The 6th International symposium on Negative Ions, Beams and Sources

Monday 03 September 2018 - Friday 07 September 2018

Budker INP, Novosibirsk

Book of Abstracts

Novosibirsk 2018

Co-hosted by

Budker Institute of Nuclear Physics and **Novosibirsk State University**

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POSTER SESSION #2

MONDAY, SEPTEMBER 3

1st Session / MonO1

Negative Ion and Neutral Beams Injectors at the Budker Institute of Nuclear Physics

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An overview of the negative ion and neutral beam injectors, developed at the Budker Institute of Nuclear Physics is presented. The highlights and innovations, used in a variety of positive and negative ion sources, produced by BINP team for plasma heating, diagnostics and for injection into accelerators are discussed. Data and long-term experience of BINP produced ion sources service at the fusion experimental devices and accelerators are described.

1st Session / MonO2

Start of SPIDER operation towards ITER Neutral Beams

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To reach fusion conditions and control plasma configuration in ITER, the next step towards establishing nuclear fusion as viable energy source, suitable combination of additional heating and current drive systems is necessary. Among them, two Neutral Beam Injectors (NBI) will provide 33MW hydrogen/deuterium particles electrostatically accelerated to 1MeV; efficient gas-cell neutralization at such beam energy requires negative ions, obtained by caesium-catalysed surface conversion of hydrogen/deuterium atoms in the ion source. ITER NBI requirements have never been simultaneously attained; so a Neutral Beam Test Facility (NBTF) was set up at Consorzio RFX (Italy). Experiments will verify continuous NBI operation for one hour, under stringent requirements for beam divergence (<7mrad) and aiming (within 2mrad). To study and optimize NBI performances, the NBTF includes two experiments: MITICA, full-scale NBI prototype with 1MeV particle energy; SPIDER, with 100keV particle energy and 40A current, aiming at testing and optimizing the full-scale ion source. SPIDER will focus on source uniformity (˜1.5m2 beam area), negative ion current density and beam optics. The SPIDER experiment, just entered into operation, will profit both from strong numerical activities, simulating experimental scenarios, and refined diagnostic instruments, providing thorough plasma and beam characterization. The contribution is dedicated to the activities carried out at the NBTF regarding SPIDER and the supplementary small facilities specifically devoted to coupling of radiofrequency to plasma, voltage holding with magnetic fields, distribution of caesium emitted from the evaporators. SPIDER has just entered into operation: the experimental plan will be described as well as the first experiments, including the preliminary characterization of the beam source features at low RF power.

This work was set up in collaboration and financial support of F4E.

2nd Session / MonO3

Long Pulse Operation at ELISE: Approaching the ITER Parameters

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The ion source of the ELISE test facility ($0.9 \times 1.0\,m^2$ with an extraction area of $0.1\,m^2$) has half the size of the ion source foreseen for the ITER NBI beam lines. Main aim of ELISE is to demonstrate, that such large RF driven negative ion sources can achieve the following parameters at a filling pressure of 0.3 Pa: extracted current densities of $28.5\,mA/cm^2$ in deuterium for a pulse length of 3600 s and $33.0\,mA/cm^2$ in hydrogen for 1000 s, a ratio of co-extracted electrons to extracted ions below one and deviations in the uniformity of the extracted beam of less than 10 %.
This presentation describes results of the recent ELISE experimental campaigns in hydrogen and deuterium. Focus is laid on long pulse operation (up to the pulse length required for ITER) with high RF power (possible are up to 75 kW/driver). The performance obtained during such pulses is restricted mainly by a strong temporal increase of the co-extracted electrons. Additionally, the co-extracted electron current can show a pronounced top-bottom asymmetry. For SPIDER and MITICA as well as for the ITER NBI system the latter can pose a risk to the extraction grid (EG), acting as a dump for these electrons: even when the measured global amount of co-extracted electrons is below the limit, a strong asymmetry can result in local overheating of the EG.
Several measures for reducing, stabilizing and symmetrizing the co-extracted electron current while not reducing significantly the extracted negative ion current have been investigated systematically. Examples are modifying the electrostatic potentials close to the extraction system by means of elements additionally introduced into the source and modifying the temperatures of different ion source components.
Presented and discussed are extracted negative ions and co-extracted electron current densities obtained during these investigations as well as results of plasma and beam diagnostics (indicating the plasma parameters and their homogeneity and the beam homogeneity, respectively).

2nd Session / MonO4

Influence of External Magnets and the Potential Rods on the Plasma Symmetry in the ELISE Ion Source

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The Neutral Beam Injection (NBI) system for ITER requires large-scale sources for negative hydrogen ions. The ELISE test facility at IPP Garching uses a 1/2 scale ITER-source (extraction area of $0.1\,m^2$ at ELISE), and shall demonstrate the feasibility of the ITER parameters (extracted $j_{H^-} = 329\,A/m^2$ for 1000 s, $j_{D^-} = 286\,A/m^2$ for 3600 s, with a co-extracted electron current below the ion current at a source filling pressure of below 0.3 Pa). In long pulses the co-extracted electron current density j_e is strongly increasing and usually limits the source performance. Two measures for stabilizing and lowering j_e have been applied at ELISE in the past: on the one hand adding bars of permanent magnets outside of the source strengthening the magnetic filter field and on the other hand the installation of potential rods perpendicular to the magnetic field lines close to the extraction system. Since $\mathbf{F} \times \mathbf{B}$ drifts lead to a vertically asymmetric plasma, an influence of both measures on the plasma symmetry is expected by modifying the magnetic field or electric potential topology in the source. The plasma asymmetry is a crucial parameter, since it may lead to an inhomogeneous beam under certain conditions. The change of the plasma symmetry close to the extraction system, determined by two double probes, is presented.

2nd Session / MonO5

Caesiated H- source operation with helium

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The consumption rate of caesium (Cs) for negative hydrogen (H^-) ion source increases when the source operation gas is changed from hydrogen to deuterium. A clear indication that a deuterium discharge erodes Cs atoms on the surface to increase work function, and thus, co-extracted electron current. We have proposed a model, that the enhanced sputtering yield of Cs from the plasma grid (PG) due to deuterium ions, which carries more kinetic energy to Cs adsorbed on the surface directly or indirectly, is the main reason for this fast dissipation of Cs. Introduction of helium (He) into discharge can verify the enhanced sputtering effect due to heavier ions in ion source discharge. Comparing the effect due to seeded Cs before and after the He injection into discharge through Cs OES signals as well as the H^- density measured with cavity ring-down method, the sputtering/evaporation enhancement due to He is estimated. Neutral atoms and positive ions in the He discharge should cause enhanced sputtering like deuterium, while the system does not generate neutron under the induction of acceleration voltage to diagnose the extracted negative ion beam. Plasma parameters of the H_2 and He plasmas will be investigated by diagnostics tools installed on NIFS-RNIS (National Institute for Fusion Science, Research and development Negative Ion Source) together with cavity ring down. Enhanced consumption rate of Cs will be compared with proposed sputtering yield data to predict the rate for deuterium operation of negative ion sources.

3rd session / MonO6

Effect of light-mass ion species on plasma characteristics in NIFS-RNIS

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Degradations of ion source performance were found in deuterium operation of negative ion source for Neutral Beam Injector (NBI) on Large Helical Device (LHD): lower ion beam current efficiency for discharge power, higher electron current ratio to ion beam current and more intense Cs atom emission (related with sputtering) in the same Cs tank temperature operation. We changed pressure inside discharge chamber, bias voltage between arc chamber and plasma grid, Cs tank temperature (Cs seeding flux) and discharge duration (discharge chamber wall temperature) to optimize beam injection power to the LHD. It is expected, that these degradation and variation of optimal operation parameter from hydrogen to deuterium operations are associated to differences of negative ion yield efficiency on plasma grid surface covered by cesium, physical and/or chemical sputtering, and plasma parameter variation by ion mass. For the sputtering and plasma parameter variation, helium and helium mixed hydrogen discharges as well as pure hydrogen and deuterium are useful. Simultaneous several plasma parameter measurements are necessary to investigate the physical differences between hydrogen and deuterium operation in the large scale negative ion source for fusion. Experiment is performed with National Institute for Fusion Science – Research and development Negative Ion Source (NIFS-RNIS) which is the most suitable ion source for this experiment, because NIFS-RNIS was the same type of the negative ion source for NBI on LHD. And NIFS-RNIS has many diagnostics: movable Langmuir Probe (n_e, T_e and V_s profile), movable cavity ring-down technique (n_{H^-} profile), millimeter wave interferometer (n_e), multi-channel laser absorption spectroscopy for cesium atom (n_{Cs} distribution), optical emission spectroscopy (hydrogen, deuterium, helium and cesium emission). We will present the differences among hydrogen, deuterium, helium mixed hydrogen discharges in NIFS-RNIS.

3rd session / MonO7

Effects of impurity ions upon Cs recycling in a negative hydrogen ion source

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Plasma surface interaction in a cesiated negative hydrogen (H^-) ion source determines the overall Cs consumption rate of the source. The Cs coverage on the plasma grid (PG) surface is reduced mainly by two mechanisms. The first mechanism is the removal of Cs from the PG by direct sputtering, or ion induced desorption. The second is the deposition of atoms that form a layer above the Cs covered low work function PG surface. The first mechanism associated with incoming ions removes some part of the loosely bound atoms on the surface to reduce the deposition rate. The second process also affects the first, because the PG surface contaminated with deposited atoms should result a Cs removal rate different from the original value of the condition with the half monolayer of Cs on top of the pure PG material.
Removal rates of Cs atoms on PGs have been estimated using a collision cascade simulation code ACAT (Atomic Collisions in Amorphous Target). The code has predicted the enhanced removal of Cs by the interlayer of medium mass number elements between the bulk PG material and the Cs top layer. The simulation has to employ several assumptions that are too ideal as the PG surface condition of an actual ion source; the simulation does not take impurity effects into account. This paper attempts to study the contribution of the second process to the Cs recycling; how the incoming atoms and ions, including those produced and transported in plasma, modify the surface condition and change the Cs coverage on the PG. Lessons from tungsten filament driven arc discharge sources are compared with the simulation results, and the expected performance including Cs recycling of a RF H^- source is discussed.

3rd session / MonO8

Study of H- extraction from a single-hole plasma electrode of C12A7 electride

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Recently it has been reported, that a high production rate of negative hydrogen ion (H^-) was observed from a nanoporous C12A7 electride surface immersed in hydrogen/deuterium low- pressure plasmas [1]. The H^- ion energy spectrum seemed to indicate that the dominant process leading to H^- ion formation was through kinetic desorption induced by low energy ions. Fundamental understanding of the production mechanism is not fully clarified yet. Negative ions can be produced through (1) charge exchange(electron pick-up) reflection process and (2) desorption process by sputtering. When the plasma electrode was fabricated with the C12A7 electride, it is not clear, whether the high production rate through desorption process is effective in a real ion source, or not. In addition, it is not clear, whether the high production rate of H^- ions on the C12A7 electride is owing to the characteristic feature of the low work function or the cage structure, that contains H^- ions in it. Present work deals with negative ion production on a C12A7 electride surface for a cesium-free ion source, and H^- extraction from a single-hole plasma electrode. In order to investigate these problems, a small device with an ECR plasma source and C12A7 electride plasma grid has been constructed. The work function of the plasma gird surface can be monitored by injecting lasers of various wavelength, and extracted H- current will be measured.

[1] M. Sasao, et al, Applied Physics Express **11**, 066201 (2018)

TUESDAY, SEPTEMBER 4

4th Session / TueO1

Progress of the J-PARC cesiated RF-driven negative hydrogen ion source

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Operation of a cesiated RF-driven negative hydrogen ion (H^-) source was initiated in September 2014 in order to fulfill the requirements on beam current upgrade in J-PARC (Japan Proton Accelerator Research Complex). The required H^- beam current from the ion source to the J-PARC accelerators has been successfully delivered without serious problems. In 2017-2018 campaign, continuous operation of the ion source for 2,080 hours from January to March 2018 was achieved with the beam current of 45 mA extracted from the source. We are conducting an endurance test of a J-PARC prototype antenna at a test bench. Approximately 1,000-hour operation with the prototype antenna was successfully performed. We will present the progress of the ion source as well as the prototype antenna test.

4th Session / TueO2

Beam Intensity Bottleneck Specification and 100 mA Operation of J-PARC Cesiated RF-Driven H^- Ion Source

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The Japan Proton Accelerator Research Complex (J-PARC) cesiated RF-driven H^- ion source has been stably operated for about four years. The J-PARC RFQ LINAC successfully accelerated the J-PARC requirement intensity of 60 mA, when a 70 mA beam was injected from the source. The high intensity beam with transverse emittances suitable for the RFQ is produced with several unique measures, such as, slight water molecules (H2Os) addition into hydrogen plasma, a low temperature (about 70°C) operation of 45°-tapered plasma electrode (PE) with a 16-mm thickness, argon and/or nitrogen elimination in the hydrogen plasma along with filter-field optimization, and so on. In order to specify the beam intensity bottleneck of the source and derive the optimal plasma, extraction and ground electrode shapes, the higher extraction and acceleration voltages (V_{ext} and V_{acc}) were examined. A 100 mA beam, whose about 92 mA beam has transverse emittances used for a common RFQ design, was stably operated with a duty factor of 5 % (1 ms x 50 Hz) by using the V_{ext} and V_{acc} of 12 kV and 50 kV, respectively. This great progress with important information on the space-charge limited bottlenecks in the extraction and acceleration gaps will derive the optimal electrode shapes for the J-PARC operation and realize the next generation benchmark H^- ion source for high intensity and high energy LINACs.

4th Session / TueO3

High Current Results from the 2X Scaled Penning Source

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To meet the full 2 ms 50 Hz 60 mA beam requirements for the Front End Test Stand (FETS) at the Rutherford Appleton Laboratory (RAL), a new cesiated Penning Surface Plasma Source (SPS) has been developed with a larger plasma volume with 2X the linear dimensions of the standard ISIS source [1].
A clean 75 mA H– beam has been measured from the 2X Scaled Source on the VESPA test stand at full 2 ms 50 Hz duty cycle. At lower 800 μs duty cycles H– beam currents of 150 mA have been measured at high discharge currents. Two different extraction geometries are studied. Emittance scans and perveance sweeps are shown.

[1] D. C. Faircloth, S. R. Lawrie, J. Sherman, P. Wise, M. O. Whitehead T. Wood and T. Sarmento. “2X Scaled Penning Source Developments”. Proceedings of ICIS2017, Geneva, 2017.

5th Session / TueO4

Arc current Transient Studies and Plasma Diagnostic for Multicusp Cesiated Surface Conversion H^- Source at LANSCE

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The Multicusp Cesiated Surface Conversion H^- Ion Source at LANSCE has provided beam at 14 mA, 120 Hz, and 10% D.F. for many years of neutron science research. Recently, random high current transients were discovered in the arc current used to ionize hydrogen in the LANSCE H^- source. Most have no effect, but more severe transients can cripple beam output. Hypothesized causes are related to cesiation effects, plasma potential changes, tungsten filament evaporation/sputtering, or from the pulsed power system. In addition, plasma diagnostics studies using Langmuir probes and laser spectroscopy are being planned to better understand source performance. The status of the arc current transient studies and plasma diagnostics will be discussed.

5th Session / TueO5

The RF H⁻ Ion Source Project at RAL

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A Penning-type surface-plasma ion source has provided H^- beam for the ISIS spallation neutron and muon facility at the Rutherford Appleton Laboratory (RAL) for nearly 35 years. The source delivers 55 mA of H^- beam current with a beam duty factor of 1.5 % at 50 Hz repetition rate and a transverse 4-rms emittance < 1.0 π·mm·mrad. Only 25 mA of H^- current is actually required for ISIS operations, so poor beam transport efficiencies in the front-end are tolerated but are inefficient in terms of ion source performance overhead. The ion source is fundamentally lifetime-limited by material erosion, redistribution and flaking, through sputtering processes. Sputtering is mostly attributed to the use of cesium: mandatory for sustaining the discharge and for H^- surface production. The limited lifetime affects the facility operational programme, necessitating a scheduled ion source replacement every 2-3 weeks in the middle of user cycles, plus very occasional unscheduled changes. It also requires significant technician effort to maintain a fleet of ten spare operational ion sources.
An RF-driven volume-production H^- ion source project was approved and its funding secured in April 2018. It is proposed that the ion source will be coupled to the spare ISIS RFQ and a new medium energy beam transport (MEBT) line to form a completely new front-end. The front-end will have much improved transport efficiency and phase space matching into the ISIS linac, reducing the ion source output requirements to around 30 mA: within the realms of cesium-free operation. The front-end will undergo long-term performance benchmarking off-line, before installation on ISIS in the 2020s. In this paper we present the overview and current status of the RF ion source project. The conceptual design of an adjustable permanent-magnet filter field is introduced, together with preliminary simulations of the H^- ion beam extraction and co-extracted electron dump. Technical solutions for the ignition element, guaranteeing reliable breakdown of the main discharge at 50 Hz repetition rate at the optimum gas pressure for H^- production, are pursued with LPSC Grenoble and are also described.

