the right side and 12 from the bottom of the vacuum vessel.

In order to design and develop this diagnostic, a forward model for estimating the signal to noise ratio, stripping losses, and beam divergence for all these lines of sights (LOS) at different operating scenarios and instrument settings is developed. The model accounts all the 1280 beamlets and its interaction with the line of sights and predicts the DSS spectrum for each beamlet-LOS interaction volume. Using this forward model, it is found that a viewing angle of 60-degree w.r.t beam axis yields a clearly resolved Doppler shifted spectrum with a signal to noise ratio of ˜100 even for low current operations (1 A), maintaining all the interface issues. Studies also indicate that a simple lens–fiber combination and a standard Czerny-Turner spectrograph having a wavelength resolution of 0.03 nm can be used for transporting and detecting the light signal. An endoscopic light collection system is proposed for light collection for obtaining a higher signal to noise ratio under low light conditions, which may help during the initial phase of operation. The expected performance of the diagnostics based on this model is discussed and a brief description of the proposed diagnostics lay out in INTF is also presented.

Poster Session 3 / 74, T7_We_11

Beam Characterization by Means of Emission Spectroscopy in the NIO1 Experiment

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The NIO1 (Negative Ion Optimization 1) experiment hosts a flexible RF H^- ion source, developed by Consorzio RFX and INFN-LNL to improve the present concepts for the production and acceleration of negative ions. The source is also used to benchmark the instrumentation dedicated to the ITER neutral beam test facility.
Many diagnostics are installed in NIO1 to characterize the source and the extracted negative ion beam. Among them, Beam Emission Spectroscopy (BES) has been installed in NIO1 to measure the divergence and the uniformity of the beam, together with the fraction of beam ions which was neutralized inside the acceleration system. The diagnostic method is based on the analysis of the Doppler shifted H_α photons emitted by the fast beam particles and collected along lines of sight. The article will present the experimental setup and the analysis algorithms of the BES diagnostic, together with a discussion of the first measurements and of their correlation with the operational parameters.

Poster Session 3 / 75, T7_We_12

Self-Consistent Potential in High Intensity Deuteron Beam Simulations and Measurements

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The space charge compensation process is important in order to transport ion beams with high perveance from the source to the RFQ. In particular, not fully compensated beams may develop halo and emittance growth at the entrance of the RFQ. The signal of incomplete compensation is the presence of a significant residual potential (in the range of 5% or 10% of the uncompensated potential). In order to investigate these phenomena, we performed CPU-time-demanding simulations with self-consistent programs from which we could extract the information about the space charge and the potential along the transfer line (consisting of three drift spaces and two solenoid), especially at the entrance and at the exit of the solenoids, with a typical D^+ beam current of 135 mA, a 0.25 mm mrad rms normalized emittance at a 100 keV input energy. We also compared the results with the FGA (four grid analyzer) measurements performed at the prototype accelerator of the IFMIF/EVEDA stage.Simulations were performed via the PIC code WARP. Particularly we compare the results obtained in the rz (cylindrical symmetry) and in the 3d xyz implementations, to verify whether the former approach (much faster) is accurate enough.

Poster Session 3 / 53, T7_We_09

Effective Transportation of Negative Hydrogen Ions in a Synthesized Hydrogen Beam

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Effective transportation of negative hydrogen ions formed during charge exchange of a high-brightness proton beam with ballistic focusing in a hydrogen charge-exchange target was observed in experiment. A beam of protons with an energy of 10 keV, a current of 4.7 A, an emission current density of 470 mA/cm^2, an angular divergence of 10 mrad, and a focal length of 200 cm was formed at 1 Hz frequency in the fast atom beam source (FABS) of the polarized ion source OPPIS at BNL. The value of H^- ion current passing through a 2 cm diaphragm located at a distance of 200 cm from the emitter was 75 mA.

The effective negative hydrogen ion beam transportation is explained by the focusing and confinement of negative ions in the positive plasma potential of the synthesized charge-exchanged beam of hydrogen particles. The paper presents the results of an experimental study of the parameters of a synthesized hydrogen beam in the region of the focus of a fast hydrogen atom beam. The results of numerical simulation of the effective transport of H^- ions in the positive potential of the synthesized beam are given. The possibilities of applying the effective transport of a negative ion beam for injection into accelerators are discussed.

Poster Session 3 / 40, T7_We_05

Status of High Intensity Low Energy Injector for Jinping Underground Nuclear Astrophysics Experiments

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China Jinping Underground Laboratory (CJPL) is currently the deepest underground Lab in the world. By taking advantage of the ultralow background in Jinping underground lab, a 400 kV high voltage accelerator driven by a 2.45 GHz ECR ion source and highly sensitive detectors are planned to be used to study directly a number of important nuclear reactions. A compact and intense 2.45 GHz permanent magnent ion source with a low energy beam transport system (LEBT) will be served as injector source to produce high intensity ion beams, such as 10 mA H+, 10 mA He+ and 2 mA He2+ to be delivered into high voltage acceleration tube. The compact LEBT consists of two 600mT maximum magnetic field solenoid lens integrated steering magnets, a 30 degree dipole magnet and two diagnostic chambers. The ion source and LEBT system have been successfully developed and commissioned on a stand along test bench, and is now connected to the 400 kV high voltage platform accelerator system in a ground level test laboratory. In this paper, the studies of this intense beam injector system, for instance, beam intensities, species and ratio, beam transmission efficiency in LEBT and also the beam matching to the downstream accelerator system will be presented.

Poster Session 3 / 41, T7_We_06

CAMFT Code for Ion Bunch Dynamics Simulation in External Fields with Parallel Computing

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The ion beams extracted from the LIS, ECRIS or EBIS are characterized by complicated charge state distribution of the ions. As a rule, for the aims of the specific experiment only one of the charge states is needed, so the charge state separation is a part of the beam formation. To predict the behavior of intense ion bunch with various distributions of the charge states in magnetic field of the separator both dipole and quadrupole type the CAMFT code is developed with one of the goal to apply the code in experiment automation system. The 3D-code current version realized with Python allows to treat various particle density distributions, various geometry of the bunch (ellipsoidal, sheet, axial-symmetric), arbitrary initial phase volumes. To provide the high accuracy and high calculation rate the parallel computing is implemented based on CUDA technology. Different tools of the result visualization are in-built. The user-friendly interface is developed.

Poster Session 3 / 42, T7_We_07

Design of a Long Pulse Beam Diagnostic Calorimeter for the Prototype RF-Driven Negative Ion Source for Neutral Beam Injection Application

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In order to study the generation and extraction of negative ions for neutral beam injection application, a prototype RF-driven negative ion source and the corresponding test bed are under construction at Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP). The target of the negative ion source is extracting a negative ion beam of 350 A/m^2 for 3600 s plasma duration and 100 s beam duration. According to the design parameters of test bed, the design of a long pulse diagnostic calorimeter for testing beam characteristics is put forward. The calorimeter adopts hexahedron block design (8 $\times$ 28 blocks) and the size of each block is 18 $\times$ 18 mm^2. In order to prolong the operation times, a tungsten plate (5 mm thickness) is fastened to the heat-loading surface of each block. The thermal performance of calorimeter is assessed using FEM for validating the feasibility of this design scheme. Mathematical simulation shows that the design can meet the requirement of beam diagnosis.

Poster Session 3 / 33, T7_We_03

Design of the Beam Extraction and Transport System for FECR

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A 45 GHz superconducting ECR ion source FECR (a Fourth generation Electron Cyclotron Resonance) is under construction at IMP. A total current of more than 20 emA is expected to be extracted from the source. Therefore, the extraction voltage is designed to be biased up to 50 kV to reduce the effect of space charge. An on-line movable four-electrode system will be adopted so that the plasma meniscus and initial beam formation can be optimized by adjusting the distance between the plasma electrode and puller. After being extracted, the multi-species ion beam will be focused by two solenoids and then analyzed by a 110-degree dipole. A sextupole magnet is planned to be placed after the dipole to reduce the non-linearities of the beam induced by the sextupole field of the ion source. This paper will present a design of the beam extraction and transport system for this new ion source. The advantage of the dual-solenoid scheme and the effectiveness of the non-linearity correction both by simulations and experiments will also be discussed.

Poster Session 3 / 35, T7_We_04

On Optical Properties of Ion Beams Extracted from Electron Cyclotron Resonance Ion Source

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Ion extraction from DECRIS-PM (Dubna Electron Cyclotron Resonance Ion Source with Permanent Magnets) source is simulated by using initial distributions of ions at the extraction aperture obtained with NAM-ECRIS (Numerical Advanced Model of ECRIS) code.Three-dimensional calculations of plasma emissive surface are done and ions are traced in the extraction region. The ion beam profiles show strong aberrations due to shape of plasma meniscus; hollow beam features are reproduced, as well as changes in profiles for different focusing conditions.

Poster Session 3 / 20, T7_We_01

Downsizing Study of SMASHI LEBT for Higher Beam Transmission

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Performance of ECRIS SMASHI (Superconducting Multi-application Source of Highly-charged Ions) has been steadily improved since 2015. As one approach of the improvement we investigated the ion beam transport in the LEBT (Low Energy Beam Transport) beamline. In the last commissioning experiment we found that the extracted beam loss is quite high (>50 %) in the LEBT, especially in the inlet of the dipole magnet [1]. Here, we tried to analyze the causes of the beam loss by way of systematic beam profile measurements and beam envelope analyses. With various extractions and beamline condition such as extraction-Einzel lens field, slit size, and the beamline length before the dipole magnet, the changes of the beam profiles have been intensively investigated. Based on the analysis, we also suggest a newly upgraded LEBT layout improved in its size and beam transmission efficiency.

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Poster Session 3 / 22, T7_We_02

Advances in Development of a New Generation of Plasma-Optical Systems

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The crossed electric and magnetic fields configuration inherent to the electrostatic plasma - optical lens (PL) provides a suitable method for establishing a stable gas discharge at the low pressure. Using PL configuration in this way a number of cost-effective and high reliability plasma devices using permanent magnets were devised. These kinds of devices are part of a large class of plasmadynamical devices (Hall-type plasma accelerators, magnetrons, thrusters). All these tools use a gas discharge in crossed electric and magnetic fields with closed electron drift for the generation, formation and manipulation of high current ion beams and dense ion plasma flows [1-3].

This background development opened up a new possibility to use PL configuration for introducing at volume of propagating along axis's dense low energy ion plasma flow produced by cathodic arc plasma sources or laser- produced plasma sources radially convergent fast electron beam generated self-consistently by ion-electron secondary emission in the near-wall plasma layer from the internal surface of the lens central electrode and serves to evaporate and thus remove microdroplets from the plasma flow. Note that application of the PL to the transport of low energy high-current ion beam can improve the delivery of plasma flow to a substrate, as well as providing microdroplet removal via the fast electrons within the lens region. Some preliminary theoretical studies and experimental tests were carried out at the Institute of Physics, National Academy of Science (NAS) of Ukraine, providing confidence and optimism that proposed idea for microdroplet elimination with application plasma optical systems with fast electrons has good potential for success. Here, we describe and highlight mainly the transport aspect and effect of fast electrons on physical characteristics low energy ion plasma beam.

