4th International Symposium on

Negative Ions, Beams and Sources

NIBS 2014

Programme and Book of Abstracts

Garching, Germany

6-10 October 2014

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General Information

Introduction

The 4th International Symposium on Negative Ions, Beams and Sources – NIBS2014 – is held in the town of Garching, which is near Munich, Germany, on October 6th – 10th, 2014. The symposium is organized by the Max-Planck-Institut für Plasmaphysik (IPP).

The original focus of the symposium, when it began in 1977, as The Symposium on Production and Neutralization of Negative Ions and Beams was on accelerator and fusion applications. The current form of the symposium welcomes contributions on any aspect of the use of negative ions in basic or applied research. NIBS2014 will cover all areas of science and technology related to negative ion production and use. The symposium presents results obtained from experimental investigations as well as theoretical modeling. The symposium is also an ideal setting for new researchers to establish contacts and see firsthand the latest developments in the field of negative ion research.

Scope and Topics

The aim of the symposium is to exchange information on science, technology, engineering, and operational experiences in all areas relevant to negative ions by providing a forum for discussion. Contributions from a wide variety of fields, such as: fusion, accelerators, material science or industrial applications are expected. The main topics of the symposium are:

1. Fundamental processes and modeling
2. H^- and D^- sources for fusion, accelerators and other applications
3. Other negative ion sources
4. Beam formation and low energy transport
5. Beam acceleration and neutralization
6. Beam lines and facilities
7. Applications

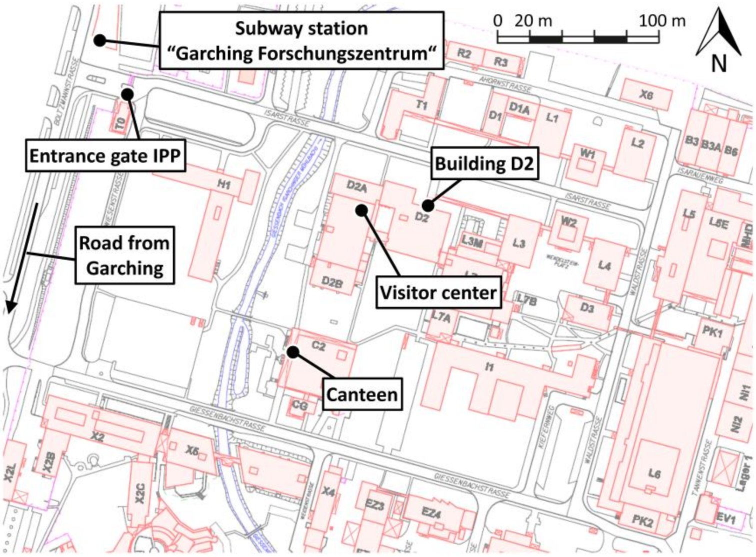
Symposium Venue

The NIBS 2014 symposium is organized by the Max-Planck-Institut für Plasmaphysik and is held in the the building D2. The lecture hall is located on the ground floor of the building and the poster sessions will take place on the second floor.

Garching is located 15 km northeast from the beautiful historic city of Munich. Munich itself is located in the state of Bavaria in southern Germany. It is a world renowned tourist destination and is easily reached by train or plane.

Travel from either Garching or the city centre of Munich to the Max-Planck-Institut can be done using the subway ("U-bahn") U6 (direction: "Garching Forschungszentrum") and getting off at the last stop.

Information on and time schedules of the public transport in and around Munich can be found on the web page of MVV München: http://www.mvv-muenchen.de/en/



Presentation Information

Oral

All papers are allocated a time of 20 minutes for the presentation and 5 minutes for questions and discussion. The lecture hall is equipped with a Windows PC. Supported presentation formats are Microsoft PowerPoint and PDF. Although a variety of standard video codecs are supported, speakers are strongly advised to provide video files separately and not only embedded in the presentation. Please be prepared to have your presentation on a portable USB flash drive and hand it out to the organisers at the technical room in the lecture hall at least by the start of the break before your session. The organizing committee asks, to speed up the process, that the file should be named:

`NIBS2014_<dayofweek>_<lastname>`

Where `<dayofweek>` is to be replaced with the weekday of the presentation and `<lastname>` with the last name of the presenter.

Poster

There are two poster sessions for the symposium. The first session is on Tuesday, October 7th and the second session on Thursday, October 9th. Both begin at 15:40 and are located on the second floor of building D2 (just up the stairs from the lecture hall where the oral presentations take place). Each presenter will be allocated 90 cm by 120 cm (approximately portrait A0). The posters should be mounted in the morning of the session and removed at the end of the session or at latest the next morning.

Social programme and Lab Tour

A welcome reception, hosted by IPP, will take place in the IPP visitor center (close to the lecture hall used for the oral presentations) on Monday, October 6th.

A half-day excursion to Andechs Monastery is planned for the afternoon of Wednesday, October 8th. Andechs Monastery sits atop Holy Mountain above the eastern bank of Ammer Lake. The monastery can be seen from miles around and is both the oldest pilgrimage church in Bavaria and is famous for its brewery.

The tour includes: a short boat trip on the Ammer lake, a guided tour of the Monastery and a dinner. More information can be found in http://www.andechs.de/nc/en.

A conference banquet will be held in the "Ratskeller" of the Rondell Restaurant in Garching beginning at 19:00 on Thursday, October 9th. The participants can take the subway U6 to reach Garching (station "Garching") and the restaurant is located at Bürgerplatz 9; a short walk from the subway station and most conference hotels. Please note: no transportation will be arranged by the local organizing committee for this event.

The conference participants are invited for a tour of both the IPP negative ion source test facilities and – if possible – of the ASDEX Upgrade tokamak on Friday October 10th, starting at 10:40. IPP is currently operating the half size ITER source on the ELISE test facility. The BATMAN test facility, where the work on RF driven negative ion sources for fusion began, focuses now mainly on R&D in physics and technology for ITER and towards DEMO. ASDEX Upgrade, the "Axially Symmetric Divertor Experiment", is Germany's largest fusion device. The aim of ASDEX Upgrade is to prepare the physics base for ITER and DEMO.

NIBS Award

The NIBS Award will be presented for innovative and significant recent achievements in the fields of the physics, theory, technology and/or applications of sources, low energy beam transport, and/or diagnostics of negative ions. The first "**NIBS Award**", donated by D-PACE Inc., Nelson, BC, Canada, will be presented at the banquet of the NIBS 2014 Symposium. It consists of a certificate and US $5,000.

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Scientific Programme

Oral Presentations

Monday, October 6th

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Poster Presentations

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Abstracts

O1-01

The development of the Neutral Beam Injector for DEMO within the EUROFUSION Activities

P.Sonato[1], M. Q. Tran[2], T. Franke[3], A. Simonin[4], A. Shivarova[5], R. Verhoeven[6], P. Franzen[7], I. Cernusak[8] and I. Furno[2]

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Within the EUROFUSION activities of Horizon 2020 towards the realisation of fusion energy one of the main objectives is the development of the DEMO design.
One of the Work Packages (WPs), in which the design activities have been subdivided, is devoted to the development of alternative and innovative concepts of the different heating systems and the consequent development of the heating and current drive system design.
The actual activities within this WP support the development of three heating systems: Electron Cyclotron, Ion Cyclotron and Neutral Beam Injectors (NBI).
The development of the Neutral Beam Heating and Current Drive system, as for all the design development activities of all the other DEMO subsystem, will benefit from the experience of the ITER construction.
The main scope of the NBI developments is improving the efficiency of the overall system, is increasing the availability and reliability and, at the end, is simplifying as much as possible the remote handling requirements in radiation-activated areas.
The Programme Management Plan includes the following main research lines:

- The development of the injector design including all the injector components, the power supplies and auxiliary plant systems.
- The development of plasma sources optimizing/minimising the use of Cs and/or producing Cs at the source surface without involving an on-site physical vapour deposition or, last but not least, to develop a plasma source in which a dominant volume negative ion production will allow to avoid the use of Cs. A number of activities are also dedicated to develop alternative RF sources.
- The development of energy recovery system to increase the overall efficiency of the system.
- The development of an alternative neutralisation system to increase significantly the neutralisation efficiency. The photo-neutralisation is the first concept to be tested.

The activities will include modelling development, engineering design work and exploitation of existing European facilities to assess the performance of all the research lines.

O1-02

Negative Ion Production in the RF Surface-Plasma Source

G. F. Abdrashitov[1], Yu. I. Belchenko[1], A. A. Ivanov[1], A. N. Dranichnikov[1], A. I. Gorbovsky[1], V. A. Kapitonov[1], V. V. Kolmogorov[1], A. A. Kondakov[1], S. G. Konstantinov[1], A. L. Sanin[1], A. N. Selivanov[1], I. V. Shikhovtsev[1], N. V. Stupishin[1], M. A. Tiunov[1], V. D. Yudin[1], M. Binderbauer[2], S. Putvinski[2], A. Smirnov[2] and L. Sevier[2]

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The first series of experiments on the multi-aperture long-pulse surface-plasma negative hydrogen ion source, constructed at Budker Institute were carried out. The source follows a traditional scheme of large-area RF negative ion sources[1]. It uses an RF driver, an expansion chamber with a multicusp confinement, magnet filter of electrons in plasma chamber, positive bias of plasma grid, and cesium deposition.

Several new concepts of the source design[2] were successfully tested:

1) keeping the extraction and plasma grids hot during the cesium operation;
2) directed cesium deposition via the long distribution tubes, attached to the plasma grid;
3) an additional magnet system to concave the field in the extraction gap.

Grids preliminary heating and their temperature control during the long pulses is ensured by circulation of hot fluid through the channels, drilled in the grids body. Cesium release from the safe pellets made of cesium chromate + titanium mixture is exploited. The procedure of directed cesium deposition was studied and standardized.

The effect of cesium on the source performance was studied. H^- beam extraction through the single and 21 apertures with diameter 1.6 cm each was explored. Beam current density and profile were measured by movable water-cooled Faraday cup, situated at 1.6 m distance from the source. H^- beam with current ˜0.5 A, energy up to 60 kV, pulse duration 3.5 s was regularly obtained accelerated and transported (status to the June 2014).

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Roles of a Plasma Grid in a Negative Hydrogen Ion Source

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The effect due to electrical bias applied to the plasma grid of a negative hydrogen (H^-) ion source has been discussed from the early work by Leung, Ehlers and Bacal [1]. Not only the H^- ion current, but also the electron current extracted from the plasma volume change as the bias voltage to the grid is changed. The dependence upon the bias voltage for H^- ion current, and that for the electron current exhibit different characteristics when the size of the grid and intensity of the magnetic filter field are different. Seeding Cs into the ion source makes the grid bias characteristics for H^- ion current and electron current extraction different, probably because of the contribution from direct H^- production at the plasma grid surface [2].

Similar characteristics of negative ion current extraction against plasma grid bias have been observed for volume production type lithium [3], sodium [4] oxygen and chlorine negative ion sources [5]. Experimental and theoretical studies on the H^- ion transport near the extraction region of the H^- sources [6-9], have revealed the existence of enhanced transport of H^- ions toward the extraction apertures correlated to the plasma grid bias. A collar structure assembled near the extraction hole [10] modifies the electrostatic potential geometry of the plasma grid, and should affect the extractable amount of H^- ion current. This paper summerises the physics processes related to optimum plasma grid bias for H^- ion source operation.

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Long-pulse production of high current negative ion beam by using actively temperature controlled plasma grid for JT-60SA negative ion source

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A negative ion source for the JT-60SA tokamak is designed to produce high current and long pulse beams with a negative ion current of 22 A (130 A/m^2) and a pulse length of 100 s. One of the key techniques toward the long pulse production of such high-current beams is the temperature-control of the plasma grid (PG) where a cesium layer is formed to reduce the work function for the surface production of negative ions. In order to maintain the low-work function during long pulse, an active control system for the PG temperature has been developed by utilizing a fluorinated fluid having high boiling point of 270 degree Celsius.
By using a prototype system for 1/10 extraction area, the rated current density of 120-130 A/m^2 has been successfully maintained for 100 s with controlling the PG temperature to 200 degree Celsius [1]. Based on this result, the PG temperature control system has been upgraded to realize the rated current of 22 A. The circulation system of the high-temperature fluid was modified to provide the fluid to the whole extraction area, and the PG was re- designed to be equipped with the same cooling channels between each extraction apertures. In the preliminary result, the rated current of 22 A has been successfully obtained for 10 s with an arc power of 195 kW, an extraction voltage of 7.5 kV, gas pressure of 0.3 Pa and ion/total currents ratio of 0.4. The further increase of the pulse length is expected by optimizing the arc discharge condition.

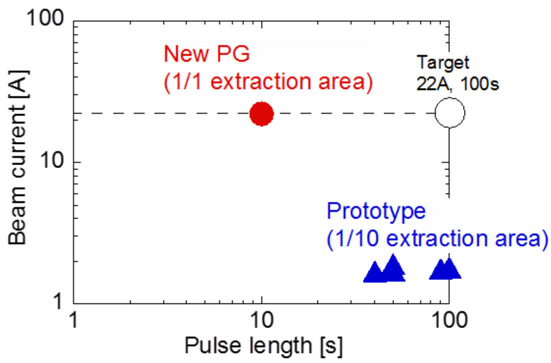

Figure 1. Progress of long pulse production by using temperature-controlled PG.

References

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H^-/D^- negative-ion surface production on diamond materials in low-pressure Cs-free H_2/D_2 plasmas

K. Achkasov[1], C. Pardanaud[1], A. Gicquel[3], A. Simonin[2], J.M. Layet[1] and G. Cartry[1]

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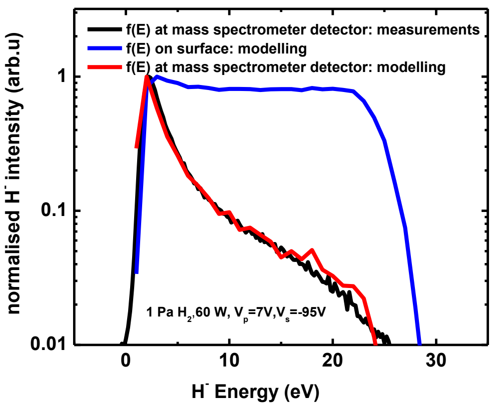
Introduction:

Negative ion surface production in plasmas is of a primary interest for neutral beam injection devices in fusion. D^- current density of 200 A/m^2 is required for ITER. The only up-to-date solution to reach such a high D^- negative-ion current is the use of cesium. Deposition of cesium on the negative-ion source walls lowers the material work function and allows for high electron-capture efficiency by incident particles and thus, high negative ion yields. However, severe drawbacks to the use of cesium have been identified and a strong reduction of cesium consumption or its elimination from the fusion negative-ion sources would be highly valuable. We are working on H^-/D^- negative-ion surface production in Cs-free H_2/D_2 plasmas.

Methodology

A sample is placed in the diffusion chamber of a low-pressure plasma reactor, facing a mass spectrometer (MS). The sample is biased negatively with respect to the plasma potential. Negative ions formed on the sample surface upon positive ion bombardment are accelerated by the sheath toward the plasma, cross the plasma and reach the mass spectrometer where they are detected according to their energy. Under this configuration, negative-ions are self-extracted from the plasma. To get insight into negative-ion surface production mechanisms, it is of primary importance to derive from the measured Negative-Ion energy Distribution Function (NIDF) the characteristics of the negative-ion emission from the surface. We have developed a modelling [1] allowing to compute from the measured NIDFs the energetic and angular characteristics of the negative-ions emitted by the surface. The model has been validated by comparison with the experiment (see figure). Based on this methodology, we are studying negative-ion surface production on diamond materials.



Diamond as negative-ion enhancer material

Diamond is well known for its ability to emit electrons at high temperature (HT) and even at low electric fields. Electron capture by positive ions or atoms impinging on a diamond surface in a plasma is thus expected to be efficient. Also, beam experiments on diamond showed surface production of H^- ions with high yields up to 5.5%. Finally, we have observed in plasma experiment that negative-ion yield on boron-doped-diamond can be increased by a factor 5 when increasing the temperature to 400°C [2]. The yield increase observed, and the exceptional electronic properties of diamond, place this material as a good candidate for the production of high yields of negative-ions in Cs-free plasmas.

In this communication we will present the methodology employed and some results obtained on a large variety of diamond materials.

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Cs doped Molybdenum as surface converter for H^- / D^- generation in NNBI sources: first steps and proof of principle

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NNBI (Negative Neutral Beam Injection) sources are based on the surface conversion of hydrogen atoms and positive ions into negative hydrogen ions. It is long known that a low work function can be obtained by evaporating Cs. However, the NNBI sources for DEMO should operate with a lower amount of Cs than the present prototype NNBI sources.

In order to reduce the Cs consumption of NNBI sources and as a proof of principle, Mo samples were implanted with a very small Cs dose of 10^{16} cm^{-2} Cs atoms leading to a surface Cs proportion of 5% (0.05 monolayers). The implanted depth profiles regularly measured by XPS / sputtering showed no evidence of Cs diffusion 9 months after implantation suggesting a long term stability of the implanted Cs for samples stored in air. The simulation by SDTRIM.SP program [1] of the depth profiles showed a good agreement with the experimental results.

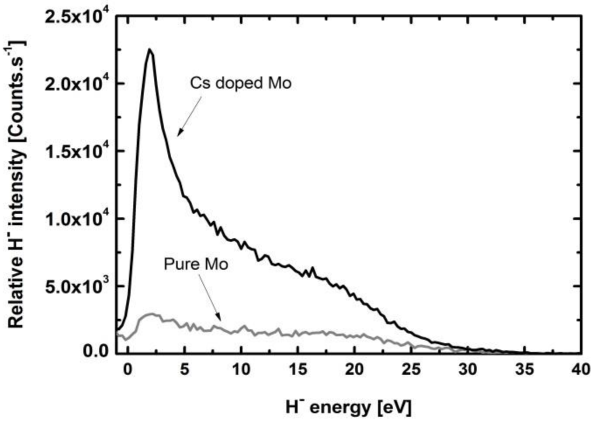

Figure 1. Comparison of the relative H^- intensity of pure Mo (in grey) and Cs doped Mo (in black).

As done in [2, 3], the exposition of the samples to a low density (10^{14} m^{-3}) H_2 plasma led to the determination of the surface H^- generation mechanisms and a comparison between the relative H^- yield of the Cs doped Mo samples and to pure Mo (see Figure 1), HOPG (highly Oriented Pyrolitic Graphite) and BDD (Boron Doped Diamond) [4], as well as the determination of the angular emission of the H^-. It was also possible to show the ease to recover the H^- yield after venting the source and to demonstrate the stability of the H^- yield during four hours of continuous plasma operation.

Future experiments will be performed by increasing the implanted Cs dose to obtain a larger surface Cs proportion. These new samples will also be exposed to higher plasma densities, closer to the one measured in NNBI sources to check their stability and the relative H^- yield.

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O1-07

Investigations on caesium-free alternatives for H^- formation at ion source relevant parameters

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High yields of negative hydrogen ions in current negative ion sources are achieved by the conversion of atomic hydrogen and positive hydrogen ions at cesiated converter surfaces.
However, due to its high chemical reactivity the application of caesium has several drawbacks [1], in particular for stable source operation. Also, for a neutral beam heating system at DEMO, problems concerning the remote maintenance occur when caesium has to be used. Therefore effective H^- formation in a caesium-free negative ion source providing high yields at low pressure is highly desired.
Investigations on materials for negative hydrogen ion formation at ion source relevant parameters are carried out at the flexible small-scale ECR test bed HOMER (HOMogeneous Electron cyclotron Resonance plasma). By using a biased meshed grid [2] HOMER is operated as a tandem-source. At discharge powers up to 1 kW and a pressure range between 0.3 to 3 Pa, the electron temperature in the downstream of the meshed grid, measured by a Langmuir probe and OES, is about 1 eV while the electron density is several times 10^{16} m^{-3} and the density ratio of H to H_2 is about 10%.
Mounted on a height-adjustable sample holder the material samples are placed into this diffusive volume where the negative ion density is measured as a function of the distance to the sample and of pressure by means of laser photodetachment. Influences due to hydrogen coverage and impurities on the sample as well as the energy of impinging ions are studied by controlling sample-temperature and -bias.
Negative ion densities, measured in combination with different material samples like tungsten, tantalum and graphites, doped graphites and diamond, are compared with results of a stainless steel reference sample.