5th Session / TueO6

Linac4 H⁻ source R&D: Cusp free ICP and magnetron discharge

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The energetic efficiency of the 2MHz radio-frequency inductively coupled plasma heating (ICP RF) of Linac4's IS03 H^- source is twice more efficient once its standard octupole cusp in offset hallbach configuration is removed. This was shown by Particle in cell Monte-Carlo (PIC-MC) simulation results using the NINJA software [1] and confirmed by plasma characterization via optical emission spectroscopy [2], an easier plasma ignition is also anticipated. In this paper, we present preliminary results of an AlN plasma chamber IS03 H^- source operated without magnetic cusp. The high intensity option for Linac4 features an adaptation of BNL's Magnetron. Simulation of this complex H_2-Cs arc discharge plasma, where electrons are emitted form a cesiated molybdenum cathode, requires characterization of the plasma impedance dependence and knowledge of hydrogen and caesium densities. We present the measured plasma impedance is over the range of discharge current, hydrogen and caesium-densities.

1) S. Mattei PhD thesis, EPFL 7907, 2017.
2) S Briefi et. al. 2017 New J. Phys. **19** 105006.
3) J. Lettry et. al. RSI **87**, 02B139 (2016); doi: 10.1063/1.4936120

6th session / TueO7

First Beam Extraction Experiments at BATMAN Upgrade

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On the BATMAN testbed prototypes of RF driven negative ion sources of about one eight of the size of the ITER source have been developed and tested since 1997. The positive results had led to the decision to equip the ITER NBI with RF sources. During the past 1.5 years this test facility has been upgraded in order to have an extraction system and source design closer to that of the ITER source and to improve the beam as well as the source diagnostics. In the new extraction system 70 apertures of 14 mm diameter are arranged similar like in one segment of the ITER NBI. The total extraction area was enlarged from 70 cm^2 to 108 cm^2 and the maximum beam energy from 33 kV to 50 kV. An additional feature is the implementation of a fourth electrode upstream of the grounded grid. By this "repeller electrode", which is on positive potential, the current of the back streaming positive ions can be reduced. In this way the space charge compensation of the beam downstream the grounded grid is expected to be changed. The filter field, previously generated only by permanent magnets placed at the lateral walls of the source, can now additionally be produced, like at the ITER source, by a current flowing through the plasma grid which enables to vary the field strength. In this paper the results of the first beam extraction experiments are reported and compared to that achieved with the previous design of the source and the extraction system with emphasis on the impact of the improved filter field.

6th session / TueO8

Spectroscopic Investigations of the Ion Source at BATMAN Upgrade

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At the BATMAN test facility, prototypes of RF driven sources of negative hydrogen ions for neutral beam heating systems have been developed successfully over the last decades. Recently, the test facility has been upgraded with a new ITER-like extraction system comparable in size to one ITER beamlet group. Like for the ITER sources, the magnetic filter field can now also be generated by a current flowing through the plasma grid with the option to use dedicatedly the permanent magnets embedded into a diagnostic flange or in an external magnet frame as in the previous BATMAN setup. In addition, the diagnostic access to the ion source plasma was improved. Together with an enhanced spectroscopic system, this offers the unique possibility to study the plasma parameters and their dependence on the magnetic filter field by emission spectroscopy more thoroughly.

The OES measurements were carried out with a high resolution spectrometer (FWHM ≈ 16 pm @ 600 nm) at three different lines of sight: one going in axial direction through the cylindrical ion source driver, one in horizontal direction through the expansion volume and one in the same direction but close to the plasma grid. Plasma parameters are obtained from the measured emissivities of the atomic Balmer series and the molecular Fulcher-transition via applying the collisional radiative models Yacora H and H_2. In addition, a refined evaluation procedure is used for investigating the rovibrational population of the hydrogen molecule allowing for a more accurate determination of the gas temperature. This is of particular relevance for calculation of the gas pressure profile in the extraction system, which is required for the determination of the H^- stripping losses in this region.

6th session / TueO9

The NIO1 negative ion source: investigation and operation experience

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The ion source NIO1 (Negative Ion Optimization 1) is a versatile multiaperture H^- source, capable of continuous regime operation, with the plasma generated by a 2 MHz/2.5 kW radiofrequency (rf) power supply and nine beamlet extraction, operated since 2014 in close collaboration between Consorzio RFX and INFN-LNL. It aims to partly reproduce the conditions of the much larger ion sources built or in construction for neutral beam injectors of fusion devices in a compact and modular ion source, where effects of individual source components can be rapidly verified and compared to simulation code results. Due to the need of assessing negative ion production limits (especially without cesiation) in continuous operation for the perspective of future fusion reactors and to the large importance of magnetic field for source optimization, several configuration changes were tried (both inside the ion source and for the embedded magnets inside the accelerator grids) and investigated, with material ranging from hard ferrite to SmCo to NdFeB. Evidence of the effect of the accelerator fringe field inside the ion source is discussed here and in companion presentations. The radiofrequency system takes full advantage of the frequency tuning amplifier capability (+/- 150 kHz installed, 0/+20 kHz used), and it is worth noting, that no adjustment of matching box capacitors was necessary in the last 3 years. Major diagnostic systems (including CCD cameras and BES measurement) have been integrated with the acquisition system along with the date measured by several power supplies (including the high voltage supplies, the RF generator and bias supplies, the pressure measurements and the beam currents).

WEDNESDAY, SEPTEMBER 5

7th Session / WedO1

Uniformity of the Large Beam of ELISE during Cs Conditioning

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The modular concept of the ITER Negative Beam Ion (NBI) source has been replicated in the ELISE test facility with half of the source size in the vertical direction; thus producing a large beam of about $1\,m \times 1\,m$. The target of ELISE is to achieve simultaneously the ITER NBI parameters in terms of negative ion extracted current (in H and D), pulse duration and ratio of co-extracted electrons below 1 at a source filling pressure of 0.3 Pa. Due to limitations of the HV power supply, only 10 s of beam extraction about every 150 s can be applied, with a maximum total voltage of 60 kV. This implies that ITER relevant beam divergences cannot be achieved; however, trends and behavior of the beam divergence in ELISE as well as beam uniformity are of great importance for ITER. The beam in ELISE is characterized by means of various diagnostics: the currents in the grid system are electrically measured and provide the total extracted negative ion current as well as information of the beam losses separately measured in the two segments of the extraction and grounded grids; the Beam Emission Spectroscopy (BES) diagnostic gives information on the beam intensity and divergence (vertical and horizontal profiles); Infra-red (IR) analysis of the diagnostic calorimeter provides a 2D map of the total beam power and, consequently, the accelerated current. The spatial resolution of the diagnostics allows for identifying and characterizing in intensity and divergence the beam segments associated to the two grid segments. The beam evolution in the segments during the Cs conditioning process (i.e. Cs evaporation in the source in order to move from the volume production of negative ions to the surface production) has allowed for optimizing the conditioning, being the beam itself an indirect measurement of the status of the negative ion production. During the Cs conditioning, the presence of two peaks in the main Doppler shifted peak in the BES spectra have been observed and characterized. When a good and stable Cs conditioning phase is obtained, beam uniformity optimization can be investigated in order to achieve the beam ITER target requirements in terms of uniformity, i.e. better than 90%.

7th Session / WedO2

Study of caesium - wall interaction parameters within a hydrogen plasma

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Understanding the distribution of caesium by plasma within the expansion region of the SPIDER beam source is essential to maximize the efficiency of negative ion surface-production. The caesium is redistributed by plasma diffusion and is greatly affected by the plasma-wall interactions with the molybdenum walls. This work considers the processes, which make up the plasma wall interaction and the transmission of generated particles across the plasma sheath. An analytic model is set-up for each of the four main processes that occur at the wall: thermal desorption (evaporation), physical desorption (sputtering), backscattering and adsorption, with the latter being most significant. These processes occur in response not only to the wall temperature but also to the influx of particles to the wall, and generate atoms/ions outwards to the plasma bulk which must first cross the collisional plasma sheath and pre-sheath. The probability of re-entering the bulk is measured by a transmission factor, which is calculated specifically for each charge state and process, as it considers the energies at which the process occurs. The transmission factor considers the mean free path of ionizing collisions, along with comparing the potential and kinetic energy of each ion with the threshold energy to leave the sheath. The combination of the probability of transmission and the fluxes generated at the wall allows for the study of the redistribution from the plasma discharge within the beam source.

7th Session / WedO3

Studies of the Cs Dynamics in Large Ion Sources using the CsFlow3D Code

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Large negative ion sources for neutral beam injection rely on surface production of negative ions on a converter surface (plasma grid) in a low temperature plasma environment. To increase the negative ion production efficiency and reduce the amount of co-extracted electrons, the work function of the plasma grid is reduced by using Cs, which is evaporated in the source and redistributed by the plasma on the inner surfaces. In order to avoid a degradation of the plasma grid work function during the beam pulse a sufficient flux of Cs onto the plasma grid needs to be maintained, especially for long pulses (several hundred seconds). The Cs flux is influenced by the plasma distribution in the source, which can be affected by a vertical drift due to the magnetic filter field. In addition, the presence of a bias potential between the plasma grid and the other source walls can affect the plasma potential profile and thus the flux of Cs^+ ions. To investigate the effect of plasma drift on Cs dynamics, the Monte Carlo code CsFlow3D has been used to simulate long pulses for the source at the ELISE test facility (half the size of the ITER-NBI source) and a vertical asymmetry of the plasma profiles, i.e. plasma density, electron temperature and plasma potential, has been implemented. The Cs flux onto the plasma grid (both neutral and Cs^+ ions), the energy distribution of the Cs^+ ions impinging the grid (depending on the bias potential of the plasma grid) as well as the neutral Cs density resulting from the simulations will be presented. The latter will be directly compared with the experimental data from TDLAS (Tunable Diode Laser Absorption Spectroscopy). Further on, an alternative configuration of the Cs oven that relies on the direct evaporation close to the plasma grid has been simulated, in order to achieve a caesiation method that is independent from the plasma parameters and capable of delivering the required flux during long pulses.

8th Session / WedO4

High brightness H^- ion source for accelerators developed at TRIUMF

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TRIUMF has developed H^- ion sources for decades and now they are being employed in machines such as the 500MeV, TR30, TR13 at TRIUMF as well as various other machines worldwide. A high current version can produce up to 60 mA of H^- beam. A new H^- ion source with a small plasma volume is being developed to produce 5 mA at a very low emittance and run years without changing the filament. Due to the low cost, low emittance and educed maintenance needs, this ion source will suit cyclotrons as well as other accelerators looking for reliable, stable operation over long time. Having four extraction electrodes, this ion source can run at optimum extraction voltage while delivering beam energies from 1 kV to 60 kV with little or no degradation to the beam quality. Performance of the source including beam current, arc parameters, emittance and filament lifetime are discussed in this paper. The source parameters effecting emittance are discussed in details.

8th Session / WedO5

Improvements to Siemens eclipse PET cyclotron penning ion source

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The Siemens Eclipse (RDS111) cyclotron utilizes an internal Penning Ion Gauge (PIG) ion source to provide the negative hydrogen ions for this 11 MeV PET cyclotron. Siemens worked with D-Pace Inc. to optimize the ion source current and transmission through the cyclotron to the radioisotope targets. The goal was to increase the target current from 120 μA (dual 60 μA) to 150 μA (dual 75 μA) and to increase the time between ion source rebuilds from 120 hours to more than 300 hours. Over 80 experiments were conducted including tests on ion sources with modified cathode, anode, and puller lens geometries and materials, hydrogen gas flow configurations, and a biased plasma lens design. Cesium was introduced to the source, which alone increased the beam current on target by over 20%. These short-term tests are being followed up with longer duration field testing.

8th Session / WedO6

Operating Experience and Recent Updates of Negative Hydrogen Ion Source at BINP Tandem Accelerator

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A continuous-wave surface-plasma negative hydrogen ion source is used at 2 MeV tandem accelerator with vacuum insulation at the Budker Institute of nuclear physics since 2006 [1]. The source uses the hydrogen-cesium Penning discharge with plasma injection from hollow cathodes, and negative hydrogen ion production due to interaction of plasma particles with anode electrode surface [2]. It routinely produces dc H^- beam in the range 1 ÷ 9 mA in daily runs with accelerated proton beam delivery to the lithium target of BNCT experimental device. Source parameters and maintenance statistics during long-term operation will be discussed. Recent upgrades, made for increasing beam current production and transport will be presented as well.

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9th Session / WedO7

Operation experience of the BINP Accelerator Mass Spectrometer

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The accelerator mass spectrometer (AMS), created at BINP, is used for an ultra-sensitive radiocarbon concentration measurements for archaeology, geology, biomedical science and other fields. The BINP AMS is based on the 1MV folded tandem accelerator with C^{+++} ion selection. The most distinguishing feature of BINP AMS is the use of electrostatic separator of ion beam, located inside the high voltage terminal. The next important distinguishing feature is magnesium vapors stripper instead of the gas stripper. Moreover, the moment of time for ion detection can be registered by TOF detector. The BINP AMS capabilities for pure radiocarbon beam selection and about 10 years operating experience will be described.

9th session / WedO8

Negative ion and helicon wave physics on the Resonant Antenna Ion Device (RAID)

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The Neutral Beam Injector (NBI) system for DEMO is designed to deliver a beam with energy 800 keV, accelerated current 34 A, and will require a neutralization efficiency for negative ions larger than 70 % [1]. Research groups in France and Switzerland are developing a new source concept for DEMO NBI based on a magnetized plasma column produced by a helicon antenna [2]. In RAID (Resonant Antenna Ion Device) at the Swiss Plasma Center, the physics of volume-produced negative ions and helicon plasmas is investigated. RAID is a linear device producing steady state plasma discharges with different gases, including H_2 and D_2, by means of a resonant helicon antenna with RF power up to 10 kW [3-4]. Previous optical emission spectroscopy (OES) data reveal a significant volume production of H^- and D^- and a favorable scaling law with power [5]. To confirm the previous results with a totally independent technique for detecting negative ions, Cavity Ring-Down Spectroscopy (CRDS) was recently installed. We present first CRDS measurements, which provide values in agreement with OES, confirming that negative ions are produced in the RAID plasma column with significant densities. RAID is also devoted to the study of helicon wave physics and, in particular, of the mechanisms that lead to the production of a steady state plasma discharge. Many physics issues on helicon plasma sources are still open regarding, for instance, how the power is deposited in the plasma. We present three-dimensional plasma density and temperature profiles measured by means of a two-axis Langmuir probe and calibrated with a 100 GHz microwave interferometer. These reveal the production of a radially peaked density and temperature plasma column with good homogeneity in the axial direction for up to one meter. This last property could be favorable for the homogeneity of negative ion production. Moreover, magnetic probe measurements are used to reconstruct the propagation of helicon waves for comparison with COMSOL simulations, with the aim of linking together different plasma regimes and negative ion production.