The experiments were carried out at the High Current Electronics Institute, (Tomsk, Russia) using a PL produced at the Institute of Physics, NAS of Ukraine. A repetitively pulsed cathodic arc plasma gun (i.e., a MEVVA ion source without the ion optic extraction system) combined with PL was used to produce energetically streaming copper plasma. The lens structure includes three cylindrical electrodes with different lengths in a magnetic field formed by permanent magnets. The lens outer electrodes are grounded and the central electrode was biased under different positive and negative potentials.

The experiments described here demonstrate the effectiveness of the electrostatic PL for focusing and manipulating wide-aperture, high-current, low-energy, streaming metal ion plasma flows. In these experiments, the self-sustained focusing of high-density, wide-aperture, low energy ion plasma flow was observed. It has been shown that the presence of fast electrons in the volume of the plasma lens both improves the propagating ion plasma flow towards the substrate and introduces additional energy for effective evaporation and elimination of microdroplets from the plasma flow. These results open up new attractive perspective for further development and application of erosion plasma sources (cathodic arc and laser-produced sources) for the synthesis of exotic films and coatings with controlled given properties.

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Poster Session 3 / 101, T7_We_13

Ion Velocity Components and Space Potential Measurements on High-Current-Density and Low-Energy Ion Beam Using Double Electrostatic Probes

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A strong spontaneous-focusing of low energy ion beam (~150 eV) having the high current density (~3 mA/cm^2) was observed using three sets of concave electrodes with nominal focal length of 350 mm [1-5], where the ion and electron current density profiles were measured by Faraday cups in an ion beam propagation chamber, to which the ion beam is injected from the ion source [6]. To study the mechanism of this focusing phenomenon, a pair of electrostatic double probes with a unique structure have been installed. Two pairs of double probes compose totally 4 tungsten tips which are installed in perpendicular and parallel directions to the ion beam, respectively. It was found that this combination enables to measure slow ions and fast beam ions components by using the probes. During the focusing phenomenon, large amounts of slow ions were produced. It is also possible to measure radial profiles of those components by sweeping the probe up and down perpendicular to the ion beam direction. Moreover, by inserting an extremely high impedance resistance between the tungsten tip and ground line in the system, it became possible to measure the space potential before and after the focusing phenomenon.

At the conference, we will present these probe measurement techniques for estimating the slow and fast ion components, and for measuring the radial profiles of space potential. Possible mechanism of the focusing phenomena will be discussed by using these results together with the results obtained by the Faraday cups.

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Poster Session 3 / 102, T7_We_14

Beam Optics Effects at the Entrance to the SARAF RFQ

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Several studies were performed over the recent years for better understanding and improving a relatively low proton beam transmission through the SARAF RFQ. A strong effect of the RFQ 176 MHZ RF field on the low energy beam optics was observed.The effect takes place in the Low Energy Beam Transport (LEBT) line at the vicinity of the RFQ entrance flange. The effect was measured for various LEBT protons beam energy. The measurements suggest that, most likely, the effect is associated with loss of the beam neutralization in the LEBT region adjacent to RFQ. Calculations of the electrical fields and beam dynamics simulations performed for the region of interest confirmed this assumption. Possible improvements of the RFQ design are discussed.

Poster Session 3 / 189, T7_We_24

Measurements and Simulations of the Beam Extraction from the ESS Proton Source

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The proton source and LEBT will be delivered to ESS in November 2017 by INFN-LNS. In order to prepare for the commissioning of this system at ESS, understanding the beam dynamics of the beam extraction and transport at low energy is important. The ion source and LEBT were commissioned at INFN-LNS in 2016-17 with measurements of the beam current, fractions of different ion species (H^+, H_2^+, and H_3^+), and emittance. In this paper we compare IBSimu simulations with these measured data. The goal is to reproduce different beam distributions at the exit of the ion source, which will help to optimize the beam optics and transmission to match the RFQ acceptance.

Poster Session 3 / 190, T7_We_25

Modeling of Beam Acceleration for the Negative Ion Source NIO1

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The RF negative ion source NIO1 (Negative Ion Optimization 1) [1], built at Consorzio RFX in Padova (Italy), aims at investigating basic issues of ion source physics while providing a tool to benchmark and validate beam simulation codes. Due to its small size and its modular design, NIO1 represents a valuable testbed for DEMO relevant solutions, such as energy recovery and alternative systems for ion beam neutralization [1]. To such purposes it is important to improve NIO1 performance to make it comparable to those expected for other negative ion sources e.g. the full-size ITER ion source prototype SPIDER [2]. In particular the latest NIO1 upgrades focused on reducing the co-extracted electrons by enlarging the magnetic field strength close to the plasma grid and on improving the beam optics. As anticipated in [3], a new extraction grid was designed [4] to guarantee a better optics and a significant reduction of the beamlet deflection which proved to be quite large with the previous set of magnets [5]. The present paper presents the computation of the NIO1 beam optics as a function of the operating parameters. Throughout this work, the finite element codes OPERA 3D [6] and EAMCC [7] were used to model the NIO1 accelerator in both its previous and new configurations. Results from simulations are also compared with the data from NIO1 beamline diagnostics [8].

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Poster Session 3 / 191, T7_We_26

Simulation of Low-Energy Ion Beam Trajectories from a Thin Wire Mesh Electrode Configuration

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The use of electrode for ion implantation was realized for plasma treatment to achieve dose uniformity and increased ion implantation energy by affecting the trajectory and energy of the ion beam [1]. The effect of the electrode addition was seen from the ion implantation of insulating materials as well as producing low-energy ion beams for material synthesis and surface modification [2]. Electrode configuration as well as electrode to substrate distance also needs to be considered since it highly affects implantation energy, shielding potential, and effective shadowing effect [2,3].

In this paper, a dual-electrode system made from 0.1 mm diameter tungsten wires with 1mm spacing between wires were used as the extraction electrode for ion beam from Argon plasma excited using 0.3mm tungsten filament where a ˜90% transparency was realized. Extraction electrode design and the corresponding ion trajectories were simulated using COMSOL. A custom-built retarding potential analyzer (RPA) and Langmuir probe measurements in the region between electrode and sample were also conducted and correlated with the simulated data.

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Poster Session 3 / 196, T7_We_27

Design and Fabrication of a Beam Dump at KBSI Heavy Ion Facility

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We have developed a beam dump that can withstand beam energy below 20 MeV. The beam dump consists of copper, graphite and is designed to prevent primary heavy ion beam and secondary radiation particles such as neutrons, electrons, x-rays, etc., from beam generated when the beam collides with the beam dump blocks. Now a beam dump is attached to the end of diagnostic chamber of accelerators. Next it will be located at the end of RFQ (Radio Quadrupole Frequency) System that was completed the fabrication of a RFQ section. The PHITS code and ANSYS steady-state thermal analysis was adapted for simulating the heat transfer, amount of production of secondary particle production after bombarding the beam dump material.

Poster Session 3 / 200, T8_We_69

Wireless Telegram Microwave ECRIS

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We have constructed tandem-type electron cyclotron resonance ion source (ECRIS) which consists of two individual ion sources [1]. We aim at synthesizing endohedral metallofullerenes by transporting metal ion beam from the first stage into the fullerene plasma in the second stage. Since the fullerene is dissociated in the second stage by use of conventional microwave source, low power microwave source is required. We have developed semi-dipole antenna and rod-type antenna in order to utilize 1.30/2.45 GHz-band wireless microwave source. The lengths are optimized for frequency of wireless microwaves. Herewith, these enable microwave to propagate to the second stage in high vacuum with co-axial mode. This paper describes investigation of properties of wireless microwave ECRIS as compared with magnetron and production of fullerene and argon ion beam using the ECRIS. It was possible to successfully ignite and sustain ECR plasma under extremely low microwave power within about 0.1 W to several Watts by use of this wireless microwave source. In addition, we discuss electric field intensity inside the chamber from wireless telegram microwaves. We are planning two frequency experiments simultaneously of 1.30 GHz and 2.45 GHz.

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Poster Session 3 / 206, T8_We_70

Producing and Identifying of Multiply Charged Fullerene Ion Beams and Their Compounds.

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Endohedral fullerene is expected to be utilized for such applications as quantum computing or magnetic resonance imaging contrast agent, because it has various material characters [1]. It is confirmed that multiply charged fullerene ion beam has been produced in electron cyclotron resonance ion source (ECRIS) at Osaka Univ. [2]. However, it can't be simply identified because spectrum of multiply charged fullerene ions overlaps dissociated single charged fullerene ions. Therefore, production of multiply charged fullerene ions can be confirmed by identifying non-overlapping fullerene ions spectrum.
The aim of this paper is to investigate production of multiply charged fullerene ions in the ECRIS. As a result, multiply charged fullerene ions have been identified and isolated isolated from dissociated ones clearly. In addition, we are planning to report the result of identifying another ion beams relevant to C60 compounds.

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Poster Session 3 / 208, T8_We_71

^{3}He Beam Development of 18 GHz SCECR-IS for Proton Generator at RCNP

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There are some needs of proton beam of several MeV in energy for the purpose of calibrating charged particle detectors. For that purpose, electrostatic accelerators are usually appropriated, but recently many electrostatic accelerator facilities have been shut down. On the other hand, cyclotrons are too large to use for such calibration. So, a proton generating system which consists of 18 GHz SCECR ion source and deuterated polyethylene target has been developed at the Research Center for Nuclear Physics (RCNP), Osaka University. The ion source provides 20 keV ^{3}He beam. As a result of $^{3}\mathrm{He}^{+d}$ reaction, protons of 14.7 MeV can be obtained. These protons are used for detector calibration inside the vacuum chamber on the LEBT of the SCECR ion source. Details of this system will be presented.

Poster Session 3 / 209, T7_We_28

Al and W Ion Beams from MEVVA Ion Source Material Radiation Resistance

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In NRC «Kurchatov institute»-ITEP the research of the material radiation resistance by accelerated metal ion beams is under progress on RFQ linac Heavy Ion Prototype (HIPr). One of the ongoing material science projects aims at the analysis of the radiation resistance of tungsten that will be used in future fusion facilities like DEMO and ITER. To provide irradiation experiments, MEVVA ion source was equipped with Al and W cathodes. This paper describes the results of time-of-flight mass-charge spectrums measurements for Al and W ion beams generated by MEVVA and results of this ion beams acceleration.