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H^- Formation by Neutral Resonant Ionization of H(*n*=*2*) Atoms

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Lyman-α radiation is intense from hydrogen plasmas, which are optically dense at this wavelength, supporting a large fraction of H(*n*=2) atoms. The excited state is produced not only in energetic electron collisions in a plasma driver, but also by recombination of H_2^+ and H_3^+, proton capture of electrons from Cs^0 vapor, and from particle-wall collisions. The "resonances", or excited states, of H^- that culminate at the H(*n*=2) threshold of H have low (≤0.65 eV) to very low (≈1 meV) energy deficits with that excited atomic state, suggesting a very high probability of excited H^- from neutral collisions between two H(*n*=2) atoms (≥10^5 Å^2). One of these states, $H^-(2p^2\ 3P^e)$, is considered "stable" with a lifetime of many milliseconds in astrophysical and quantum chemical studies. While, to date, unobtainable in the laboratory due to the parity inhibition of photonic production, it is accepted as the source of phenomena in astrophysical plasmas. We assumed that this state was produced in an ionic pair by collisions of H(2p) atoms and sought a path through the potential energy surfaces of H_2 leading to an $H^+H^-(1s^2)$ pair. The ionic crossing with $^1\Sigma^+_u$(1 and 2) doubly excited neutral states of H_2 to the singly excited B"B $^1\Sigma^+_u$(3) and the $^1\Sigma^+_u$(6) outer potential wells at n=3,4 thresholds lead to the unexcited ion pair, yielding an H^- and an H^+, the latter which captures an electron from Cs^0 to become H(2p) in a feedback that increases volume-produced H^- with Cs vapor. The Cs^+ ion neutralizes by absorbing a free electron, decreasing the local electron density by an amount equal to the generated H^- density. We devised a partial collision-radiation model to explore the reaction rates needed in the double to single conversion of excited states and found that high emission currents were supportable under reasonable assumptions. We sought any experimental evidence that would support this view of volume ion production. Komppula, et al (2013), indirectly compares H^- production in a non-cesiated ion source to Lyman-α intensity that implies H^- is proportional to the square of H(2p) density. Figure 4 of Nakano, et al. (2013) shows H^- emission even when the plasma grid is biased -3 V, as expected if the H^- have energies up to 3.25 eV, which we predict from the potential energy surfaces involved. We suggest that neutral resonant ionization of H(n=2) atoms can be a large source of hydrogen anions.

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O1-09

Alternative RF coupling concepts for H^- ion sources

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RF driven negative hydrogen ion sources typically utilize inductive coupling for plasma generation. In order to reach the discharge parameters which give the optimum source performance high RF powers of up to 100 kW are required. As these high RF powers pose very high demands on the generators and the RF circuits, it is highly desirable to improve the efficiency of the RF system.
Besides the application of solid state RF generators (see [1]) more efficient RF coupling concepts are investigated. Promising candidates are Helicon coupling, a wave heating mechanism requiring an external magnetic field, and the improvement of conventional ICP coupling by using ferrites (as already done at some accelerator ion sources, see [2] for example) which concentrate the RF field into the discharge chamber might fulfil the task. The aim is to reduce the required RF power while those plasma parameters which are important for the negative ion production on a cesiated surface have to be retained: the positive ion density and the density of atomic hydrogen. As both concepts require rather complex changes in the design of the ion source their fundamental feasibility and their impact on the plasma parameters is investigated at two small laboratory experiments, CHARLIE (**C**oncept studies for **H**elicon **A**ssisted **R**F **L**ow pressure **I**on sourc**E**s) and PlanICE (**Pla**nar **I**nductively **C**oupled **E**xperiment). Both experiments operate in a range between 0.3 and 10 Pa and are equipped with diagnostics which allow the determination of all relevant plasma parameters such as the electron temperature, density (as measure for the positive ion density) and the ratio of atomic to molecular hydrogen (as measure for the atomic hydrogen density). Recent results of both experiments will be presented.

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O1-10

Ion source development for a Photoneutralization based NBI system of Fusion reactors

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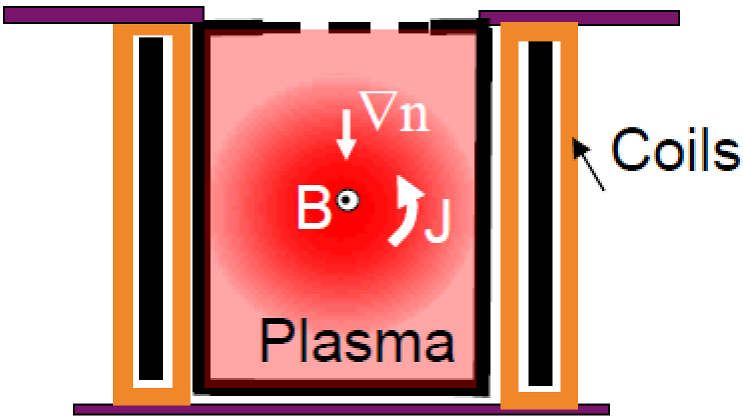
The next step after ITER is to demonstrate the viability and generation of electricity by a future fusion reactor (DEMO). The specifications required to operate an NBI system on DEMO are very demanding. The system has to provide a very high level of power and energy, (~100MW of D^0 beam at 1 MeV), including high wall-plug efficiency (η>65 %). For this purpose, a new injector concept, called Siphore, is under investigation between CEA and French universities. Siphore is based on the stripping of the high energetic negative ions by photo-detachment provided by several Fabry-Perot cavities (1-2 MW of light power per cavity) implemented along the D^- beam. The beamline is designed to be tall and narrow in order that the photon flux overlaps the entire negative ion beam. The paper will describe the present R&D at CEA which addresses the development of an ion source and pre-accelerator prototypes for Siphore, the main goal being to produce an intense negative ion beam sheet. Cybele is based on a magnetized plasma column where hot electrons are emitted in the source center. Parametric studies of the source are performed using Langmuir probes in order to characterize the plasma under different aspects and to compare with numerical models under developments in French universities.



Cybele source principle: Horizontal cross section

O1-11

Design of a Scaled Penning Surface Plasma Source for the Front End Test Stand

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The Front End Test Stand (FETS) at the Rutherford Appleton Laboratory (RAL) requires a 60 mA, 2 ms, 50 Hz Hminus beam. The present source can only deliver the current and pulse length requirements at 25 Hz. At 50 Hz there is too much droop in the beam current.
To rectify this, a scaled source is being developed. This paper details the new source design and the plasma and thermal modelling work that guided the design. An update on the status of the FETS project is also provided.

O1-12

Development of Versatile Multiaperture Negative Ion Sources

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Enhancement of negative ion sources for production of large ion beams is a very active research field nowadays, driven from demand of plasma heating in nuclear fusion devices and beam compression applications. As a versatile test bench, the ion source NIO1 (Negative Ion Optimization 1) is being commissioned by Consorzio RFX and INFN. The nominal beam current of 130 mA at -60 kV is divided into 9 beamlets, with multiaperture extraction electrodes. The plasma is sustained by a 2 MHz radiofrequency power supply, with a standard matching box. A High Voltage Deck (HVD) placed inside the lead shielding surrounding NIO1 contains the radiofrequency generator and the plasma grid and bias plate current power supplies. An autonomous closed circuit water cooling system was installed for the whole system, with a branch towards the HVD, using carefully optimized helical tubing. Insulation transformer is installed in a nearby box. Tests of several magnetic configurations will be performed. Status of experiment and related theoretical issues will be described in the present paper.

O1-13

The progress and future plan of development of high current ion source for neutral beam injector in the ASIPP

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The Experimental Advanced Superconducting Tokamak (EAST) is one of the fully superconducting tokamaks, its aim at the long-pulse operation (1000 s) to study the physics of steady-state operation for nuclear fusion sciences. In order to heat and drive the EAST plasma to support the fusion research, the high power Neutral Beam Injection (NBI) systems should to be developed.

The high current ion source is one of the key components of neutral beam injector, which includes positive ion based source and negative ion based source. A high power hot cathode positive based ion source, which is based on the US common long pulse ion source, is developed in the Institute of plasma physics, Chinese Academy of sciences (ASIPP). The ion source is consists of a bucket plasma generator with multi-pole cusp fields and a set of tetrode accelerator with slit apertures. The plasma chamber has dimension of 26cm * 65cm, and 30cm depth. There have 40 lines Sm-Co permanent magnets on the chamber to form an axial line-cusp configuration. The 32 hair-pin shape filaments are used to emit primary electrons, which is 160mm long with diameter of 1.5mm. The high power of 100kW hydrogen plasma can be generated. The accelerator has four layers of grids and each grid has 64 rails. The extraction area is 12cm * 48 cm, and has the transparence of 60%. There are four ion sources are developed and tested so far. The first grids are circular shape for the first two ion source and the other two have been changed to diamond shape.

For the four ion sources, the 4MW hydrogen ion beam is extracted with beam energy of 80 keV. The arc efficiency is about 0.6 A/kW, and the beam perverance is 2.8 uperv with the beam divergence angle of 1.4 in Y direction and 0.65 in X direction. The proton ratio is 70% with the beam energy of 65 keV, which is measured by DSS.

Long pulse operation is also tested to support long pulse operation of the EAST. The 100 s long pulse neutral beam is extracted with beam energy of 50 keV on the ion source test bed. The beam power is 1.8 MW. Consider the high beam deposition on the calorimeter, the beam is modulated with frequency of 2.5 Hz and duty cycle is 25%, and the modulation frequency and duty cycle also can be changed. Two of the ion sources are installed on the first beam line of the EAST, other two ion source will be installed on the second beam line later.

In order to long pulse operation of ion source, the RF ion source is designed and developed to replace the arc plasma chamber. The driver is designed with diameter of 20cm and depth of 13 cm. The maximum RF power of 80 kW at a fixed frequency of 1MHz is inductively coupled into the plasma via a water-cooled antenna in the shape of a 6 turn induction coil.

In the future, we will develop the negative ion based source based on the arc and RF ion source, to support the fusion research with high parameters.

O2-01

Ignition Tuning and Recent Performance of the pulsed SNS H^- source for 1.4 MW Neutron Production

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After acquiring several reliable spare targets, SNS ramped the beam power from 850 kW to 1.4 MW. This required an increase in H^- beam pulse length from 0.88 to 1.0 ms at 60 Hz, which resulted initially in slow 2 MHz power ramp-ups and in plasma outages after several weeks of uninterrupted operation. Such ignition problems appear after long service cycles, apparently when the breakdown voltage of the high purity hydrogen starts to exceed the induced electric fields. When this effect was first encountered, the RF was reconfigured to start with 10 cycles of 1.96 MHz, which yielded the shortest H^- beam rise times and practically eliminated the plasma outages [1].

However, the outages recurred when increasing the duty factor, and an effort was made to improve the tune of the ignition frequency by carefully measuring the first 10 RF power oscillations. With a 1.96 MHz plasma, the absorbed RF power peaked at 30 kW during the 7th oscillation and then decreased due to an increasing mismatch with the plasma. However, without an initial plasma the absorbed RF power peaked at 71 kW during the 10th oscillation without being able to break down the plasma after the continuous plasma tripped. When the ignition frequency was increased to 1.985 MHz, the pulse length could be increased to 1 ms and no plasma outages have been encountered since. This paper discusses various efforts to tune the ignition frequency more precisely on a working source, where most of the responses are dominated by the plasma.

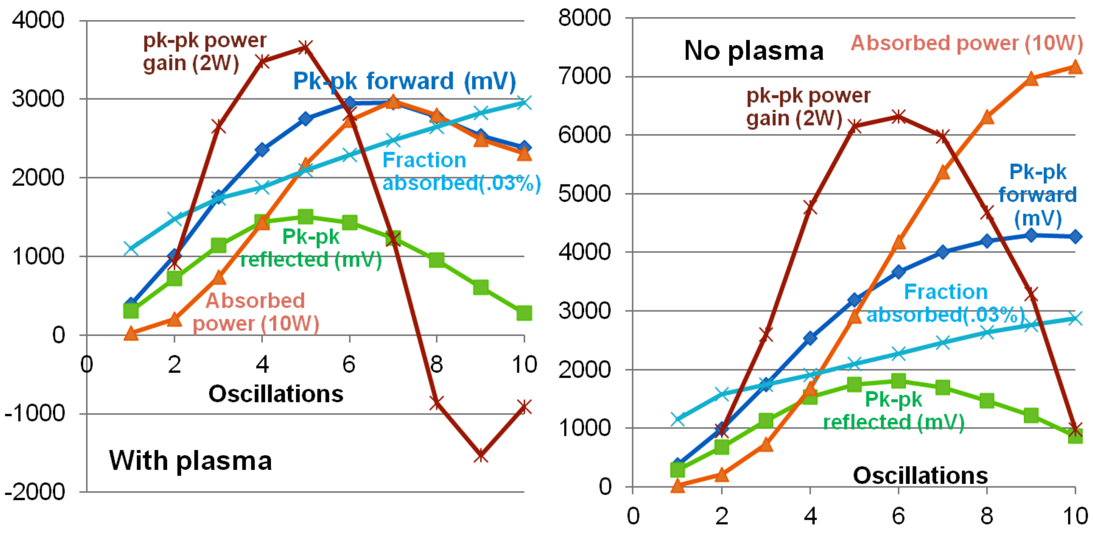

Figure 1. RF parameters of the first ten oscillations of the SNS H^- source with and without plasma.

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O2-02

Meeting the Future Needs of the SNS Facility using the External Antenna Ion Source and the Newly Constructed RFQ Test Stand

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The Spallation Neutron Source (SNS) now routinely operates near 1.2 MW with the near-term goal of delivering 1.4 MW of beam power to target. H^- beam pulses (~1 ms, 60Hz) are produced by an RF-driven, Cs-enhanced, multi-cusp ion source closely coupled to an electrostatic LEBT (Low Energy Beam Transport) which focuses the 65 kV beam into an RFQ (Radio frequency Quadrupole) accelerator which in turn injects the SNS Linac. Currently the source/RFQ system delivers 30-40 mA pulsed current to the linac. Plans are being considered to upgrade the SNS facility to accommodate a 2nd target station which will require ~50 mA of pulsed linac beam current at a similar duty-factor. This paper summarizes ongoing experiments involving the external antenna source and an electron dump power supply RC filter to maintain a constant electrode voltage despite the initial electron current exceeding the supply's rating. In addition, the design, status and schedule of a newly constructed ion source/RFQ test stand at the SNS will also be presented. Finally, how the integration of these systems will meet the long term goals of the SNS facility will be discussed.

O2-03

Applications of Optical Emission Spectroscopy for the SNS H^- Ion Source Plasma Ignition and Parameter Studies

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The SNS H^- ion source is driven by a 2-MHz high-power (~60 kW) pulsed RF with ~1.0 ms pulse length at 60 Hz. A 13.56-MHz continuous low-power (~300 W) RF is used to facilitate the ignition of the high-power pulsed plasma. Sometimes the pulsed plasma experiences delayed ignition or fails to sustain a stable plasma. These issues are believed to be associated with the 13.56-MHz RF system not being able to fully support continuous plasma. Optical emission spectroscopy with a variable timing delay is used to study the plasma status in between the high power pulses and in the initial ignition stage as well as in any given part of the high power pulses. The plasma emission spectroscopy is also used to detect impurities and estimate the plasma parameters such as particles densities and temperatures. This paper discusses the experimental setup and initial results.

O2-04

CERN's Linac4 H^- Sources: Status and Operational Results

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Two volume sources equipped with DESY and CERN plasma generators and a low voltage electron dump were operated at 45 kV in the Linac4 tunnel and on a dedicated test stand. These volume sources delivered approximately 20 mA and ensured the commissioning of the Radio Frequency Quadropole accelerator and of the first Drift Tube Linac section. CERN's prototype of a cesiated surface source equipped with this electron dump was operated continuously from November 2013 to April 2014 on the ion source test stand and is scheduled for installation in the tunnel in during 2014. Before cesiation, the prototype conditioned in volume mode provided up to 30 mA H^- beam. Short cesiations, of the order of 10 mg effectively reduced the intensity of co-extracted electrons down to 2 - 8 times the H^- current; this cesiated surface operation mode delivered up to 60 mA H^- beam. An H^- beam of the order of 40 mA was sustained up to four weeks operation with 500 μs pulses at 1.2 s spacing. A new extraction was designed to match these beam properties. A copy of BNL's magnetron produced at CERN was tested at BNL and delivered at 40 kV an H^- beam exceeding Linac4's nominal intensity of 80 mA.
In this contribution, the performances, dynamic response to cesiation, stability and availability of these prototypes are described. The needed optimization of the emittance of H^- beam above 40 mA is presented, which requires an evolution of the front end that encompasses implementation of a large ceramic insulator.

O2-05

Optimization of the beam extraction systems for the Linac4 H^- ion source

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The development of the Linac4 and its integration into CERN's acceleration complex is part of the foreseen luminosity upgrade of the Large Hadron Collider (LHC). The goal is to inject a 160 MeV H^- beam into the CERN PS Booster (PSB) in order to increase the beam brightness by a factor of 2 compared to the 50 MeV proton linac, Linac2, that is currently in operation.

The requirements for the ion source are a 45 keV H^- beam of 80 mA intensity, 2 Hz repetition rate and 0.5 ms pulse length within a normalized rms emittance of 0.25 mm mrad.

The presently installed beam extraction system has been designed for an H^- ion beam intensity of 20 mA produced by an RF-volume source with an electron to H^- ratio of up to 50.

For the required intensity upgrades of the Linac4 ion source, a new beam extraction system is being produced and tested; it is optimized for a caesiated surface RF-source with a nominal beam current of 40 mA. The simulations based on simulations with IBSIMU code and test results are presented.

At the Brookhaven National Laboratory (BNL), a peak beam current of 140 mA was demonstrated with a magnetron H^- source at an energy of 40 keV and a repetition rate of 2Hz. A new extraction system is required to operate at an energy of 45 keV; simulations of a two stage extraction system dedicated to the magnetron are presented.

Maintenance and Operation Procedure, and Feedback Controls of the J-PARC RF-driven H^- Ion Source

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In order to satisfy the J-PARC (Japan Proton Accelerator Research Complex) second stage requirements of an H^- ion beam of 60mA within normalized emittances of 1.5πmm•mrad both horizontally and vertically, a flat top beam duty factor of 1.25% (500μs×25Hz) and a life-time of 2000 hours, the J-PARC cesiated rf-driven H^- ion source [1] was developed by using an internal-antenna developed at the SNS (Spallation Neutron Source) [2]. The maintenance and operation procedure to minimize the source replacement time on the beam line, which is very important to maximize the J-PARC beam time, especially for the antenna failure, is presented in this paper. The Ar purged source after the pre-conditioning with pre-cesiation to produce the required beam at a test-stand successfully produced the required beam on the beam line with slight addition of Cs. The feedback controls of 2MHz rf-matching, an H^- ion beam intensity and addition of Cs are also presented. The rf-matching feedback by using two VVCs (vacuum variable capacitor) produced the almost perfect matching with negligibly small reflected rf-power [3]. The H^- ion beam intensity was controlled within errors of ±0.1mA by the rf-power feedback. The amount of the Cs was also controlled by remotely opening the Cs-valve to keep the rf-power lower than a settled value.

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O2-07

First Beam Measurements on the Vessel for Extraction and Source Plasma Analyses (VESPA) at the Rutherford Appleton Laboratory (RAL)

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In order to facilitate the testing of advanced H^- ion sources for the Front End Test Stand (FETS) and ISIS facilities at the Rutherford Appleton Laboratory (RAL), a Vessel for Extraction and Source Plasma Analyses (VESPA) has been constructed. This will perform the first detailed plasma measurements on the ISIS Penning-type H^- ion source using emission spectroscopic techniques. In addition, the 30-year-old extraction optics are re-designed from the ground up in order to fully transport the beam. Using multiple beam and plasma diagnostics devices, the ultimate aim is improve H^- production efficiency and subsequent transport for either long-term ISIS user operations or high power FETS requirements. The VESPA will also accommodate and test a new scaled Penning H^- source design. This paper details the VESPA design, construction and commissioning, as well as initial beam and spectroscopy results.