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[2] A. Simonin et al. "*Negative ion source development for a photoneutralization based neutral beam system for future fusion reactors*" New J. Phys. **18** 125005 (2016)

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9th session / WedO9

Characterization of the helicon plasma generated inside the Cybele negative ion source with different magnetic field configurations

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The Cybele negative ion source is designed and operated at the IRFM in CEA Cadarache for the development of the future NBI system SIPHORE for future fusion reactors [1]. The main objective is to create a thin and tall (blade-like) negative ion beam (H^-, D^-), which will be neutralized by the laser photodetachment. For this purpose Cybele has an aspect ratio (1.2 m high, 0.15 m wide) which is directed to the creation of a dense and homogeneous magnetized plasma column in order to produce and extract negative ions on the side edge along the main axis.
In 2011, IRFM started a collaboration with EPFL Lausanne for the development of a bird-cage type Helicon antenna on the RAID testbed dedicated to the Cybele source. The RAID testbed is equipped with a set of coils (40cm diameter) outside the vacuum chamber to generate an axial magnetic field. The helicon plasma column obtained on RAID exhibits very promising characteristics [2] for its application on Cybele. It is an ideal configuration for the propagation of the helicon waves in the plasma but this closed magnetic confinement is not suitable for the implantation on the plasma edge of extraction and acceleration systems.
In 2017 a similar Helicon antenna was installed in the top of the Cybele source to study the negative ion extraction from the helicon magnetized plasma column. For this purpose, the first step of this study is focused on the exploration of different magnetic confinement of the plasma column which should be compatible both with the propagation of the helicon waves in the Cybele plasma column and the beam extraction. Two magnetic field configurations are under investigation: the first one is based on two lateral coils sitting on opposite sides of an iron rectangular frame, which surrounds the source; the second one is based on a set of 11 coils implemented within the source volume under vacuum. Plasma diagnostics by Langmuir probes allow characterizing the plasma parameters under these two different configurations. The experimental results and the comparison between these two configurations will be presented.

10th session / WedO10

Complete compensation of criss-cross deflection in a negative ion accelerator by magnetic technique

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During 2016, a joint experimental campaign was carried out by QST and Consorzio RFX on the Negative Ion Test Stand (NITS) at the QST Naka Fusion Institute, Japan, in order to validate some design solutions adopted in MITICA which is the full-scale prototype of the ITER NBI, presently under construction at Consorzio RFX, Padova, Italy.
The main purpose of the campaign was to test a novel technique, for suppressing the beamlet criss-cross magnetic deflection. This new technique, involving a set of permanent magnets embedded in the Extraction Grid, named Asymmetric Deflection Compensation Magnets (ADCM), is potentially more performing and robust than the traditional electrostatic compensation methods. The results of this first campaign confirmed the effectiveness of the new magnetic configuration in reducing the criss-cross magnetic deflection. Nonetheless, contrary to expectations, a complete deflection correction was not achieved. By analyzing in detail the results, we found indications that a physical process taking place just upstream of the plasma grid was giving an important contribution to the final deflection of the negative ion beam. This process appears to be related to the drift of negative ions generated in the plasma source, in presence of magnetic field transverse to the extraction direction, and results in a non-uniform ion current extraction at meniscus. Therefore, the numerical models adopted in the design was improved by including this previously disregarded effect, so as to obtain a much better matching with the experimental results. On this basis, new permanent magnets were designed and installed on the Extraction Grid of NITS. A second QST-Consorzio RFX joint experimental campaign was then carried out in 2017, demonstrating the complete correction of the criss-cross deflection and confirming the validity of the adopted solution and of the hypothesis behind the new models.
This contribution presents the results of the second joint experimental campaign on NITS along with the overall data analysis of both campaigns, and the description of the improved models. A general picture is given of the relation among magnetic field, beam energy, meniscus non-uniformity and beamlet deflection and divergence, constituting a useful database for the design of future machines.

10th session / WedO11

H^- beam formation and electron dumping strategies

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Today's new developments, such as CERNs Linac4 injector, pose strong demands on the extraction and LEBT systems. Designing such systems is challenging. First of all the H^- ion beam formation is difficult to model: the physics, taking place at the extraction sheath is rich and approximations have to be made. The extraction system is strongly affected by the need for co-extracted electron separation from the ion beam using a magnetic filter at a relatively early stage to avoid adverse space charge effects on the ion beam, mainly observed as increased transverse emittance. In many cases the electron beam power sets limits to the energy at which the dumping can be performed. As a result one of the three methods is often chosen for separating the electrons: (1) dumping at the puller electrode before acceleration to full energy, (2) dumping at a decelerating einzel lens or (3) dumping at an intermediate low energy electrode before the puller electrode.
This paper discusses the H- beam formation and emittance in the light of the results from CERNs Linac4 RF-driven ion source and the TRIUMF-type filament-driven ion source and discusses the different extraction and dumping strategies used in these sources.

10th session / WedO12

Development of OPPIS Ion Source for Polarized Negative Ion Beam Production

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The polarized beam for RHIC spin physics experimental program is produced in the Optically Pumped Polarized H^- Ion Source (OPPIS). The present RHIC OPPIS produces 0.5–1.0 mA current in 300 μs pulse duration. The polarized H^- ion beam of 35 keV beam energy out of the source is accelerated to 200 MeV in a linear accelerator for strip injection to Booster. The H^- ion pulse is captured in a single Booster bunch, which is accelerated in the Booster and then transferred to the AGS, which is accelerated to 24.3 GeV for injection to RHIC.
The RHIC polarized H^- ion source had been upgraded to higher intensity and polarization by using a very high brightness fast atomic beam injector developed at BINP, Novosibirsk. In this injector the proton beam is extracted by a four-grid multi-aperture ion optical system and neutralized in the H_2 gas cell downstream from the grids. The proton beam is extracted from plasma emitter with a low transverse ion temperature of ˜0.2 eV which is formed by plasma jet expansion from the arc plasma generator. The multi-hole grids are spherically shaped to produce "geometrical" beam focusing. The atoms of the beam formed by the injector get into a strong magnetic field, where they lose the electron in the helium target, and then they capture the polarized electron in the target of rubidium vapor. The transfer of the spin projection from the electron to the nucleus of the atom occurs in the region of Sona transition at the exit from the magnetic field. Negative hydrogen ion beam is formed when electrons are captured by the atoms of a polarized beam in a stationary recirculating sodium vapor target.
Effective transportation of non-polarized 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 atomic beam injector. 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.

THURSDAY, SEPTEMBER 6

11th session / ThuO1

Fluid Modeling of Negative Hydrogen Ion Sources

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Negative hydrogen ion sources are widely used to produce neutron beams, relevant to both accelerators and fusion devices. There are a number of different kinds of negative hydrogen sources in use today, including inductively coupled plasma sources (ICPs). For instance, coils external to the ion source chamber can be designed to deposit power into hydrogen plasmas to create highly excited ionic states, which then can produce negative hydrogen ions. Modeling ICP ion sources using traditional Particle-In-Cell (PIC) codes is difficult because of inherent separation of time scales between electron and ion motions severely limits the number of RF periods that can be modeled with currently available computational resources. In some cases, fluid-based models can be used to overcome these difficulties. For these models, simplifying assumptions are made about the electrons and their energy distributions that enable longer time steps. The loss of information about electron kinematics may not be so important in determining the plasma chemistry and valid predictions of ion source performance can in some cases be obtained using fluid-based models.
We present our progress developing a drift-diffusion model implemented using the USim plasma- fluid framework. This model is able to capture both the deposition of energy into the source plasma and diffusion of energy and density from rf and DC power sources, and also the production of different ion species and vibrational states through inclusion of plasma chemistry models. We first determine the largest reaction rates in the production of negative hydrogen using a global model, which depends on the specific parameters of the ion source being modeled, such as neutral gas density and geometric factors for surface processes. These rates determine the ion species that are needed in simulations in order to model negative hydrogen production. rf power deposition into the plasma is done separately from the drift-diffusion solve, but for dense plasmas modeled here, the numerical time-step restrictions for rf power deposition are typically larger than those for modeling the plasma chemistry, and so do not reduce simulation performance.
Fluid model equations corresponding to electron number and energy density are solved numerically on either structured or unstructured meshes. Source terms for the electron number densities are determined by the plasma chemistry, while sources for the energy density equations are a result of both inelastic collisions and energy deposition from external electromagnetic fields. We apply our models to the simulation of the SNS external antenna negative hydrogen ion source, and demonstrate the feasibility of using fluid-based models for simulation of these types of ICPs for negative hydrogen ion production. We note that we are developing model capabilities that are general enough to be applied to a large variety of different geometries, electric field configurations, and plasma parameters.

This work was performed under the auspices of the Department of Energy, Office of Basic Energy Sciences Award #DE-SC0009585.

11th session / ThuO2

The Particle Tracking Code BBCNI for Negative Ion Beams and its Application to BATMAN Upgrade

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For the continued improvement and development of large negative hydrogen ion sources for NBI applications, beam characterization is of critical importance for understanding and predicting the interaction of the beam with, for example, a gas neutralizer system. The relationship between the results of beam diagnostics and the physical properties of the beam is not a trivial one, and a full understanding of the data requires the support of a simulation.
This simulation should be fully 3D, in order to encompass the complex electric and magnetic fields, and needs to provide simulated diagnostics that recreate what is present in the experiment. A PIC simulation is unsuitable due to the very large size of the domain, but information at the particle level is still required, as no assumptions about velocity or spatial distributions can be made. Thus a particle tracking code is required; one that calculates the trajectories of particles through pre-supplied electric and magnetic fields.
The code BBCNI [1] has been designed to fulfil these requirements, and is presented here after significant upgrades and improvements. In the code, particles are accelerated from the plasma side of the extraction grids of the system being modelled, and their trajectories are calculated to the calorimeter with a fully relativistic treatment. Along these trajectories, particles can interact with the background gas to undergo reactions and emit photons. Particles hitting any physical object are recorded, allowing the reconstruction of the heat loads on beam line components and the calorimeter. Diagnostic planes can be inserted into the simulation domain to record particle properties at any location in space. Generated photons are recorded, and post-processed to generate spectra simulating the diagnostic results of a Beam Emission Spectroscopy (BES) system. Full traceability of these spectra allow specific features to be linked to specific particle populations and areas of the beam, providing a much-needed understanding of experimental results. While the code is currently configured to assist with the understanding of beam diagnostics on the BATMAN Upgrade and ELISE test facilities at IPP, it is designed to be flexible, and could in principle be applied to any similar ion source.
In order to demonstrate the capability of the code, the first experimental BES results from the BATMAN Upgrade test facility are also presented. Analysis and interpretation of the data in terms of beam properties is demonstrated. A comparison between the experimental spectra and those generated by BBCNI is shown, and the similarities and differences are discussed.

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11th session / ThuO3

Effects of the extraction voltage on the H- beam optics for H^- ion sources

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Development of H^- ion sources which can produce high beam intensity with a small beam divergence angle is useful in plasma heating systems for magnetic fusion reactors and accelerators for high-energy physics. Since one of the main requirements for the extracted particle beam in Linac4 H^- ion source is to minimize the beam divergence and emittance, it is of vital importance to further our understanding of the extraction mechanisms. However, as of today, the beam formation mechanisms in such H^- ion sources are yet to be fully understood. In previous work by S. Abe the dependence on the beam divergence angle of the extraction voltage by using a 2D Particle In Cell (PIC) model for the extraction region of H^- ions source for Linac4 was analyzed [1]. It was shown that the divergence angle has a minimum value and that this minimum value can be further decreased by taking charge exchange and elastic collisions into account, which play a key role in the flow reversal of H^- ions produced at the PG. The H^- ions extracted from the bulk plasma region due to flow reversal has smaller divergence angle than H^- ions extracted directly from the Plasma Grid (PG) surface. The extracted negative ion beam thus consists of two components: the beam core and the beam halo. [2]

The purpose of this study is to clarify the extraction mechanisms of the surface produced H^- ions, in order to optimize the beam optics by varying the PG shape in negative ion sources such as the Linac4 H^- ion source. We, therefore, intend to evaluate the extracted H^- beam divergence angle for various extraction voltages by using a 3D PIC model for the geometry of Linac4 H^- ion source [3]. Furthermore, we intend to survey the extraction mechanisms of H^- ions produced at the PG surface. In particular, the tendency of velocity reversal due to elastic collisions and charge exchange of the surface produced H^- ions will be studied.

The results of the extraction mechanism of the surface produced H^- ions are presented. The tendency of the results corresponds to experimental measurements and contributes to validating the 3D PIC model by comparison with experiments and thus further improves our understanding of the extraction mechanisms of H^- ions.

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12th session / ThuO4

Role of angular orientation of dipoles on work function during caesium deposition on a metal surface – a phenomenological model

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It has been experimentally proven that adsorption of alkali metals like Caesium (Cs) on tungsten reduces tungsten's effective work function. The work function of pure W surface is 4.55eV and that of pure Cs is 2.14 eV [1]; however with fractional monolayer (0.6 – 0.7) of Cs coverage on W surface makes the effective work-function of the W surface as low as 1.5 eV [2]. It is well known from previous experiments, that chemisorption of foreign atoms on metal surfaces give rise to a strong double-layer. This may be positive outwards or negative outwards according to the nature of adsorbed atoms. The ionization potential of Cs (3.85 eV) is smaller than the work function of polycrystalline tungsten (4.5 eV). Consequently, the electropositive Cs will give up its valence electron to the metal, forming an electrical double layer with positive outwards and hence reducing the effective work function. The theory of adsorbate-induced work function change (WFC), is to a large extent based on the classical dipole model given by Langmuir [3], which had been further modified by Miller, by a simple point dipole depolarization model [4]. However, this experimentally observed anomalous variation of work function during Caesiation has not been explained before using classical model for the full fractional range of monolayer formation ($\theta \leq 1$). In the present work it is shown analytically, that the orientation of dipoles in the classical model indeed plays a significant role and explains the experimental trend of anomalous variation of work function. Fractional monolayer can be achieved by time-varying controlled deposition of Cs atoms on a metal surface.
The existing classical model is based on a 2D square lattice of parallel point dipoles with an axis perpendicular to the line joining them. At a low coverage of adatoms, surface dipoles are non-interacting owing to which they tend to form an array of dipoles, all identically normal to the surface. However, at high coverage ($\theta > 0.5$) in addition to the point depolarization, we propose that the repulsive interaction among the neighboring dipoles due to their closeness may lead to change in the orientation of the dipoles. Thus by including an effective angular orientation factor (AOF) of mutually interacting dipoles, we have made an analytical approach to extend the existing classical model. This phenomenological simple model reasonably explains the experimental results of anomalous variation of work function during Cs deposition on W surface.

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12th session / ThuO5

Methods of Beam Emittance Measurements of High Power Negative Ion Beams for NBIs

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The development of a high power negative ion beam accelerator is one of the key aspects in the neutral beam injection system (NBI) for fusion reactors. For example, the ITER NBI requires 1 MeV deuterium negative ion (D^-) beams with a current density of 200 A/m2 and a divergence angle of < 7 mrad. Such high power beam accelerations have been demonstrated in a MeV test facility (MTF) in QST for the ITER NBI. In the beam acceleration tests at high negative ion beam energies of 1 MeV, unknown divergent beam components which is unfavorable for beam transport, so-called beam halo, is always observed in the beam footprint. Though the beam emittance is an important parameter that offers valuable information relating to the formation of the beam halo and poor beam optics, the conventional emittance measurement method is not applicable for such high power beams. In this study, the measurement methods for the emittance of the 1 MeV high power beams are being newly developed to understand the characteristics of the ion beam for maintaining the sufficient emittance of the negative ion accelerator.

As the material to measure this high power beam, a one-dimensional carbon fiber composite (CFC) target is selected, whose melting point is 2000 ^{0}C. Measurement methods being studied are the pepperpot type and slit-collector type meters. For the pepperpot type emittance measurement, a multi-aperture CFC plate with 0.5 mm diameter pinholes is placed in front of another CFC target allowing the small portions of the beam to pass through. The temperature profile of the H^- ion beamlets being projected on this CFC target are measured using an infrared camera to observe the emittance spread. The advantage of this thermal measurement is the simple configuration and lack of additional electrical components that can contribute to the noise in the signal. Another method to be tested is the slit-collector type where an array of slits produces the beamlets while collectors are arranged to scan the cross-section and measure the transverse emittance with high spatial resolution. The reliability of this electrical type of detection will offer a good comparison to the pepperpot method as to identify the key features of each measurement technique. Examining the beam emittance will also reveal the characteristics of the diverging beam components crucial to beam transport. From performance of the different emittance measurement methods, a beam diagnostics system will be proposed suitable to monitor the ITER-class negative ion beam.