Poster Session 3 / 210, T7_We_29

Child-Langmuir-limited Current in the Negative Ion Source NIO1

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Negative ion sources are the first stage of several types of accelerators, ranging from medical applications to materials testing and to heating systems for nuclear fusion devices. One of the most important aspects of the sources is the amount of extracted ion current, which depends on the extraction voltage and on the availability of ions inside the source plasma; this situation is described by the Child-Langmuir law. The extraction of ions from the source is facilitated by an initial ion velocity. In the case of negative ions, plasma electrons also play a role in the definition of the maximum extractable ion current, which can be significantly decreased for the possibly combined effects of large electron current and magnetic field configuration.

The present contribution gives a comprehensive theory of the electrostatic extraction of particles from the meniscus, the plasma boundary which forms at the apertures of a negative ion source in the aforementioned conditions. A normalised treatment is adopted, which is suitable for application to different types of plasmas.

Data from the flexible multi-aperture RF-based caesium-free negative ion source NIO1 are studied, which exhibit saturation in the extracted current depending on the plasma parameters both in hydrogen and in oxygen.

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Poster Session 3 / 212, T8_We_72

The Development of Proton ECRIS for Boron Neutron Capture Therapy

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For overcoming limitation of convectional particle therapy, the development of Accelerator-based Boron Neutron Capture Therapy (A-BNCT) is in progress by Dawonsys Co. Ltd. Dawonsys developed a duoplasmatron ion source for A-BNCT and KBSI (Korea Basic Science Institute) is developing an Electron Cyclotron Resonance Ion Source (ECRIS) as alternative candidate of duoplasmatron. The proton ion source of A-BNCT must satisfy some requirements such as high voltage flatform over 50 kV, small emittance below 0.2 mm.mrad, and high current over 50 mA. In this paper, we will report results of design study and manufacturing issues.

Poster Session 3 / 213, T7_We_30

The Study of Wien Filter for Gas Cluster Ion Source

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The Korea Basic Science (KBSI) is developing a Gas Cluster Ion Source (GCIS) for X-ray Photoelectron Spectroscopy (XPS) and Secondary Ion Mass Spectroscopy (SIMS) since 2014. The experimental system was installed for generation of argon gas cluster ion beam using GCIS which consists of cluster generator, ionizer, Wien filter, accelerator, micro lens and target. For analysis of gas cluster ion beam, we had manufactured a Wien filter with wide range. From experimental results of Wien filter with wide range, a compact Wien filter for GCIS beam line was developed. In this paper, feasibility design studies of Wien filter related to analysis of cluster ion beam are exposed.

Poster Session 3 / 217, T7_We_31

MEVVA Single Aperture Extraction System

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Since the 90s the ion beam irradiation experiments are under development at the heavy ion RFQ HIP-1 (Heavy ion Prototype) in the Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of National Research Centre «Kurchatov Institute»; ("Kurchatov institute" - ITEP). The linac provides accelerated beams of Cu^2+, Fe^2+ ions with current up to 6 mA and energy 101 keV/n [1]. Now HIP-1 is used for simulation experiments for reactor material radiation-resistance inestigation by heavy ion beams. Investigated samples are irradiated by beams of metal ions and gas up to fluences 1016. The grid beam extraction system the MEVVA ion source [2] is used now. To increase the life time of extraction system as well as the matching of beam from ion source to the RFQ the accel-decel one hole extraction system is under development. This paper presents results of new extraction system simulation. Also it describes experimental approbation of new extraction system.

Poster Session 3 / 220, T8_We_73

Ferromagnetic Enhanced Inductively Coupled Plasma Cathode for Thruster Ion Neutralization

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Plasma cathodes can be used as electron sources in electric propulsion applications. Unlike hollow cathodes where a low work function insert material that needs to be heated to elevated temperature is utilized for the electron emission, plasma cathodes do not need to be preheated, and could be switched on instantaneously. Recently, at Bogazici University Space Technologies Laboratory (BUSTLab), radio frequency (RF) plasma cathode devices for use as electron sources of plasma thrusters have been studied, manufactured and successfully tested [1]. Introduction of a ferromagnetic cores enhances the power transfer efficiency of the inductively coupled plasma (ICP), allowing the elimination of a matching network [2]. In this paper we present the design, manufacture and test of a prototype radio-frequency cathode with ferrite core for use in space propulsion applications as an electron source. The matching effectiveness, the power efficiency and propellant utilization of the developed ferrite core RF cathode device have been studied.

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Poster Session 3 / 224, T7_We_32

Longitudinal Emittance and In-Situ Plasma Potential Measurements of Ion Beams from the High Temperature Superconducting ECR Ion Source, PKDELIS

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At the Inter University Accelerator Centre, Delhi, the High Current Injector Programme mainly consisting of an 18 GHz High Temperature Superconducting ECR Ion Source on a 100 keV high voltage platform followed by radiofrequency quadrupole and drift tube linear accelerators will serve as an alternate injector to the existing Superconducting Linear accelerator. Studies related to the longitudinal emittance measurements before injection into the radiofrequency accelerators are important to understand the longitudinal optics through the system. Earlier studies [1] have shown that plasma potentials in an ECR ion source inherently produces energy spread in the extracted ion beams, which can adversely affect the transmission through the downstream radiofrequency quadrupole accelerator. In the present study, longitudinal emittance measurements will be carried out for various ion beams using a multi-harmonic buncher and a fast Faraday cup. The influence of the plasma potential, measured in-situ, on the longitudinal emittances will be presented.

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Poster Session 3 / 230, T8_We_74

Electron Cyclotron Resonance Ion Sources for Solar and Semiconductor Applications

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A high current microwave ion source (MWS) has been developed by Phoenix Nuclear Labs (PNL) to cater the high beam current requirement for various applications in semiconductor, solar and power device fields. The source consists of solenoid electromagnets surrounding a microwave resonant cavity producing a magnetic field tuned to match the electron cyclotron resonance (ECR) of 2.45 GHz microwaves. The microwave power induces production of ions efficiently which are extracted into a high current, low emittance beam with a set of electrostatic lenses. The extracted ion beam is couple to a DC electrostatic accelerator that transport the ion beam to the end station via suitable mass analyzing magnet and focusing elements.

The MWS ion source design does not feature any filaments, electrodes, or other consumable components which guarantees exceptional reliability and long lifetimes. This also enables to minimize particles and metals contamination in the system. Continuous uptime of >99% and thousands of hours of operation have been demonstrated on multiple systems. The total beam current extracted from the ECR ion source is typically about 50 -100 mA at 50 kV for Hydrogen. For Deuterium beam it is 50-75 mA at 50 kV with an average current density of 125 mA/cm^2. Extracted deuterium beam currents as high as 90 mA have been measured with current density of 225 mA/cm^2. In addition, the high gas efficiency of the ion source allows a relatively low input gas flow rate of 1-5 SCCM, which reduces vacuum pumping requirements for the rest of the system.

With the push to reduce the cost of the wafers used for applications in Semiconductor, Solar, LED and other power device applications, SOI Technology and Smart Cut Technology which uses Hydrogen ions for bonding and splitting wafers are getting lots of attention. With the very good Hydrogen beam current which boosts up throughput for those applications, it is important to characterize the beam quality and corresponding metrics.

An overview of the PNL ion source will be given and operational data along with some test results on the beam quality on wafers will be reported.

Poster Session 3 / 243, T8_We_75

The Optimization of Evaporative Cooling Magnet for LECR4 Ion Source

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The LECR4 ion source (Lanzhou ECR ion source No.4) has been successfully put into service at IMP since February 2014. It includes the evaporative cooling magnets to provide the injection and an extraction magnet field. It is the first time for evaporative cooling technology used in ECR ion source in the world. According to the running of LECR4 in the following 4 years, the evaporative cooling technology can lead higher power density in coils and easy operation and maintenance. To increase the current density of coils and decrease the volume of magnet, the optimization analysis is taken in this paper, which includes the structure of coil unit and ion current in a constant magnet field of LECR4. The preliminary results of analysis show that the current density can be increased by 10% under a good cooling condition and the diameter of magnet can be decreased by 20%. The optimization is a condition of considerable improvements for LECR4 and other ion sources design.

Poster Session 3 / 252, T8_We_76

Design of a 400kV High Intensity Accelerator Facility for Jinping Underground Laboratory for Nuclear Astrophysics

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Jinping Underground laboratory for nuclear astrophysics (JUNA) will take advantage of the ultralow background of the deep underground, using a high intensity accelerator facility and highly sensitive detector to measure directly tiny reaction rates which in laboratories at the Earth's surface are hampered by the cosmic-ray background into detectors. The design of a 400 kV, 10 mA accelerator specially for JUNA are reported. A 2.45GHz ECR ion source is used for H+ or He+ beams of few tens mA magnitude and a 10GHz ECR ion source for He2+beam of few mA magnitude. The beam is accelerated by an electrostatic accelerating tube to 70˜400keV for H+ &He+ and 150˜800keV for He2+. The ion source and LEBT beam line are placed on the platform of maximum 400kV. The layout of accelerator and design considerations, such as high intensity beam accelerating, transmission, monitoring, cooling and other special features applied in the Jinping deep underground lab will be presented.

Poster Session 3 / 254, T7_We_33

Spatial Distributions and Characterizations of Ion Flow Produced from Laser-Induced Plasmas in Capillary Targets

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A new type of laser ion source was developed to produce low charge state positive, negative, and cluster ions by constricting a plasma in a narrow cylindrical volume formed by the target ion material. The basic operation of the ion source involves the ablation of a spot within a cylindrical hollow target by a Q-switched laser. The focused laser strikes the inside surface of the target at a shallow angle with respect to the target axis to make the plasma expand in a slantwise direction. This makes the produced ions flow in a direction oblique to the target axis. Spatial distribution of the ion flow measured by a travelling Faraday cup showed asymmetry, and a proper optimization of the extraction system was found necessary to extract produced ions to form a beam.

An array of miniature Faraday cups designed to move along different axes is used as a position-sensitive detector for ions extracted from a dense laser-induced plasma constricted in a hollow cylinder target. The ion detection system should provide a better understanding of both plasma plume expansion and ion propagation from the narrow cylindrical volume under an electrostatic acceleration field. By changing the position of the Faraday cup array, space dependent time-of-flight signals are measured to determine ion species and currents at different points along the cross-sectional area in front of the target. A series of measurements by changing the position of the array can visualize a two-dimensional (2D) spatial distribution of ions propagating through the extraction system under different experimental parameters; optimal laser settings and Faraday cup array positions will be chosen, and target materials to be investigated will include graphite, aluminum, and copper. The streaming neutral gas injection scheme will be applied to the ion source system to study the effect onto cluster agglomeration process in plasma.