Ion Extraction from a Saddle Antenna RF Surface Plasma Source*

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The development of a saddle antenna RF surface plasma source (SA RF SPS) was proposed to improve H^- ion production efficiency and SPS reliability and availability [1]. Improved plasma generation using a SA SPS was considered in [2-3]. H^- ion extraction at low RF power was considered in [4]. Existing RF SPSs for accelerators have efficiencies of H^+ and H^- ion generation 3-5 mA/cm^{2}kW, where about 50 kW of RF power is typically needed for 50 mA beam current production [5]. Extraction of positive and negative ions from the SA RF SPS at higher RF power is considered in this work. The extracted collector current can be increased significantly by increasing the longitudinal magnetic field in the discharge chamber. At low RF power, the efficiency of positive ion generation in the plasma has been improved up to 200 mA/cm^2 per kW of RF power at 13.56 MHz. Initial cesiation of the SPS was performed by heating the cesium chromate cartridges by discharge as was done in the very first versions of the SPS [6, 7]. A small oven for cesium compounds and alloy decomposition by heating [8, 9] was developed and tested. After cesiation, the current of negative ions to the collector was increased from 1 mA to 10 mA with RF power 1.5 kW in the plasma (emission aperture is 6 mm diameter) and up to 30 mA with 4 kW RF power in the plasma and longitudinal magnetic field of 250 Gauss. Stable generation of H^- beam without intensity degradation was demonstrated in the AlN discharge chamber for a long time.

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High Stored-Energy Breakdown Tests on Electrodes made of Stainless Steel, Copper, Titanium and Molybdenum

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The ITER neutral beam system will provide 1 MeV beams. One expects that in accelerator and bushing a stored energy of around 500 J will be present that cannot be adsorbed by the snubbers. IRFM have conducted resilience tests on electrodes made of Cu, stainless steel 304L, Ti and Mo against breakdowns up to 170 kV and 300 J.

Electrodes made out of these four materials have all been exposed to 10000 seconds HV on-time while separated over a distance of 11 mm in vacuum. As a result they suffered around 1000 breakdowns each. Figure 1 shows that damage and cratering occurred on all electrodes. The variation in voltage holding capability was not big, all electrodes held between 140 and 170 kV after conditioning. The voltage holding tended to decrease somewhat after the optimum performance had been reached. The depth of the damage features on cathode and/or anode cannot be related to the high-voltage performance. The rugosity Ra on the anodes became around 2.5 µm after the breakdowns, except for Mo which reached Ra=1.3 µm.

Using electrodes polished to mirror finish reduced the breakdown rate significantly during the conditioning phase, until a point is reached when the electrodes appear sufficiently damaged for the benefit to go away. After this, the polished electrodes suffered a breakdown rate comparable to the unpolished (machined) ones.

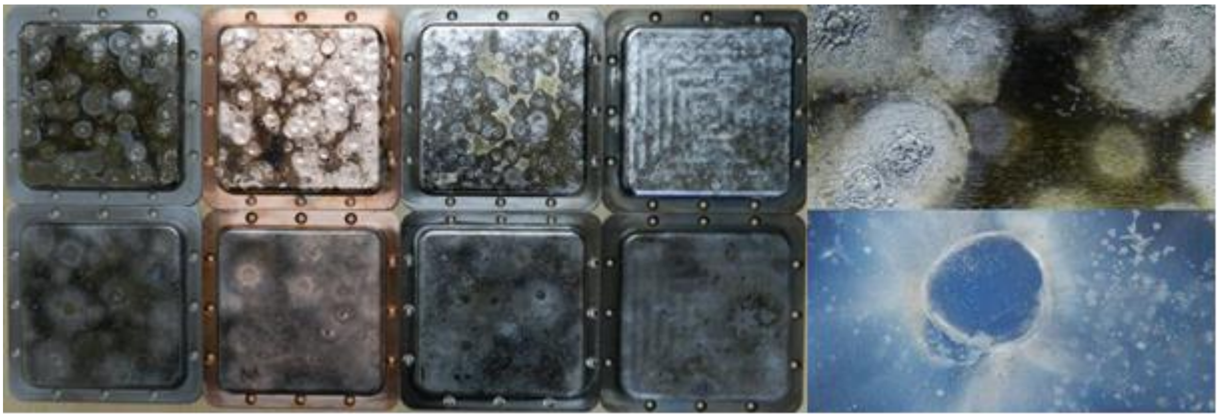

Figure 1. Electrodes (10x10 cm^2) after the tests. The top row are the anodes, the bottom row are the cathodes. From left to right: Stainless steel baked at 800 °C, copper, titanium, molybdenum and a detail of the Ti electrodes. The detail on the right corresponds to a 4x2 cm^2 section of the Ti anode and cathode.

O2-10

Mo layer thickness requirement on the ion source back plate for the HNB and DNB ion sources in ITER

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All the inner surfaces of the ion sources and the upstream surface of the plasma grid of the ITER neutral beam ion sources are proposed to be coated with molybdenum. This is done to avoid sputtering of the base material (Cu or CuCrZr) by the ions in the source plasma (D^+, D_2^+, D_3^+ or H^+, H_2^+, H_3^+). The sputtering of Mo by the ions in the source plasma is low compared to that from Cu, and the threshold energy for sputtering ≈80 eV) is high compared to the energy of the ions in the source. However the D_2^+, H_2^+ and D^+, H^+ ions backstreaming from the accelerators will have energies that substantially exceed that threshold and it is important that the Mo layer is not eroded such that the base material is exposed to the source plasma. In the case of the HNB, the backstreaming ion power is calculated to be in the order of ~1 MW, and the average energy of the backstreaming ions is calculated to be ≈300 keV.
The ion sources in the HNB beam lines, 40 A 1 MeV D and 46 A 870 keV H beams, are supposed to operate for a period of 2 x 10^7 s. For the DNB, 60 A 100 keV H beams, the corresponding number is 1.4 x 10^6 s considering a beam duty cycle of 3s ON/20s OFF with 5 Hz modulation. The Mo layer on the ion source back plate should be thick enough to survive this operational time. Thickness estimation has been carried out taking into account the sputtering yields (atoms/ion), the energy spectrum of the backstreaming ions and the estimated profiles on the ion source back plate. The methodology and the results of these calculations shall be presented and discussed.

3D modeling of a fusion-type high-power negative ion source: impact of biasing the plasma grid on the plasma asymmetry

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Asymmetric plasma profiles result from the electron drift dynamics inside the magnetic filter field in fusion-type high power negative ions sources [1]. The presence of the chamber walls in the $\mathbf{J_e}\times\mathbf{B}$ direction ($\mathbf{J_e}$ is the electron current density from the driver to the extraction region, and $\mathbf{B}$ is the magnetic field in the filter) is responsible for the plasma asymmetry in the filter and extraction region. The enhancement of the plasma asymmetry induced by biasing the right-hand-side electrode of the ion source (so-called plasma grid) is analyzed using a three-dimensional (3D) Particle-in-Cell model with Monte-Carlo Collisions (PIC-MCC) [2].
We specialize to the one-driver IPP tandem-type negative ion source operated at BATMAN (Max-Planck-Institut für Plasmaphysik, Garching, Germany). The ion source is separated into two distinct compartments: an ICP driver coupling about 100 kW of RF power (1 MHz frequency) to hydrogen or deuterium plasma. The plasma expands into the expansion chamber (rectangular box larger than the driver) which is magnetized. The magnetic filter field is generated by permanent magnets located on the lateral side of the ion source and we study the so-called standard configuration where the maximum field amplitude is found on the plasma grid (PG), ~75G on axis. The magnetic field acts as a barrier on the electrons; the electron current and energy flux is consequently strongly reduced inside the expansion chamber, leading to a significant drop of the electron temperature. The ion source has two sub-regions where the electron kinetics is quite different. An upstream region (including the driver) with a high electron temperature, typically of the order of 12 eV (electron density $n_e \sim 10^{18}$ m^{-3}), and where most of the chemistry takes place (dissociation and vibrational excitation of molecular hydrogen or deuterium, ionization and formation of the different sub-type of positive ions). This region generates nearly all the particle fluxes which drift toward the (PG) and are precursors for the generation of negative ion on its surface. The PG connects the ion source with the negative ion accelerator. For the case of ITER, it has 1280 apertures over a 0.2 m^2 extraction area. It is covered with a cesium layer in order to enhance negative ion yield (by lowering the work function of the underling metal). Downstream the magnetic barrier, plasma conditions are more quiescent; the electron temperature is about 1 eV ($n_e \sim 2\times10^{17}$ m^{-3}) which is the optimal situation for both volume production of negative ions via dissociative attachment with vibrationally excited molecular hydrogen (or deuterium) and extension of their survival rate.
The simulation results show that the plasma asymmetry is a non-linear function of the PG bias. For a bias voltage sufficiently high such that the total particle currents collected on the PG is electronegative, the plasma asymmetry becomes significant in BATMAN. The plasma potential amplitude in the expansion chamber is in that regime lower than the value of the bias. In addition, we will discuss preliminary calculations on the effect of a PG bias for the half-size (4 drivers) large volume ITER-type ion source (test facility ELISE, IPP, Garching, Germany) using a 2.5D PIC-MCC model [3].

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O3-02

Spatial Distribution of the Plasma Parameters in the rf Driven Negative Ion Source Prototype for Fusion

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A numerical model, based on the fluid plasma theory, has been developed for description of the spatial distribution of the plasma parameters (electron density and temperature, plasma potential as well as densities of the three types of positive hydrogen ions) of the IPP prototype RF negative hydrogen ion source. The model covers the driver and the expansion plasma region of the source with their actual size and accounts for the presence of the magnetic filter field with its shape and location as well as for the plasma grid with the bias applied to it. The specific geometry of the source – a cylindrical driver and a rectangular expansion plasma volume – calls for three-dimensional model description which, with the actual topology of the magnetic filter field introduced, is a complex and time consuming task. For this reason, two two-dimensional models, respectively, with an axial-symmetry and in a planar geometry, are considered both showing to be close enough to the three-dimensional case, at least without a magnetic filter. Since the two-dimensional planar-geometry model has the advantage to accounts for the ExB and diamagnetic drifts, the results from it (both with and without magnetic filter present) are compared with experimental data from probe diagnostics [1]. The latter has been carried out by using two Langmuir probes, axially movable in parallel from the exit of the driver till the extraction region of the source. Thus, the study stresses on three aspects: (i) proper geometry of a two-dimensional model description, (ii) benchmarking of the code to the experimental results, and (iii) the influence, via the charged-particle and electron-energy fluxes, of the magnetic filter and of the bias applied to the plasma grid on the spatial structure of the discharge.

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O3-03

Towards a realistic 3D simulation of the meniscus in negative ion sources

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The development of a large (A_{source}= 0.9×2 m) negative hydrogen ion (NI) source constitutes a crucial step in the construction of the Neutral Beam Injector (NBI) of the international fusion reactor ITER. The source should deliver 59A (200A/m^2) of extracted D^- under the pressure 0.3 Pa - scientifically and technically a very challenging goal.
The 3D numerical modelling is used to improve the understanding of the plasma behavior in the meniscus region close to the extraction system exploiting the 3D PIC MCC code ONIX [1]. Being very close with experiments conducted at the BATMAN testbed gives an important added value to these simulations by the realistic input parameters: plasma features, magnetic field distribution, geometry of the extraction aperture, etc. Hence, the code evolved following scrupulously the experimental conditions. The recent version of ONIX includes the biasing of the plasma grid (V_{bias}= -5 to -10V with respect to the plasma potential) and the distribution of the Cs^+ ions. These novelties bring the numerical results in better agreement with the experimental measurements.
This contribution is focused on a study of the extracted electron and negative ion (NI) currents for different state of the Caesium conditioning process. It is shown that the extracted NI current can reach values of ~32mA/cm^2 for good Cs conditions when the negative ion density in the bulk plasma region is $n_{H^-}=10^{17}$ m^{-3}. The shape and position of the meniscus were analyzed for simulations of both good perveance (V_{ext}=5kV) and maximum extracted NI current (V_{ext}=10kV). The meniscus position in the case of 5kV is closer to the inner surface of the plasma grid, as expected, but still away of the aperture. It is found that such a meniscus position increases the relevance of the direct extraction of the surface produced negative ions. Finally, a parametric study of the initial energy and the emission rate of the negative ions produced at the plasma grid surface were performed. The higher the starting energy the higher the amount of NI overcoming the virtual cathode generated from the negative space charge in vicinity to the plasma grid. Finally, the simulations show that the density of the negative ion in the bulk plasma increases about 3 orders of magnitude when the NI initial energy rises from 1 to 5eV.

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O3-04

Numerical Modeling of the Spallation Neutron Source H^- Ion Source

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Ion source rf antennas that produce H^- ions can fail when plasma heating causes ablation of the insulating coating due to small structural defects such as cracks. Reducing antenna failures that reduce the operating capabilities of the Spallation Neutron Source (SNS) accelerator is one of the top priorities of the SNS H^- Source Program at ORNL.

Numerical modeling of ion sources can provide techniques for optimizing design in order to reduce antenna failures. There are a number of difficulties in developing accurate models of rf inductive plasmas. First, a large range of spatial and temporal scales must be resolved in order to accurately capture the physics of plasma motion, including the Debye length, rf frequencies on the order of tens of MHz, simulation time scales of many hundreds of rf periods, large device sizes on tens of cm, and ion motions that are thousands of times slower than electrons. This results in large simulation domains with many computational cells for solving plasma and electromagnetic equations, short time steps, and long-duration simulations. In order to reduce the computational requirements, one can develop implicit models for both fields and particle motions (e.g. divergence-preserving ADI methods), various electrostatic models, or magnetohydrodynamic models. We have performed simulations using all three of these methods and have found that fluid models have the greatest potential for giving accurate solutions while still being fast enough to perform long timescale simulations in a reasonable amount of time.

We have implemented a number of fluid models with electromagnetics using the simulation tool USim and applied them to modeling the SNS H^- ion source. We found that a reduced, single-fluid MHD model with an imposed magnetic field due to the rf antenna current and the confining multi-cusp field generated increased bulk plasma velocities of > 200 m/s in the region of the antenna where ablation is often observed in the SNS source. We report here on comparisons of simulated plasma parameters and code performance using more accurate physical models, including effects of anisotropic plasma pressures parallel and perpendicular to magnetic field lines, addition of an Ohm's law for describing evolution of self-induced fields in the plasma, different models for viscosity and conductivity, single-fluid two- temperature models, and two-fluid models. We also report on progress extending our physical models to include physical sputtering of neutral atoms from the antenna surface, neutral fluid flow and subsequent ionization, plasma chemistry such as electron impact ionization, recombination, excitation, and dissociation, and modeling of secondary electron production and dielectric surface charging.

Study of the different Cs conditioning states of the Linac4 negative hydrogen ion source by 3D PIC-MCC numerical simulations using ONIX code

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At CERN, a high performance negative ion (NI) source is required for the 160 MeV H^- linear accelerator Linac4. The source should deliver an 80 mA H^- ion beam within a normalized rms emittance of 0.25 mm mrad, which is technically and scientifically very challenging. Recently, the operation of the so-called IS02 source has started with enhanced NI production using Cs vapor. The optimization of this source requires deep understanding of the underling physics concerning the production and extraction of the negative ions from both the plasma volume and the Cs covered plasma electrode.
The ONIX (Orsay Negative Ion eXtraction) code was exploited to address this problem. The code was initially developed to model the radio-frequency negative ion source of the ITER Neutral Beam Injector [1] and it has been modified and adapted to investigate the transport of NI and electrons in the extraction region of the Linac4 ion source. Recent update of the code includes the distribution of Cs^+ for more realistic simulations. Indeed, the presence of heavy Cs^+ ions helps to reduce the depth of the negative potential well in front of the plasma grid, which limits the NI extraction in spite of the high surface production.
This paper focuses on the modeling of the Linac4 IS02 ion source. The different states of the Cs conditioning were simulated via parametric study of the NI emission flux from the plasma electrode and the Cs^+ density distribution in the bulk plasma region. The simulations show that for a "good" Cs condition regime (NI emission rate of 3000 A/m^2 and n_{Cs+}=3.8*10^{16} m^{-3}) the total extracted NI current could reach ~70 mA. For the "bad" Cs condition state (NI emission rate of ~300 A/m^2 and n_{cs+}=3.3*10^{15} m^{-3}) the total extracted NI current decreases down to ~20 mA. These results were benchmarked with good agreement against experimental measurements with the IS02 ion source.

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Numerical analysis of Negative Ion beam formation and aberrations in different plasma sources & accelerators by coupling two 3D PIC-MCC codes ONAC and ONIX

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The nuclear fusion reaction between deuterium and tritium requires very high temperature of plasma species, beyond 10 keV. Neutral beams based on the neutralization of energetic Negative Ions (NI) is nowadays the solution selected to provide energy to the plasma. Over the last ten years, several configurations for NI production and acceleration have been proposed.
At CEA/IRFM the SINGAP (single gap) accelerator has been built, tested at up to 940 keV and characterized in term of divergence and beam cross section distribution [1]. Further, the yet to be built ITER system with the 7-grid 1 MeV electrostatic accelerator was simulated [2]. Recently, CEA/IRFM designed a new linear column NI plasma source, called Cybele, allowing the use of a floating (biasing) large surface, which helps in the conversion of H atoms into negative ions very close to the extraction region.
The ONIX (Orsay Negative Ion eXtraction) 3D Particles-in-Cell Monte Carlo Collisions (PIC-MCC) code was initially developed to model the ion extraction in the radio-frequency negative ion source for ITER [3]. The ONAC (Orsay Negative ion ACceleration) 3D PIC-MCC code was developed to self-consistently simulate the NI acceleration, the acceleration of the co-extracted electrons and the elementary processes that occur inside the accelerator involving the NI, such as the stripping of the NI and the ionization of the background gas by the beams. ONAC is capable of using as an input, the preliminary conditions (the 3D phase space and current density distribution) of the NI and the co-extracted electrons simulated by ONIX for ion beam aberration studies and assessment of the real power loads downstream in the accelerator channel.
Coupled ONIX and ONAC simulations will be performed on three ion source and accelerator systems, SINGAP, ITER-like and Cybele. The results will be compared with each other. In the case of SINGAP, ion beam optics simulations dedicated to study beam aberrations will be discussed and compared with the experimental results.

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O3-07

Study of negative hydrogen ion beam optics using the 3D3V PIC model

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Negative ion based neutral beam injection system (N-NBI system) is one of the promising candidates for plasma heating and current drive of magnetic fusion reactors. The negative ion source which can produce negative ion beams with high power and long pulse is the key component for the N-NBI system. One of the essential issues for the design and development of such a negative ion source is to clarify negative ion trajectories in the cesiated volume ion source, especially to understand the physics of the beam halo formation.

Our previous study by the 2D3V-PIC (two dimension in real space and three dimension in velocity space)・(Particle In Cell) model shows that the curvature of the plasma meniscus causes the beam halo in the negative ion sources [1, 2]. The negative ions extracted from the periphery of the meniscus are over-focused in the extractor due to the electrostatic lens effect, and consequently become the beam halo. In order to clarify the mechanism of negative ion extraction under real conditions with the complicated magnetic field, the 3D simulation code [3] has been developed. Our preliminary result indicates the E x B drift of electrons due to the magnetic filter, and the resultant asymmetry of the plasma meniscus. It is supposed that the asymmetry of the plasma meniscus causes the asymmetry of negative ion beam profile including the beam halo. The detail results of negative ion beam profile and the emittance diagram will be presented in the conference.

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O4-01

Research Progress on Ionic Plasmas Generated in an Intense Hydrogen Negative Ion Source

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Characterisic features of ionic plasmas, observed in a high-density hydrogen negative ion source, are presented. The ionic plasma, which consists of hydrogen positive- and negative-ions with quite low-density of electrons, is realized in the ion extraction region, from which the negative ions are extracted through the plasma grid. A symmetry I-V curve is observed with a Langmuir probe, and the negative ion density, i.e., the ionic plasma density, as high as the order of $1x10^{17}m^{-3}$, is measured with cavity ring-down method [1]. Reduction of the negative ion density is observed by the negative ion extraction, and at that time the electrons flow into the ionic plasma region to conserve the charge neutrality. The electric field applied for the negative ion extraction has a long-range influence on the particle transport in the plasma, suggesting a different mechanism of the sheath formation from that in such plasmas that electrons play a dominant role. With 2D image measurement of the Hα emission caused by mutual recombination of the negative ions and protons, it is observed that the negative ions are extracted from a wide region apart from the plasma grid apertures [2]. This indicates that the applied extraction field should drive the negative ion transport in the ionic plasma. The electron density near the plasma grid is measured with millimeter-wave interferometer. The electron density is observed to increase at the negative ion extraction. The particle dynamics against application of the electric field and the related sheath formation in the ionic plasma are investigated with various diagnostics, and the results are discussed.