12th session / ThuO6

Development of a new beamlet monitor system: time resolution and phase space structure

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Development of negative ion sources and development of the accelerator of negative ion beams are of crucial importance for nuclear fusion research. In order to evaluate beam optics, and to investigate the characteristics of meniscus formed between negative ion beam region and plasma region, detailed measurement of beam property is required. Therefore, we have developed a new beamlet monitor system to evaluate negative ion beam properties in experiments. The beamlet monitor system for negative ion beams has four diagnostics in one hexagonal box, which can be moved remotely in the vertical direction (y-direction in the experiment) by a linear drive system. One diagnostic is fast beamlet monitor (FBM) with 32-channel electrode array (8x4) for beam current profile measurement. The time resolution is up to 50 MHz for electrical circuit and data acquisition, and the space resolution is 4.1 mm in the horizontal (x-direction) and 4.9 mm in the vertical. The other diagnostics are pepper pot-type phase space structure analyzers (PPSA). The copper plate with two-dimensional pinhole array (18 x 14) and kapton foil are utilized for detecting beam burn pattern, which shows the information of phase space structure. The hexagonal box is installed in NIFS neutral beam test stand (NIFS-NBTS). The detector can be switched by rotating the box on a shot-by-shot basis. Therefore, the beam information from different diagnostics are obtained with almost the same beam condition. The demonstrations of beam measurement with the beam monitor system were performed. In the case of FBM, it was confirmed that the secondary electron current can be suppressed with the application of DC bias of +70 V to the electrodes, and the absolute value of the beam current was obtained. The two-dimensional beam profile was also obtained by detailed scan of the detector position with the linear drive. In the case of PPSA, the clear beam burn pattern was obtained on the kapton foil, and the phase space structure was constructed by the burn pattern. In the symposium, the details of the beamlet monitor system and the initial results in the experiments will be presented, and the comparison of the two dimensional beam-let profiles obtained by FMB and PPSA will be discussed.

13th session / ThuO7

Experimental study of electrostatic residual ion dump

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Reference design of the Residual Ion Dump (RID) for the ITER NBI system is based on an electrostatic deflection of the residual negative and positive ions to in-line dump panels. According to 4-channels beam line concept, RID forms four narrow (about 100 mm in width) vertical channels with the aid of 5 panels (1.8 m long and 1.7 m in height). Two middle panels are negatively biased with about 20 kV. This concept has the advantage of compact design with quite moderate power density (PD) load onto the panels – peak PD is less 8 MW/m^2. However, such a concept has never been earlier tested in any operating NBI system, all of them used magnetic deflection systems with remote ion dumps. This report describes experimental investigation of the electrostatic RID concept, which was carried out at the test stand IREK at the Kurchatov Institute. The main physical questions were: - Effect of the ion beam space charge on the RID deflection properties. - Secondary electrons production and their behavior in the crossed electric and magnetic fields, which can have an influence on the high voltage holding and state of operability. Tested RID was designed with following conditions: - Mono-atomic and mono-energetic positive helium ion beam with energy up to 50 keV instead of hydrogen beam with complex composition. - One RID channel consisting of two panels 1x1 m and 150 mm in width, one panel is under negative potential up to 12 kV. - Special magnetic system (MS) which produces rather uniform vertical magnetic field in the RID volume to simulate the ITER NBL conditions. Moreover, the MS was designed to produce B_z up to 0 , 13 T to compare electrostatic and magnetic deflection. Experimental results showed that: - The space charge of the beam with current at a level of 4÷5 A influences significantly on the required deflecting voltage – it was necessary to increase it about twice in compare with calculated without space charge. - Secondary plasma gives also noticeable effect on the increase of the deflecting voltage. - Drift of secondary electrons in crossed ExB fields does not influence noticeably on the high voltage holding. The modeling program was developed which described the electric field distribution in the RID volume with account of the beam space charge and calculated trajectories of the deflected ions. The results of calculations were in good agreement with the experimental one. So, this program was used for calculation of the mixed beam of positive and negative deuterium ions (about 2 A each per one channel) deflection in the ITER RID. It was shown that 1 MeV ion current densities are small enough and moreover at the initial part of the RID channel positive and negative beams compensate space charge of each other. So, the deflecting voltage of 20÷25 V will be enough for stable RID operation.

13th session / ThuO8

Development of surface-plasma negative ions sources at BINP

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A review of surface-plasma negative ions sources developed in the Budker Institute of Nuclear Physics for use in accelerators and neutral injectors for fusion experimental devices in last decade is presented. Physical processes, main properties and features of surface-plasma sources with various high-current discharge drivers are analyzed. Key issues and solutions in achieving the sources high power efficiencies, reliable long-term operation and easy maintenance will be discussed.

13th session / ThuO9

Negative Ion Beam production and Transport via the LEBT of the HV injector prototype

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High-voltage negative-ion based injector is under development at Budker Institute of Nuclear Physics. Negative ion part of injector is studied at separate test stand and consists of: 1) the long-pulse RF surface-plasma source, 2) low energy beam transport line (LEBT), 3) single aperture 0.5-1 MeV accelerating tube. Deflecting magnets and high speed 10^5 l/s cryopumps, that are installed in LEBT, purifies the beam from the co-streaming fluxes of electrons, hydrogen atoms and molecules, and 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.

Paper presents experimental results on 1 A, 90 keV H^- beam production and transport through the LEBT to the multisection calorimeter installed at distance 3.5 m from the source. The parameters of the transported beam were measured at distance 1.6 m by the movable Faraday cup and at the LEBT exit - by beam calorimeter. The efficiency of beam transport vs various source and LEBT parameters will be presented and discussed.

FRIDAY, SEPTEMBER 7

14th session / FriO1

Negative ion production study on nanoporous 12CaO.7Al2O3 electride surface in low pressure H_2 plasma

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In ITER and Demo devices, the heating of fusion plasma will be mainly provided by the injection of 1 MeV neutral deuterium atom (D) beams into tokamak. Such energetic neutrals are delivered by neutral beam injection (NBI) device. The key component of ITER NBI device is D^- negative ion source, where a D^- current density of 200 A/m2 is required. ITER negative ion (NI) source is based on Cs injection. It is nowadays the only scientific solution to reach such high D^- negative ion current. Cesium (Cs) is injected in vapor state inside the negative ion source. It deposits on the surface of plasma grid. Deposition of Cs on the grid lowers the material work function which reaches value close to 2 eV. This effect increases electron capture efficiency by particles from the plasma backscattered by the surface. Therefore, high NI yields is produced. However, severe drawbacks to the use of Cs have been identified, hence a strong reduction of Cs consumption or its elimination from the fusion negative-ion sources is highly valuable. For this reason, we are working on H^-/D^- negative ion surface production in Cs-free H_2/D_2 plasmas.

Surface negative ion production measurements are performed in the diffusion chamber of a plasma reactor [1]. The sample is placed inside the plasma. It is negatively biased with respect to the plasma potential. So, the plasma positives ions are accelerated towards the sample surface by the electric field formed in the sheath. The positive ions bombardment leads to a negative ions surface production on the surface. The produced negative ions are accelerated towards the plasma and self- extracted from the plasma to a mass spectrometer, where they are detected according to their energy. This measurement gives the negative ion energy distribution function (NIEDF). In this work, surface negative ions production is studied on Nanoporous 12CaO. 7Al2O3 electride surface. The material surface is exposed to low pressure hydrogen plasma created by a 2.45 GHz generator. NIEDFs were recorded in following experimental conditions: 1 Pa H_2 gas pressure and microwave injected power of 60 W. The influence of surface temperature, bias and plasma exposure time on negative-ion yield is investigated. The target was negatively biased at 20 – 170 V, and it was heated from room temperature to 500 ^{0}C. The effect of the duration of high energy H_3+ bombardment on material surface was also studied. Different NIEDF measurement on nanoporous 12CaO. 7Al2O3 electride surface are compared to NIEDFs measured on our reference material HOPG (highly oriented pyrolytic graphite) and on molybdenum Mo surface. A high production rate of H- negative ions was observed from Nanoporous 12CaO. 7Al2O3 electride surface compared to Mo surface. The NIEDF peak intensity on electride surface is 25 times the NIEDF peak intensity on Mo surface at a surface bias of -20 V [2]. This high production of NI yield on material surface may be attributed to its low work function of 2.4- 2.7 eV. In this contribution, we shows that the electride material has potentials to be used as a production surface of cesium-free negative ion sources for neutral beam injectors in nuclear fusion.

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14th session / FriO2

Performance of Radio frequency plasma generator for neutral beam injector

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The China Fusion Engineering Test Reactor (CFETR) is a next generation fusion device towards the using of fusion energy. The main machine of CFETR and the auxiliary plasma heating tools including the Neutral beam injector (NBI) were under design. The high power ion source is the most precision and important part of NBI. A negative ion source was designed for the key technology study and performance tests of high power ion source. The plasma generator contains a RF driver and a expansion chamber. The diameter of driver is 20 cm and the height is 15cm. Six turns of external coils was used for the plasma generation. A matching unit was design to transfer the RF power (100kW @ 1MHz) to the coils. Several diagnostic tools were used for the plasma parameters measurement. The RF plasma generator was tested with high density plasma generation and long pulse operation. The details of experimental results will be presented in this paper.

14th session / FriO3

Modelling of beam transport and interactions with beamline components in the CFETR neutral beam test facility

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The neutral beam injection (NBI) will be a fundamental method for plasma heating and current drive in the China Fusion Engineering Test Reactor (CFETR). As the most critical step towards the CFETR-NBI system, a research project of the CFETR neutral beam test facility (CFETR- NBTF) has be started in China. The objectives of the first phase of CFETR-NBTF are to produce a negative hydrogen ion beam of >20A up to 200kV for 3600s and to attain a neutralization efficiency of >50%, thus a neutral beam power of >2MW is foreseen onto the calorimeter. A full-comprehensive model has been developed in the COMSOL environment to optimize the physical design of the CFETR-NBTF beamline system, in terms of the gas distribution, the beam neutralization, the beam separation, and the power deposition onto the beamline components. This model can calculate the particle motion in electromagnetic fields, including not only the primary beam, but also the co-extracted electrons and the secondary particles. The preliminary results reported here are focused on the neutralization of negative ion beam in different gas inflow and the power deposition of different particles on the residual ion dump due to electrical separation.

15th session / FriO4

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 with a solenoidal magnetic field is described. Dependences of a beam current on RF power, extraction voltage, solenoid magnetic field, gas flow are presented. Compact design of RF SPS is presented.

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

15th session / FriO5

Plasma characterization of a Hall Effect Thruster for a Negative Ion Source concept

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Negative ion sources are a key component of neutral beam injection systems. A novel concept for a negative ion source based on existing well tested Hall Thrusters (HT) is presented. The thruster has been designed in order to maximize the hydrogen dissociation process so that the atom flux which exits the thruster has an optimized energy to generate negative ions when impinging on a low work function surface. The novel concept can in principle offer several advantages, for instance a limited amount of co-extracted electrons, a more uniform generation of negative ions and a lower rate of destruction of negative ions. The thruster has been completed and is now in operation. In this contribution, the behavior of the thruster with different mass flow rate and voltage is presented. In particular, the first measurements of the plume plasma parameters by a Langmuir probe are shown, both with nitrogen and with hydrogen as injected gas. The spatial profile of the plasma electronic temperature and density have been obtained by scanning the region outside the exit plane of the thruster. The measurements are aimed to determine the best position of a caesiated sample in order to maximize the generation of the negative hydrogen ions.

15th session / FriO6

Negative Hydrogen ion density measurement in a permanent magnet based Helicon Ion source (HELEN-I) using cavity ring-down spectroscopy technique

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Negative ion source based neutral beam injection system is one of the most efficient method of fusion plasma heating. Negative ion source is used instead of positive ions in case of higher power NBIs, due to high neutralization factor in the beam energy range useful for ITER type fusion reactors. To understand the efficiency of negative ion source, negative ion density measurement is a prerequisite. In the present work ,a highly sensitive cavity ring-down spectroscopy(CRDS) system has been developed and employed in a in house developed permanent magnet based Helicon plasma source (HELEN-I) operated in volume production mode, to measure the line integrated negative ion density in it. The present CRDS system uses a Nd-YAG laser of wavelength 1064nm A stable optical cavity is created by using highly reflecting mirrors of reflectivity ˜99. 99% . The stable cavity is part of the plasma chamber and is created in such a way that hydrogen plasma is present within the cavity volume. When the laser enters the cavity through the first mirror, it suffers multiple reflections on the inner surfaces of the cavity mirrors and therefore passes through the plasma volume multiple times. The transmitted intensity through the second mirror is measured with a photo detector. During the travel time ˜(100 micro sec),the laser photon photo detach the loosely bound electrons from negative hydrogen ions in the plasma volume within the line of sight of the laser beam. As a result, the laser pulse intensity goes down exponentially with time. The characteristic of the temporal decay of the laser pulse intensity, known as ring down time (RDT) is a function of line of sight integrated negative ion density.

The experimental result of the negative ion density measurement by CRDS system for different working pressure, axial magnetic field and RF(13. 56 MHz) power are discussed. It is seen that at high power range (800-950 W), when the plasma source is working in Helicon(w) mode, having plasma density of order of 10^{18} m^{-3} and a plasma temperature of ~2 eV. The corresponding line integrated negative ion density of ~10^{16} m^{-3} in volume mode without any application of transverse filter magnetic field.

POSTER SESSION #1

P1– 01

Study of the Materials on Plasma Electrode Surface for Negative Ion Extraction in Hydrogen and Deuterium Operation

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Current fusion plasma research requires a high intensity neutral beam of either hydrogen or deuterium to heat the plasma. The intensity of the negative hydrogen (H^-) ion current extracted from an ion source chamber depends on both the plasma electrode (PE) surface material and the bias voltage against the plasma potential. The amount of the negative deuterium (D^-) ions should exhibit similar dependence for these factors, but with some difference due to the larger mass.

In this study, hydrogen and deuterium plasmas are produced in a cylindrical ion source with 150 mm diameter and 200 mm height. The cylindrical wall is surrounded with 16 rows of plasma confinement magnets. Tungsten and tantalum cathode filaments of 0.5 mm diameter produce the DC discharge plasma and evaporate the vapor to deposit the materials onto the PE surface. An extraction electrode and a Faraday cup are biased at 800 V against the ion source chamber anode. A Langmuir probe, located near the PE, detects plasma current, out of which an electron temperature and electron density near the extractor are determined. A DC laser photodetachment coupled to extraction current signal measurement yields information on H^- and D^- transport.

P1– 02

Plasma Electrode Structure Suitable for H^- Extraction from a Bernas Type Ion Source

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Effect of the plasma electrode position upon the negative hydrogen (H^-) ion beam current extracted from a Bernas type ion source have been studied. In the previous study plasma electrode located inside of the arc chamber covered almost all length along the plasma column sustained in a liner confinement magnetic field. In this study the amount of H^- beam current was measured as a function of the voltage to the plasma electrode, which was located outside of the arc chamber. The area of the plasma electrode exposed to the ion source plasma was reduced to 26 mm × 85 mm.

Effect of filament materials on the H^- ion beam production efficiency of the Bernas type ion source has been also experimentally studied. Tungsten and tantalum are tested for comparison. Dependence of H^- ion current and that of extracted electron current were studied by applying bias voltage on the plasma electrode for two different filament materials. H^- beam current increased by about 200% with the present plasma electrode structure compared with the previous design. The amount of co-extraction electron current was reduced to two thirds of the original amount. More than 30% increase in H^- ion beam current was observed with the tantalum filament. The amount of co-extraction electron current decrease by 40% with the tantalum filament as compared with that for a tungsten filament.