Poster Session 3 / 256, T7_We_34

Low Energy Ion Beam Line for Twin EBIS

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The external beam line for the Twin Electron Beam Ion Source (EBIS) is intended for transmission of highly charged ions extracted from EBIS for consequent injection into a high-frequency RFQ, and for general diagnostics of ion beams being extracted from or injected into the EBIS. For medical or industrial applications it can be mostly light ions with charge to mass ratio of 0.5 – 0.4. The extracted beam can also be directed into a Time Of Flight mass-spectrometer (TOF). An optional injection of ions from an external ion source into the EBIS is foreseen. The electrostatic switchyard provides fast change of the ion beam direction. Special care is taken of the quality of the focusing elements and the bending in terms of acceptance and spherical aberrations. Simulations of ion extraction and injection are presented along with details of the LEBT design.

Poster Session 3 / 258, T8_We_77

Design and Experiment Study of an Internal Cold-Cathode Ion Source for the 230 MeV SC Cyclotron

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A new proton therapy facility with 230 MeV SC cyclotron is being built by China Institute of Atomic Energy(CIAE). An internal cold-cathode ion source is designed and tested, which will be mounted in the SC cyclotron central region. It consists of a chimney, an upper and a lower cathode fixed by the chimney. The design considerations and some testing works are presented. The magnetic field in the central region is about 2.35 T, and there is a rf bridge passing though the central region, so there is a little space for the ion source. So, the ion source is small, the chimney size is only $\Phi 1.5$ mm $\times$ 50 mm, the extraction slit is 2×0.5 mm, and the tilt angle is 30 degrees. The experiments have been done on the test stand, and the beam properties for different settings of the ion source will be presented in the paper.

Poster Session 3 / 259, T7_We_35

The Beam Injection Line Test of CYCIAE-100 Cycotron

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A 100 MeV high intensity proton cyclotron, CYCIAE-100, has been built at China Institute of Atomic Energy (CIAE) as a driving accelerator for the Beijing Radioactive Ion-Beam Facility (BRIF). The proton beam of 25 uA/100 MeV has been used at the primary test in 2014. Now the proton beam of 1000uA/1MeV has been obtained. This paper will depict the injection beam line, including the H^- multi-cusp ion source, solenoid, steering, quadrupole-truplet lens, buncher, central region. The efficiency with different beam density will also be exposed in the paper.

Poster Session 3 / 261, T8_We_78

New Calibrated Evaporation Oven for Time of Flight Mass Spectrometer in Offline SPES Laser Laboratory

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In the framework of the research and development activities of the SPES project regarding the optimization of the radioactive beam production a new home-made Time of Flight Mass Spectrometer (ToF-MS) has been built in the off-line laser laboratory.
Thanks to this instrument it is possible to test resonant laser ionization processes of stable species, to evaluate their ionization efficiency and even isotope separation capability.
Nowadays a Nd:YAG laser is used to evaporate atoms by laser ablation in the spectrometer, making these atoms available for laser resonant ionization processes.
The new evaporation oven, replacing the ablation system, is designed to guarantee a more stable and calibrated atom flux, making possible laser ionization efficiency measurements, which are inapplicable with the current system.
This work will present the design of the new graphite oven system, its preliminary heating tests, and first measurements aimed to evaluate the evaporation profile generated by the heated furnace.
Furthermore, in its final realization, the ToF-MS with the new evaporation oven system will be used, coupled to a standard SPES hot cavity and extraction system, to realize a test bench machine for deeper laser ionization efficiency measurements applicable for the SPES laser ion source.

Poster Session 3 / 267, T8_We_79

Fabrication of Swelling Structure on SiC Surface by Using Multi-Charged Ar Beam

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Silicon carbide (SiC) crystal, which has good mechanical and electric properties, is a promising materials. Owing to its ultrahigh-hardness and chemical stability, it is difficult to fabricate structures in micro-nano meter scale by means of conventional fabrication processes. Ion beam technology, which has been successfully applied in industrial fields such as semiconductor devices, is a promising candidate to solve the problem. In previous experiments, a swelling structure, which is fabricated by means of ion-beam induced expansion effect, has been observed for SiC crystal [1, 2]. The object of the present study is to show the feasibility of ion-beam induced swelling effect as a fabrication method for SiC crystal. Based on the experimental results, a fabrication of multi-step structure on SiC crystal has been demonstrated.

Ar-beam, which was prepared by ECR ion source (10 GHz - NANOGAN), was irradiated on 6H-SiC crystal and a swelling height was measured with a profilometer as a function of the fluence. The swelling height has shown clear relation with irradiation parameters, a fluence and energy of Ar beam. The swelling height has increased with the fluence and reached its saturation value at the fluence of 5×10^{15} ions/cm^2. By using Ar^{7+} beam with 700 keV, the maximum height of 100 nm was obtained. Based on those results, two-step irradiation of Ar beam on 6H-SiC was performed. Irradiation parameters and areas of two independent irradiations were different for each other. Two-step structure has been successfully fabricated by the two-step irradiation. In order to confirm the possibility of the swelling structure as mechanical devices, irradiation-induced modification of mechanical properties of SiC crystal was evaluated by means of nano-indentation method. No serious deteriorations have been observed under the present irradiation conditions.

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Poster Session 3 / 273, T8_We_80

A Test Stand for the Development of Ion Sources at CERN-ISOLDE

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ISOLDE is a radioactive ion beam facility within CERN's proton accelerator complex. Ion beams of more than 70 different elements can be produced using different ion source types available at ISOLDE. Most commonly used are the positive surface ion source, the Resonance Ionization Laser Ion Source (RILIS) and the Forced Electron Beam Induced Arc Discharge (FEBIAD) ion source. In recent years the availability of negative ion beams at ISOLDE was re-established and the development program of negative ion sources was revitalized.

Currently both development studies and routine production share the same target and ion source infrastructure, including the off-line mass separator and calibration test stand, and since the target production schedule has to be prioritized this creates a bottleneck for development work. This is being addressed by the construction and commissioning of a new "Off-line 2" facility. In addition a dedicated test stand for ion sources has been conceived, which will allow basic validation of new sources or design concepts before they are tested further with the mass separator.

Here we present the design of the new ion source test stand. The two main features are an ion extraction system that allows us to measure the total ion beam current, and a residual gas analyzer that allows us to monitor source degradation and outgassing. A data acquisition and control system will facilitate the automation of repeated measurement tasks, thereby also enabling long-term performance tests, rigorous quality control and stress testing. Eventually we will perform destructive tests which will give insight in to failure modes and operational limits, the lack of knowledge of which is often a limiting factor in achieving optimal ion source performance under on-line conditions.

We will give an overview of the ion source types available at ISOLDE, describe the ion source test stand, and present an outlook towards its proposed applications. The results obtained for the negative ion source development will be also be discussed.

Poster Session 3 / 274, T8_We_81

Development of a Large RF Bucket Ion Source for Large Area Ion Beam Milling Processes to Fabricate Micro-structures

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Bucket ion sources for neutral beam injectors [1] have been applied to industrial applications such as ion beam milling processes [2] for fabrication of micro-structures of hard disk drives, semiconductor devices, piezoelectric devices etc. Large area ion beams (maximum diameter of 580 mm) by the sources could enable high-throughput commercial processes in factories [3]. However, lifetime of the filaments limits the longest available operation time between maintenances to as much as several tens hours.
A novel RF bucket ion source was developed for higher availability without filaments and active ion species like oxygen. Conventional RF inductively coupled plasma sources have no magnet to confine plasma on the side wall inside the RF coil and it can cause plasma loss on the side wall and sputtering of the side wall, which lead to lower plasma production efficiency and shorter life time due to the sputtering.
In the developed RF bucket ion source, multi-cusp magnets are set inside the RF coil between slits on the Faraday shield around the discharge chamber to confine plasma [4]. The RF discharge chamber is an insulator cylinder with the surrounding Faraday shield, the magnets and the RF coil. This configuration reduces plasma loss and sputtering of the side wall. It enables high throughput process with long available operation time between maintenances and does not cause any disturbance on inductive coupling of RF power to plasma.
The RF bucket sources produced large area ion beams with beam extraction area of 300 mm diameter. Ar ion beam current density is more than 1 mA/cm^2 and beam current is around 1 A. The RF bucket ion sorces have been installed in the ion beam milling systems, which are continuously operating for 24 hours per day without stop at commercial industrial factories for fabrication of micro-structures. It could also produce active ion species such as O, F and others, which are expected to contribute to other novel application processes.

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Poster Session 3 / 278, T8_We_82

MELISSA: the MEDICIS Laser Ion Source Setup At CERN

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The set-up of the CERN-MEDICIS facility for production of novel radioisotopes for biomedical applications is in the process of completion. The Radiochemical Laboratory for the extraction of samples of medical radionuclides and the dedicated Mass Separator Bunker have been built, the radiation protection is prepared, and the associated infrastructure is reaching an advanced stage [1]. For the first launch of the mass separation process, scheduled for the second half of 2017, a conventional ISOLDE surface ion source is going to be used to demonstrate the general operational capability of the facility.

To provide a high purity ion beam for extraction of radionuclides in accordance with medical standards, a resonance ionization laser ion source based on the ISOLDE/RILIS type [2] will be implemented during a first facility upgrade in 2018. The RILIS technology will ensure a reduced contamination of the ion beam with any undesirable isobars, and will further help to optimize operation conditions of the ion source unit itself for each chemical element. This system will assist in the goal of rapidly achieving radiopharmaceutical-standard sample purity.

The MEDICIS Laser Laboratory MELISSA is presently being designed. Using the well-established technology of the CERN-ISOLDE RILIS Lab and with support from the LARISSA workgroup of the Mainz University, the dedicated laser laboratory room, suitable for the installation and reliable operation of the laser system, is being prepared. In addition, a laser beam transfer line and a launch system into the CERN MEDICIS bunker are under development. It is planned to install a solid-state laser system based upon the standard Mainz University Titanium:sapphire laser design, as e.g. presently in use at the ISOLDE RILIS. Comprehensively automated operation, active stabilization, and therefore unsupervised operation is envisaged [3].

The multi-step laser ionization schemes for efficient and pure production of various innovative medical radionuclides are being identified and characterized at the RISIKO mass separator and laser ion source test facility in the Mainz University [4]. Primarily, the CERN-MEDICIS project is to be applied for specific radioisotopes in the lanthanide range. The status and outlook of all these activities will be discussed in the presentation.

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Poster Session 3 / 279, T8_We_83

Source Commissioning for Carbon Ion Treatment Beams at MedAustron

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MedAustron is a hadron therapy facility in Wiener Neustadt, Austria, based on the PIMMS design (Proton-Ion Medical Machine Study). The injector features three Supernanogan ECR ion sources from Pantechnik. One is reserved for proton therapy, one for therapy with carbon ions, and the third one serves as a backup and might be used for clinical and non-clinical research in the future. Patients are being treated with protons since December 2016. In parallel, the carbon ion beam commissioning is ongoing. In this paper results and status of the commissioning of the source for carbon ion beams are presented.