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O4-02

Integration of the Magnetic Field Design for SPIDER and MITICA Negative Ion Beam Sources

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The design of the magnetic field configuration in the SPIDER and MITICA negative ion beam sources has evolved considerably during the past four years, with respect its original design [1, 2]. This evolution, passing through intermediate steps [3, 4], was driven essentially by three factors:

a) the experimental results of the large RF-driven ion sources at IPP (mainly BATMAN and ELISE), which have provided valid indications on the optimal magnetic configurations for reliable RF plasma source operation and for large negative ion current extraction,
b) the comprehensive beam optics and heat load simulations, which showed that the magnetic field configuration in the accelerator was crucial for keeping the heat load due to electrons on the accelerator grids within tolerable limits, without compromising the optics of the negative ion beam in the foreseen operating scenarios,
c) the progress of the detailed mechanical design of the accelerator, which stimulated the evaluation of different solutions for the correction of beamlet deflections of various origin and for beamlet aiming.

On this basis, various new requirements for the magnetic field configuration in the SPIDER and MITICA beam sources have been progressively introduced and updated until the design converged. The paper presents how these requirements have been integrated into the final design solution.

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O4-03

Design, Installation, Commissioning and Operation of a Beamlet Monitor in the negative ion beam test stand at NIFS

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In the framework of the accompanying activity for the development of the two neutral beam injectors for the ITER fusion experiment, an instrumented beam calorimeter is being designed at Consorzio RFX, to be used in the SPIDER test facility (particle energy 100keV; beam current 50A), with the aim of testing beam characteristics and to verify the source proper operation. The main components of the instrumented calorimeter are one-directional carbon fibre carbon composite tiles.

Some prototype tiles have been used as a small-scale version of the entire calorimeter in the test stand of the neutral beam injectors of the LHD experiment, with the aim of characterising the beam features in various operating conditions. The extraction system of the NIFS test stand source was modified, by appliyng a mask to the first gridded electrode, in order to isolate only a subset of the beamlets, arranged in two 3x5 matrices, resembling the beamlet groups of the ITER beam sources.

The present contibution gives a description of the design of the diagnostic system, including the numerical simulations of the expected thermal pattern. Moreover the dedicated thermocouple measurement system is presented.

The beamlet monitor was succesfully used during a full experimental campaign, during which the main parameters of the source, mainly the arc power and the grid voltages, were varied. This contribution describes the methods of fitting and data analysis applyed to the infrared images of the camera to recover the beamlet optics characteristics, in order to quantify the response of the system to different operational conditions. The results concerning the beamlet features are presented as a function of the source parameters.

This work was set up in collaboration and financial support of F4E.
Contribution by Consiglio Nazionale delle Ricerche and Japan Society for the Promotion of Science is also acknowledged.

O4-04

Dependence of the Source Performance on Plasma Parameters at the BATMAN Test Facility

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BATMAN is a NNBI test facility at the Max-Planck-Institut für Plasmaphysik (IPP) Garching, equipped with the IPP prototype source [1]. Due to its easy access for flexible exchange of diagnostics and components, BATMAN is the preferable NNBI test facility at IPP for research of physics aspects.

The investigation of the dependence of the source performance (high j_{H^-}, low j_e) on relevant plasma parameters is desirable in order to find key parameters for the operation of the source as well as to deepen the physical understanding. The most relevant source physics takes place in the extended boundary layer, which is the plasma layer with a thickness of several cm in front of the plasma grid: the production of H^-, its transport through the plasma and its extraction, inevitably accompanied by the co-extraction of electrons. Hence, a link of the source performance with relevant plasma parameters in the extended boundary layer is expected.

In order to characterize electron and negative hydrogen ion fluxes in the extended boundary layer, Cavity Ring-Down Spectroscopy and Langmuir probes have been applied for the measurement of the H^- density and the determination of the plasma density, the plasma potential and the electron temperature, respectively. The plasma potential is of particular importance as it determines the sheath potential profile at the plasma grid: depending on the plasma grid bias relative to the plasma potential, a transition in the plasma sheath from an electron repelling to an electron attracting sheath takes place, influencing strongly the electron fraction of the bias current and thus the amount of co-extracted electrons.

Dependencies of the source performance on the determined plasma parameters will be presented, especially dedicated to a comparison of hydrogen and deuterium operation. This comparison is of particular interest, since a larger amount of co-extracted electrons in deuterium operation usually limits the source performance.

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Evaluation of Negative Ion Distribution Changes by Image Processing Diagnostic

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Distribution of negative ions and its behaviors are the important factor for optimization of homogeneous and high power neutral beam for neutral beam injector (NBI). We have measured a negative ion density near the plasma grid (PG) surface used a cavity ring-down spectroscopy (CRDS) diagnostic in the arc discharge source in National Institute for Fusion Science (NIFS) [1]. In addition, we have developed a spectrally selective imaging system for H_α emission which is performed well to understand the distribution of negative ions and is extraction behavior close to the PG surface [2]. The system consists of a optical filters, a quartz lens, an image conduit and a CCD image detector. The line of sight is arranged parallel to the PG surface and the viewing angle is covered in the range of 30 mm from the PG grid surface. We have found the signal reduction in both a H^- density and a H_α emission during beam extraction. The H_α intensity is strongly related to the H^- density because the excitation process for mutual neutralization between H^+ and H^- ions [3] is dominant in the low temperature (~1eV) and high H^- density condition such as in an ionic plasma. Therefore the subtraction image for H_α emission (ΔH_α) from during beam extraction and to before beam extraction is the key parameter for understanding H^- extraction. We found the reduction distribution on the ΔH_α image; the reduction area expanding to the 20 mm from the PG surface and the reduction value is much larger near the PG apertures. These results suggest the H^- ions produced on the PG surface widely distributed in the extraction region during arc discharge, then it extracted from the PG apertures during beam extraction. We also observed the ΔH_α distribution by changing bias voltage. The reduction value of H_α emission decreased in the higher bias voltage. The difference in ΔH_α distribution in the different bias voltages most likely caused by the space potential in the extraction region that is to be important parameter for the distribution of the negative ion density and extraction current.

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O4-06

Can we estimate plasma density in ICP driver through electrical parameters in RF circuit?

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Invasive plasma diagnostics, like probes as well as optical plasma diagnostics are not included in inductively coupled plasma (ICP) based ITER NB source design to avoid regular maintenance. Due to overall system design and interface issues non-invasive probes like optical emission spectroscopic diagnostics are also not included in the present ITER NB design. As a result, beam current through the extraction system in the ion source is the only measurement which indicates plasma condition inside the ion source. However, beam current not only depends on the plasma condition near the extraction region but also on the perveance condition and also negative ion stripping. Nevertheless, inductively coupled plasma production region (RF driver region) is placed at distance (~ 30cm) from the extraction region. Due to that, some uncertainties are expected to be involved if one tries to link beam current with plasma properties inside the RF driver. Plasma characterization in source RF driver region is utmost necessary to maintain the optimum condition for source operation. In this presentation, a method of plasma density estimation based on density dependent plasma load calculation is described.

O4-07

Doppler Shift Measurement of Balmer-Alpha Line Spectrum Emission from a Plasma in a Negative Hydrogen Ion Source

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Balmer-series emission spectroscopy is widely utilized to characterize fundamental atomic processes occurring in a negative hydrogen (H^-) ion source [1,2]. A single narrow band interference filter has visualized two-dimensional Balmer-alpha intensity distributions of a plasma in a H^- ion source being developed at the National Institute of Fusion Science (NIFS) [3]. The measured distributions show strong correlation to the bias applied to the plasma grid of the NIFS one third model H^- ion source, which can be interpreted as the increased H^- ion density near the extraction apertures due to surface production of H^- at the plasma grid. The flow of atomic hydrogen which should reflect the transport of H^-, however, has not been experimentally confirmed yet.

Calculation results on energy distribution of surface produced H^- ions predict the existence of H^- component with the kinetic energy as high as the potential difference between the plasma and the plasm grid [4]. The one third H^- ion source can be operated with the grid bias voltage several volts positive or negative to the plasma potential. The resulting change due to the grid bias in energy distribution function of hydrogen atoms produced from mutual neutralization of H^- ions can be detected as the Doppler shift and/or boradening of Balmer-alpha line spectrum emissions.

An optical fiber cable attached to the window port of the NIFS one third H^- ion source delivers light emission signal from a plasma in the extraction region to optical spectrometers. A 75 cm focal length grating spectrometer produces a light emission spectrum image onto a CCD image sensor, or a slit through which the light is detected by a photomultiplier tube. Another Fabry-Perot type high resolution spectrometer measures the wavelength spectrum around the center of the spectrum to estimate effective temperature of atomic hydrogen.

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Laser measurement of the photodetachment cross-section of H^- at the wavelength 1064 nm

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The photodetachment cross-section of either D^- or H^-, which is of importance for designing photodetachment-based neutral injection devices, was very rarely measured in actual experiments. The only precise measurements known in the literature are one with a classical lamp and filters, in 1955 [1], and one from spectroscopy of a hydrogen-arc discharge in 1976 [2]. The values found at the time were 3.9(5) and 3.6(3) 10^{-21} m^2, respectively, at the wavelength 1064 nm. The order of magnitude of the cross-section was confirmed by laser photodetachment experiments carried out for plasma diagnostics purposes in the 70's [3].

A number of theoretical calculations of the same cross-section were performed since 1933. Most of them converged towards a 3.6 10^{-21} m^2 value. A handful of calculations that may have taken into account electron correlations in more elaborate ways nevertheless provided significantly higher values, up to 5.6 10^{-21} m^2 at the same 1064 nm wavelength [4].

We have implemented a new method for measuring photoexcitation cross-sections, which relies on the expected behaviour of the signal in the saturated regime, when excitation is provided by a Gaussian light beam. The method is applied to photodetachment of an H^- beam by a single-mode pulsed Nd:YAG laser. The obtained value, $4.6(8)\times10^{-21}$ m^2, is corroborated by the more usual procedure which consists in fitting the experimental detachment yield curve, as a function of the laser pulse energy, with the numerical result of space and time integration of the photodetachment signal, for different possible values of the photodetachment cross-section. The final value $4.5(6)\times10^{-21}$ m^2 appears greater than the one known from the older measurements and most *ab initio* calculations. This higher value, if confirmed, is only good news for neutral beam production, but would suggest that theorists revisit the H^- photodetachment problem.

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O4-09

Long pulse acceleration of MeV class high power density negative H^- ion beam for ITER

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For ITER neutral beam system, negative deuterium ion beam of 1 MeV, 40 A (current density of 200 A/m^2) is required for 3600 s. To demonstrate ITER relevant negative ion beam acceleration, beam acceleration test has been carried out at MeV test facility in JAEA. The present target is H^- ion beam acceleration up to 1 MeV with 200 A/m^2 for 60 s, which beam energy and pulse length are the present facility limit. Long pulse beam acceleration test has been carried out at high power density beam since 2013. One issue for the long pulse beam acceleration was high grid power loading. The power loading was reduced by improving beam deflection by residual magnetic filter and H^- ion beam of 881 keV, 130 A/m^2 was successfully accelerated for 8.7 s.[1] Previous extraction grid (EXG) was designed for short pulse operation and had not enough cooling capability. To extend pulse duration time up to facility limit at high power density beam, new EXG has been developed with high cooling capability, which electron suppression magnet is placed under cooling channel similar to ITER. In addition, the aperture size of the electron suppression grid (ESG) is enlarged from 14 mm to 16 mm and the aperture displacement of ESG is modified to reduce collision of negative ion beam on the grid. By these modifications, total grid power loading has reduced from 14 % to 11 % at optimum perveance. As a result, beam acceleration up to 60 s which is the facility limit, has achieved at 700 keV, 100 A/m^2 of negative ion beam without breakdown.

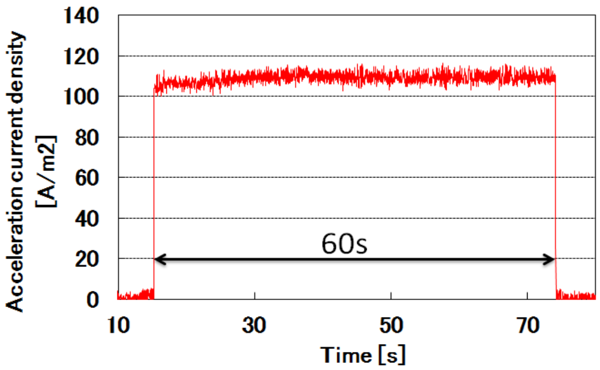

Figure 1. Acceleration current density for 60 s at 700 keV

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O4-10

High current production of the uniform beams by modifying the magnetic filter in JT-60 negative ion source

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The JT-60 negative ion source with the largest ion extaction area of 1100 x 450 mm^2 in the world is designed to produce 500 keV, 22 A, 100 s negative ion beams for JT-60SA. However, such as a power and long-pulse beams have not been achieved yet because of a poor spatial uniformity of the negative ions. In the previous studies, the origin of the non-uniformity of the beams was found to be due to a magnetic drift of the primary electrons emitted from filaments. In order to improve the beam uniformity, a tent-shaped magnetic filter has been applied to the JT-60 negative ion source [1]. The beam uniformity of the beams, defined as normalized ion extraction area giving a ±10 % deviation to the beam intensity averaged over the total ion extraction area, was logitudinally improved from the original external filter of 45 % to 70 %. The tent-shaped filter also degrated the horizontal uniformity. To improve the horizotal uniformity without degrading the logitudinal one, the tent-shaped filter was weakened from 660 Gasus•cm to 400 Gasus•cm. This reduction improved horizontal uniformity from 75 % to 90 %, resulting in an improvement of the beam uniformity over the total ion extraction area from 45 % to 60 % as shown in figure 1. This successfully leads to a 32 A of H^- ion beams from a total ion extraction and a 22A from 60% of the total ion extraction area. The increase of the extracted electrons by the reduction filter strength was not more than 10% and is acceptable level of the power loading of the extraction grid. In conclusion, the experimanl results fulfill the requirement for JT-60SA.

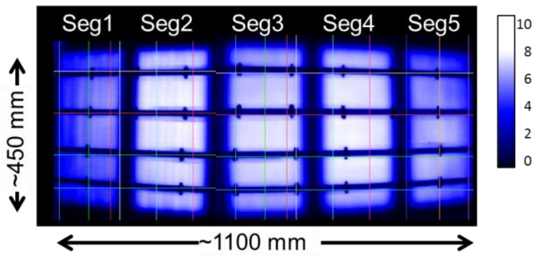

Figure 1. Footprint of the negative ion beams after the modification

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O4-11

A New Ion Source Test Facility for Negative Ion Beams

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D-Pace is developing an Ion Source Test Facility (ISTF) which shall be used for developing D-Pace's negative ion beam source products in collaboration with and at the site of Buckley Systems in Auckland, New Zealand. The ISTF has a five-fold purpose as described below:

1) It shall provide a means to develop a new industrial CW 13.56 MHz H^- volume-cusp 30 keV source based on technology licensed from and co-developed with University of Jyvaskyla [1]. To date Universty of Jyvaskyla has achieved a 1 mA beam current in the lab, and the group is utilizing a small aperture solution aiming at normalized 4rms emittances less than 0.2 mm·mrad. At this stage, D-Pace will take the design and head towards a larger aperture, higher current solution (5 – 15 mA) where the normalized 4 rms emittances required for industrial radioisotope production can be relaxed to 0.8 mm·mrad.
2) It shall provide a means to provide a factory beam test for D-Pace's standard TRIUMF licensed filament-based 15 mA, 30 keV H^- DC volume-cusp ion source product [2] prior to shipping. Up till now this factory beam test has been done, upon request, at TRIUMF at considerable expense to the customer.
3) D-Pace shall use the ISTF to further develop the filament-based TRIUMF licensed H^- ion source technology into the 20-30 mA DC range [3].
4) The ISTF enables a variety of D-Pace turn-key products such as emittance/phase space scanners, wire scanners, Faraday cups, slits, collimators, AC X-Y Beam Scanners, and Low Energy Beam Transport (LEBT) systems to be tested with beam.
5) The ISTF will have more than one ion source test bay, and will be available on a reasonable rent basis for labs, institutes, and companies to undertake their own testing and development.

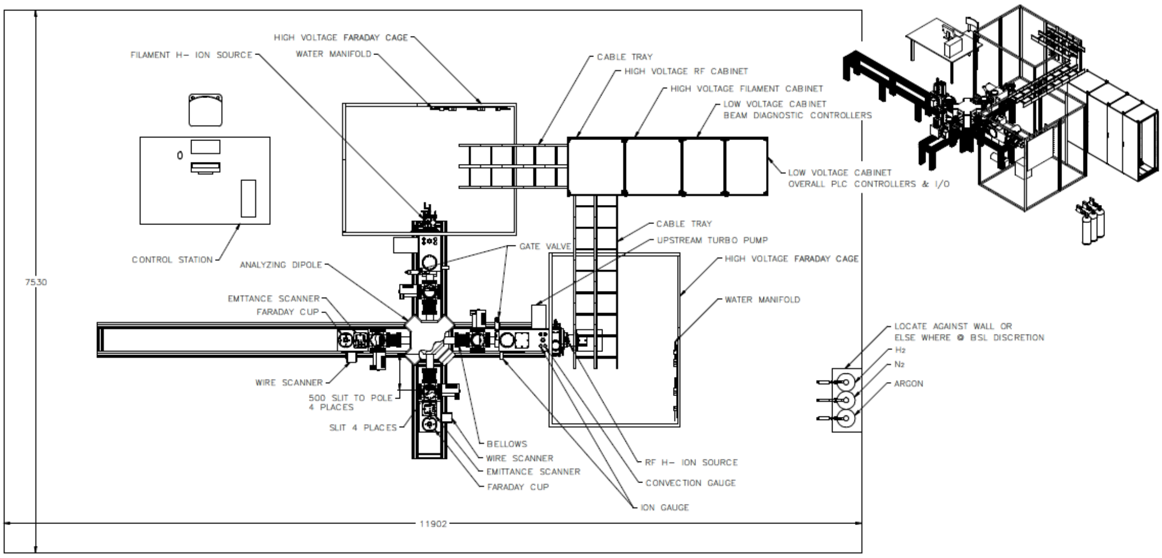

Figure 1. Plan view of the Ion Source Test Facility to be located at Buckley Systems factory in New Zealand.

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O5-01

Status Of The ELISE Test Facility

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The neutral beam test facility ELISE (Extraction from a Large Ion Source Experiment), located at the Max-Planck-Institut für Plasmaphysik (IPP) in Garching, is operational since beginning of 2013. ELISE, equipped with a large RF driven ion source (1x0.9 m^2 with an extraction area of 0.1 m^2) of half the size of the ion source for the ITER neutral beam injection (NBI) system, is an important step in the European R&D roadmap for the construction of the neutral beam heating systems, defined by the ITER domestic agency F4E. The early experience of the operation of such a large RF driven source will give an important input for the design of the Neutral Beam Test Facility PRIMA in Padova and the ITER NBI systems and for their commissioning and operating phases.

The paper summarizes the results of ELISE operation in the last two years, both for hydrogen and in deuterium, for the different experimental programs: (1) low RF power operation without and with Cs, (2) short pulse, high RF power operation, and finally (3) long pulse, high RF power operation. It discusses critical issues like Cs conditioning and long pulse stability, and the dependence of the source and beam performance on operational parameters.

O5-02

Size Scaling of Negative Hydrogen Ion Sources for Fusion

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The prototype source for the neutral beam injection system of the international fusion experiment ITER is an RF driven ion source consisting of a cylindrical driver and a rectangular expansion chamber of 1/8th of the size required for ITER. The prototype source is and was operational at the short pulse test facility BATMAN [1] and at the long pulse test facility MANITU [2], respectively. In 2013 the half size source at the test facility ELISE [3, 4] went into operation having the same width but only half the height of the expansion chamber of the ITER source (0.9 x 1 m^2) with an extraction area of 0.1 m^2 and 640 apertures. At ELISE the plasma is generated by four drivers powered by two RF generators with 180 kW generator power each at a frequency of 1 MHz. To gain early experience with an ITER like source, the ELISE source and extraction system is designed as close as possible to the ITER design.