P1– 03

Theoretical models of collisional transport in negative ion source sheath

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The complexity of the negative ion sheath is immediately evident, for several reasons: the electrons are magnetized, so that a collisionless model is clearly faulty and overoptimistic, since it neglect electron extraction (an undesired effect). As in other sheath models, the kinetic effects are important, so that the self-consistent electric potential is naturally determined by an integral equation. Even if numerical model to the state of arts allows to treat important 2D and perhaps 3D effects, they are inconsistent with the actual size of the Debye length: reliability of modified vacuum permittivity ε_0 models is often invoked in the literature; moreover, large programming effort is needed for parallelization and months are a typical run time. On the other hand theoretical model is limited to 1D variation of the electric potential $\varphi(z)$ with z the extraction axis, and of the magnetic field $B_x(z)$; nevertheless it worthwhile to develop because it can give insight on the critical physics to possibly verify in simulation and on the design parameters. In this paper we complete the investigation on the singular effects of the Coulomb collision and discuss representation of wall collision, in kinetic and fluid models; for typical source parameters, the electron-neutral collisions (included in the theoretical model) result not much larger than the former, so motivating this analysis. From practical point, the need of a comparatively larger extraction voltage (with respect to the unmagnetized case for H^- only) affecting source bias current is emerging.

P1– 04

Global Model of Multi-Chamber Negative Hydrogen Ion Sources with Multi-aperture Extraction System

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Conventional global models for plasma discharge chambers solve volume averaged continuity equations, electron and total energy equations supplemented by quasineutrality condition in order to obtain plasma components number densities and electron and heavy species temperatures. These models are limited to single chamber designs. Their main advantage is a rapid evaluation of parameter space that is used to select the most important plasma components and chemical reactions, and obtain basic plasma scaling parameters.
We present a new global model for simulations of multi-chamber negative hydrogen ion sources. This is an extension of our previous verified global model for a single-chamber design. Our new model consists of separate global models for each chamber with interface boundary conditions that are solved simultaneously to get macroscopic parameters (number densities and temperatures) of all species in each chamber. The model includes electrons, 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^-) and a comprehensive set of surface and volume chemical reactions. In addition, the global model includes boundary conditions for multi-aperture extraction system.
We validate our model by comparing simulation results for a plasma composition and species temperatures in the negative hydrogen ion source developed at IPP Garching.

This work was performed under the auspices of the Department of Energy, Office of Basic Energy Sciences Award #DE-SC0009585.

P1– 05

Modelling and optimization of neutral beam injectors for fusion neutron source "DEMO-FNS"

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Neutral beam injection (NBI) system of the thermonuclear neutron source DEMO-FNS is suggested for a steady-state plasma heating and current drive. The injector scheme for DEMO- FNS incorporates a negative ions source coupled with accelerator delivering D- beam accelerated to 500keV with the current 40A. The subsequent neutralization and ions removal from the beam, as well as its further path to plasma lead to a significant distance between beam source and injection point (˜20 m). An effective beam transmission to such a long distance with minimum losses is a challenge, requiring a detailed 3D modelling of the beam and a beamline structure optimization. The simulation includes minimization of beam losses due to direct interception and reasonable reduction of beam particles loss due to reionization. The optimization problem has proved to include a large amount of parameters, constraints, and it is rather sensitive to small deviations of input data, therefore the models should be fine-tuned and allow for high accuracy estimations. The most important conditions affecting the injector performance, constraints and operation scenarios are discussed in this report, as well as the performance criteria for the baseline (assumed) configuration. The NBI system for DEMO-FNS is simulated by beam tracing codes – PDP and BTR, both developed earlier and verified for the ITER project. Optimal geometry searching methodology and the investigation results of various NBI operation modes are presented. An optimal self-consistent injector configuration and the initial ion beam are chosen. Brief the evolution of the beam power profile and total losses, detailed load distributions for all elements of the NBI are calculated.

P1– 06

A Simple Model of Source of Negative Ions by Cesium Sputtering

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Source of Negative Ions By Cesium Sputtering (SNICS) is widely used in tandem accelerators for Accelerator Mass Spectrometry (AMS) to quantify the isotope ratios of long-lived radionuclides with very high precision. Unfortunately, still, the mechanisms for negative ion creation, as well as the operation of the source are not completely understood and could be possible for additional optimization, regarding to provide a higher AMS detection sensitivity. In this order, a 2D-axisymmetry, as well as a 3D simple models of SNICS source are developed on COMSOL Multiphysics. The purpose of these models are to examine the influence of the bias of the electrodes of the source and the position of the ionizer. The results are for the potential distribution, regarding to ion-optics of the source, particle trajectories, regarding to properties of the extracted ion beam current, as well as space charge effects.

P1– 07

Analysis of Plasma Impedance in the Linac4 H- Source

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A new linear accelerator Linac4 [1] is being commissioned 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 40-50 mA, 45 keV H- beam. The power transfer efficiency between the RF generator and the ion source plasma is one of the important parameters that determine 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 order to match the impedance, it is essential to analyze the plasma impedance. In this study, we analyze the plasma impedance by using the numerical simulation code [2]. The model consists mainly two parts. One is the two-dimensional model of RF electromagnetic field, which calculates the electromagnetic fields numerically by solving Maxwell equations using the Finite Difference Time Domain (FDTD) Method. The other part is the particle dynamics model with the three-dimension in real and velocity space. The equations of motion for the charged particles are numerically solved. The particle velocity is also changed by collision process, which is modeled by Monte Carlo method.
We are now analyzing the plasma resistance and inductance under the steady state. As the first step, the absorbed power to plasma is calculated by using Pointing theorem. The next step, the plasma resistance and inductance are modeled from the absorbed power to plasma. Also we have developed the impedance prediction model, which is the theoretical model [3] assuming Maxwellian distribution. The comparison between the results of the numerical simulation and those of the theoretical model will be presented.

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P1– 08

Numerical Simulation for the Development of 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 dependence of the H^- production on the operation parameters and optimize the H^- production in the source.

In this study, we focus on the H^- surface production, which is a dominant process of H^- production. We've developed a 3D particle simulation model which simulates the H^- surface production process in the source. The simulation process consists of (i) electron transport analysis and (ii) neutral transport analysis. In the former, the electron energy distribution function: EEDF in the source has been calculated by KEIO-MARC code [3, 4, 5]. In the latter, following calculation has been conducted, 1) the transport processes of neutrals (H_2, H) are simulated considering the important collision processes by using Monte Carlo Method, 2) the H atom flux onto the Plasma Grid (PG) is calculated, and 3) the H^- production on the PG surface is calculated by using Rasser's formula [6].

Based on the above model, we are now performing a series of numerical simulations. In this paper, we report the dependence of H^- surface production on the following parameters, (a) the position of the filament and (b) the configuration of filter magnetic field. These simulation results will be useful for the optimization of the H^- production in the source.

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P1– 09

Evaluation of the temperature dependance of the Cesium deposition on the plasma grid in the JT-60 negative ion source

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Modeling for a longer stable production of the negative ion beams in the JT-60 negative ion source is constructed, based on the experimentally obtained temperature dependance of the cesium (Cs) adsorption/desorption. In this model, a thickness of the Cs layer on a plasma grid (PG) in this source is evaluated, because the Cs layer lowers a work function of the PG to enhance the negative ion production. By using this model, slight degradation of the negative ion beams for a 100 s pulse operation in this source is understood. As a result, it is found, that the thickness is determined by a balance of the adsorbed/desorbed amounts of Cs in the PG and a chamber wall and of the introduced/evacuated one. In addition, it is suggested, that the origin of the degradation of the beams is an excessive deposition of the Cs on the PG, due to rising the temperature of the chamber wall and increasing the desorbed Cs from it. For suppression of the degradation and longer stable production of the negative ion beam, temperature dependance of the thickness of the Cs layer on the PG is examined by changing temperatures of the PG, chamber wall and Cs oven, and combination of the optimal temperature at them is preliminary proposed.

P1– 10

Observation of low frequency oscillation in a filament-arc-based negative ion source

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Development of high-density negative ion plasmas and control of behaviors of the negative ion plasmas and beams are performed for a variety of application of negative ion beams. Three negative ion beam injectors based on filament-arc source have been operational for plasma experiment in Large Helical Device. In order to improve the negative ion beam performance in deuterium beam operation, further investigation of particle dynamics and beam characteristics in the negative ion source are experimentally performed in NIFS-NBTS.
Recently, an oscillation with the frequency of several hundred Hz was observed in the plasma. The oscillation seems to be driven by a power supply for biasing plasma grid, and should be suppressed for working injector. In this study, however, the oscillation is useful to investigate the dynamic response of the beam to the plasma near the plasma grid. The observed oscillation of the plasma will be presented, and the response of the beam characteristics will be discussed.

P1– 12

Langmuir Probe Investigations of Different Magnetic Filter Field Configurations at BATMAN Upgrade

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The Neutral Beam Injection (NBI) system for ITER requires large-scale sources for negative hydrogen ions. BATMAN (Bavarian Test Machine for Negative Ions) is dedicated to physical investigations due to its flexible access for diagnostics and exchange of source components.
In 2017, several critical hardware components were upgraded (see W. Kraus contribution for details), and BATMAN Upgrade is now commissioned. Among these upgrades, a major change was made on the magnetic Filter Field (FF): it is now possible to generate the FF by a current flowing through the first grid of the extraction system, the plasma grid (PG). The magnetic field intensity in front of the PG roughly scale as 2 mT / kA, and reaches around 6 mT for a maximum current of 3 kA. This value is comparable to the 4.1 mT resulting from the use of permanent magnets installed in the movable frame when located as close as possible to the PG (2x4, z = 9 configuration). However, the main difference between current and permanent magnets generated magnetic fields is the topology that affects the transport of charged particles from the driver where they are generated, to the PG.
The influence induced by the different magnetic field configurations (but also without FF) on the plasma parameters, such as the plasma and floating potential, electron temperature, plasma asymmetry. . . have been determined by two symmetrically arranged Langmuir probes, located in the PG vicinity. Furthermore, pressure and power scans were performed to better quantify the FF role on the plasma parameters near the PG.

P1– 13

Studies on the voltage hold off of the SPIDER driver coil at high Radio Frequency power

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SPIDER is the prototype of the ion source of the ITER Neutral Beam Injector presently in operation at the Neutral Beam Test Facility in Padova, Italy, designed to deliver an ion current density of 355A/m2 in H- (285 A/m2 in D-) and to accelerate the beam of extracted particles up to 100 keV energy. SPIDER is equipped with a plasma source composed of 8 Radio Frequency (RF) drivers each transferring 100 kW power at the frequency of 1 MHz to the plasma via magnetic inductive coupling. The driver coil is separated from the plasma by a dielectric driver case; it works at an estimated pressure of about 0.06 Pa (in Hydrogen operation and with source pressure of 0.3 Pa) and it reaches a voltage of 12 kV rms at full power. A set of 4 dielectric supports called combs, placed around the driver case, assures the separation in between coil turns. Both the combs and the driver case contribute to the mechanical support of the coil. The present design of the SPIDER plasma source is the one implemented during the procurement of the source and follows the concepts previously developed and proved at IPP Garching. However, further studies have proceeded in parallel to the SPIDER construction, both at theoretical and experimental level, due to its more stringent requirements. One important topic analyzed has been the power handling capability of the driver; in fact, the performance in terms of ion current of the beam source increases with the radiofrequency power level, which however raises issues related to the voltage hold off of the driver components. The risk of possible breakdowns at the driver coils with the power increase, already experienced on other devices, has been identified for SPIDER too; the paper reports the present status of the electrical analyses of the SPIDER driver coil region.

P1– 14

Development of the Cs-seeded RF negative ion beam source in Korea

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The development of a Cs-seeded RF negative ion beam source has been started as a collaborative research project between two institutes KAERI and NFRI, towards ITER neutral beam injector (NBI) technology. The final performance objective of the source is to produce 200 keV, 0.5 A deuterium ion beams. The preliminary experiments for the performance evaluation of the RF plasma source was conducted. The RF-compensated Langmuir probe was used to measure the electron energy probability functions (EEPFs), and the electron temperatures and the electron densities were calculated from the obtained EEPFs. The obtained plasma parameters in this way were used to calculate various RF source characteristic parameters. In particular, the negative ion density were estimate through the balance model calculations, in which the negative ions are assumed to be produced mainly by the volume production mechanism, that is, the dissociative attachments of low energy electrons to vibrationally excited hydrogen molecules. The extraction and the acceleration grids for the beam energy up to 30 keV were installed and the beam extraction experiments were carried out to check the actual performance of the source. Then, the evaporated Cs was seeded into the expansion chamber controlled by the dispenser current. In order to find the optimum operating conditions for high-performance ion beams, various beam extraction experiments were accomplished with several external parameters such as the Cs-evaporation rate, the temperature of the plasma grid (PG), etc. Detailed system description and the experimental results are presented.

P1– 15

Inductive RF drivers for neutral beam injectors at BINP

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In the last decade, a series of high power neutral beam injectors for plasma heating and diagnostics in magnetic fusion experiments has been developed at the Budker Institute of Nuclear Physics. In the injectors, the plasma emitter is produced by inductively coupled radio frequency discharge. With this emitter of difference size, positive ion hydrogen and deuterium beams with energy up to 60 keV and power up to 1.6 MW can be provided. In the last few years, the negative ion sources with the RF drivers have been developed for the injector with higher energies. This paper presents an overview of the design, parameters and performance of the developed plasma drivers.

P1– 16

Calorimeters for high power ion and neutral beam injectors

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The significant part of any high-power neutral beam injector is the beam absorber, which serves also as a calorimeter. The power neutral beam injector operates in multi-megawatt range and the peak-power densities normal to the beam axis can reach few tens kW/cm^2, especially for injectors with beam focusing. With these parameters the main problem is the crisis of the heat transfer between the inner wall of the cooling channel and the cooling water, which limit allowable power density at calorimeter surface by the 5-7 kW/cm^2 [1]. The operation at a high power density requires the high water velocity and flow rate. In addition, it means a complicate water-cooling system and calorimeter construction. In this paper, the calorimeter based on the tubes with narrow annular cooling channels and with spiral flow swirler described. This construction is technologically simple and has a higher heat transfer characteristic at a moderate flow rate and velocity in comparison with the typical design based on twisted tape in a cylindrical cooling channel as a flow swirler. Simple methods of beam overlap with the location of pipes in one echelon offered. This method allow sufficiently simplify the calorimeter design. The construction designed and tested in 2008 for 1.7 MW injector. The neutral power flow density at axis was 12-15 kW/cm2. About 2 thousand pulses were made during tests, the systems of 6 power injectors operates with such type calorimeters [2].

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P1– 17

Thermal characterization of the SPIDER diagnostic calorimeter

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In order to verify the accomplishment of the ITER requirements regarding the maximum allowed beam non-uniformity (below ±10%), beamlet divergence and stripping losses during short pulse operation (several seconds), a diagnostic calorimeter, named STRIKE [1], will be exposed to the negative hydrogen ion beam of the ITER ion source prototype SPIDER [2]. The facility, located at Consorzio RFX (Padova, Italy) has started the experimental activities in 2018 at Consorzio RFX (Padova, Italy). The STRIKE sensor is constituted by 16 unidirectional carbon fiber-carbon matrix (CFC) composite tiles (376 mm × 142 mm × 20 mm), arranged in a 4 × 4 matrix, resembling the arrangement of the SPIDER beamlet groups. By exposing the tiles to the beam and recording their temperature with infrared cameras the beam energy flux can be retrieved by calorimetry. The requirements of the 1D CFC material include a large thermal conductivity along the tile thickness (one order of magnitude larger than in the other two directions), uniform parameters over the tile surface and the capability to withstand localized heat loads in the order of 10-20 MW/m2. The realization of large CFC tiles satisfying all of these requirements is not straightforward and tests were performed in the last years on many prototype versions from different manufacturers. This contribution gives an overview of the tests performed to assess the thermal properties of the tiles composing the actual STRIKE, to be installed in the SPIDER vacuum vessel during 2018. The spatial uniformity of the parameters and the ratio between the thermal conductivities are assessed by means of a CO_2 power laser at Consorzio RFX. Non-linear thermal finite-element simulations are carried out and compared with the experimental data to interpret them and to estimate the thermal conductivities. This work was set up with partial financial support of F4E.