Poster Session 3 / 282, T7_We_36

Metal Ion Filtering of Vacuum Arc Ion Source Through an Inclined-Aperture Extraction Grid

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The paper reports a novel method of increasing the fraction of H ion produced by vacuum arc ion sources with metal hydride cathodes, which applies the ionic selectivity of inclined-aperture extraction grid to separate and filter heavy metal ions. Since H ion and Ti ion produced by vacuum arc discharge have great differences in kinetic energy and mass-to-charge ratio, H ions are easy to pass through the inclined-aperture grid, while most of Ti ions are blocked and absorbed by the grid wall. Using a 2D particle-in-cell simulation, the ionic selectivity of inclined-aperture extraction grid is demonstrated. The numerical simulation results show that after ion filtering through the extraction grid, the fraction of H ion is increased from 39% to more than 80%. The increased amplitude of H ion fraction depends on the thickness of the grid.

Poster Session 3 / 284, T7_We_37

Linac4 Source Extraction and Low Energy Beam Transport Study

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In the framework of the LHC Injector Upgrade program, a new normal conducting linac (Linac4) operating at the frequency of 352 MHz has been recently commissioned to the final energy of 160 MeV. Linac4 will be connected to the LHC injector chain in 2020 and it is expected to provide a 40 mA, 400 µsec H^- beam for charge-exchange injection into the Proton Synchrotron Booster.

The Linac4 pre-injector includes a 45 keV, 2 MHz rf-driven, cesiated H^- source, a magnetic Low Energy Beam Transport and a 3 MeV Radio Frequency Quadrupole. Currently the pre-injector is limited to beam currents of 35 mA.

A campaign of beam measurements at 45 keV under controlled variation of the system parameters has been performed during 2017 to improve the understanding of pre-injector dynamics and to devise a method to overcome the present limitation. This paper reports the results of the measurements and preliminary conclusions on the dependence of current and emittance on the relevant parameters.

Poster Session 3 / 287, T7_We_38

Ion Source and Front End Commissioning at the Facility for Rare Isotope Beams

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The installation and testing of the commissioning 14.5 GHz ECR ion source ARTEMIS at the Facility for Rare Isotope Beams (FRIB) was completed in the fall of 2016. The ion source is providing beam to the FRIB Front End and will be used throughout the commissioning of the linac accelerator. The paper reviews the first commissioning result and beam measurements with Argon and Krypton beams obtained in the low energy beamline (LEBT) of FRIB. Plans for early operations with the ion source are being developed and are focused on developing a base of solid beams and minimizing background contaminants.

Poster Session 3 / 290, T7_We_39

Effect of Grid's Geometry on the Space Charge Induced Divergence of a Multi-Beamlet Ion Beam

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In a broad beam ion source for industrial applications such as sputter deposition, ions produced by DC or RF electrical gas discharge, are accelerated into many beamlets by means of an electrostatic extraction system. The accelerating stage is composed of two multi aperture grids (screen grid and extraction grid). The confluence of individual beamlets results in the formation of an ion beam drifts toward sputter target. The control of ion beam's intrinsic divergence induced by space charge effect is essential to eliminate undesirable material sputtering.

In this paper, the drift of an Ar^{+} ion beam is simulated via the CST particle studio software by considering the space charge effect. We investigate the effect of grid's geometry on the properties of ion beam. We show that the space charge induced divergence of ion beam is significantly influenced by several geometrical factors such as the diameter of apertures, the thickness of grids and the distance between grids.

Poster Session 3 / 291, T7_We_40

Preliminary Oxygen Ion Beam Acceleration Test for the RISP Injector

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Injector beam test facility at Rare Isotope Science Project (RISP) was prepared to test ion beam acceleration before installation of the accelerating instruments at accelerator tunnel. The facility consists of an electron cyclotron resonance ion source (ECRIS), a low energy beam transport (LEBT), a radio-frequency quadrupole (RFQ), and a medium energy beam transport (MEBT). The initial tests of ECRIS beam extraction and RFQ beam acceleration was performed. The reference particle of the beam test was oxygen ions with the kinetic energy of 10 keV/u at ECRIS exit and RFQ entrance. After RFQ the oxygen beam was successfully accelerated to around 500keV/u. Preliminary test results of the ion beam will be presented during this conference.

Poster Session 3 / 286, T8_We_84

EBIS-Based HCI Micro-Beams

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We describe the development of an ion beam irradiation system with focused beams of highly charged ions (HCI), whereby the use of HCI of noble gas creates unique features leading to applications which can complement the existing equipment market. The developed, built and commissioned facility consists of an electron beam ion source (EBIS), a downstream Wien filter for the ion mass and charge state separation, an ion-optical column for the fine-focussed ion beam formation, a specimen chamber with a simple sample transfer system, a sample table with sub-micrometer positioning precision and a TOF-SIMS spectrometer for surface analysis.

Compared to known classical focussed ion beam systems and commercially available solutions, the system differs significantly in the following items:

- nearly all elements of the PSE will be available in a broad ion charge spectrum for applications,
- fine-focussed noble gas ion beams can be used as non-toxic projectiles for materials analysis and surface modifications,
- different kinetic energies are available even without changing the acceleration potential by selecting a different charge state of the used element, allowing e.g. different implantation depths in solids,
- two-dimensional and three-dimensional "chemical maps" of different samples can be created by combining the HCI-FIB's SEM imaging capability with the TOF-SIMS technique,
- optimized projectile-energy combinations provide optimal conditions for the analysis of biological or other soft-matter samples.

The first experiments yielded argon and helium ion beams with currents of approx. 2 nA at d = 1 mm, 50 pA at d = 50 µm and 5 pA at d = 20 µm. (d - ion beam diameter)

Potential applications of the described technique are fields such as photolithography-free structuring for nanoelectronics (ion-beam-induced etching, nanomasks, nano-column epitaxy), intensive local sputtering of micro-regions, or delivering selected ion species and ion charges to selected places for structuring via single ion implantation (vacancy centers, doping) and materials analysis.

Poster Session 3 / 14, T8_We_41

Generation of Pure Boron Plasma for Ion Beam Formation and Surface Modification

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The paper reviews recent results of further developments and applications with several options generating pure boron plasmas for ion beam formation and surface modifications. The following methods of generation of boron plasma were used:
• igniting and keeping alive cathode spots in vacuum arc with pure boron cathode;
• self-sputtering mode of planar magnetron discharge with pure boron target;
• operation of planar magnetron discharge with pure boron target at medium range frequency;
• electron beam evaporation and ionization of pure boron substrate at fore-vacuum pressure.

Special features of the generation of boron plasma are described; results of measurement plasma parameters are presented as well as some physical mechanisms of boron plasma generation are discussed.

Acknowledgement

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Poster Session 3 / 16, T8_We_42

Study of Energy and Mass-Charge Spectra of Ions Emitted by a Hydrogen Penning Plasma Source.

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In the present work, the study of the discharge characteristics of the Penning plasma source (PS) by analyzing the energy and mass-charge spectra of ions emitted by PS in the longitudinal direction is presented. Characteristic anode dimensions of the PS are 15 mm x Ø12 mm and the magnetic induction magnitude is 80 mT. It was shown that there were sharp 'jumps' in the discharge current (up 300 A to 700 A) at high pressures (above 5 mTorr). This effect is explained by increasing of the plasma density at the center of the discharge and increasing potential depression (when discharge regime changes). The energy distribution of ions for various discharge voltages and pressures are measured. Shape and position of energy spectra are shown depending on the discharge mode. At an anode voltage of 2 kV, the potential depression varies from 600 to 1100 V. The component composition of the extracted ion beam was determined. The part of atomic ions (protons) was up 5 to 10%, it increases with the anode voltage (from 1 to 3.5 kV) or the discharge power input (from 0.2 to 3 W). The experimental current-voltage characteristics of the discharge measured in this work are in good agreement with the theoretical estimates of the discharge current, calculated with respect to the measured the potential depression.

Also numerical simulations of the Penning plasma source were performed using 3D particle in cell (PIC) combined with Monte-Carlo collisions code VSim on uniform 128 x 128 x 128 grid. Energy and mass spectra of H_2^+, H^+ ions, both in Penning discharge cell and after the extraction were obtained. Difference between numerical and experimental energy spectra shifts are discussed.

Poster Session 3 / 19, T8_We_43

Generation of Boron Ion by Vacuum Arc Ion Source with Lanthanum Hexaboride and Boron Carbide Cathodes

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Boron ion beams are widely used for technologies. Firstly, it is boron doping of semiconductors, and secondly it is ion beam modification of the surface. Boron compounds have a high hardness, so such modification can significantly increase the life time of tools and machine parts. The boron rich ion beams were generated by vacuum arc ion source with two boron-containing cathodes. These are lanthanum hexaboride and boron carbide cathodes. The electrical conductivity of that cathodes was much more pure than that for boron and it allowed a stable work of a sub-millisecond pulse vacuum arc with hundreds amperes current. The parameters of the boron reach ion beam were measured. Using the time-of-flight mass spectrometer, the mass-charge state compositions of such ion beams were determined and compared with the stoichiometric composition of the cathodes. For lanthanum hexaboride and boron carbide cathodes the 100 /cm^2 cross section ion beams with 250 μs pulse duration and 0.5 A pulse current at 60 kV extractor voltage and ion boron particle fraction of 85 % and 80 %, correspondently, were obtained. The work was supported by the Russian Science Foundation under grant # 16-19-10034.

Poster Session 3 / 21, T8_We_44

Magnetron Discharge-Based Boron Ion Source

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An ion source was designed utilizing a planar magnetron with 2-inch diameter pure boron target. The discharge can operate both in DC and pulsed mode. Boron as a semiconductor has low conductivity at a room temperature, which still is sufficient to start low-current (2 mA) high-voltage (2000 V) DC discharge. Due to the target heat insulation, it gradually rises the temperature to 300 ºC and more, enabling to apply high-current pulses to the discharge gap. An improved time-of-flight methodic was used to measure the ion species in the plasma and the beam. The ion composition of plasma was examined within a wide range of DC and pulse parameters: pulse duration of 5 - 250 µs, repetition rate of 20 - 5000 Hz, pulse current up to 100 A. It was shown that boron ions are mostly singly ionized, and their fraction may exceed 95% at certain conditions. The rest sort of ions are singly and doubly charged working gas ions (argon or krypton were used). The work was supported by the Russian Science Foundation under grant # 16-19-10034.