The paper focuses on physical aspects, operational issues and the performance of these size scaling experiments, i.e. from the prototype source towards the ITER relevant size at ELISE. The following aspects are going to be addressed: the magnetic filter field applied to reduce electron density and temperature, the biasing of the plasma grid applied to suppress the co-extracted electrons, consequences on plasma drifts, the RF efficiency with respect to atomic and positive ion fluxes towards the grid, and the caesium conditioning, its distribution as well as the caesium consumption. Operation in deuterium will be compared to operation in hydrogen.

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O5-03

Advanced ion beam calorimetry for the test facility ELISE

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The negative ion source test facility ELISE (Extraction from a Large Ion Source Experiment) is in operation since the beginning of 2013 at the Max-Planck-Institut für Plasmaphysik (IPP) in Garching bei München [1]. The large radio frequency driven ion source of ELISE is about 1x1 m^2 in size and can produce a plasma for up to 1 h. Negative ions can be extracted and accelerated by an ITER-like extraction system made of 3 grids with an area of 0.1 m^2, for 10 s every 3 minutes. A total accelerating voltage of up to 60 kV is available, i.e. a maximum ion beam power of about 1.2 MW can be produced. ELISE is equipped with several beam diagnostic tools for the evaluation of the beam characteristics.
In order to evaluate the beam properties with a high level of detail, a sophisticated diagnostic calorimeter has been installed in the test facility at the end of 2013. The diagnostic calorimeter is split into 4 copper plates with separate water calorimetry for each of the plates. Each calorimeter plate is made of 15x15 copper blocks, which act as many separate inertial calorimeters and are attached to a copper plate with an embedded cooling circuit. The block geometry and the connection with the cooling plate are optimized to accurately measure the time-averaged power of the 10 s ion beam. 48 thermocouples are installed in as many blocks to reconstruct two vertical and two horizontal beam profiles. In addition, the surface of the blocks is covered with a black coating that allows infrared (IR) thermography which provides a 2D profile of the beam power density.

The paper describes the beam calorimetry in ELISE, including the methods used for the IR thermography and beam profile evaluation. The results obtained for different experimental conditions will be presented and discussed.

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Optical Cavity Design for application in NBI systems of the future generation of Nuclear Fusion reactors

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The ITER construction raises the question of the next step toward a real Fusion power plant, DEMO, which should be the first fusion reactor with electricity production. One of the main targets of DEMO being the demonstration of electricity generation with self-sufficient fuel supply at a moderate cost; in this respect, an enhancement of the NBI system efficiency is required. A project for a new injector concept, called Siphore (SIngle gap PHOtoneutralizer energy RE-covery injector), has been started by collaboration between CEA and several French universities. The fundamental aspect of Siphore is the implementation of Fabry-Perot cavities (1-2MW of light power per cavity) to photo-neutralize a high energetic beam of D-. The photodetachement, which substitutes the ITER gas cell neutralizer, should allow the implementation of an energy recovery system and reach a DEMO relevant NBI wall-plug efficiency (η>60%). The work which will be presented aims to analyze the possibility of realizing an optical cavity with suitable properties for applications in NBI systems of future generations of nuclear fusion reactors. So far, the main issue for the implementation of the Siphore photo-neutralization principle appears to be the absorption of the intracavity optical power by the mirror coatings. Indeed, this causes important temperature gradient, with consequent deformations of the mirror surfaces. On one hand, the mirror curvature radii can change (e.g. a flat mirror can assume a curvature radius of few thousands meters) leading to modifications of the mode resonating inside the cavity and to stability issues; on the other hand, mirror surface deviations from a spherical profile generate scattering losses (few hundreds of ppm). As a consequence, the reachable intracavity power for a given input power is reduced[1]. Several thermal effect compensation systems are then considered, in order to reduce the thermal effects on the cavity mirrors.

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O5-05

A CW radiofrequency ion source for production of negative hydrogen ion beams for cyclotrons

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A new MCC30/15 cyclotron has been installed at the JYFL accelerator laboratory providing up to 200 µA 30 MeV H^+ and 60 µA 15 MeV D^+ for use in nuclear physics experiments and applications. The filament-driven ion source currently used for production of the injected H^- and D^- beams is limited to about 130 h continuous operation between filament changes when high beam intensity is needed. The ion source is located in the cyclotron vault and therefore a significant waiting time for the vault cooldown is required before filament change is possible. This kind of operation is not acceptable as 350 h and longer experiments are expected.

A CW 13.56 MHz radiofrequency-driven ion source RADIS [1] for production of H^- and D^- beams is under development at the University of Jyväskylä for replacing the filament-driven source. The RF ion source has a 20-pole multicusp plasma chamber, an electromagnet-based magnetic filter and an external planar spiral RF antenna behind an AlN window. The extraction is a 5-electrode system with an adjustable puller electrode voltage for optimizing the beam formation, a water-cooled electron dump electrode and an accelerating einzel lens. At 3500 W of RF power, the source produces 1 mA of H^-, which is intensity needed at injection for production of 200 µA H^+ with the filament-driven ion source. A simple pepper-pot device has been developed for characterizing the beam emittance. The source performance, the emittance measurements and the results from the durability test are reported. Also plans for improving the power efficiency are discussed.

References

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O5-06

CW Hydrogen Negative Ion Beam Production with 2.45GHz Microwave Driven Cs Free Compact Volume Ion Source with Permanent Magnet at PKU

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Some circular accelerators that used for PET only need several mA H^- ion beam for their routine operation. Caesium free negative ion source is a good choice for those facilities because of its simple structure and its easy operation requirement. At Peking University (PKU) we developed a 2.45 GHz microwave driven permanent magnet volume effect H^- ion source. It is a non- caesium type. Its discharge chamber dimension is ϕ 40 mm x 70 mm and its outside size is ϕ 140 x120 mm. The magnet field was provide by permanent magnet. Test was carried out in early June. An 8 mA CW pure H^- beam at 30 kV through a ϕ 6 mm aperture with 500 W rf power has been produced with this compact source. Its power efficiency reaches 16 mA/kW and beam intensity is about 53 mA/cm^2. Four hours successive running proves its high quality. Details will be given in this paper.

P1-01

Photoelectron emission from metal surfaces induced by VUV-emission of filament driven hydrogen arc discharge plasma

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Photoelectron emission measurements have been performed using a filament-driven multi- cusp arc discharge volume production H^- ion source (LIISA). It has been previously measured with the same ion source that 15-30 % of the discharge power is dissipated via light emission in the measured VUV-range (120-250 nm) [1]. This implies that plasma dynamics and their contribution to H^- production may be affected by surface processes on plasma chamber walls induced by radiation exceeding the surface work function of the wall material. Photoelectron emission is significant only in the short wavelength range of hydrogen spectrum due to the energy dependence of the common metal's quantum efficiency. This is demonstrated experimentally by filtering the wavelength range of the radiation incident on the sample surface. It is shown that the photoelectron emission from Al, Cu, Mo, Ta, and stainless steel (SAE 304) surfaces is predominantly caused by radiation at wavelengths below 150 nm. In the experimental set-up the photoelectron current is measured from the target, which is placed axially towards the extraction aperture, and the emitted photoelectrons are collected with a biased anode. Photoelectron currents are measured as a function of discharge current and voltage and neutral hydrogen pressure. The maximum photoelectron flux from the plasma chamber wall is estimated from the measured currents by taking into account the measurement geometry and integrating over the observed plasma volume and the observed space angle.

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Temperature and substrate dependencies of the work function of cesiated materials under ion source conditions in vacuum and plasma

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Negative hydrogen ion sources for the neutral beam injection system (NBI) of ITER are based on the surface conversion process: atomic hydrogen and hydrogen ions produced in a low-temperature hydrogen plasma are converted to negative ions at a low work function surface. For this purpose the so-called converter surface is covered with caesium resulting in a significantly reduced work function and thus increased H^- production. Maintaining a stable low work function converter surface is a main task for generating sufficient negative hydrogen ions and a constant and reproducible ion beam. However, due to the high chemical reactivity of the alkali metal, impurities from the background gas and particles from the hydrogen plasma can be embedded into the caesium layer which deteriorates the work function.

In order to investigate influencing factors on the work function of cesiated surfaces under ion source conditions, fundamental studies are carried out at the dedicated experiment ACCesS (**A**ugsburg **C**omprehensive **Ces**ium **S**etup) [1,2]. The experiment is equipped with a multitude of simultaneously applicable diagnostics and a reliable caesium source [3] based on a caesium alloy dispenser. The investigations are geared towards the dependencies of the work function of stainless steel and molybdenum samples on the caesium flux onto the surface, the surface temperature and the influence of plasma exposure.

Thereby, the surface temperature affects the impact of impurities on the caesium layer as well as the equilibrium caesium coverage. The interaction with a low-temperature hydrogen plasma in front of the surface can, in turn, have several additional effects: cleaning of the caesium layer due to impinging ions and intensive UV radiation on the one hand, and degradation of the layer due to incorporation of particles from the plasma and erosion of the caesium coating on the other hand. The impact and interplay of these aspects under ion source conditions is crucial for generating and maintaining a stable low work function converter surface for ITER NBI.

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P1-03

Neutral particle dynamics in SPIDER

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Extension of previous studies [1,2] on modelling of the spatial distribution of the plasma parameters in the SPIDER source [3] of negative hydrogen/deuterium ions, currently under development in Consorzio RFX (Padua) regarding ITER is presented. The gas-discharge conditions (applied rf power, input gas flow rate, geometry of the extraction grid) are according to Ref. [3]. The study is within the fluid plasma theory for low-pressure discharge description. The model is two-dimensional, with axial symmetry: The modelling domain is half of a driver with the volume from the large-area chamber (common for all the eight drivers) belonging to it. The rf power deposition via cylindrical coil inductive driving is simulated with super-Gaussian distribution both in the radial and axial directions. Detailed description of the neutral particle dynamics and of the surface processes on the walls [4] is stressed on. The initial set of equations includes the particle balance equations of the electrons, of the three types of positive hydrogen ions and of the hydrogen atoms and molecules, the energy balance equations for electrons, hydrogen atoms and molecules and the Poisson equation. The obtained results are for the spatial distribution of the plasma parameters and of the fluxes (particle and energy fluxes) in the source. Comparison with the former results [1] shows the influence of the neutral particle dynamics on the discharge behaviour. The discharge regime is also discussed.

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P1-04

Single discharge of the matrix source of negative hydrogen ions: influence of the neutral particle dynamics

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The study presents two-dimensional (2D) fluid-plasma-model description of a planar-coil inductively-driven discharge, considered as a single element of the matrix source of negative hydrogen ions [1]. The concept for the source design is based on theoretical results for strong accumulation of the ions at the position of maximum of dc potential in small radius discharges [2−6]. The modelling directed up to now towards description of the charged particle behaviour (with account for the free-fall regime of discharge maintenance at low gas pressures and a stress on the negative ion behaviour) as well as of the discharge electrodynamics (the rf power deposition at inductive discharge driving) has been carried out under the conditions of a constant gas pressure in the source and with an assumption for the gas temperature value, i.e. the redistribution of the hydrogen atoms and molecules is given by the equation of state. This study, avoiding the assumption for a constant gas pressure, answers the question for the influence of the neutral specie dynamics on the discharge structure. Involving recent experience on modelling of a multi-chamber source [7], the modelling of the single element of the matrix source is extended here with accounts for the energy balance of the neutral species (hydrogen atoms and molecules), for the input gas flow (with regards to the experiments which are in a flowing gas) as well as for the surface processes at the walls.

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A Collisional Radiative model for caesium and its application to an RF source for negative hydrogen ions

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A collisional radiative (CR) model for caesium in low-temperature, low-pressure hydrogen-caesium plasmas is introduced[1]. This model includes the caesium ground state, 14 excited states, the singly charged caesium ion and the negative hydrogen ion. The reaction probabilities needed as input are based on literature data, using some scaling and extrapolations. Additionally, new cross sections for electron collision ionization and three-body recombination have been calculated.

The relevance of mutual neutralization of positive caesium ions and negative hydrogen ions is highlighted: depending on the densities of the involved particle species, this excitation channel can have a significant influence on the population densities of excited states in the caesium atom. This strong influence is successfully verified by optical emission spectroscopy measurements performed at the IPP prototype source for negative hydrogen ions. Figure 1 shows population densities of three excited states in the caesium atom measured by optical emission spectroscopy for two lines of sight (LOS) compared to values calculated by the CR model. For the second LOS a good agreement between measurement and the model is possible only when the mutual neutralization channel is taken into account.

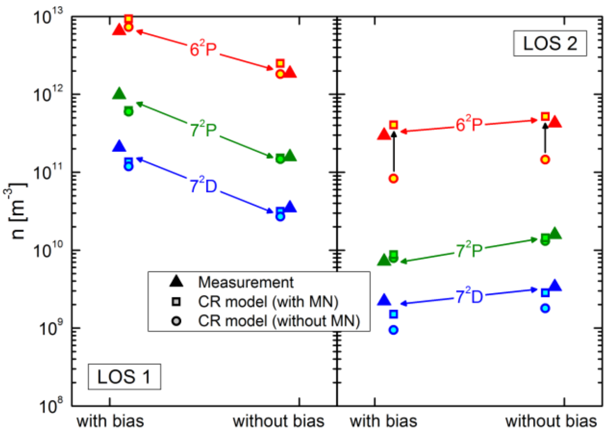

Figure 1. Measured and calculated population densities for three excited states in the Cs atom.

This means that population models for caesium in the electronegative plasma of the boundary layer in negative ion sources based on surface conversion (i.e. in plasmas with a high density of H^-) need to take into account the mutual neutralization process. Depending on the field of application such models can either be an extended Corona model or the present CR model. Since the latter takes into account several excited states and additionally the caesium ion, it represents an important prerequisite for deducing the total caesium density (including the population densities of the excited states and the density of the ion).

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Numerical and experimental study of atomic transport and Balmer line intensity in Linac4 negative ion source

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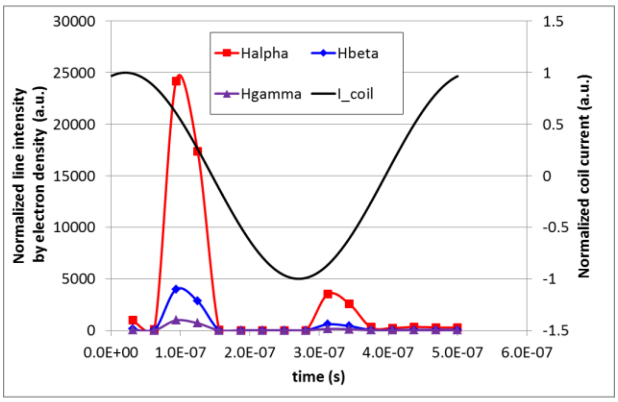
Balmer lines emission observed in the RF-driven hydrogen plasma generators of Linac4 ion sources are studied by numerical analysis based on atomic transport and Collisional Radiative (CR) models which take into account the effect of non-equilibrium Electron Energy Distribution Function (EEDF) in the RF plasma.

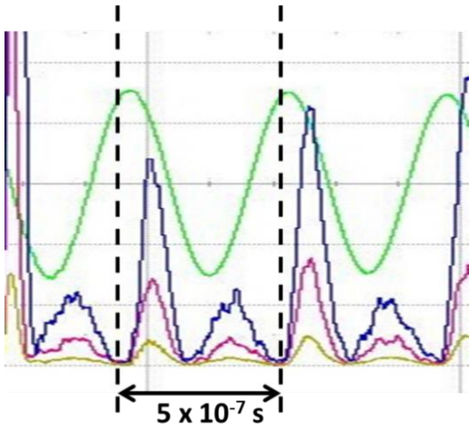
The obtained Balmer H_α, H_β and H_γ lines intensities are compared to time resolved photometry measurements to validate our physical model (Fig.1). A preliminary result suggests that the capacitive coupling of the RF field taking place during the initial phase of plasma ignition determines the time structure of the Balmer lines [1].

The simulated emission provides relative intensities of the Balmer lines that are compared to spectrometry measurement. Absolute calibration of the light collection system is described and leads, within the precision of the measurement, to quantitative information on the photon fluxes within the hydrogen plasma.

Simulation of electronic and atomic density distributions will improve the understandings of the dominant observables namely quantitative photometry and spectrometry. The flux of neutrals, should contribute to improve the understanding of negative hydrogen ion production rate in Cs-seeded surface sources.



(a)



(b)

Fig.1 Qualitative comparison of Balmer line emission simulated by CR model (a) to combined photometry, and spectrometry measurements (b).

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P1-07

Negative Hydrogen Ion Yields at Plasma Grid Surface in a Negative Hydrogen Ion Source

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We have shown that energy and angular distributions of hydrogen atoms leaving the surface due to hydrogen ion impact can be computed by the ACAT (Atomic Collision in Amorphous Targe) code [1]. In the previous study, the final charge state of an outgoing hydrogen atom was not considered. Several theoretical models to compute negative ionization probability have been reported and these can be coupled to the ACAT code to estimate the total negative ion yield by hydrogen impact. We have introduced the amplitude model proposed by Rasser *et al* [2] and the threshold model based on experimental result by Seidel *et al* [3] into the ACAT code. Figure 1 shows the calculated results of H^- ion yield due to the backscattering of an incident hydrogen ion and that due to ion induced desorption for the threshold model.

The desorption component, as it contains substantial amount of low energy hydrogen atoms, produces less negative ions compared with back-scattering component at low potential difference between the plasma and the plasma grid. Meanwhile, the average kinetic energy of surface produced H^- ions due to reflection increases with the potential difference. Higher energy H^- ions should traverse the low electron temperature extraction region, and reach driver region to be neutralized in high electron temperature plasma.

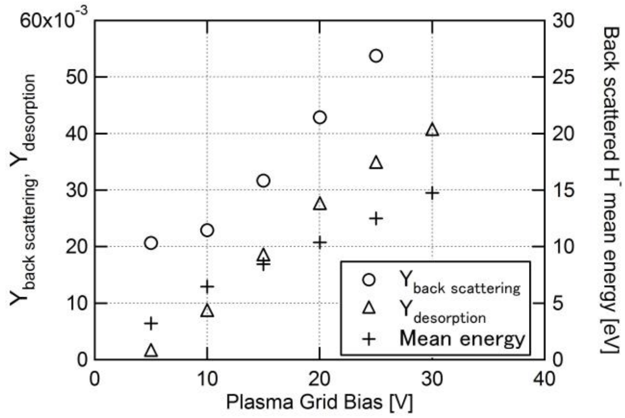

Figure 1. Probabilities to be reflected and desorbed as a H^- ion from cesiated metal surface. The plasma potential is assumed to be zero.

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Thermodesorption analysis: input in understanding of negative ion surface production

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Negative ion surface production in plasmas has been studied in the context of fusion where H^- surface production in Cs seeded plasmas is of a primary interest for neutral beam injection devices. Although surface production is much lower in Cs free plasmas, it may be non-negligible. Indeed it has been observed that significant numbers of H^- ions can be created on a HOPG (Highly Oriented Pyrolitic Graphite) surface upon positive ion bombardment in H_2 plasmas.

In the experiment reported here, a sample was placed facing a mass spectrometer in the diffusion chamber of a low-pressure plasma reactor. Measurements were performed at 2.0 Pa hydrogen gas pressure with an injected RF power of 20 W in the capacitive coupling mode. The sample was biased negatively with respect to the plasma potential, this resulting in surface formation of H^- ions upon positive ion bombardment. Surface produced H^- ion distribution functions (NIDFs) were measured by means of the energy-resolved Hidden EQP mass spectrometer while heating the sample from room temperature to 750°C.