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P1– 18

Diagnostics of Caesium emission from SPIDER caesium oven prototype

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The use of caesium vapour is mandatory in plasma sources for negative ion beams to achieve a sufficient negative ion density. In the SPIDER ion source, three caesium ovens will provide a sufficiently high caesium flux to the walls of the ion source, but also a relatively even caesium distribution in the ion source volume. In order to qualify the caesium ovens in terms of repeatability of the evaporated caesium flow, and to characterize the caesium flux emitted from its nozzle, a set of diagnostics was installed in the small test facility CAesium Test Facility (CATS). This paper reports on the present configuration of the diagnostic set-up. Surface ionization probes are installed in front of the nozzle apertures. Movable surface ionization detectors are used to reconstruct the angular distribution of the emission. A quartz microbalance is installed at a fixed position, to provide the cumulated caesium over time. Finally, the laser absorption spectroscopy measures the line-integrated caesium density. An example of combined measurement is presented.

P1– 19

Design of the Calorimeter for High-Power RF Negative Ion Source

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To study and optimize negative ion production for the HUST (Huazhong University of Science and Technology) radio frequency negative ion source, an instrumented calorimeter is under construction with the aim of testing beam characteristics and verifying the source proper operation. Based on the comparative analysis of different calorimeter structures and actual requirements of the HUST source, this paper chooses a quasi-adiabatic physical structure for calorimeter which is composed of 8×8 copper targets and a cooling backplane for beam diagnosis. For this structure, the main error of existing beam power calculation model comes from water-cooling, which is corrected and greatly reduced in this paper. The calorimeter can sustain the high power loads (up to 3 MW/m2) and can generally reflect the distribution of it. According to the thermal analysis and physical requirements, a calorimeter has been designed and manufactured. In addition, the experiment has been carried out. This paper gives an overview of the design and the experiment result.

P1– 20

Experimental investigation of a high power long-pulse neutral beam profile diagnostic based on secondary electron emission

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Diagnostic of neutral beam (NB) profiles in powerful long-pulse injectors intended for plasma heating and current drive in fusion devices is a problem task in consequence of very high NB power density (PD) at a level of tens MW/m2. NB profiles give an information required for determination of such important parameters as the beam divergence angle and accuracy of its axis aiming onto a tokamak entrance window. However, with so high PD use of probes introduced directly in the beam is impossible.
In the case of the ITER heating injector V-shaped calorimeter is designed for the NB commissioning and determination of its parameters. It consists of two panels, each is formed by a set of horizontally oriented cooled tubes arranged in two layers (“front” and “back”). Use of the thermocouples, placed on the tube ends, allows to measure only horizontally averaged NB vertical profile but horizontal profile remains unknown.
This report describes method of measurement of the beam detailed profiles at the calorimeter using matrix of positively biased collectors, each of them is placed between tubes of “back” layer in shadow of “front” layer tube, i.e. does not see the beam. Each collector is to collect secondary emission electrons resulting on surfaces of neighboring tubes under the beam bombardment. Such collector matrix is to provide determination of horizontal and vertical profiles in any section of the beam footprint [1].
Proposed method was tested on the injector test stand IREK with tubular V-shaped calorimeter. Measurements were carried out with use of positive hydrogen ion source with beam energy and current at a level of 40 keV/40 . The calorimeter was equipped with a set of secondary-emission electron (SEE) collectors and of tungsten probes, directly entered into the beam. Initially experiments were carried out with relatively short pulses at a level of 0.4 s for comparison of normalized profiles measured by both methods and results demonstrated quite good coincidence of the profiles.
Further measurements were done with SEE collectors at pulse duration up to 5 s. An influence of secondary plasma electrons was investigated with changing its density by an increase of the gas pressure in the IREK vacuum vessel.

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P1– 21

Initial results of optical emission spectroscopy based on a collisional radiative modeling in the RF hydrogen negative ion source in NFRI

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A prototype radio frequency (RF) negative hydrogen ion source is under developing under the cooperative research project between the National Fusion Research Institute (NFRI)and the Korea Atomic Energy Research Institute (KAERI). An inductively coupled plasma (ICP) of 2 MHz radio frequency is developed so far, and three grids accelerator and Cesium injector will be developed in the near future. For the plasma diagnostics system, optical emission spectroscopy (OES) based on a collisional-radiative (CR) modelling is on preparation with the 3-lens fiber collector and a spectrometer. The advantages of CR-OES are as followings: 1. It is a non-invasive method that is usable even in the high power experimental condition. 2. It provides plasma parameters as well as the densities of ion species. As a first stage of the diagnostics setup, the results from the CR-OES will be compared to the RF compensated Langmuir probe measurement. The application of the method to the neutral beam injector in Korea Superconducting Tokamak Advanced Research (KSTAR), a positive ion source based on arc discharge, and its result will be introduced as well.

P1– 22

Demonstration of 500 keV negative ion beam accelerations for 100s toward JT-60SA N-NBI ion source

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For plasma heating of JT-60 Super Advanced (SA), a negative ion source of 500 keV, 22 A (130 A/m^2) and 100 s is required as beam source of negative ion base neutral beam injector (N-NBI). So far, these goals have been achieved independently, but not simultaneously. One of issues is limitation of applicable arc power by anomalous discharge between plasma chamber wall/plasma and cathodes (filaments), so-called "arcing". In order to prevent arcing occurrence, the arrangement of filaments was improved. The emission electrons from filaments move along the cusp magnetic field for plasma confinement. The electrons produced near by chamber wall where cusp magnetic field is strong easily come into chamber wall and cause arcing between chamber wall and filaments. Moving filaments away from chamber wall to reduce cusp magnet field strength around filaments increase critical arc power, possible arc power without arcing. Another issue is gradual decrease of beam current in long pulse beam. So far, it had been found that the thickness of cesium (Cs) layer on plasma grid (PG) introduced to increase production of negative ions changed by temperature change of PG and the method to maintain PG temperature using hot brine to keep beam current constant was developed. In spite of the maintain PG temperature. The fact that temperature of chamber wall increase up to around 100 ^{o}C and the Cs light in plasma increased as temperature of plasma chamber increased implied that pile up of Cs desorbed from a hot chamber wall on PG caused the beam current decreasing. In previous experiment, it was found that the temperature of chamber wall higher than 60 ^{o}C causes enough desorption of Cs to reduce beam current. In order to reduce Cs desorption from chamber wall, cooling system of plasma chamber was improved to keep temperature of chamber wall under 60 ^{o}C in long pulse operation. The other issue is heat load on acceleration grids. For 100 s stable operation of JT-60SA N-NBI, heat load on each acceleration grids is required to be less than 0.6 MW. However, heat load on grounded grid was around 10 % of beam power, that is 1.1 MW for 500 kV and 22 A, at first. So far, using Field Shaping Plate had it to be possible to reduce heat load on grids from 10 % to 7 % of beam power, 0.8 MW for 500 kV and 22A. This time, the new acceleration grids having thinner thickness of 15 mm instead of 20 mm were employed to reduce heat load further 40 % (7 % to 5 % of beam power) about grounded grid. The simultaneous operation applying these improvements has been performed using a small KAMABOKO ion source, JT-60SA original accelerator and power sources of MeV accelerator. Up to now, acceleration voltage of 500 kV and pulse width of 100 s had been achieved simultaneously, and beam current density has been increased aiming 130 A/m^2. The applied improvements and result of this operation will be presented.

P1– 23

High Voltage Negative Ion Beam Injector for Tandem Accelerator

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An electrostatic vacuum-insulation tandem accelerator is under operation at Budker Institute of Nuclear Physics since 2006. The 2 - 2.5 MeV protons with continuous accelerated current more than 5 mA are produced [1]. To increase the injected current, the new injector with pre-acceleration of negative ions was developed. The injector consists of the high current negative ion source version [2], of bending magnet, and of pre-accelerator. The bending magnet made of permanent magnet segments with correction coils provides the negative ion beam focusing and separation from the concomitant fluxes of electrons, heavy ions and neutrals. The pre-accelerating tube is designed to accelerate the beam up to energy of 150 keV. The source and its subsystems are installed at the high-voltage platform. The description of new injector and first results on 15 mA negative ion beam production, transport and acceleration will be discussed.

[1] A. A. Ivanov, D. Kasatov, A. Koshkarev et al. “Obtaining a Proton Beam with 5-mA Current in a Tandem Accelerator with Vacuum Insulation”, Technical Physics Letters, 42, p. 607 (2016).

[2] Yu. Belchenko, A. Sanin, and A. Ivanov, “15 mA CW H- Source for Accelerators”. AIP Conference Proceedings 1097, 214 (2009).

P1– 24

Development of power supplies systems for CW negative ion sources at BINP

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A series of Surface-Plasma negative ion Sources (SPSs) were developed and produced at BINP in the last 30 years. The energy of H- beams, delivered by SPS is varied in the region 10 - 120keV, the beam current – in the range from several mA CW up to several Amps in the long-pulsed operation [1]. A typical Power Supply system (PS) of the ion source provides the powering and controlling of SPS circuits voltage, current and timing. The high-current SPS uses a cesium deposition for H- yield enhancing and for the co-extracted electrons flux decrease. As a result of cesium deposition, the specific of SPS is the occasional HV breakdowns in ion optical system and an increased level of electric noise in the discharge and ion optical system circuits. This noise is inherent for the discharges in magnetic field. An adequate PS and control systems were designed and manufactured in BINP workshop for the SPS reliable operation under these conditions [2]. The report describes the principles, schematic and design solutions of PS, produced at BINP for SPSs.

[1]. Yu.I. Belchenko, V.I. Davydenko,P.P. Deichuli et al. Studies of ion and neutral beam physics and technology at the Budker Institute of Nuclear Physics SB RAS. Physics - Uspekhi, **61**, #6, (2018); doi: 10.3367/UFNe.2018.02.038305

[2]. P. V. Zubarev, A. D. Khilchenko, A. N. Kvashnin, D. V. Moiseev, E. A. Puriga, A.L. Sanin and V.Ya. Savkin. Computer System for Unattended Control of Negative Ion Source. AIP Conf. Proc. **1390**, 634 (2011); doi: 10.1063/1.3637435

P1– 25

Improvements in D^- ion extraction in a multicusp ion source

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D-Pace's multi-cusp ion source achieves high DC beam currents for negative hydrogen ions in both the TRIUMF licensed filament-powered ion source (˜18mA) and the University of Jyväskylä licensed RF ion source (˜8mA). However, the DC beam currents achieved from this source for negative deuterium ions is only 1/3 that of negative hydrogen ions. An earlier study [1] revealed, that it is possible to extract more negative deuterium ions from the source by increasing the intensity of the magnetic dipole filter field in the plasma chamber, which enables the reduction of plasma electron density and electron temperature. In this paper, we investigate the effect of this increased field on the negative deuterium beam current achieved from the source and also the effect of adding an einzel lens for focusing of the beam.

[1] A. George, S. Melanson, D. Potkins, M. Dehnel, N. Broderick, H. McDonald and C. Philpott, "Optimization of D^- ion production in a multicusp ion source," in Proc. 9th Int. Particle Accelerator Conf. (IPAC'18) [To be published]

P1– 26

RF system test for CSNS external antenna negative hydrogen ion source

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An RF H-minus source with external antenna is under development for the upgrade of China Spallation Neutron Source (CSNS), which requires a H^- beam of 40 mA peak current at 25 Hz repetition rate and 1 ms pulse length. The 2 MHz RF power is generated by a solid-state amplifier. Then a 50 kV insulation transformer is used to protect the amplifier from electric flash. The matching circuit consists of a 13:2 impedance transformer, a tunable capacitor, and a water-cooled dummy load. In the off-line test, the amplifier produces a maximum peak power of 80 kW at a duty factor of 2.75%. And the total transmission efficiency from the amplifier to the load is higher than 90%. The on-line plasma coupling test is in preparation and expected to start in June. Since the impedance of the RF plasma changes with RF power, RF frequency, and gas flow, an RF network without impedance transformer is under development to match the impedance of plasma within a wider range.

P1— 27

Influence of 30 MHz and 2 MHz RF plasma upon plasma electrode potential in the J-PARC RF-driven H⁻ ion source

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In 2017, a Radio Frequency (RF) negative hydrogen ion (H^-) source has been applied for J-PARC user operation and accelerator study by producing the peak beam current of H^- up to 45 mA and 68 mA at low energy beam transport (LEBT) line, respectively. For further increase in the beam current, bias voltage application on a plasma electrode (PE) is one of the possible candidates. In the previous arc-discharge-type H^- ion source, ±10 V bias voltage applied to the PE has led to increase of approximately 10 mA H^- current and to suppression of electron current [1]. However, in the present J-PARC RF source, producing a high-density RF plasma near PE, strong oscillation of PE potential (to source chamber) takes place due to incoming positive and negative charged particles from the RF plasma. In the present study, the PE potential is measured by a voltmeter with several resistances in parallel under 30 MHz, 10 –100 W DC plasma and 2 MHz, 5 – 20 kW pulsed plasma operations. Dependence of the potential waveform upon the different conditions as mentioned above are explained in the presentation.

[1] H. Oguri, *et al.*, Rev. Sci. Instrum. **73**, 1021 (2002).

P1— 28

Influence of 2 MHz RF source for a high-intensity RF-driven H⁻ ion source upon a hydrogen plasma produced in and an H⁻ beam extracted from the source

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We showed a result that an H^- beam extracted from the J-PARC (Japan Proton Accelerator Research Complex) H^- ion source plasma fluctuates at the rf-induction frequency [1]. In order to investigate the influence of the rf power induction at the frequency of 2 MHz upon the produced plasma in the source and the beam extracted from the source, we construct test benches that enable measurements of the plasma parameters in the ion source and the beam emittance at the exit of the low energy beam transport line with the configuration similar to the J-PARC linac. We present the details of the test bench results.

[1] K. Shinto et al., "Observation of beam current fluctuation extracted from an rf-driven H^- ion source" presented on ICIS2017, 15th – 20th Oct 2017, Geneva, Switzerland, AIP Conference Proceedings (in press).

P1– 29

Caesium capture by POCO CZR-2 Graphite on the penning-type H^- VESPA source at ISIS

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The standard ISIS Penning-type H– ion source operates with plasma and beam duty cycles of 4% and 1.25%, respectively, at 50 Hz repetition rate. It uses pulsed hydrogen injection, whereas cesium (Cs) is injected continually from an external oven. The oven is usually operated at around 160 °C, which is a compromise between high H– output, long-term plasma stability and low spark rate. Neutral Cs escapes the ion source between plasma pulses and must be trapped. On the ISIS operational source, a refrigerated 'cold box' is used to trap Cs vapor, however up to 40% beam-loss occurs on this bulky assembly. A vessel for extraction and source plasma analyses (VESPA) has demonstrated improved beam transport with the cold box removed, albeit at a higher un-trapped Cs flux. Therefore a new system is being trialed on the VESPA involving POCO CZR-4 graphite used as a Cs getter. Four blocks with a mass totalling 200 g are positioned downstream of the ion source on a mounting frame, such that they face the source directly with a large combined surface area. The blocks were designed in ANSYS for sufficient thermal isolation to permit in-vacuum bake-out at up to 800 °C. A suite of three quartz crystal microbalances (QCMs) detect Cs flux at various positions in the vacuum vessel. The flux is measured at a range of graphite heating powers to ascertain the gettering efficiency vs. temperature. In general, they work best around room temperature so are a true passive Cs trap, effective for any ion source facility which uses Cs.
Initial results are presented comparing the Cs flux measured using QCMs to the Cs0 and Cs+ optical emission intensities as a function of Cs oven temperature. This allows a comparison between the amount of Cs present inside the pulsed plasma and the time-integrated Cs flux escaping between plasma pulses, which is subsequently captured. These quantitative Cs measurements and trapping schemes are important for long-term operation of a Penning source with twice the linear dimensions (the '2X source'), which has been demonstrated to emit a substantially higher Cs flux through its larger beam emission aperture.

P1– 30

Research and development of power feed-in system for RF negative ion source on ASIPP

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A negative ion source test facility was developed for the ion source performance tests. In order to support the experimental research, a power feed-in system was designed, which contains a solid state radio frequency (RF) generator and a matching network of L type with high voltage transformer. The design of RF generator was presented in this paper according to the requirements and characteristics of plasma discharge of RF ion source. Combine with the impedance characteristics of plasma discharge of RF ion source, the matching network was designed with high voltage transformer, including the calculation and simulation of main parameters of each parts of matching network. The characteristic of RF power matching was studied to gets high efficiency power transferred into the RF ion source. It can generate stable plasma with high power and long pulse duration.