Poster Session 3 / 23, T8_We_45

A Pulsed Vacuum Arc Ion Source with a Pure Boron Cathode

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The report presents experimental research results on a pulsed vacuum arc ion source with heated elemental boron cathode. Boron is a semiconductor having a high specific resistance (~1.8 MOhm×cm) under normal conditions and is difficult to sputter and to evaporate. Therefore in the known ion sources, the initiation of an arc discharge with a pure boron cathode requires preliminary heating-up of the cathode to temperatures up to 1000 °C. We have designed a high-temperature cathodic unit which enabled to operate a cathodic arc from pure boron material and used a special technique for the arc triggering and one allowed to decrease the cathode temperature up to 600 °C. The arc discharge was operated at 100 A with pulse duration from 100 µs to 300 µs. Boron ions were produced almost entirely in a singly and doubly ionized state with a ratio close to 1:1.

Work supported by a The Russian Science Foundation (grant number of 16-19-10034)

Poster Session 3 / 27, T8_We_46

Ion Beam Lithography, a Promising Technique for Patterning of Graphene Oxide Foil

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Graphene Oxide is an insulator consisting of oxygenated functional groups, so that, for restoring its electrical conductivity, chemical or heat treatments can be employed. Presently, a selective deoxygenation of graphene oxide has been conducted for design and fabrication of graphene based devices. The Ion beam lithography is considered a powerful route for patterning onto graphene oxide foil. A stream of Helium ions were used for both direct patterning onto a graphene oxide foil and online characterization of its structural and compositional properties. Helium ions with energy of 1.2 MeV and controllable fluencies have been used to induce insulator-metal transition in the GO foil. The Scanning Electron Microscopy, Energy Dispersive Spectroscopy, Rutherford Backscattering Spectrometry and Elastic Recoils Detection analyses have been accurately employed to reveal and to monitor the deoxygenation of the Graphene oxide foil demonstrating the reliability of direct patterning using ion beam lithography technique.

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Poster Session 3 / 52, T8_We_47

Development of a Compact Internal PIG H^+ Ion Source for Industrial Use

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For industrial application, cyclotrons have been available for radioactive ion beam (RI) production and hadron cancer therapy. Industrial fields welcome the compact machine and furthermore require high current output. Downsizing cyclotrons are achieved with high magnetic field generated by superconducting coils but in case of proton, high magnetic field makes it difficult to extract an external ion source as low energy protons orbit the small radius. On the other hand, internal ion sources are often used for it.
PIG type ion sources are used as internal ions sources for cyclotron, which take the own magnetic field provided by cyclotron itself. Hot cathode type ion sources have another parameter for plasma parameters when comparing with cold type and it makes hot cathode type possible to control beam current finely. We report the progress of our development of a compact internal ion source which is PIG type with hot cathode.

Poster Session 3 / 55, T8_We_48

Development of New Electromagnets for a Microwave Ion Source

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A microwave ion source is a long-life ion source because of few expendable items. Therefore, it is useful for various applications in industrial and medical fields such as ion implantations of semiconductors and particle therapies. We have previously reported on development of a microwave ion source for ion implantations. The magnetic field of the microwave ion source is generated by electromagnets which consist of two coils and iron yokes, and its magnetic field was a non-mirror magnetic field, what is called off-resonance. In addition, no magnets were installed to generate a cusp magnetic field. Therefore, the electron temperature in the plasma was low and it was hard to ionize molecules which have strong chemical bonds, e.g. BF_3. This ion source was suitable for production of high intensity beams of singly charged ions and ions of molecules whose chemical bonds are week. However, it was hard to produce highly charged ions and ions of strong chemical bond molecules. Thus, in order to produce high intensity ions beam of these molecules, we started to develop a new microwave ion source. In this paper, we report on development of a new plasma chamber and new electromagnets which consist of three coils and iron yokes. These electromagnets are capable of generating both a mirror magnetic field and a non-mirror magnetic field by tuning the current of each coil. The mirror magnetic field is expected to strengthen confinement of electrons in the plasma for production of highly charged ions or ions of gases whose chemical bonds are strong. In the case of the non-mirror magnetic field, the magnetic field in the plasma chamber is higher than the electron cyclotron resonance (ECR) magnetic field to produce intense beams singly charged ions. Furthermore, we also report on development of permanent magnets to generate a cusp magnetic field to generate a radial confinement effect.

Poster Session 3 / 57, T8_We_49

Acceleration of Ion Beams Using a Scalable Microelectronmechanical-System-Based RF Structures

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Reducing the size, weight and power (SWAP) of ion accelerators is one of the driving forces in developing new accelerators for applications in research and industry. We recently demonstrated a novel multi-beamlet ion accelerator [1] formed from stacks of wafers (PC board in the first demonstrations) and fabricated using microfabrication approaches. The concept of this microelectron-
mechanical-system (MEMS)-based RF structure is based on the earlier work of by Maschke [2] on the Multiple Electrostatic Quadrupole Array Linear Accelerators (MEQALAC). Alternating gradient quadrupoles are placed between acceleration units to form the accelerator. An initial matching unit consisting of six electrostatic quadrupoles (ESQ), manufactured by 3D-printing, is used to tune the beam envelope parameters including the effect of space charge and emittance before injecting the ions into the RF structure. The ions are then accelerated in subsequent RF gaps, powered by a high-Q, on-chip LC circuit. More ESQs are inserted between RF units to focus the beam transversely along the beam line.
In the proof-of-principle experiment, a filament-discharge multi-cusp ion source [3] with a 3×3 array of extraction apertures was used to generate the injected ion beams, e.g. Ar^+, He^+ or H^+. The inner diameter of the ion source chamber is 7.5 cm. With fourteen permanent cusp magnets along the chamber wall, the uniform plasma region is approximately 3 cm in diameter. The total deliverable current can be easily scaled up by increasing the number of beamlets extracted from a larger uniform plasma area. For example, to achieve 300 mA total beam current, considering beamlet fill factor of ˜10% packing density (e.g. 1 mm diameter aperture with a pitch size of 3 mm), the ion source needs to be capable of producing ion current density at 100 mA/cm^2 across an area of 6 cm in diameter. This is certainly within reach of present ion sources, for example, filament-driven, RF-driven ion source.

Acknowledgement

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Poster Session 3 / 58, T8_We_50

The Construction of the Inner Ion Source for SC200 Compact Superconducting Cyclotron

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The SC200 compact superconducting cyclotron is supposed to contribute on the proton therapy under the collaboration of the Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP) and the Joint Institute for Nuclear Research (JINR). The energy of cyclotron is 200Mev with the maximum proton beam current of ~400nA from the cyclotron outlet. The hot cathode Penning Ionization Gauge (PIG) type proton source will be used in the cyclotron. The purpose of the article is to introduce the inner ion source from the design, simulation and dedicated test. Through the analysis and bench experiment results, the ion source shows a good performance which can provide enough protons to reach the cyclotron beam current. The lifetime of filament can reach more than 50 hours and the source operates at least 1h continuously. A layer-to-layer intensity modulation of the scanned beam is realized with the filament current and the arc voltage that need to vary the extracted beam current between maximum and zero. For the research the request for higher flexibility, in particular for faster beam intensity modulation. In order to explore capabilities of the machine for such research mode, a real-time control system of the arc power supply for ion source has been developed and will also be presented.

Poster Session 3 / 59, T8_We_51

The Trajectory Simulation and Optimization of Ion Source Chimney for SC200 Cyclotron

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SC200 is an isochronous cyclotron which generate 200 MeV, 500 nA proton for particle therapy. As an important component of the cyclotron, the ion source chimney needs to be tested and optimized. The simulation results and optimization of ion source in test-bed for SC200 are described in this paper. The simulation results show that the extraction slit with different sizes and shapes has an influence on the emittance of the extraction beam. To verify the simulation results, the performance of the designed ion source chimney with optimized slits was measured, including the beam current intensity and the beam emittance.

Poster Session 3 / 62, T8_We_52

Improvement of Microwave Injection for Heavy Ion Production at Compact ECR Ion Source

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There is a desire that a carbon-ion radiotherapy facility will produce various ion species for fundamental research. Although the present Kei2-type ion sources are dedicated for the carbon-ion production, a future ion source is expected to enable : 1) carbon-ion production for medical use, 2) various ions with a charge-to-mass ratio of 1/3 for the existing linac injector, and 3) low cost for modification. A prototype compact electron cyclotron resonance ion source, named Kei3, based on Kei series has been developed to correspond to produce these various ions at National Institute of Radiological Sciences. The Kei3 has an outer diameter of 280 mm and a length of 1120 mm. The magnetic field is formed by the same permanent magnet as Kei2. We investigated basic performance of the Kei3 source in a previous experiment. Maximum beam intensity of C^{4+}, N^{5+}, O^{6+} and Ne^{7+} were 565 μA, 185 μA, 99 μA and 50.5 μA, respectively.
In order to increase a beam intensity of heavy ion such as argon, we modify the microwave injection. The rf shield in the plasma chamber was used as a tuner of a microwave. The rf shield was installed at the position of a mirror peak of injection side, and it can move 30 mm upstream from there. As a result, we found an optimal position of rf shield for production of highly charged Ar ion. In this paper, modification of microwave injection and ion production (e.g. carbon and aluminium ion) are described.

Poster Session 3 / 66, T8_We_53

ECR-Source of an Intense Beam of Low-Energy Hydrogen Ions

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ECR-based ion source provide a continuous beam formation without maintenance, which is important for applications, for example, in industry and medicine.
The paper presents an ECR source under development with an intense beam of hydrogen ions with energy up to 8 keV and a current of up to 4 A, formed by a multi-aperture four-electrode ion-optical system. The hydrogen plasma is created by an ECR discharge at a frequency of 2.45 GHz. The magnetic system of the discharge consists of two radially magnetized rings of NdFeB. The rings have an internal diameter of 10 cm and are located at a adjustable distance of 60-90 mm. The resulting plasma flows through the hole in one of the rings and forms a plasma emitter.

The ion beam is formed by a fine-structure four-electrode multi-aperture ion-optical system with an emission diameter of 5 cm. In this system, molybdenum grids in the ion-optical system of fast hydrogen atom injector [1] FABS for a source of polarized ions OPPIS at BNL are used.

The first results on ignition of a microwave discharge at a power of 1.5 kW and the extraction of low-energy ions are obtained. The system was tuned to obtain an even distribution of the plasma density on the surface of the emission grid by matching the microwave path with the gas-discharge chamber and optimizing the magnetic system.

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Poster Session 3 / 78, T8_We_54

Interaction of Intense Pulsed Ion Beams with Matter: Fluence and Dose Rate Dependent Energy-Loss

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The Neutralized Drift Compression eXperiment (NDCX-II) at Lawrence Berkeley National Laboratory is an induction accelerator designed to deliver intense nano-second pulses of ions, up to several tens of nC/pulse, with kinetic energy up to 1.2 MeV [1]. A filament-driven multicusp plasma ion source [2] is used to generate pulsed helium ion beams. Both filament and arc power supplies are pulsed to produce a plasma discharge for 300 µs. Applying a 1 µs long voltage pulse of 150 kV to the injector during that period leads to the extraction of pulsed helium ion beams above 100 mA. The ˜12 m long induction linac is capable of accelerating and rapidly compressing beam pulses by adjusting the slope and amplitude of the 12 compression and acceleration voltage waveforms in each acceleration gap. Peak voltages range from 15 kV to 200 kV with durations of 0.07 - 1 µs. At the exit of the last acceleration gap the bunch duration is 30-40 ns with a head-to-tail velocity ramp that further compresses the beam to a pulse length of 2 ns FWHM. The final spot size has a diameter of 2 mm FWHM.