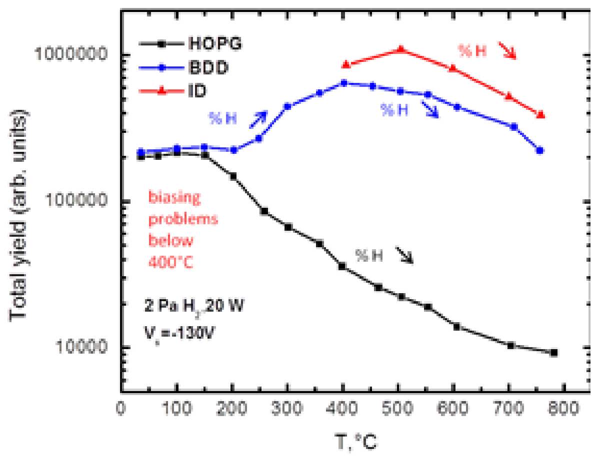

Figure 1. Temperature evolution of NI yields for different materials at 2.0 Pa H_2, RF injected power of 20W and the surface bias of -130V.

The evolution of the negative ion yields (defined as the area below IDF curves) with surface temperature for HOPG, boron-doped diamond (BDD) and intrinsic diamond (ID) films is represented in Figure 1. The NI yield on HOPG decreases monotonously with temperature starting from 150°C. On the contrary, BDD and ID show up to 5 times NI yield increase at 400°C and 500°C correspondingly, which together with their electronic properties makes them promising materials for negative ion surface production.

In order to understand the nature of the NI yield evolution with temperature which is related to the surface state change, the thermodesorption (TPD) analysis was involved. The samples were exposed to D_2 plasma at usual conditions (2.0 Pa, 20 W) for 30 minutes. After the exposure, the samples were transferred at air to the TPD equipment consisting of an ultra high vacuum chamber with background pressure 5×10^{-10} Torr which is fitted with a differentially pumped mass spectrometer system and oven for heating the sample. Measurements were carried out preferably just after the sample exposure.

An extensive bibliographic research helped to trace the surface state changes of the materials with temperature and identify the phases responsible for the elevated negative ion production. Estimation of the spectrometer mass sensitivity has allowed the calculation of the full amount of desorbed species and their dynamics. The negative yield evolution has been shown to correspond to the total deuterium content on the surface.

P1-09

Study of the Negative Ion Extraction Mechanism from a Double-Ion Plasma in Negative Ion Sources

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To clarify the extraction mechanism of H^- ions from H^- negative ion sources is an important subject for optimizing the negative ion beam current. Double-ion plasma layer, which is consisting of H^+ and H^- ions, has been observed in the vicinity of Plasma Grid (PG) of Cs-seeded H^- negative ion sources [1], [2].

We have developed a 2D3V Particle-In-Cell (PIC) model of the extraction region, aiming to clarify the basic extraction mechanism of H^- from the double-ion plasma. The result shows the same tendency of the H^- ion density n_{H^-} as that observed in the experiments, i.e., n_{H^-} in the upstream region away from the plasma meniscus (H^- emitting surface) has been reduced by applying the extraction voltage.

After the system reaching the quasi-steady state in the simulation, a relatively slow temporal oscillation of the electric potential compared with the electron plasma frequency has been observed in the upstream region from the plasma meniscus and propagating towards the plasma meniscus. In other words, small fluctuating electric fields are still existing, even after the extraction field has been shielded out from the plasma region and the plasma meniscus has been formed. It is possible for the H^- ions to be transported by this fluctuating electric field towards the plasma meniscus and then extracted. Therefore, it is important to understand the cause of the fluctuating electric field.

This paper will show the result of a systematic study by a) theoretical approach (e.g., deriving a dispersion relation for the electronegative plasma under the same condition in the numerical simulation), and by b) numerical approach (e.g., Fourier analysis of temporal and/or spatial spectrum of the fluctuating electric field for the numerical simulation results).

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P1-10

Study of Plasma Meniscus Formation and Beam Halo in Negative Ion Source Using the 3D3VPIC Model

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In surface-produced hydrogen negative ion sources of neutral beam injection (NBI) system for fusion devices, heat load on the acceleration grid caused by beam halo may limit the injection power and the beam pulse length. It has been shown in Ref. [1] that the beam halo is possibly caused by the relatively deep penetration of an H^- ion emitting surface (plasma meniscus) into the source. The plasma meniscus is formed in the H^+- H^- double ion plasma close to the plasma grid (PG) under the strong H^- surface production. It has been shown in Ref. [2] and [3], the thickness of the double ion plasma layer and plasma meniscus formation depends on electron confinement time, which is determined by the ratio of the characteristic time of electron escape along the magnetic field and the characteristic time of electron diffusion across the magnetic field.

However, the above analysis has been obtained by 2D3V particle in cell (PIC) simulation. A self-consistent three dimensional PIC code of extraction region in negative ion sources based on Ref. [4] have been developed in Ref. [5]. The purpose of this study is a) to clarify the effect of the electron loss along the filter field line on plasma meniscus formation and b) to propose how to control the plasma meniscus. Especially, the dependence of the plasma meniscus on the electron loss rate at the inner wall of the ion sources will be investigated and reported in the presentation.

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Electron Temperature Profile Measurements on a Spontaneous-Focusing State in High-Current-Density and Low-Energy Ion Beam Using the Concave shape of Electrodes

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A spontaneous-focusing phenomenon of low energy ion beam (~150 eV) with high current density (~3 mA/cm^2) was observed using three sets of concave electrodes with nominal focal length around 350 mm (acceleration, deceleration and grounded electrodes) [1-3]. To study the mechanism of this phenomenon, electrostatic probes with unique structure have been installed into an ion beam propagation chamber into which the ion beam is injected [4]. We have tried to measure radial profiles of ion and electron current densities, electron density, electron temperature and space potential by using Faraday cups and the probes under the strong flux of ion beam component. The radial profiles of electron density and temperature have been measured by the double probe, which gives the electron density about ~1.7×10^9 cm^{-3}, and the electron temperature about ~0.8 eV at the center of ion beam in the spontaneous-focusing state. A large amount of low temperature electrons is accumulated around the center region of the ion beam, when the ion beam is in the spontaneous-focusing state. Asymmetric I_p - V_p scanning signal indicates the existence of slow ions and fast beam ions components in the double probe measurements using the P_1 and P_3 pairs as shown in Fig.1 where the probe is along with the ion beam line. It is found that the applied the probe voltage affects on the ion current density in the ion beam propagation chamber. However, the effect is much smaller in the double probe than that in the single probe. In the presentation, we will present the measured results of double probes having perpendicular and parallel directions to the ion beam, single probe and Faraday cups, and will compare their results for estimating possible errors.

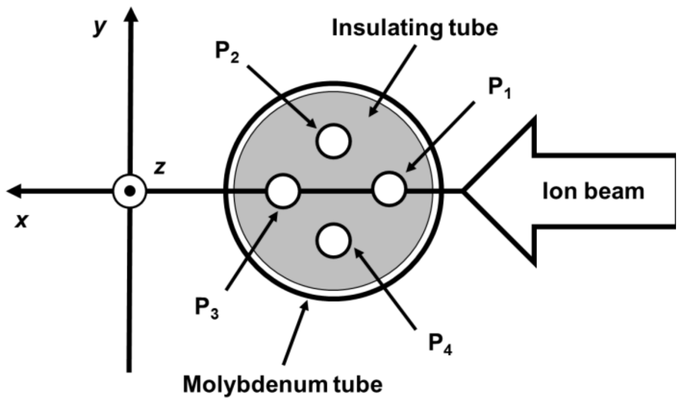

Figure 1. Cross-sectional view of the electrostatic probe.

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P1-12

Optimization of a Single Element of the Matrix Source Regarding the Extracted Current of Negative Hydrogen Ions

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The study presents experimental results for the extracted negative hydrogen ion current (and the co-extracted electron current) from a source based on volume production of the ions: a source with the design of a matrix of low gas-pressure small-radius discharges with planar coil inductive driving. The experiments have been carried out in a two-chamber source transformered into a single element of a matrix source by inserting the extraction device (a Faraday cup) at the end of the first chamber, at the transition between the two chambers. The first chamber of the source is a quartz tube with a radius of 2.25 cm; a 3.5 turn planar coil is used for the rf discharge driving. First results on the extraction [1] have shown high current density of the negative ions, moreover, obtained without any optimization. The optimization of the single discharge of the source with regards to the extracted current presented here shows the influence of: (i) the length of the discharge tube, (ii) the reference electrode in the discharge volume, (iii) the position of the magnetic filter [2, 3], and (iv) the position of the permanent magnets for separation of the co-extracted electrons from the extracted negative ions in the extraction device. The gas-discharge conditions are: gas-pressure of 6 mTorr and applied rf power varied between 50 W and 200 W.

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Emittance measurements of the J-PARC RF-driven H^- Ion Source

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The J-PARC (Japan Proton Accelerator Research Complex) cesiated rf-driven H^- ion source was successfully developed to satisfy the J-PARC second stage requirements of an H^- ion beam of 60mA within normalized emittances of 1.5πmm•mrad both horizontally and vertically, a flat top beam duty factor of 1.25% (500μs×25Hz) and a life-time of 2000 hours [1, 2]. In the source, the interesting dependences of the transverse emittances on the temperature of the plasma electrode (PE) and the 2MHz rf-power were observed. In this paper, the emittances measured for more various conditions are presented. The detailed specifications of the emitannce monitors are also presented.

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P1-14

Spectral diagnostics based on Doppler-broadened H_α line shapes in a single element of the matrix source

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The study is in the trends of current activity in the work on the matrix source of negative hydrogen ions [1] directed towards the neutral gas component behaviour. A method for emission spectral diagnostics of the source is developed, which can be readily applied to various low pressure hydrogen discharges. It is based on analysis of Balmer line profiles. The spectral diagnostics from line profiles faces several challenges connected on one hand with the need of high spectral resolution, sensitivity and linearity of the detecting system. On the other hand the analysis of the experimental data requires appropriate models for the line shapes taking into account details of the plasma kinetics. The study presents a simple setup, consisting of a Fabry-Perot interferometer and a digital camera used for spectral investigation of a single element of the matrix source of negative hydrogen ions: a small radius discharge with planar-coil inductive driving. The gas-discharge conditions are: applied rf power P = (50 – 150) W at a frequency of 27 MHz and gas pressure in the range p = (90 – 160) mTorr. The observed atomic spectral line profiles have a complex shape consisting of a central nearly Gaussian-shape peak and a wide pedestal. The developed model takes into account the fine structure of the Balmer lines and provides description of the line pedestal following Ref. [2]. The results from fitting the experimental line shapes indicate the existence of thermal atoms as well as of non-thermal hydrogen atoms created by exothermic reactions. Based on these data estimates of the temperature of hydrogen atoms are presented.

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P1-15

Characterization of Large-Area High-Power RF Ion Source for Neutral Beam Injectors

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Large-area high-power radio-frequency (RF) driven ion source is being developed in Germany for the heating and current drive (H&CD) of an ITER device [1]. Negative hydrogen (deuterium) ion sources will be a major component of neutral beam injection (NBI) systems in the future large-scale fusion devices such as an ITER and DEMO. Positive hydrogen RF ion sources were a major component of the NBI systems on ASDEX-U and W7-X devices [2]. A test large-area high-power RF ion source (LAHP-RaFIS) is being developed for steady-state operation (more than 300 seconds) at the Korea Atomic Energy Research Institute (KAERI) to extract the positive ions, which can be used for the NBI heating and current drive systems in the present fusion devices, and to extract the negative ions for negative ion-based plasma heating and for future fusion devices such as a Fusion Neutron Source and Korea-DEMO [3]. The test RF ion source consists of a driver region, including a helical antenna and a discharge chamber, and an expansion region (magnetic bucket type). RF power can be transferred at up to 10 kW with a fixed frequency of 2 MHz through an optimized RF matching system. An actively water-cooled Faraday shield is located inside the driver region of the ion source for the stable and steady-state operations of high power RF discharge. The uniformities of the plasma parameter are measured at the lowest area of the expansion bucket using two RF-compensated electrostatic probes along the direction of the short- and long-dimensions of the expansion region. The distribution of plasma parameters is compared with axial and azimuthal arrangements of the bucket magnet in the expansion region.

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P1-16

Spatial distribution of electron density in large-scaled negative ion source

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The surface wave probe (SWP) is installed to the large-scaled negative ion source in order to measure the local electron density. The behavior of the electron in the extraction region has been investigated without beam extraction by the SWP [1]. In recent studies, the drop of the negative hydrogen density has been observed in the vicinity of the plasma grid when the extraction voltage is applied [2]. In this paper, we show the spatial distribution of the electron density during beam extraction and discuss the dynamics of the electron in the extraction region.

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P1-17

Effects of source size of plasma production on H^- production and beam extraction for neutral beam system

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High performance ion sources are required for neutral beam injection heating in the next generation. Our previous studies have shown that a field effect transistor (FET)-based high power RF amplifier with the frequency below 0.5 MHz enables us to operate RF ion sources[1, 2]. As a next step, we have developed a large-scaled ion source consisting of Alumina ceramic tube with 230 mm in inner diameter and 300 mm in length, which are wound by a RF loop antenna. Characteristics of plasma production in the source were measured with helium and argon gases as well as hydrogen gas in order to clarify the high density plasma production with this source. High density hydrogen plasma more than 10^{18} m^{-3} was obtained at p = 0.3 Pa and H^- beam was measured by a calorimeter. In this presentation, we report recent experimental results of high density hydrogen plasma production, beam extraction and attempt for photo-neutralization.

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P1-18

A multi-beamlet analysis of the MITICA accelerator

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The thermo-mechanical analysis and the mechanical design of the accelerator of MITICA (i.e. the full size prototype of the ITER neutral beam injector under contruction at RFX) are based on the calculation of the power deposition induced by particle impacts. This calculation is performed by EAMCC, a relativistic particle tracking code based on the Monte-Carlo method for describing collisions inside the accelerator, under prescribed electric and magnetic fields. The magnetic field maps are produced by 3D codes, while the electric field maps come from the 2D axisimmetric code SLACCAD.
In order to perform a multi-beamlet analysis, which allows to take into account the beamlet-beamlet repulsion, and to consider other effects neglected under the hypotesis of axisimmetric geometry, a fully 3D version of the code is required. Moreover, an accurate description of the variation of the two fields inside the accelerator requires an electric and a magnetic fields maps with a sufficiently fine mesh, but the size (in terms of required memory) of these 3D maps does not allow to extend the domain of an accurate simulation over a single beamlet.
In this paper a modified version of EAMCC, fully 3D, capable of modifying the mesh of the 3D maps and of dealing with uneven meshes is presented. A finer mesh is used just in the regions where a more detailed description of the fields is required, for a more realistic simulation.
A comparison between the original code and the modified version is presented at first, as a validation of the modifications introduced in the latter. Subsequenlty, the main results of a single-beamlet analysis performed with the two versions of the code are shown and the differences between the 2D and the 3D simulations discussed. The last part is dedicated to the multi-beamlet simulation of the accelerator.

P1-19

An electrostatic steering system to focus the beamlets in advanced neutral beam injectors

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Neutral beam injection is the main method to heat the plasma in magnetic confinement fusion devices. In high energy injector (E>100 KeV/amu), it is convenient to produce neutrals by conversion of negative ions via electron detachement reactions.
In the case of large fusion devices, as ITER, several Ampere of H^- or D^-, current are required to satisfy the heating power demand, calling for a large extraction area on the ion source, hence for the use of gridded electrodes in the accelerator, allowing the acceleration of thousands of beamlets together.
A careful aiming system is required to merge these beamlets, and to deliver their power in the plasma chamber, usually placed far from the the accelerator: in the case of the ITER, the focal point is 24.5 meters away from the beam source. In nowadays injectors, the aiming is realized by aperture offset tecnique or by grid shaping. This paper discuss an alternative concept of beamlets aiming, based on an electrostatic "steerer" to be placed at the end of the accelerator. A feasibility study of this component is also presented, and its main advantages and drawbacks with respect to other methods are discussed.

P1-20

Semi-analytical Modeling of the NIO1 Source

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NIO1 is a compact and versatile negative ion source, with a total current of 130 mA accelerated to 60keV. Negative ions are created inside the plasma, which is inductively coupled by an external RF cylindrical coil operating in the range of 2 ± 0.2 MHz. The plasma is confined in the source chamber (a 50 mm radius cylinder) by a multipole magnetic field and the ions are extracted through a 3x3 matrix of apertures. The use of cesium, to enhance the negative ion production by H_0 bombardment of the surfaces, is foreseen in a second stage of the operation, so that at present time the source is operating in a pure volume configuration. This paper presents a set of analytical and numerical models, aimed to describe the main physical phenomena occurring in the source, including the RF coupling with the plasma, the evolution of plasma parameters in the source, the electron and energy distribution under the effect of the magnetic filter field and the accelerated beam optics. With respect to more sophisticated models of negative ion sources here we aimed to develop fast tools capable of qualitatively describing the response of the system to variations in the basic operating parameters. The findings of these models are finally compared with the first results of NIO1.

P1-21

Negative Ion Beam Characterisation in BATMAN by mini-STRIKE: Improved Design and New Measurements

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The ITER project requires additional heating provided by two injectors of neutral beams resulting from the neutralisation of accelerated negative ions. To study and optimise negative ion production, the SPIDER test facility (particle energy 100keV; beam current 50A) is under construction in Padova, with the aim of testing beam characteristics and to verify the source proper operation. The SPIDER beam will be characterised by the instrumented calorimeter STRIKE, whose main components are one-directional carbon fibre carbon composite tiles.
Some prototype tiles have been employed in 2012 as a small-scale version (mini-STRIKE) of the entire system to investigate the features of the beam of the device BATMAN at IPP-Garching. As the BATMAN beamlets are superposed at the measurement position, about 1m from the grounded grid, an actively cooled copper mask is located in front of the tiles; holes in the mask create an artificial beamlet structure.
Recently the mini-STRIKE has been updated, taking into account the results obtained in the first campaign. In particular the spatial resolution of the system has been improved by increasing the number of the copper mask holes. Moreover a custom measurement system has been realized for the thermocouple signals and employed in BATMAN in view of its use in SPIDER.
The present contribution gives a description of the new design of the system as well as of the thermocouple measurements system and its field test.
A new series of measurements has been carried out in BATMAN. The results of the BATMAN beam characterisation in different experimental conditions are presented, including a campaign with varying vessel pressure to investigate the effect of space charge compensation.

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

Metal Negative Ion Beam Extraction from a Radio Frequency Ion Source

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A capacitively coupled 13.56 MHz radio frequency (RF) driven magnetron sputter type ion source has generated negative ions by Cs addition [1]. However, the amount of Cs consumption was very high (about 100 mg/hr), and further investigation for the method to produce negative ion more stably is continued. The concept of volume production of hydrogen negative ions has been successfully applied to the production of a negative lithium ion beam [2], and a negative sodium ion beam [3]. Meanwhile, RF sputtering process can form metal particle flux in the plasma source to produce positive ion beams [4]. Thus, we have started to investigate volume production of metal negative ions via RF sputtering processes.

The ion source has 60 mm inner diameter and 67 mm length. Two rows of permanent magnets are arranged at the side wall of the cylindrical chamber. Together with three rows another circular row of magnets and a single cylindrical magnet attached at the end flange form a radial cusp magnetic field. The 53 mm inner diameter 60 mm long hollow cylindrical sputter target is made of 0.5 mm Cu. Radio frequency power at 13.56 MHz is directly supplied to the target to maintain plasma discharge and induce self-bias to the target for sputtering. When enough power is directed to the target, substantial amount of metal atom flux builds up in the source for ion production. However, Ar gas introduction is required to maintain a stable discharge.

As a preliminary test, positive ion beam current ratio of Cu^+/Ar^+ is being measured.

The ion beam current ratio of Cu^+/Ar^+ is still only 7.0 % at about 1 Pa Ar gas pressure because of poor RF power matching to the sputtering electrode. Extraction of Cu negative ion beam will be tested after optimizing the RF power input to the system.