P1– 31

Electromagnetic and thermal analyses of Faraday shield of various materials and structures for a ICP source

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Faraday shield (FS), a thin-wall metal structure with slits, is used in inductive coupled plasma (ICP) sources to protect the ceramic tube from the plasma erosion and to eliminate capacitive coupling. Through the slit, electromagnetic energy is coupled into the driver to excite and sustain plasma, hence FS is an important component of ICP source. Material and structure, which has significant effect on the distribution of electromagnetic field inside the driver and temperature distribution on FS, is a critical issue for FS. In this contribution, influence of Faraday shield of various materials and structures on electromagnetic and thermal performance is discussed. FS made of copper, aluminum, molybdenum and stainless steel, as well as FS of different geometry, different size and different number of silts, are investigated. Electromagnetic field, RF power loss and temperature distribution of different FS is compared according to numerical simulations of a 3D actual source. This work can be used as a reference for the design of Faraday shield.

POSTER SESSION #2

P2– 32

Design of the RF Negative Hydrogen Ion Source at HUST

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The radio frequency driven source for negative hydrogen ions, to investigate the physics of production and extraction of the H^- ions, is under construction at Huazhong University of Science and Technology. Plasma generated from RF driver expands to the surface of plasma grid. Extraction system with three grids is designed to extract and accelerate the H^- beams. The design parameters of the ion source are: beam current 0.35 A; extraction voltage: 10 kV; accelerator voltage: 20 kV; pulse length<10 s; H^- current density: 0.25 mA/mm^2.

P2– 33

Towards efficient integration of cusp and dipole filter magnets in a compact H^- source

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The RF compact negative ion source NIO1 installed at Consorzio RFX, in collaboration with INFN-LNL, allows to test several magnetic filter configuration inside the ion source and their relation with the fringe field of the electrons suppression magnets embedded into the extraction grid (by convention z is the extraction axis, while extraction grid magnets deflects electrons along y direction). NIO1 has been designed to produce 9 H^- beamlets (in a 3x3 pattern), each with current below 2 mA and 20 kV acceleration voltage in this first phase without source cesiation and up to 15 mA and 60 kV after careful cesiation. Since no cesium has been used yet in NIO1, the negative ion production relies on the volume process only. The most important role in order to improve the efficiency of this process is played by the magnetic filter field inside the source (of course, when NIO1 cesium operation will begin, filter effect will be mixed with cesium effect and acceleration voltage holding). The original source filter had an intensity up to B_x= 3 mT and it was provided by current, circulating in the plasma electrode, with source performance improving with B_x. To increase filter strength, further current increase is impractical. Therefore, we need to develop hybrid systems, where part of the filter is provided by permanent magnets (PMF) and another part may be tuned by current (CDF).
The several possible configurations are here fully described and simulated with Opera3D. In particular, the cusp field, which confines NIO1 plasma can be partly altered, to provided also a dipole field. A simple PMF concept, giving B_y = 15 mT was designed and tested with no particular success, which can be explained by excessive value or by field orientation: simulations proving detrimental effect of filter and deflection interference are shown. More elaborate concepts, providing B_x > 4 mT up to 12 mT (depending on PMF sizes) are here described.
The aim of this contribution is to show the studies of an innovative configuration for cusp magnets, together with an innovative technique to shape permanent magnets, in order to produce a filter field parallel (PMF) to the one generated by mean of electric current (CDF), retrieving also the possibility of field tuning by changing the current in the circuit. The finite element code OPERA 3D is used for this investigation and to study the effect of different solutions on beamlet optics.

This work was set up with partial financial support of F4E/EUROfusion.

P2– 34

Gasdynamic ECR ion source for negative ion production

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H^- ion sources are needed in various areas of nowadays physics, such as for beam injection into cyclotrons and storage rings and for plasma heating in experimental facilities studying the possibility of thermonuclear fusion. According to the recently proven fact, that gasdynamic ECR ion source based on ECR discharge in a simple mirror trap could be very efficient for proton beam production, we use that gasdynamic plasma source at the first stage of volumetric ion production through dissociative electron attachment. Experiments were performed with 37 GHz, up to 100 kW gyrotron radiation in a dual-trap magnetic system, which consists of two equal simple mirror traps. The first trap was used for plasma production under ECR conditions with parameters listed above. Dense hydrogen plasma flux from the first trap was allowed to flow into the second trap through a perforated plate, which prevented propagation of heating microwaves into the second one. That helps to separate "hot" and "cold" electrons generation areas. In the current work we present the recent experimental results on this topic. The significant difference compared with previous experiments is preliminary cleaning the chambers with a warm-up and a long pumping out. We achieved the negative ion current density on the level of 80 mA/cm^2 with the 1 mm aperture of plasma electrode.

P2– 35

Graphical representations of spectral data of negative ions

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The purpose of the work is to expand the electronic database "Electronic structure of atoms" [1] through the information on the negative ions of various chemical elements. As far as the authors are aware, at present there is no specialized database on negative ions in the scientific literature and Internet. The collection and analysis of information on atomic systems can be documented in a tabular or graphical representation. It is convenient to have accurate and extensive data on the spectra of elements in the form of tables, while the graphical form is good for general orientation in the electronic structure of atomic systems. In atomic spectroscopy, a graphical form of displaying information in the form of Grotrian diagrams is generally used, the main purpose of which is to provide a visual representation of the distribution of excited states of electron configurations and present the most intensive transitions. For neutral atoms and positive ions, the experimentally measured spectral lines lie at the base of plotting the diagrams. According to these data, the spectral terms and configurations are theoretically calculated. In view of the unusual use of quantum laws for negative ions, as well as the scarcity of information about their spectra, the method for constructing of Grotrian diagrams of negative ions is somewhat different. At first, the energies of the spectral terms are found from the published experimental data. After that the wavelength of the spectral line is calculated from the energy difference between the two terms. As a rule, the multiplicities of terms are indistinguishable. Let's take the chlorum (Cl) as an example. Comparing the diagram of positive ion Cl II [1] and constructing the same for negative ion according on the data taken from [2], we can reveal significant differences. First of all, resonance lines of ions belong to different spectral areas and there is no data on the intensity of spectral lines of the negative ion. The tabulated values for the positive ion Cl II are presented much more completely, than that for the negative ion of this element: 274 levels and 691 lines for Cl II, and only single data for the negative ion. The authors expect that the systematization of experimental data on the spectral properties of negative ions and its representation in a graphical form will be useful to physicists working with these atomic systems.

[1] http://www.grotrian.nsu.ru
[2] Massey H. Negative ions. 3rd edition. Cambridge (UK): Cambridge University Press, 741 p.

P2– 36

Carbon Film in Radio Frequency Surface Plasma Source with Cesiation

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It is assumed that persistent cesiation in the SNS RF SPS is related to deposition of carbon film on the collar converter. The work function dependence for graphite with alkali deposition has no minimum typical for metals and semiconductors and the final work function is higher. For this reason, the probability of H^- secondary emission from cesiated metal and semiconductors can be higher than from cesiated carbon films but the carbon film maintains cesiation longer and can operate with low cesium consumption.

P2– 37

Polarized negative ion source with multiply spherically focusing surface plasma ionizer

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It is proposed one universal H-/D- ion source design combining the most advanced developments in the field of polarized ion sources to provide high-current high-brightness ion beams with >90% polarization and improved lifetime, reliability, and power efficiency. The new source utilizes high-intensity resonant charge-exchange ionization of neutral atoms by negative ions generated by cesiated surface-plasma interactions via a multi-spherical negative ion focusing element. Multi- spherical focusing of the negative ions strongly suppresses the parasitic generation of unpolarized H-/D- ions. By incorporating new and novel designs for the dissociator and plasma generator in parallel with the multi-spherical focusing, the design can suppress adsorption and depolarization of particles from the polarized beam greatly improving performance over current concepts.

P2– 38

Ultracold Muonium Negative Ion Production

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A new, efficient method to produce ultracold negative muon ions is proposed. The muonium atom is made up of an anti muon and an electron and is given the chemical symbol Mu. A second electron with binding energy or electron affinity of 0.75 eV makes the Mu- ion, which is in many ways almost identical to the H- ion that is used for charge-exchange injection into most proton particle accelerators. Muonium negative ions were observed in 1987 by interaction of muons with a foil. Using the foil charge-exchange approach, the efficiency of transformation of muons to negative muonium ions has been very low 10^{-4}. However, by using a hot tungsten or palladium single crystal foil treated by cesium deposition, the production efficiency can be improved up to 50%. The process described here has surface muons focused onto a tungsten or palladium single crystal foil (that can be heated up to 2000 Celsius) 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.

P2– 39

H^- ion source emittance measuring device

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The "pepper-pot" emittance measuring device developed earlier for INR RAS 400 keV H^- LEBT channel was applied with minor modification to control the transverse emittances at the exit of H^- ion source for 7 - 15 keV beam energy. It includes the pepper-pot mask, the quartz screen, the CCD camera, PC, the software for camera data processing and beam phase portrait formation. The issues of obtaining sufficient signal level at such low ions energy, methods of subtracting the signal of non-ion-beam illumination of quartz screen from the full amplitude of the signal as well as issues of data processing and presentation of phase portraits are discussed.

P2– 40

Injection of Atomic Hydrogen from a Thermal Cracker Cell to Plasma Grid Surface of H^- Ion Source

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The principle mechanism of the negative hydrogen (H^-) ion current enhancement due to Cs injection can be attributable to the reflection of atomic hydrogen at low work function plasma grid surface. To directly confirm the contribution of atomic hydrogen (H^0) flux in the actual ion source operating condition, H^0 sources of different types are attached to a small multicusp type H^- ion source. Our previous work using a microwave driven atomic source revealed that low energy H^0 injection into a cesiated hydrogen plasma resulted in reduction in H^- ion current despite the original expectation. The possible reason can be the inadequate formation of surface produced H^- by H^0 injection that did not surpass the destruction of H^- due to injected H^0. In this report, high temperature hydrogen atoms formed in a thermal cracking cell strike the plasma grid surface of the H^- ion source. The velocity distribution from this type of atom source can be broader than the microwave atom source, and H^- can be surface produced with higher efficiency due to the high velocity component in the velocity distribution. The H^- current and the co-extracted electron current are compared for the conditions with and without Cs supply. Unlike the hydrogen atoms produced in the microwave discharge, it was observed that thermal hydrogen atoms destroyed the volume produced H^- ions in the certain condition without Cs as shown in Fig. 1. We will report the effect of H^0 injection by thermal cracker cell to compare with the effect due to low energy H^0 injection from a microwave discharge cell. The effects will be investigated under both condition with and without Cs coverage.

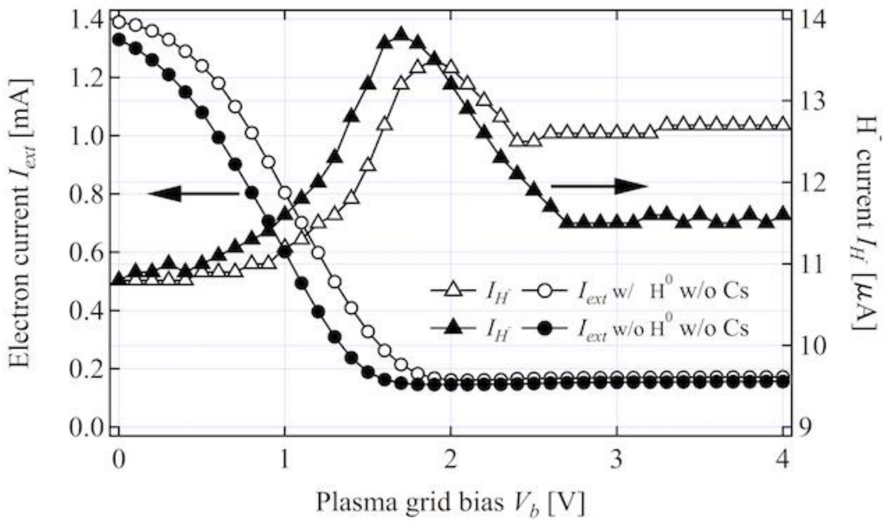

Fig. 1. The influence on extracted H^- ion current for thermal hydrogen atom injection. These characteristics were taken under the 1.5 Pa and 0.5 A discharge current condition with 0.4 mm diameter tungsten filament.

P2– 41

Design of Negative Ion Source Using a Plasma Electrode of C12A7 Electride

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Alkali metal such as cesium covers the plasma electrode to enhance the negative hydrogen ion surface production in a negative ion source. Accumulation of Cs in the source shortens the maintenance cycle of the apparatus. In this research, inorganic material, C12A7 electride, which has low work function and high electric conductance, is studied as a candidate material for a new type of cesium-free plasma electrode. One of the key issues of this type of ion source design is in-situ baking mechanism and the temperature control system of the plasma electrode made of C12A7 electride.
Figure 1 shows the result of the ohmic heating test of electride; i.e., direct electrical current was induced to the sample. The value of conductivity increases with increasing temperature. The sample heating up to 328.5 °C caused non-uniform temperature distribution, and the material became fragile. Another key issue is removal of impurity layer formed on the electride. We design a negative ion source having an ECR plasma source and a three electrode extractor: acceleration and deceleration grids, with the electride plasma grid having an indirectly heating system. The preliminary results on the characteristics measurements of the ion source will be presented.

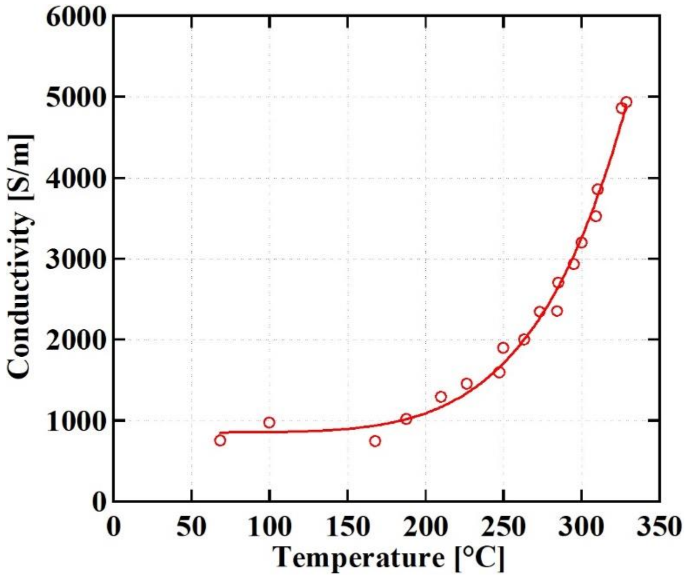

Figure 1.

P2– 42

Measurement of Negative Carbon Ions near a Plasma Deposited Carbon Thin Film by Laser Photodetachment

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Plasmas to prepare functional carbon films contain negative carbon ions which should modify the sheath structure on the formed films. The density distributions of carbon negative ions in the sheath region around the carbon film must critically determine the property of the film. A DC photodetachment method was utilized to measure negative carbon ion density in the plasma formed by discharge between a carbon hollow cathode and a hollow anode.
A DC glow discharge was maintained between carbon electrodes of cylindrical 19 mm inner diameter, 23 mm outer diameter and 45 mm long. These electrodes were placed 14 mm apart facing each other. The chamber was made of electrically insulating borocilicate glass. A Langmuir probe is inserted into the chamber in the direction perpendicular to the carbon electrode tubes. The position of the probe tip can be adjusted in the direction along the probe. A glass substrate for a thin film deposition was set near the carbon cathode. By using a 808 nm (1.53 eV) semiconductor laser exceeding the electron affinity of negative carbon ions (1.27 eV), a signal corresponding to the local negative ions density was measured to construct the spatial distribution of negative ions. The laser passed through the axis of the carbon cylindrical electrodes. The photodetachment signal induced onto the discharge current was detected with a two-phase lock-in amplifier synchronized to the amplitude modulation of the laser power. The effect on the formed film due to the presence of negative ions in the sheath region is investigated through X-ray diffraction and scanning electron microscope.