These unique beam properties enable the study of dynamics of radiation effects in materials, including studies of the fluence and dose rate dependence of the energy loss in materials. The applied velocity tilt that longitudinally compresses the beam causes a certain time dependent energy profile of the beam and complicates a precise energy determination. Due to this, conventional beam diagnostics, like time-of-flight measurements, are imprecise since the inferred energy distribution is ambiguous. This results in greater uncertainty for the energy distribution of the beam. Recent energy-loss measurements using time-of-flight diagnostics at NDCX-II show a discrepancy between measured and simulated energies of about 50 keV. The beam behavior is simulated using the Particle-in-Cell code Warp [3] and various properties of the beam can be predicted at any stage in the accelerator. So far the predictions of the arrival time of the beam from Warp are in fair agreement with experiments, which leads to the question of how good Warp is at predicting the energy distribution of the beam. To accurately measure the energy distribution of the beam it is necessary to have a time independent energy measurement. A tool to perform such a measurement is a Thomson parabola. Based on the deflection of charged particles by electric and magnetic fields, this device differentiates energy as well as charge-to-mass ratio. With a microchannel plate detector or a scintillator it is possible to visualize this differentiation, which results in parabolic particle distributions on the position sensitive detector. A Thomson parabola has been designed for the special application of measuring the energy spectra of NDCX-II beams with an energy resolution of about 10 keV. Direct measurements of energy distributions using the Thomson parabola spectrometer and comparison with Warp simulations will be presented.

This work was performed under the auspices of the U. S. Department of Energy under contracts DE-AC02-05CH11231 (LBNL) and DE-AC52-07NA27344 (LLNL).

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Poster Session 3 / 88, T8_We_55

Inverse Heat Flux Evaluation of Diagnostic Calorimeter Data by Neural Networks

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The instrumented calorimeter STRIKE (Short-Time Retractable Instrumented Kalorimeter Experiment) has been designed with the main purpose of characterizing the SPIDER negative ion beam in terms of beam uniformity and divergence during short pulse operations. STRIKE is made of 16 1D Carbon Fibre Composite (CFC) tiles, intercepting the whole beam and observed on the rear side by infrared (IR) cameras.
As the front observation is not convenient, it is necessary to solve an inverse non-linear problem to determine the energy flux profile impinging on the calorimeter, starting from the 2D temperature pattern measured on the rear side of the tiles.
Most of the conventional methods used to evaluate the inverse heat flux are unbearably time consuming, so the need to have a ready-to-go instrument to understand the beam condition while operating SPIDER becomes stringent.
The present contribution demonstrates that, once properly trained, the neural networks provide a fast evaluation of the impinging flux, within seconds. Furthermore, they do not need to optimize any parameters as this operation is already included in the self-adjustment of the network weights during the training.
The neural networks are also capable of dealing with non-linearity and non-stationarity of the impinging heat fluxes.
The method has been trained and tested with stationary and non-stationary heat fluxes, showing to be a reliable tool for STRIKE real time operation.

Poster Session 3 / 91, T8_We_56

Production of Nitrogen-Fullerene Compound Ion Beams on Tandem-Type Electron Cyclotron Resonance Ion Source

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A new tandem type source on the basis of electron cyclotron resonance (ECR) plasma has been constructed for producing synthesized ion beams in Osaka University [1]. Both stage plasmas can be individually operated, and produce ions in which the energy is controlled by a large bore extractor and can also be transported from the first to the second stage. We have already investigated the basic operation and effects of the tandem type electron cyclotron resonance ion source (ECRIS) [2]. It is considered to be suitable for production of new materials, and then we will aim at producing synthesized ion beams as the new source can become a universal source to be available to wide-range mass/charge (m/q) operations. Firstly,we have already produced and extracted multicharged fullerene ion beams on the second stage by using pure C60 vapor source [3]. Next we have been trying to produce endohedral fullerenes in the ECRIS. In the first step, we have been using gaseous material, i.e. nitrogen and argon. In this paper we describe initial experimental results succeeding production of nitrogen-fullerene compounds. Since our final goal is production of metal endohedral fullerenes, e.g. iron endohedral fullerene, we will try to conduct them in the tandem-type ECRIS in the near future.

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Poster Session 3 / 96, T8_We_57

Carbon Pulsed Evaporator for Carbon Plasma Source

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Carbon plasma source has been developed. The application of the carbon source is carbon material deposition. Hydrocarbon gas and hydrogen gas are generally used for the carbon material deposition. In this case, main plasma component is hydrogen and hydrocarbon. Carbon is not main component of the plasma. The carbon plasma source can provide carbon gas. In my device, carbon can be the main component of the plasma. The carbon evaporator is operated independently with the back-ground gas. Hydrogen can be mixed with the carbon gas. This device can be operated under two component gas, hydrogen and carbon without any hydrocarbon gas. This device will provide a new parameter area for carbon material deposition.
The solid carbon material is used for the particle source. Capacitor bank feeds the Mega-watt class electrical power into the carbon plasma source. The carbon is heated and is evaporated in mili-seconds, and the evaporated gas flow is diffused in several seconds. The carbon gas pressure is maintained by the repetitive operations and controlled by the charging voltage of the capacitor bank and the repetition interval. The carbon plasma source is coaxial shape, and consisted with center carbon electrode and with outer carbon pipe. The center carbon electrode is terminated with outer carbon pipe by carbon plate. The evaporated carbon particles flow in the plasma chamber with multi-cusp magnetic fields.
Order of 10-4 Torr of carbon pressure is obtained in the cusp field chamber. These microwave powers are escalated in the test phase. The carbon pulsed evaporator is used for pure carbon plasma and for two-component plasma with hydrogen. The carbon gas pressure control and the hydrogen gas pressure control provide new parameter region for carbon material deposition.

Poster Session 3 / 98, T8_We_58

The Ion Source for the Commissioning of ELENA Ring

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The commissioning and first results of the ion source to test the Extremely Low Energy Antiproton Ring ELENA are presented. ELENA is a compact ring for cooling and further deceleration of 5.3 MeV antiprotons delivered by CERN Antiproton Decelerator (AD) down to 100 keV. Because of the long AD cycle of 100 s, one ion source for protons and H^- with a kinetic energy of 100 keV has been installed for commissioning and start-ups. The complete device is described including the control and power subsystems. The beam profiles and the emittance for protons and H^- were measured with a wire scanner and a pepper-pot diagnostics. The current was also measured by means of a current transformer. The ion source meets the parameters required by ELENA testing program in order to tune the decelerator ring before starting with the antiproton beam.

Poster Session 3 / 104, T8_We_59

A New Control System for High Resolution In-Gas Laser Ionization and Spectroscopy Studies

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The Heavy Elements Laser Ionization and Spectroscopy (HELIOS) project at KU Leuven has the goal of performing In-Gas Laser Ionization and Spectroscopy (IGLIS) measurements on the actinide and superheavy (transfermium) elements. These studies will allow to deduce atomic properties, e.g. ionization potentials, electronic transition energies and strengths, isotope shifts, nuclear charge radii, and nuclear properties, nuclear spins and nuclear electromagnetic moments with high precision owing to an improved spectral resolution down to 100 MHz (FWHM) for these elements. In these spectroscopic measurements, step-wise laser ionization of the involved isotopes takes place in the supersonic jet formed by a de Laval nozzle installed at the gas cell exit. The in-gas-jet method allows an increase in resolution of at least an order of magnitude, owing to the low particle density, low temperature and small velocity spread in the supersonic jet, compared to the in-gas-cell laser ionization measurements. Furthermore, the complete set up is developed as a new in-gas jet ion source for the selective production of radioactive ion beams in the heavy element region and around 100Sn. These include isomeric beams making use of the laser ionization mechanism.

A complete characterization of the in-gas-jet method can only be achieved when factors such as frequency stability and power of the lasers as well as the spectral linewidths are minimized, and the timing for data acquisition of multiple systematic measurements can be synchronized. Therefore, a dedicated control system has been developed at KU Leuven. The program enables the stabilization of the laser wavelength, reducing the laser frequency fluctuations from 50 MHz down to 7 MHz. This corresponds to the precision of the wavelength meter used to measure the laser wavelength. This reduction in frequency fluctuations is necessary to be able to accurately perform spectroscopy on peaks with a Full Width at Half Maximum (FWHM) in the order of tens of MHz. Furthermore, the control program synchronizes the full command to several types of data acquisitions e.g. time-of-flight measurements for isotope separation in an Atomic Beam Unit (ABU) and image acquisitions for Planar Laser Induced Fluorescence (PLIF) spectroscopy of the seeded atoms in the supersonic jet. This synchronization and increases the signal-to-noise ratio and enables study of systematic effects by comparing the results of PLIF spectroscopy with those obtained in the ABU.

Poster Session 3 / 115, T8_We_60

Production of Proton Beam with ZrH_2 Pellet Target

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We have been developing on proton beam generation with a Laser ion Source (LIS). A LIS has its uniqueness in providing various species of ion beams only by changing solid material target which is irradiated by high intensity pulsed laser. The methods to provide heavy ion beams such as Au or Fe solid target were already established, but there has been no attempt to produce proton beam with LIS. To generate proton beam with LIS, solid materials which generate proton beam are required. Conventionally, proton beam is provided with ion sources using gaseous hydrogen. In the past [1], we confirmed proton generation from a LIS with metal hydride targets. This time, we installed a pellet target made of ZrH_2 powder in the LIS and successfully observed proton beam current of 120 \mu A which was obviously distinguishable from Zr ion beam current. In this presentation, we will give more details on this experiment.