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P1-23

Temporal Characteristics of Negative Ions in the Pulsed RF Hydrogen Ion Source

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Compared with surface-produced negative ion sources using Cs, volume-produced negative ion sources have advantages that they have good reproducibility and then do not need for Cs conditioning. In RF negative ion sources without Cs, hydrogen negative ions are mainly produced in dissociative electron attachment by collisions of highly vibrationally excited hydrogen molecules with low energy electrons. The dissociative electron attachment also requires high energy electrons which are efficient for generation of highly vibrationally excited molecules. The control of electron energy or electron temperature is thus essential in volume production of negative ion. Conventional approach to electron temperature control is a separation of the reactor into RF driver of high electron temperature and expansion region of low electron temperature. In contrast with conventional spatial control, temporal control using pulsed RF power has been investigated by experiments and global model analysis. Pulse frequency and duty were varied in the range of 0.2 ~ 10 kHz and 5 ~ 95 %. Higher electronegativities (i.e., the ratio of the negative ion density to the electron density) with several tens of percent were observed in after-glow, compared to a few percent electronegativities of active-glow. This is attributed to the rapid decrease of electron temperature by collisional energy loss and relatively longer life time of highly vibrationally excited molecules than one of charged particles, which results in improved dissociative electron attachment. This also leads to sheath collapse which is favorable for negative ion transport. More details on experimental data and analysis of the optimum pulse frequency and duty for higher negative ion current will be presented.

Low EnergyBeam Transport System Developments

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For high brightness beam production it is important to preserve the brightness in the low energy transport system (LEBT) used to transport and match the ion beams in to the next stage of acceleration, which are mostly RFQs. One recent review of LEBT for positive and negative ion beams is presented in [1]. Now is commonly accepted that LEBT systems for high current accelerator applications require solenoid focusing with a space charge compensation, while electrostatic focusing has only been demonstarted with up to ~60 mA.

Two solenoid LEBTs are succesfully used for high current (>100 mA) proton beam transportation. However, preservation of low emittances (~0.15 mm mrad) requires the addition of a heavy gas (Xe, Kr), which causes ~10% of proton loss in ~1 m long LEBT [2]. Similar Xe densities would be required to preserve low emmittances of the H^- beams, but such gas densities cause unacceptably high H^- beam losses [3]. A strong electrostatic focusing LEBT has been successfuly adopted for transportation of high current H^- beams in SNS front end [4]. Some modifications of such electrostatic LEBTs can be expected to improve the reliable transport of intense positive and negative ion beams without greatly degrading their low emittance. Proposed improvement of electrostatic LEBT are discussed.

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CW Operation of a Saddle Antenna RF Surface Plasma Ion Source*

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CW operation of a saddle antenna RF surface plasma ion source (SA SPS) has been tested in a test stand [1].
A general design of the CW SA SPS is close to the pulsed version [2,3]. Some modifications were made for improving a cooling and cesiation stability. The extracted collector current can be increased significantly by optimization of the longitudinal magnetic field in the discharge chamber.
CW operation with negative ion extraction was tested up to RF power 1.2 kW from RF generator (~0.8 kW in the plasma, 0.4 kW is dissipated in the antenna and a matching network). Initial cesiation of the SPS was performed by heating the cesium chromate cartridges by discharge as was done in the very first versions of the SPS [4, 5]. A small oven for cesium compounds and alloy decomposition by heating [6, 7] was developed and tested. With an optimized cesiation a collector current can be increased up to Ic=5.2 mA with an extractor current Iex=15 mA. A specific power efficiency of negative ion beam production is up to spe=18 mA/cm^2 kW. (in existing RF SPS the spe~2-3 mA/cm^2 kW [8]; In TRUIMFe [9] arc discharge negative ion source the best spe~4 mA/cm^2 kW). The collector was heated by the beam up to yellow color. This is a good evidence of negative ion extraction to the collector. The collector current is decrease significantly when the extraction (electron) current increases (not optimal cesiation).

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P1-26

BATMAN Beam Properties Characterization By The Beam Emission Spectroscopy Diagnostic

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The ITER neutral beam systems are based on the production and acceleration of negative ions (H/D) up to 1 MV. The requirements for the beam properties are strict: a low core beam divergence (< 0.4 °) together with a low source pressure (< 0.3 Pa) would permit to reduce the ion losses along the beamline, keeping the stripping particle losses below 30%. However, the attainment of such beam properties is not straight forward.
At IPP, the negative ion source testbed BATMAN (BAvarian Test MAchine for Negative ions) allows for deepening the knowledge of the determination of the beam properties. To this purpose, one of the diagnostic routinely used is the Beam Emission Spectroscopy (BES): the Hα light emitted in the beam is detected and the corresponding spectra are evaluated to estimate the beam divergence and the stripping losses. The BES number of lines of sight in BATMAN has been recently increased: five horizontal lines of sight providing a vertical profile of the beam permit to characterize the negative ion beam properties in relation to the source parameters. Different methods of Hα spectra analysis are here taken into account and compared for the estimation of the beam divergence and the amount of stripping. In particular, to thoroughly study the effect of the space charge compensation on the beam divergence, an additional Hydrogen injection line has been added in the tank, which allows for setting different background pressure values (one order of magnitude, from about 0.04 Pa up to the source pressure) in the beam drift region.

P1-27

Experimental Study of H^- Scattering on Gas and Carbon Thin Targets

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The important problem in formation of high energy neutral H^o beams with high brightness is the angular scattering of neutrals in the target, as the emittance of produced H^o beam includes a scattered particles component.
The results of the experimental study of the H^o atom production as a result of H^- ion detachment on thin gas and carbon targets in the energy range of E_{H^-} ~ 20 keV ÷ 5MeV are presented. This energy range is characterized by the beginning of the Born approximation in theory of the ion detachment, where a good agreement of the predicted distributions and the experiment is the most important.
To study the angular scattering of beams the ribbon-like ion beams were used. The needed ribbon-like beam was formed by a number of diaphragms after the ion source, electrostatic accelerator and magnet separator of particles. Angular resolution $\theta \sim 2\cdot10^{-6}$ radian was achieved.

P1-28

Infrared imaging diagnostics for INTF Ion Beam

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The ion source for Indian Test Facility (INTF) is expected to deliver 60A negative hydrogen ion beam current of energy 100keV. The beam will be operated with 5Hz modulation having 3s ON/20s OFF duty cycle. To characterize the beam parameters several diagnostics are at different stages of design and development. One of them will be a beam dump, made of carbon fiber composite (CFC) plates placed perpendicular to the beam direction at a distance 1m approx. The beam dump supposed to handle ~ 6MW of beam power with peak power density ~ 35MW/m^2. The diagnostic is based on thermal (infra-red) imaging of the footprint of the beamlets on the beam dump using IR camera from the rear side of the dump. The beam dump will measures beam uniformity, beam-let divergence and also stripping losses of the negative ions. It also measures total beam power using calorimetric method by measuring temperature rise of the plates due to the energetic beam interception, using embedded thermocouples. The design of this CFC based beam dump needs to address several physics and engineering issues, including some specific points based on manufacturers inputs. The paper will describe an overview of the diagnostic system and its design methodology highlighting those issues and the present status of its development.

P1-29

Beamlet Tilting due to Magnetic Field in Beam Accelerator of NBI Source

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Beamlet-monitoring experiment with a combination of the NIFS teststand and “mini-STRIKE”, which is a test device of the beam monitor to be installed at “SPIDER”, has been carried out as an international collaboration program between NIFS and Consorzio RFX. The monitor plates of the mini-STRIKE are made of one-directional CFC tiles, whose fiberes are directed to the beam axis and the beamlet footprints exposed on the plates are observed with IR camera on the opposite side of the exposed surface as shown in Fig. 1. A negative ion source with the a half size of the LHD source is applied for this experiment, and the monitor plates are placed at 0.76 m apart from the exit of the grounded grid of the ion source. The beamlets are extracted from 5 (H) x 3 (V) apertures of the plasma grids by masked with Mo plates. Each beamlet distribution is clearly identified as a thermal image on the monitor plate, and beamlet tilting has been observed. The titling is affected with electron deflection field and the tilting directions flip alternatively row by row.
In this talk, we compare the tilting characteristics with the beamlet-monitoring results obtained at the LHD beamline [1] as well as simulation results of the beamlets.

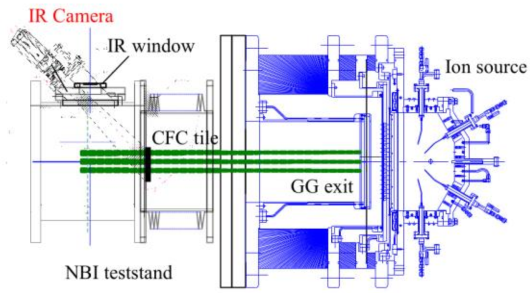

Figure 1. Schematic view of “MiniSTRIKE” installed at NIFS-NBI teststand.

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Powerloads on the front end components and the duct of the heating and diagnostic neutral beam lines at ITER

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The heating and current drive beam lines (HNB) at ITER are expected to deliver ~16.5 MW power per beam line for H beams at 870 keV and D beams at 1 MeV during the H and the D phases of ITER operation respectively. On the other hand the diagnostic neutral beam (DNB) line shall deliver ~2 MW power for H beams at 100 keV during both the phases. The path lengths over which the beams from the HNB and DNB beam lines need to be transported are 25.6 m and 20.7 m respectively. One of the two HNB beam lines, HNB1, has a cross over with the DNB beam line.

Both, the HNB and the DNB beam lines need two active gas feeds into the ion source, for the production of the negative ion beams, and into the neutraliser, for neutralisation of the accelerated ion beams. In addition to those gas enters the beam lines from the ITER machine through the HNB and the DNB duct openings and gas is generated by beam impacting beamline components and in the NB duct. In the case of HNB1 and the DNB, gas from one beam line flows into the other at the crossover. The gases are pumped by the cryopumps on each side of the beam line components in the vacuum vessels or they flow into the tokamak. All the gas sources along the beamline, the pumping speed of the cryopumps and the geometry of the injector determine the equilibrium gas profile along the beam path. Interaction of the accelerated beam with the residual gas in the beam line results in re-ionisation, which is one of the causes of power loss from the beam. The ions produced as a result of re-ionisation are influenced by the magnetic fields from the ITER machine and, depending on their larmor radii, they deposit power on the various front end components, the duct and the blanket modules and that causes gas to be released from those surfaces. The strength of the magnetic fields, and therefore the trajectories of the re-ionised particles will depend on the scenario of operation of the ITER machine. Some beam is also lost during the transport from the accelerator to the tokamak via direct interception by beamline components and various surfaces in the ducts. It is necessary to correctly determine the operational power load and the power densities on the different panels of the front end components and the duct to ensure that they are designed to survive for the lifetime of ITER. The main factors contributing to these are the divergence of the beamlets and the halo fraction in the beam, the beam aiming, the horizontal and vertical misalignment and the gas profile along the beam path, which determines the re-ionisation loss, and the re-ionisation cross sections. The gas profiles have been determined using a modified version of the Monte Carlo Gas Flow code (MCGF) which takes into account the HNB-DNB cross over and the BTR code has been used to obtain the power loads and the power densities on the various surfaces of the front end components and the duct modules for different scenarios of operation mentioned above. The worst case power loads and power densities for each surface have been used to study their thermo-mechanical behaviour and manufacturing feasibility. The iterative process has finally converged to finalisation of the design of these components. The details of these calculations and results obtained will be presented and discussed.

P2-01

Development of two negative hydrogen ion sources with hot cathode at IMP

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This paper presents design and development of two negative hydrogen ion sources with hot cathode for a PET cyclotron at IMP. These two sources, named LNHIS1 and LNHIS2, were adopted respectively Halbach hexapole magnetic field and CUSP ten-pole magnetic field to confine plasma. LNHIS1 performed a dc H^- beam of 1 mA with $\varepsilon_{n,rms} = 0.08\pi$ mm mrad @ 25 keV extraction energy and 900 W arc power，whose beam current density was about 5.5 mA/cm^2, while LNHIS2 offered a dc H^- beam of 1.5 mA @ 25 keV extraction energy and 2000 W arc power, whose beam current density was about 8.4 mA/cm^2. Conclusion was given that Halbach hexapole confinement was suit for negative hydrogen ion source, at least for low emittance H^- beam of 1 mA.

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P2-02

Concepts of Caesium Evaporation and Control at IPP

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Large negative ion sources as required for the neutral beam heating system of ITER rely mainly on the conversion of atoms and positive ions into negative ions at surfaces with a low work function. Caesium is typically used to achieve this effect; it is deposited in thin layers onto tungsten or molybdenum surfaces. However, to maintain pure caesium layers over long periods in the hydrogen plasma environment, causing deactivating and re-distribution effects, requires precisely controlled evaporation of Cs into the source. This is a demanding and not yet finally solved task.

For the negative ion test facilities BATMAN and ELISE, different Cs ovens have been developed using now a device that allows controlling oven temperature and evaporation separately [1]. The ovens are heated via commercial heating elements to temperatures above 250 °C; they are operated in air and thermally insulated on the outside. For the Cs reservoir two concepts are in use: either a 1.2 g dispenser or a 1.0 g liquid Cs ampulla, which is cracked in vacuum. The evaporation is controlled via an electric current through the dispenser (up to 10 A) or the temperature of the reservoir for the latter type. Two all metal valves are used to separate the oven for re-filling from the ion source. To measure the Cs flux leaving the oven, a surface ionization detector (SID) has been developed [1] and installed in front of the oven nozzle. The SID strongly supports stable source operation and is also used in a dedicated Cs oven test bed.

This paper describes the oven concepts and experiences gained at IPP, addressing also specific challenges like Cs contamination, heating aspects, controllability and reproducibility.

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P2-03

Experimental study of waveguide coupled microwave heating with a conventional multicusp negative ion source

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Negative ion production with conventional multicusp plasma chamber utilizing 2.45 GHz microwave heating is demonstrated. The experimental results were obtained with the multicusp plasma chamber and extraction system of the RF-driven RADIS ion source [1] and a waveguide microwave coupling system which is almost similar to the one used with the SILHI ion source [2]. The results demonstrate that at least one third of negative ion beam obtained with 1 kW of 13.56 MHz RF power can be achieved with 1 kW of 2.45 GHz microwave power without any modification of the plasma chamber. The co-extracted electron to H^- ratio and the optimum pressure range were observed to be similar for both heating methods. The behaviour of the plasma implies that the energy transfer from the microwaves to the plasma electrons is mainly an off-resonance process. Possible improvements of the microwave heating efficiency that could eventually outperform the RF- heating efficiency are discussed.

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P2-04

Comparison of measured and modelled negative hydrogen ion densities at the ECR-discharge HOMER

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Surface production of negative hydrogen ions in ion sources via cesiated converter surfaces provides high ion yields, but can entail difficulties due to the high chemical reactivity of caesium [1]. Particularly to prevent problems concerning the remote maintenance at the neutral beam injection at DEMO, equally effective yet Cs-free H^- formation in ion sources is desired.
Therefore, fundamental studies are carried out at the small-scale ECR test bed HOMER (HOMogeneous Electron cyclotron Resonance plasma) at a pressure range between 0.3 and 3 Pa and discharge powers up to 500 W. To reduce the losses of negative ions in the plasma volume, HOMER is operated as a tandem-source: via the application of a meshed grid [2], the plasma is divided into a heated and a diffusive, non-heated part.
In order to examine alternative converter materials [3] and investigate the influence of the operational parameters of HOMER on the negative ion yield, the diagnostic quantification of the negative ion density is performed via laser photodetachment. Thereby the local negative ion density in the vicinity of a probe surface can be obtained relatively to the electron density measured by a Langmuir probe. The absolute value of the negative ion density measured by laser photodetachment is benchmarked via high sensitive, line-of-sight averaged Cavity-Ring-Down-Spectroscopy (CRDS), which directly measures the absolute ion density with high accuracy and reliability. In order to identify dominant loss processes of negative ions and to investigate the influence of various plasma parameters on the ion density, a 0-dimensional model is utilized. Based on plasma parameters obtained via Langmuir probe and OES, this model balances relevant gain and loss mechanisms of negative ions in the plasma volume and thereby calculates the ion density which is adapted to the measurements of CRDS.

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P2-05

Particle simulation of RF H^- Source including Coulomb collision process

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A numerical simulation code[1] based on the Electromagnetic Particle in Cell (EM-PIC) Model with Monte Carlo method for Collision processes (MCC) has been developed to understand the RF-ICP plasma. The code has been applied to a series of the numerical analyses of Linac 4 H^- source plasmas. Linac 4 H^- source [2] is usually operated at 2 MHz, in pulses of 0.5 ms and with a repetition rate of 1 Hz. In these numerical studies of Linac 4 source, the following effects have been studied : 1) the effect of cusp magnetic field on joule heating by the inductive coupling [3], 2) the effect of the initial H_2 gas pressure on the plasma density ramp-up[4]. In addition, 3) the effect of cpacitive coupling has been included in the code and has been studied in Ref.[5].

In these previous analyses, most of important collision processes between electrons and neutrals (H, H_2) have been taken into account by MCC as mentioned above. The code, however, doesn't include electron-electron Coulomb collision process which has to be modeled in order to calculate accurately the Electron Energy Distribution Function (EEDF) in RF H^- ion sources. The rate of H_2 dissociation reaction, which produces hydrogen atoms (H), depends on EEDF and electron density, and the flux of H on the plasma grid produces hydrogen negative ions (H^-) by surface production. In order to estimate the H^- production we have to evaluate EEDF and electron density. It is difficult to understand the relation between the electron density, EEDF and the RF input parameters experimentally, so numerical simulation plays a key role. Therefore, the aim of this study is to model Coulomb collision and calculate more accurate EEDFs.

We are now implementing Coulomb collision process into the code using the binary collision model in the same manner as the KEIO-MARC code (**K**inetic **E**lectron transport simulation of **IO**n source plasmas in the **M**ulti-cusp **ARC** discharge) [6]. As the first step, the implementation without domain decomposition in the code and the calculation of the EEDF are now underway. Coulomb collision mainly affects the process of the EEDF relaxation, especially in the low energy range of the EEDF. The resultant change of the EEDF could affect the RF-plasma characteristics, e.g., transport processes in the real space, and reaction rates with neutrals. The comparison between the results with and without Coulomb collision for Linac 4 H^- source plasma will be presented.

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P2-06

Laser Photodetachment Measurements of H^- Production in the Presence of Different Material Surfaces

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Diamond shows great potential as an alternative to caesium for H^- surface production in future fusion NBI ion sources. Kumar et al. [1] have shown boron-doped polycrystalline diamond (BDD) produces a five times higher yield than highly oriented pyrolytic graphite (HOPG), the next best candidate material to replace caesium in H^- ion sources. Here we investigate the possibility of using a magnetron as an alternative source configuration for H^- production in the presence of different material surfaces. Preliminary results show negative ion densities, obtained by laser photodetchment, of up to 3.5 x 10^{15} m^{-3} for W and Cu surfaces. In a continuation of this work we will show the spatial distribution of H^- concentrations in both DC and RF source configurations, both with and without the presence of diamond samples ($1cm^2$) prepared by CVD.

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P2-07

NIO1 diagnostics

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The radio frequency ion source NIO1, jointly developed by Consorzio RFX and INFN-LNL, will generate a 60kV-135mA hydrogen negative ion beam, composed of 9 beamlets over an area of about 40 x 40 mm^2. This experiment will operate in continuous mode and in conditions similar to those foreseen for the larger ion sources of the Neutral Beam Injectors for ITER. The modular design of NIO1 is convenient to address the several still open important issues related to beam extraction, optics, and performance optimization. To this purpose a set of diagnostics is being implemented. Electric and water cooling plant related measurements will allow monitoring current, pressure, flow, and temperature. The plasma in the source will be characterized by emission spectroscopy, cavity ring-down and laser absorption spectroscopy. The accelerated beam will be analyzed with a fast emittance scanner, its intensity profile and divergence with beam emission spectroscopy and visible tomography. The power distribution of the beam on the calorimeter will be monitored by thermocouples and by an infrared camera. This contribution presents the implementation and initial operation of some of these diagnostics in the commissioning phase of the experiment, in particular the cooling water calorimetry and emission spectroscopy.

P2-08

Rod-filter-field Optimaization of the J-PARC RF-driven H^- Ion Source

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The J-PARC (Japan Proton Accelerator Research Complex) cesiated rf-driven H^- ion source was successfully developed to satisfy the J-PARC second stage requirements of an H^- ion beam of 60mA within normalized emittances of 1.5πmm•mrad both horizontally and vertically, a flat top beam duty factor of 1.25% (500μs×25Hz) and a life-time of 2000 hours [1]. In the source, the rod-filter-field effect was successfully tuned to produce the necessary beam with a 2MHz rf-power as low as possible by a newly devised method of the center-gapped rod-filter-magnets. In this paper, the rod-filter-filed optimization by using the center-gap (CG), off center twin-gaps (TG) or center- and twin-gaps (CTG) and two different cross-sections (RFM1:4.75mm×10mm and RFM2:5mm×10mm) of rod-filter-magnets are presented. In both of the rod-filter-magnets with the different cross-sections, the rf-power was successfully reduced to the almost the same values by using the gaps of around 2mm. However, it takes several times longer period to condition the source to produce the necessary beam with RFM2 compared with RFM1.