P2– 43

Beam Current Stability Improvements of Negative Carbon Ions in a Multi-Cusp Ion Source

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Ion implantation requires a high beam current stability to ensure a uniform implantation dose across the wafers. This requires ion sources with a stable extraction system to achieve a high beam current stability. Our goal is to extract 0.5 mA of C_2^- with less than 10 glitches per hour, with a glitch defined as any variation greater than +/- 5% of the nominal beam current. The beam energy should be between 10 keV and 30 keV while the normalized 4 RMS emittance should be less than 1 mm•mrad. We've shown that high negative carbon ion current densities could be obtained with a multi-cusp ion source when acetylene was used as the feed gas (0.25 mA of C_2^-), but there was significant sparking between the electrodes, which led to frequent beam current glitches (~1000 / hour). In this study, we investigate the different factors that contribute to the sparking between the electrodes. We found that the sparking is highly correlated to the dumping of the co-extracted electrons and the beam strike on the electrodes. Extraction simulations were completed to determine how the electron dumping can be improved and how the beam strikes on the electrodes can be reduced. Furthermore, we modified the magnetic configuration in the plasma chamber to decrease the electron density close to the extraction aperture, which reduced the co-extracted electron current by a factor of almost 5 and reduced sparking frequency to about 20 glitches per hour. However, there was a corresponding decrease in the extracted beam current due to the smaller aperture sizes needed to reduce the sparking, with only 0.05 mA of C_2^-.

P2– 44

Sputter negative ion source at BINP Accelerator Mass Spectrometer

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Accelerator mass spectrometry is a powerful analytic method used in archaeology, geology, biology and medicine. Due to its huge resolution, even single atoms are statistically observable for standard 1 or 3 mg target samples. The main problem of the method is to clear the ions beam off the molecular isobars. The use of the negative ions and stripper to change the charge state of ions solves the problem. Thus, one of the important part of the accelerator mass spectrometer is the sputtering negative ion source. Mainly the carbon is of the interest for accelerator mass spectrometry but the mass spectrum is just slightly limited with some elements not producing negative ions. The carbon negative ion sputtering source, developed at Budker Institute of Nuclear Physics, is working successfully at the Accelerator Mass-Spectrometer of the Center of Kaynozoy Geochronology. The source operating characteristics will be presented. The construction, results of operation and status of the source will be discussed.

P2– 45

Improving the transported negative ion beam current in NIO1

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In order to reduce the beam losses of the negative ion beam in the NIO1 experiment, the vacuum system was improved by installing an additional cryogenic pump. In the upgraded configuration, the negative ion beam can be operated in two regimes of high and low background pressures. The gas flow in the improved configuration was simulated, characterizing the existing pumping system and verifying the best configuration for the improved pumping scheme. The charge state of the negative ion beam moving through the background hydrogen gas is calculated, thus providing the stripping losses inside the accelerator and in the transport region. The expected values are compared with the experimental data obtained with a diagnostic beam dump, a one-dimensional carbon fiber calorimeter, and other beam-plasma diagnostics measuring the parameters of the secondary plasma. The collected electric current and the heat flux reconstructed from thermal measurements are compared with the expected beam particle flux. The measurements indicate as expected an increase of negative ion current at full acceleration and a decrease of the plasma electron contribution.

P2– 46

Langmuir probe analysis in negative ion beams

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Negative ion beams are used as precursors of neutral beams for additional heating of fusion plasmas. By ionizing the background gas, positive ions are confined and cumulated in the negative potential well of the ion beam, until the space charge is neutralized and the negative ion beam can propagate in the absence of defocusing electric fields. Experimental measurements of the negative ion beam plasma parameters can provide essential data for the beam neutralization in gas and plasma neutralizers. This paper presents a method to analyze Langmuir probe data obtained in a negative ion beam, in which the beam ion current dominates on the current given by the secondary ion and electron plasma. The sheath model is discussed for different compensation degrees of the beam space charge, also including the secondary electron emission form the surface. The analytical curves are fitted to experimental data by adjusting the plasma parameters. Plasma potentials along a profile transverse to the beam axis are deduced from the probe data.

P2– 47

Beam steering characteristics of ferromagnetic electrode

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In hydrogen negative ion sources, co-extracted electrons are dumped on extraction grid (EG) with electron deflection magnets (EDMs). The negative ion beam trajectory is slightly perturbed by the EDM field, and the aperture displacement technique has been applied in negative ion sources for fusion in order to compensate the beam deflection [1]. Recently, it was proposed that the beam deflection can be intrinsically cancelled by the asymmetric EDM field [2]. In this concept, the asymmetric field is formed by the combination of the conventional EDMs and additional set of permanent magnets.
In this study, a ferromagnetic steering grid (SG) was used as an alternative way to realize the asymmetric EDM field. The beam acceleration experiments were carried out in the NIFS R&D negative ion source (NIFS-RNIS), and the beam footprint was measured with a beamlet monitor system consisting of an infrared camera and 1D carbon fiber composite (CFC) tiles at various operational conditions. Analysis of the beam trajectory is being carried out with OPERA-3d code. In the presentation, we will discuss the beam steering characteristics of the ferromagnetic SG.

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[2] G. Chitarin et al., Rev. Sci. Instrum. **85**, 02B317 (2014).

P2– 48

Measurement of the space charge effect of a negative hydrogen ion beam

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For the development of boron neutron capture therapy at the Budker Institute of Nuclear Physics it was created a source of epithermal neutrons [1], based on a tandem accelerator with vacuum insulation. In the accelerator it was obtained a stationary proton beam with 2 MeV energy and up to 5 mA current [2]. In order to increase the proton current, it has been in depth studied the transport of a negative hydrogen ion beam and its injection into an accelerator in detail. To measure current and profile it was used a wire scanner OWS-30 (D-Pace, Canada), supplemented with rings under negative potential for suppressing secondary electron emission. The current and the transverse profile of the beam were measured as a function of the residual gas pressure regulated by the installed leak. It is found that, while the pressure of the residual gas is increasing, the current and the transverse beam size are decreasing. The current decrease is caused by stripping, the decrease in the transverse dimension is due to the weakening of the space charge effect, due to the increasing amount of positive ions. The density of the negative hydrogen ion current has a maximum value at the intermediate value of the residual gas pressure. Based on the results of measurements of the wire scanner, the radial profile of the beam was obtained, which turned out to be hollow due to the effect of the space charge of the beam and the spherical aberrations of the magnetic lenses. The paper presents and discusses the results of numerical simulations and experiments. Recommendations are given for injection conditions for increasing the proton current.

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2. A. Ivanov et al. *Suppression of an unwanted flow of charged particles in a tandem accelerator with vacuum insulation*. JINST, **11**, P04018 (2016)

P2– 49

Measurement of the negative ion beam with D-Pace OWS-30 wire scanner

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A source of epithermal neutrons based on vacuum-insulated tandem accelerator and a lithium target was proposed and developed for the technique of boron neutron capture therapy. A stationary proton beam of 2 MeV with a current of up to 6 mA was obtained in the accelerator. To optimize the injection of a beam of negative hydrogen ions into the accelerator, a wire scanner OWS-30 (D-Pace, Canada) was installed. The main problem is that using the profilometer in the form in which it is provided does not allow us to determine the main beam parameters such as position and size. Also, the electron emission does not allow to measure the total beam current and may lead to incorrect measurement of the beam profile. We have modernized the scanner by placing the metal rings in front and behind the scanner with a negative potential to suppress the secondary emission of electrons from the scanner wires. We have developed a software in which methods for calculating the position and size of the beam, methods for calculating the total current are implemented. Modernization of the scanner has made it possible to expand its capabilities. The suppression of the secondary electron emission made it possible to reconstruct the current profile of the ion beam and determine the value of the total current. The developed program allowed to display the coordinates of the beam, its dimensions and the total current. We are the first who proposed and implemented a new way of measurement of the beam emittance. A movable diaphragm was inserted in front of the wire scanner. Ion beam passing through the aperture of the diaphragm was measured with high quality detalization when the diaphragm was moved along one radius. The use of a modernized scanner made it possible to detect the effect of space charge and the effect of spherical aberration of focusing magnetic lenses on a beam of negative hydrogen ions. The use of the modernized scanner made it possible to optimize the injection of a beam of negative hydrogen ions into the accelerator, which led to an increasing in the proton current and an improvement of the accelerator stability. The modernized scanner with an additional program for processing the results data and visualization has become a reliable device for beam diagnosing and for controlling its entry into the accelerator.

P2– 50

A plasma target for neutralization of the negative ion beam

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The results of the experimental study of confinement of low-temperature plasma target for neutralization of high-energy negative ion beam are presented in the paper.
The plasma target cylindrical vacuum chamber is 1.2 m long and 0.2 m in diameter. The axisymmetric multicusp magnetic field is formed at the periphery of the target chamber by using an array of the permanent NdFeB magnets, which are placed closely on the thin chamber walls. The target chamber is ended by the two diaphragms with the two 0.1 m diameter apertures for the negative ion beam passing through. For reduction of the plasma losses through the ends, the inverse magnetic field are formed in the apertures [1].
The plasma is produced in the target by ionization of the working gas by electrons, which emitted by six plane LaB_6 cathode, which are placed uniformly over azimuth at the center of the plasma target near the wall. The plasma parameters were defined from Langmuir probes measurements and from recharging of diagnostic atomic beam. In short pulses at 200 kW power, the hydrogen plasma with density $\approx 2 \cdot 10^{13}\ cm^{-3}$ is produced. Degree of plasma ionization reaches 50 %.

1. G.I. Dimov, A.V. Ivanov, Fusion Science and Technology, 2013, **63**, issue 1T, p.111-114.

P2– 51

Damage simulations for large laser mirrors of laser neutralizer under proton and deuteron bombarding.

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In non-resonant photon trap concept for neutralization of powerful negative ion beams one of problems is bombarding mirrors by high energy particles. They are occurred due to scattering ions or atoms on residual gas in transport channel. The simple estimation shows that it may be main cause of mirror damage. The simulation o f particles scattering by background gas and interaction with mirror materials is presented in this report.

P2– 52

Secondary Electrons Problem Study for Beam Energy Recovery for Fusion: Experimental apparatus

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In the ITER fusion project two deuterium Neutral Beam (NB) injectors of 40 MW will be used to further heating the TOKAMAK plasma up to the ignition temperature. The neutralization method of the two D-beams, the gas cells, has an efficiency of about 60%, then residual charged beams of about 40% have to be deflected and dumped before the injection in the plasma. In order to improve the electrical efficiency of the NB production, a beam recovery system of the residual charged particles can be studied. Since a scaled ITER type negative ion source, NIO1 (Negative Ion Optimization 1), has been developed at RFX (Padua) in collaboration with INFN-LNL for studying and improving the ion extraction efficiency of the future NB an experimental test on beam energy recovery of the NIO1 beam has been recently proposed. One important issue related to the beam energy recovery and mostly to the beam dumping are the secondary electrons generated by the interaction of the ions with the collector walls. They may escape from the collector electrodes causing damages and, at least, reduce energy recovery efficiency. A Proposal of an experimental test on the secondary electrons production in the beam energy recovery has been done to study that problem. In this contribution, the experimental apparatus set up for the test along with the simulations of the measurements are presented and discussed.

P2– 53

MITICA Intermediate Electrostatic Shield: concept design, development and first experimental tests identification

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The high-Q operation of the ITER tokamak will require two Neutral Beam Injectors (NBIs) for plasma heating and current drive. Each beam will be generated by a 40A current of Deuterium negative ions, accelerated up to the specific energy of 1MeV and then neutralized. The power delivered to the plasma by each NBI shall reach 16 MW with a duration up to 1h. The beam source will be constituted by an RF-driven negative ion source at –1 MV potential, by a Multi-Aperture, Multi-Grid (MAMuG) electrostatic accelerator (consisting of 5 stages at intermediate potentials), and a gas-box neutralizer at ground potential. All components will be installed in a vacuum vessel (also at ground potential), together with a high-capacity cryo-pumping system which controls of the background gas pressure.

In order to validate the ITER NBI design and address all the outstanding issues related to these demanding requirements, a full scale prototype called MITICA (Megavolt ITER Injector & Concept Advancement), is under construction in Padova at Consorzio RFX. Voltage insulation in vacuum and/or very low-pressure gas on a single gap is indeed one of the expected issues, which MITICA will have to deal with. In this paper, a numerical tool, called Voltage Holding Prediction Model (VHPM) and based on the clumps theory in vacuum, is applied to the MITICA beam source for evaluating and optimizing the high voltage insulation of the experiment. The tool parameters have been recently "calibrated" based on the (few) experimental results presently available in the case of large gaps. Since the initial results suggest that the breakdown probability will be rather high when the beam source will operate at nominal voltage (-1MV), preemptive solutions for increasing the voltage holding capability in the gaps between the beam source, the accelerator grids and the vacuum vessel have been considered ad compared. A very effective solution for increasing the voltage holding capability of the system consists in the use of an intermediate electrostatic shield between the source and the vessel.

Using the above-mentioned numerical tool, a conceptual design of such intermediate electrostatic shield has been developed and optimized, taking into account also mechanical constraints, and the effects of the presence of the shield on the background gas pressure distribution.

Finally also an experimental program for anticipating the full-scale voltage holding tests is studied and proposed, using the real MITICA vacuum vessel (on-site) together with a beam source mock-up (with a simple geometry) without and with an intermediate electrostatic shield, in order to get a first voltage holding characterization of the vacuum vessel, to evaluate the effect of the shield, and to benchmark the VHPM for large gaps.

P2– 54

Development of Radio Frequency based negative ion source test bed

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Neutral beam injector (NBI) is an effective plasma heating and driving method for fusion sciences research. The China Fusion Engineering Test Reactor (CFETR) is under design and will be developed in the near future. In order to support the development of CFETR, a negative ion based neutral beam injector was under design. The ion source is the most precision and important part of NBI. A negative ion source test bed was developed in the Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP).
The negative ion source test bed contains of two 1MHz RF frequency power with 50 kW and 100kW respectively, a dummy load, a bias power supply and an ion extraction power supply (16kV@20A), a matching unit with high voltage transformer, a vacuum chamber, gas inlet system ang gas pumping system, which is shown in Fig.1. Several diagnostic tools was employed for the plasma parameters measurement, such as the Langmuir probe, the microwave interferometer, the optical emission spectrometer (OES), cavity ring-down spectroscopy system (CRDS), the thermocouple system (TC) and water flow calorimeter system (WFC).
The negative ion source was designed and tested on the test bed. It contains the RF based plasma generator and negative ion accelerator. There are several types of RF plasma generator developed: as single driver source, double source and larger area driver source. The negative ion accelerator was design and preliminary tested too. The details of the negative ion source test bed and the experimental results of RF plasma generator and the negative ion beam extraction will be presented in this paper.

P2– 55

Concept of plasma heating and current drive neutral beam system for fusion neutron source "DEMO-FNS"

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Steady-state operation of a fusion neutron source (FNS) requires plasma heating and current drive by means of additional power delivered by neutral beams. Six neutral beam injectors (NBI) will provide DEMO-FNS machine with additional heating power up to 30 MW, with neutral particle energy 500 keV. NBI systems developed for ITER can serve as the prototype for DEMO-FNS, as both systems have similar ion source current, with accelerated beam power in ITER NBI (1MeV) being twice as large as in DEMO-FNS. The paper describes the NBI system with account of its integration to DEMO-FNS tokamak complex. Significant differences in the design elements of injectors for DEMO-FNS are associated with smaller values of critical parameters such as injected power, the values of peak power densities on the walls along the beam path, smaller gas flows in the injector compared to the injectors being developed for ITER. At this stage, we deliberately do not consider systems that are auxiliary to the injection complex of fast atoms, but we emphasize the complexity of their design and integration into tokamak systems. We proposed the ITER NBI parameters revision to optimize the design of the injector and its components for the DEMO-FNS facility. Optimal configuration of the beam transmission line has been chosen and the loads on its elements have been calculated.

P2– 56

40 years of negative ions at Fermilab

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This paper will be an overview of the history of negative ion source used at Fermi National Accelerator Laboratory (FNAL). It will cover the original design of the magnetron ion source, still used today, to present operations. Initially FNAL accelerated protons in the linear accelerator (LINAC) for the physics program. As the need for proton flux increased, it became clear that the LINAC was limited to less than 100mA due to beam loading of the RF. As a result, negative ions along with charge exchange injection into the Booster was the path forward. The first negative ions were accelerated in the LINAC in 1977. Since then, there have been many improvements in beam intensity, quality and most importantly lifetime of the ion sources.