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Poster Session 3 / 121, T7_We_15

Development of a Prototype of PIG Ion Source with Electric Magnets for a Compact Ion Microbeam System

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The ion microbeams ranging from several hundred keV to several MeV have, so far, been formed by a large microbeam system with the total length of about 30 m that comprises an accelerator, a beam transport line and focusing lenses.The installation of the microbeam system in a common experimental room with a typical size of about $4 \times 4 \times 4\mathrm{m}^3$ is difficult. A MeV compact ion microbeam system is developed to enable us to install in the experimental room. In the development a 120 keV compact ion microbeam system, hereafter compact microbeam system [1], is constructed using a three-stage acceleration lens and a duoplasmatron-type ion source with electric power consumption over 500 W and brightness of about 10 Am-2sr-1V-1 at about 1 keV as a prototype of the MeV compact ion microbeam system. A hydrogen ion beam of 2.6 m in diameter has, so far, been experimentally formed using the compact microbeam system. In parallel with the reduction of the beams diameter the increase of the beam energy is studied on the basis of developing and improving some elemental technologies. An ion source of the small electric power consumption is developed to put it in a small space applied to the high voltage of MV. The present ion source supplies the low energy and the brightness ion beam that are appropriate for the three-stage acceleration lens, whereas it needs large electric power to heat the filament and frequent exchanges of it.The supply of the large electric power is difficult in the MeV compact ion microbeam system. A solution of the reduction of the electric power consumption is to use a PIG ion source with a cold cathode that is generally low electric power consumption and a compact size. However, the PIG ion source has beam energy over several keV and low brightness, while beam energy of less than 1 keV level is required for the compact microbeam system.

In this study, a PIG ion source generating a hydrogen ion beam with low energy, high brightness, and low electric power consumption of less than several keV, over 10 Am-2sr-1V-1, and less than the wattage of several tens, respectively, which matches the demand of the three-stage acceleration lens, is developed to enable us to install it in a high voltage space of the MeV compact ion microbeam system.

The high brightness of ion beam is an important parameter for the compact microbeam system to obtain relatively large beam current at a focused point when an ion beam with a smaller diameter is formed. The extraction of ion beam from high density plasma in a small space in a PIG ion source was considered to be effective to generate the ion beam with the high brightness. The generation of strong magnetic field in the small space is required to realize this consideration. The magnetic field was calculated using a magnetic field calculation code at magnetic circuits with various shapes. It has two coils placed at the both sides of anode in an iron yoke to obtain the strong magnetic field. The magnetic field over 1.5 T in the small space was numerically obtained by applying 800 AT and 400 AT to up and down coils, respectively. The small space for generating plasma is 1 mm$\Phi \times$ 1.5 mm with the anode of 0.8 mm in thickness. The coil turns of up and down are 800 and 400. The iron rods are used as the return yoke in the magnetic circuit to cool down the coils by the air. The ion source was placed in a test bench. The preliminary experimental results showed that the extracted hydrogen ion beam current and its brightness were measured to be over 10 A and 20 Am-2sr-1V-1 at about 2 keV and electric power consumption of less than 30 W, which almost satisfies the requirements.

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10th Session / 257

Generation of Magneto-Immersed Electron Beams

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There are many applications of electron beams in accelerator facilities: for electron coolers, electron lenses, and electron beam ion sources (EBIS) to mention a few. Most of these applications require magnetic compression of the electron beams to reduce the radius of the electron beam with goal to either match the circulating ion beam (electron lenses and electron coolers) or to increase ionization capability for production of highly charged ions (EBIS). The magnetic compression of the electron beam comes at a cost of increasing the share of transverse energy and therefore the angles of electron trajectories with the longitudinal axis. Considering the effect of magnetic mirror it is highly desirable to produce a laminar electron beam in the electron gun. Analysis of electron guns with different configurations is given with emphasis on generating laminar electron beams.

10th Session / 30, T8_CO_24

Design Optimization of the Nano-Aperture Ion Source for Proton Beam Writing Applications

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Microscopy has spurred development in many fields and has been an integral part of scientific development for more than hundred years. Any form of microscopy is limited by the wavelength of the probe used. Microscopy using fast protons with a wavelength of ˜10s fm has several advantages over traditional forms of microscopy. A MeV proton mainly interacts with substrate electrons. Due to the mass mismatch between protons and electrons a proton beam will follow a practically straight path in material. In proton-electron collisions the substrate electrons just get enough energy to break bonds within a range of ˜1 nm of the original proton track. Current proton microscopes are typically very large, are not user-friendly and have an ion source brightness which is typically several million times less compared to competitive beam sources. We have demonstrated the potential of proton beam writing (PBW) as a promising candidate for next generation lithography down to 19 nm.
Through the implementation of a nano-aperture electron impact gas ion source (NAIS) we have shown breakthrough results, opening up the way to improve ion beam brightness by a million times [1,2]! This will have major implications. Firstly, it potentially allows the spot size for fast protons to breach the single digit nm regime. Secondly, it allows the possibility of miniaturizing the size of a proton microscope to that of a table top system [3]. This will allow us to design a proton microscope with lithographic capabilities that are better than state of the art electron beam writing systems and possibly breach the 1 nm feature size in lithography.
The NAIS chip tests are performed inside a JOEL JSM-5600 tungsten filament scanning electron microscope. A focused electron beam is injected into a NAIS chip to ionize gas, subsequently an ion beam is extracted from the NAIS chip through DC bias across the chip. The NAIS is aimed typical dimensions below 1 µm and ˜ 1 eV energy spread, with an expected hydrogen reduced brightness of ˜ 10^6 A/(m^2srV). Unlike point ion sources, the NAIS has low emitting current density but with high angular current intensity, resulting in low Coulomb effects and large range of operating probe current. The NAIS chip fabrication process is optimized aiming for high brightness and low energy spread. In this paper we will discuss the latest results on this optimization process and performance.

Acknowledgement

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Brightness talk

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11th Session / 305

Advances in Gas-Cell Based Resonance Laser Ionisation Methods for Radioactive Ion Beam Production

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The Leuven Isotope Separator Online (LISOL) facility, at the Cyclotron Research Center (CRC), Louvain-la-Neuve, was operated as a gas-cell-based laser ion source to produce rare ion beams by the In-Gas Laser Ionization and Spectroscopy (IGLIS) technique [1]. After almost two decades of operation high-purity radioactive ion beams of more than 15 different elements were obtained exploiting various production mechanisms. Production and thermalization of radioactive species in a cell filled with ultra-pure buffer gas was used in combination with resonant laser radiation for selective ionization of the isotopes of interest either within the gas cell or in the jet formed in the supersonic expansion of the nuclear reaction products while being transferred from a high to a low pressure environment [2]. The photo-ions were then transported by a radio-frequency sextupole ion guide (SPIG) up to the mass separator, where they could be segregated from non-isobaric contamination.

In the last experiments at LISOL, the proof of principle of the in-gas-jet method in on-line conditions was demonstrated with the successful production and laser spectroscopy studies of pure radioactive ion beams of neutron deficient isotopes of $^{214-215}$Ac [3]. The results revealed a significant improvement of the selectivity and the attainable spectral resolution with respect to the gas-cell method without loss in efficiency.

In this talk I will summarize the recent results obtained with the IGLIS technique and will report on the new developments and prospects for future applications of the technique at the new generation radioactive beam facilities [4].

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11th Session / 357

Design and test of the TRIUMF EBIS RIB Charge breeder

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Invited Talk

11th Session / 204, T6_CO_19

On-line Operation of the EBIT Charge Breeder of the ReA Post-Accelerator

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The electron-beam ion trap (EBIT) charge breeder of the ReA post-accelerator at the National Superconducting Cyclotron Laboratory (Michigan State University) started on-line operation in September 2015. During the past years, the EBIT charge bred many pilot beams of stable isotopes (e.g., ^{39}K, ^{85}Rb) and several rare-isotope beams (e.g., ^{46}Ar, ^{46}K, ^{34}Ar, ^{47}K, ^{37}K) for the nuclear-physics program. A unique operating aspect of the ReA EBIT is the breeding of high charge states to reach high re-accelerated beam energies. Efficiencies in single charge states of more than 20% were measured with ^{47}K $^{17+}$ and ^{34}Ar^{15+} with efficiencies integrated over all charge states of more than 65%. Breeding high charge states demands long breeding times, increasing the ejected ion number per pulse. Another unique operating aspect is the ability to spread the distribution in time of the ejected ions to lower the instantaneous rate delivered to experiments. Pulse widths were stretched from 25 microseconds up to 70 milliseconds. This presentation summarizes the current status of the ReA EBIT system and shows the results of charge-breeding efficiency measurements and time stretching of ejected pulses obtained with stable- and rare-isotope beams over the first two years of on-line operation.

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ICIS 2017 Highlights

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12th Session / 359

CERN accelerators

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CERN has the world's largest and most complex installation of particle accelerators and detectors to study the basic constituents of matter, probing the fundamental structure of the universe. The chain of accelerators provides protons for collisions in the Large Hadron Collider (LHC) up to collision energies of 13 TeV, but also a variety of other particles (ions, antiprotons, molecules,…) for a multitude of experiments in a wide energy range. Many challenges are linked to the present accelerator operation, but there is an even more challenging program to further improve the LHC performance, in view of a planned significant luminosity increase for the High-Luminosity LHC.

The presentation will give a brief introduction to the CERN accelerator complex. It will show an overview of the large variety of CERN's accelerators, and it will present a few examples of mastering the challenges in the quest of improving their performance.

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ISOLDE and n-ToF Physics

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ISOLDE is the CERN facility dedicated to the production of radioactive ion beams for many different experiments in the fields of nuclear and atomic physics, materials and life sciences. The Isotope Separator On Line method involves in this case the bombardment of a thick target with an intense proton beam, producing high yields of exotic nuclei with half-lives down to the millisecond range. By a clever combination of target and ion source units pure beams of over 1000 different nuclei of 74 elements have been produced and delivered to experiments where properties of the nuclei such as masses, radii, decay modes, structure and shapes are determined. Since more than ten years ISOLDE offers the largest variety of post-accelerated radioactive beams in the World today. Presently the Facility is undergoing an upgrade of its experimental capabilities; mainly an increase of post-accelerated energy from previous 3 MeV/u to 10 MeV/u and it is ready to accommodate a fourfold increase in intensity. The goal of the neutron time-of-flight, n-ToF, Facility is to provide unprecedented precision in neutron kinetic energy determination, which will bring the much-needed precision in neutron-induced cross-section measurements. These measurements are vital for a range of studies in nuclear technology, astrophysics and fundamental nuclear physics. The main feature of n-ToF is the extremely high instantaneous neutron flux (105 n/cm^2/pulse) feeding two experimental stations one vertical at 18 m and the long distance one at 182 m. n-ToF provides neutron rates some three orders of magnitude higher than existing facilities, allowing measurements to be made more precisely and rapidly than in the past. In this short talk I will present some highlights of these facilities with emphasis on the vanishing of classical magic numbers in Nuclear Physics and the emerging of new ones. How a nucleus with exotic shape can help to study physics beyond the standard model and an example of a joint contribution of these two facilities to address the cosmological lithium problem.

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SPS physics

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LHC Phenomenology & Physics

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Challenges of the LHC detectors

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This presentation will introduce the LHC detectors, their primary physics goals and the resulting design choices. The sensitivity to certain key measurements for each experiment will be discussed, alongside latest physics highlights. An overview of the experiments data taking status and their Phase 1 and Phase 2 upgrade plans will be shown.