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P2-09

Progress in the development of an H^- ion source for cyclotrons

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A multi-cusp H^- ion source has been developed for cyclotrons in medical use. H^- ion beams of 15 mA and 16 mA have been obtained in Cs-free and Cs-seeded operations respectively[1]. However, further enhancement of the beam current is demanded to produce higher flux of neutrons in cancer therapy and to give large-scale medical radioisotope production.

In this paper, additional studies on the existing ion source and the concepts for the design of the new source to achieve the next goal of producing an H^- beam with 20mA will be presented.

In order to understand the ion source characteristics, the experimental results were compared with the beam optics calculation. Figure 1 shows the optimum voltage of the extraction electrode (EE) as a function of the beam current obtained by the beam optics calculation, and Figure 2 shows the experimental result. Conceptual design of the new source has been developed together with the new magnetic cusp and filter field structure, the configulation of the plasma electrode, and preliminary calculations.

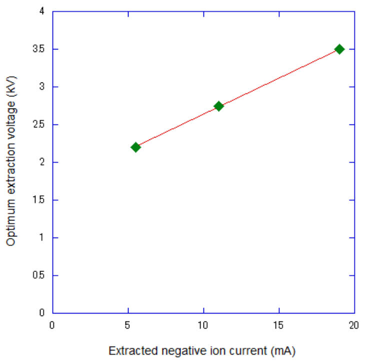

Figure 1. The calculated optimum EE voltage

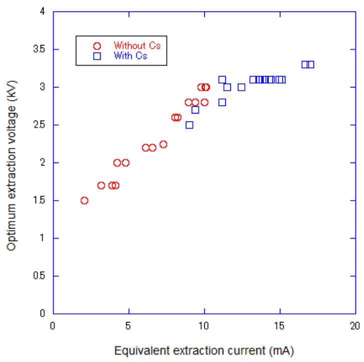

Figure 2. The experimental result of the optimum EE voltage

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P2-10

Reduction of Beam Current Noise in the FNAL Magnetron Ion Source

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The new FNAL Injector Line with a circular dimple magnetron ion source has been operational since December of 2013. Since the new injector came on line there have been variations in the H^- beam current flattop observed near the downstream end of the linac. Several different cathode geometries including a hollow cathode suggested by Vadim Dudnikov [1] were tried. Also different mixtures of hydrogen and nitrogen ranging from 0.25%N, 99.75%H to 3%N, 97%H were tried. The results of these studies in our test stand will be presented in this paper.

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P2-11

Operation of RF Negative Ion Source in a pure-hydrogen mode

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The multiaperture long-pulsed surface-plasma negative ion source is constructed at Budker Institute[1]. It includes an RF plasma driver, an expansion chamber with multicusp magnetic field, an external magnetic filter and four-electrode ion-optical system for beam extraction and acceleration. The customization of RF driver to operate at the negative ion source was done. The hydrogen filling procedure, necessary for stable long pulsed operation, and an optimal distribution of hydrogen within the source was worked out. The RF drivers with various geometries of the Faraday shield were studied. Beam current was measured by movable water-cooled Faraday cup, situated at the distance of 1.6 m from the source.
A pure-hydrogen operation with H^- beam extraction through the single aperture in the plasma grid was explored first. Beam with ion emission current density up to 2 mA/cm^2 and energy up to 75 kV was obtained. The dependences of beam current on RF power, on hydrogen supply, on plasma grid current and potential, etc. have been collected. The regular temporal increase of H^- ion production due to deposition of impurities on the plasma grid surface was detected and studied. The results of H^- beam production with extraction through the 21 apertures will be presented as well.

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Laser photodetachment diagnostics of a 1/3-size negative hydrogen ion source for NBI

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To investigate the flows of charged particles in front of the plasma grid (PG) in a negative hydrogen ion source, the information of the local densities of electrons and negative hydrogen ions (H^-) are necessary. For this purpose, the laser photodetachment is applied for pure hydrogen plasmas in a 1/3-size negative hydrogen ion source in NBI test stand. We are going to put forward the results obtained with Cs-seeded plasmas.

P2-13

VUV Emission Spectroscopy Diagnostics of a 14 GHz ECR Negative Hydrogen Ion Source

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The cutoff electron density as high as 2×10^{12} cm^{-3} for 14 GHz microwave opens a possibility for efficient productions of negative hydrogen(H^-) ions through an electron cyclotron resonance(ECR) process. The shorter wavelength of the microwave also makes a compact ion source which is desirable for H^- production as the distance between the driver region and the extraction region is smaller. The other feature of high frequency driven H^- ion source is the possibility for direct vibrational/ rotational excitations of hydrogen molecules and molecular ions by microwave power. A compact 14 GHz ECR H^- ion source [1] has been operated with pure volume mode, and the VUV emission spectra are observed through the extraction aperture.
A Nd-Fe-B permanent magnet produces a magnetic field with the intensity as large as 5 kG corresponding to the ECR condition for 14 GHz in a 55.5 mm diameter 42.5 mm long alumina discharge chamber. The source is evacuated with a 2000 *l/s* turbo molecule pump coupled to a rotary pump. Across the pumping station, volume inside of the ion source is observed by a VUV spectrometer (Model VM-502 of ACTON Co. Ltd) to measure emission spectrum of the plasma. A typical spectrum is shown in Fig. 1. As shown in the figure, the spectrum shows the concentration of band spectrum emission around Lyman-α. The present configuration is limited to a small solid angle for plasma observation. The system is currently modified to increase the observation solid angle through reducing the distance between the ion source extraction aperture, and the input slit of the spectrometer from 130 cm to 70 cm. The detailed study on the VUV emission spectra will be done and compared with the past data [2].

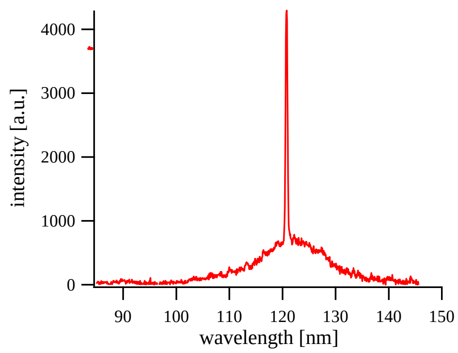

Fig. 1 The VUV spectrum of Lyman-α from a plasma excited by 14 GHz microwave

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P2-14

Negative Hydrogen Ion Beam Extraction from an AC Heated Cathode Driven Bernas-Type Ion Source

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The neutral beam injection(NBI) system for ITER will employ RF ion source for production of negative hydrogen(H^-) ions. A hot cathode arc discharge has a limitation in the cathode lifetime, while it has some advantages in stability and the wide range of extraction current density. High temperature cathode driven sources produce ion beams for semiconductor and material processing industries. Barnas-type ion sources employed for medium current ion implanters have been studied the performance through modifying the cathode structure and the operation procedure to extend the cathode lifetime[1]. The cathode erosion was found concentrated at the negative leg of a filament hot cathode, but the local concentration of filament erosion has been improved by running an AC filament heating current[2]. As the result of supplying an AC filament heating current in the frequency range from 20 Hz to 2 kHz, the life of a hot filament cathode has been prolonged as much as 1.4 times the original value.

A cylindrical vacuum chamber containing a Bernas-type ion source is 200 mm in inner diameter and 400 mm in length. The dimensions of the ion source arc chamber are 90 mm high, 36 mm wide and 29 mm deep. The tungsten filament cathode is 0.3 mm in diameter and 90 mm in length, while the center 30 mm part is exposed to the plasma. The AC cathode heating currennt is produced by a function generator coupled to a power amplifier. An external magnetic field in the direction perpendicular to the beam extraction axis is formed by a pair of electromagnets set on both sides of vaccum chamber. The magnetic field of the intensity from 0 to 15 mT passes through the center of the ion source and makes a magnetic filter configration to generate H^- ions efficiently. The extracted beam current of H^- ions is measured by the beam profile monitor composed of an array of the Faraday cups. The distance from the ion source to beam profile moitor is 100 mm. A discharge current, frequency, external magnetic field and gas pressure characteristic of H^- ion beam extracted from a plasma excited by an AC driven filament cathode is being investigated. The fluctuation of the plasma is observed as the location of the hot spot on the filament in the static magnetic field changes due to AC filament operation. Merits of AC filament operations on H^- ion source performance will be presented.

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P2-15

Radiofrequency-induced high density plasma production for negative ion source and other applications

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Here a rf negative hydrogen ion source is operated at several MHz and basic characteristics of the plasma production are investigated to discuss the effect of the driving frequency on the ion source performance. The source consists of a 70-mm-diameter ceramic cavity wound by a rf loop antenna and furtuer surrounded by two solenoids, which can provide an axial magnetic field for improvement of the production efficiency. The results are compared with the previously reported performance operated at a few hundreds of kilohertz.

Furthermore, we will show a new concept of the high density plasma production method utilizing both the rf plasma production and the electrode discharge, which is named helicon MPD and originally developed for a space propulsion device. The source is preliminarily tested with 10 mTorr argon and plasma density above 10^{20} cm^{-3} is successfully obtained, where a few hundreds of kilowatts can be supplied with a pulse width of about 0.5 msec from the charged alminum electrolytic capacitor. The application to the hydrogen negative ion source will be discussed in the presentation.

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P2-16

Development of millimeter-wave interferometer for measuring electron density with beam extraction

T. Tokuzawa[1], M. Kisaki[1], K. Nagaoka[1], K. Tsumori[1], K. Ikeda[1], H. Nakano[1], S. Geng[2], M. Osakabe[1], Y. Takeiri[1] and O. Kaneko[1]

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In the NIFS 1/3-scaled negative ion source for LHD, the Cavity-Rign-Down (CRD) method and Langmuir probe are utilized for studying the dynamics of the negative ion and electron during beam extraction, respectively. The Langmuir probe can give the information on the electron density qualitatively, but it has difficulty in obtaining the electron density precisely due to the strong magnetic field in the plasma chamber and the contribution of negative ions to the electron saturation current.

The millimeter-wave interferometer is one of the presumable tools for measuring the electron density under such condition. Previously, we had installed the millimeter-wave interferometer to the negative ion source and successfully obtained the electron density in the pure hydrogen and Cs-seeded plasmas. The millimeter-wave interferometer has been upgraded in order to measure the electron density with applying the high voltage on the plasma chamber. Figure 1 shows the time evolution of the electron density obtained with improved millimeter-wave interferometer in the pure hydrogen plasma. The beam was extracted from 10.8 s to 11.8 s. The electron density changes with the arc power and rapidly rises when the extraction voltage is applied. Amount of the electron density change before and after the beam extraction is 2.6×10^{17} m^{-3}. It has been observed that the negative ion density shows the different response to the extraction voltage and it rapidly drops with beam extraction. In the presentation, the improvements on the diagnostic system will be described in detail and the response of the electron to the extraction voltage in other conditions (e.g. Cs-seeded plasma and different bias voltages) will be discussed.

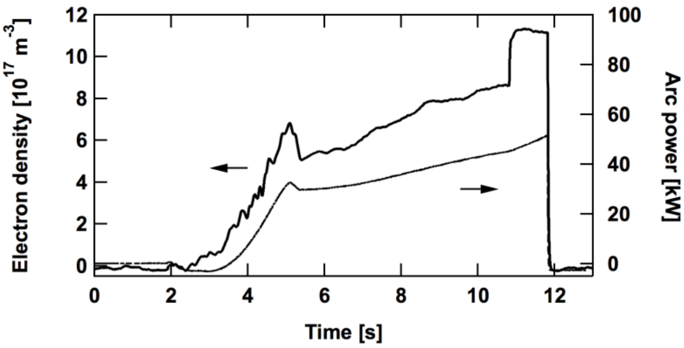

Figure 1. Time evolution of electron density measured with millimeter-wave interferometer.

P2-17

A Wire Calorimeter for the SPIDER Beam: Experimental Tests and Feasibility Study

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To study and optimise negative ion production and acceleration, in view of the use of neutral beam injectors in the ITER project, the SPIDER test facility (particle energy 100keV; beam current 50A, divided into 1280 beamlets) is under construction in Padova, with the aim of testing beam characteristics and to verify the source proper operation by means of several diagnostic systems.
An array of tungsten wires, directly exposed to the beam and consequently heated to high temperature, is used in similar experiments at IPP-Garching to provide a qualitative investigation of the beam optics, which is one of the most important issues.
The present contribution gives a description of an experimental investigation of the behaviour of tungsten wires under high heat loads in vacuum. Samples of tunsten wires are heated by electrical currents and the emitted light is recorded by a camera in the 400-1100nm wavelength range. Simultaneously, the voltage applied to the wire is measured to study the influence of temperature on emissivity.
Previous literature is applied to the interpretation of the measurements. The feasibility study of a wire calorimeter for SPIDER is finally proposed; to this purpose, the expected behaviour of tungsten with the two-dimensional beam profile in SPIDER is numerically addressed.

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

P2-18

Design of the new extraction system for the NIO1 negative ion source

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NIO1 is a compact source of negative ions jointly developed by RFX and INFN, to study the physics of production and acceleration of H^- beams. Negative ions, up to 130 mA, are extracted from a radiofrequency driven plasma, by means of a gridded electrode (plasma grid, PG) featuring 9 apertures arranged in a 3x3 lattice. The same aperture pattern is replicated in the following electrodes, namely an extraction grid, EG, and a post acceleration grid, PA, where the ions can reach the maximum energy of 60 keV.
All electrodes are realized in copper, by electro-deposition technique, leaving empty slots in the metal to place magnets and to flow water for the grid cooling.
The first set of electrodes was completed, installed in the source and successfully tested. At the same time, an upgrade of the extraction system was carried out, in order to optimize the beam optics and to explore alternative electrostatic configurations. In particular, the accelerator will be modified by completely replacing the EG grid, exploiting the modularity of NIO1. The new electrode will also features other slots in between apertures, to place additional magnets. This allows testing different magnetic configurations, to optimize electron filtering and residual ion deflection.
The present paper describes the theoretical activities driving the design of these new extractors, carried out with most updated numerical codes, and exploiting the synergy with the refined modeling of the 40 A ITER negative ion sources, under development at Consorzio RFX. Beam simulations are performed both with tracing codes (OPERA, SLACCAD BYPO) and with particle in cell codes (ACCPIC).

P2-19

RF low-level control for the Linac4 H^- source

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The H^- source for the Linac4 accelerator at CERN uses an RF driven plasma for the production of H^-. The RF is supplied by a 2 MHz RF tube amplifier with a maximum power output of 100 kW and a pulse duration of up to 2 ms. The low-level RF signal generation and measurement system has been developed using standard CERN controls electronics in the VME form factor. The RF frequency and amplitude reference signals are generated using separate arbitrary waveform generator channels. The frequency and amplitude are both freely programmable over the duration of the RF pulse, which allows fine-tuning of the excitation. Measurements of the forward and reverse RF power signals are performed via directional couplers using high-speed digitizers, and permit the estimation of the plasma impedance and deposited power via an equivalent circuit model. The low-level RF hardware and software implementations are described, and experimental results obtained with the Linac4 ion sources in the test stand are presented.

P2-20

Preparation of an ion source for an extra low energy synchrotron

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ELENA is a compact ring for cooling and further deceleration of 5.3 MeV antiprotons delivered by the CERN Antiproton Decelerator (AD) down to 100 keV [1]. Because of the long AD cycle of 100 s, it is foreseen to install a source for protons and H^- with a kinetic energy of 100 keV for commissioning and start-ups. The source, designed to provide 0.2 to 2.0 μs pulses with $3{\cdot}10^7$ ions, is based on an existing multicusp volume source from the COSY/Jülich injector [2]. It is currently under preparation at the Forschungszentrum Jülich and is going to be delivered to CERN in 2015. The current status of the preparations and the performance will be presented.

The work is supported within the framework of the Helmholtz Association's Accelerator Research and Development (ARD) program [3].

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P2-21

Solid State RF Amplifier for Powerful Negative Hydrogen Ion Sources

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Radio frequency ion sources used in neutral beam injection systems (NBI) of fusion machines are currently supplied by self-excited RF generators. Efficiency, reliability and matching properties can be improved substantially by replacing the oscillators by solid state amplifiers, which are based on transmitters used for AM broadcasting. At IPP such a 1MHz/75kW amplifier has been successfully tested with a negative ion source [1]. The maximum VSWR (standing wave ratio) was adjusted to 2, corresponding to a reflected power of 11 %. Matching to the load can be performed either by a change of the capacitance in series to the RF coil or of the frequency.

High operational reliability and matching to the plasma load with VSWR close to 1, i. e no reflected power, has been demonstrated. Due to the effective protection system no damages by high reflected power occurred, even not during plasma ignition.

Although due to the fixed frequency the matching range is smaller than with the oscillators, it is wide enough to cover the range of load variations caused by different source parameters in typical operation. From the changes of the matching capacitances, which are required for reaching the minimum VSWR at different operational parameters, the plasma resistance as a function of these parameters has been calculated.

This paper describes the matching experiments including an automatic matching to minimum reflected power and the reliability tests performed with the solid state amplifier.

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Upgrade of BATMAN test facility for H^- source development

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The radio frequency (RF) driven source for negative ions has been successfully developed at IPP since 1996 on the test facility BATMAN [1]. The required ITER parameters have been achieved with the prototype source consisting of a cylindrical driver on the back side of a racetrack like expansion chamber. The extraction system, called "Large Area Grid" (LAG) [2] was derived from a positive ion accelerator from ASDEX Upgrade using its aperture size (ø 8 mm) and pattern but replacing the first two electrodes and masking down the extraction area to 70 cm^2.

BATMAN is a well diagnosed and highly flexible test facility which will be kept operational in parallel to the half size source test facility ELISE to improve the understanding of the formation and extraction of negative ions. It is therefore planned to upgrade BATMAN with a new ITER-like extraction system representing almost one ITER beamlet group, namely 5 x 14 apertures (ø 14 mm). Additionally to the standard three grid extraction system a repeller electrode upstream of the grounded grid can optionally be installed which is positively charged against it by 2 kV to enhance space charge compensation downstream of the grounded grid and to avoid positive ions being accelerated backwards into the ion source. For the magnetic filter field a plasma grid current up to 3 kA can be applied as well as permanent magnets embedded into a diagnostic flange or in an external magnet frame. Furthermore different source vessels and source configurations are under discussion for BATMAN, e.g. using the AUG type racetrack rf source as driver instead of the circular one or modifying the expansion chamber for a more flexible position of the external magnet frame.

The paper focusses on the design of the new extraction system and its integration into the BATMAN test facility. Further source and driver geometries will also be described, addressing the expected benefits.

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P2-23

Study of a Negative Ion Source in Sheet Plasma

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Stationary production of negative ions are important to play an essential role in Neutral beam injection (NBI). Cesium seeded Surface-production of negative ion sources are used for NBI. However, Cesium seeded surface-production of negative ion sources are not desirable from the point of view of operating steady state ion sources.

We carried out the development of negative ions by volume-production in hydrogen sheet plasma [1]. The sheet plasma is suitable for the production of negative ions, because the electron temperature in the central region of the plasma as high as 10 – 15eV, whereas in the periphery of the plasma, a low temperature of a few eV of obtained. The negative and positive ions density (H^-, H^+, H_2^+, H_3^+) were detected using an "omegatron" mass analyzer, while the electron density and temperature were measured using a Langmuir probe. The negative ion current density is evaluated by Faraday-cup.

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P2-24

Update on Developments at SNIF

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The Small Negative Ion Facility (SNIF) at CCFE has been undergoing continuous development and enhancement to both improve operational reliability and increase diagnostic capability. SNIF uses a RF driven volume source with a 30kV triode accelerator. A new "L" circuit RF matching unit has been installed, allowing full, reliable exploitation of the 5kW RF power supply at 13.56MHz. RF interference has been reduced allowing greater reliability of the high voltage power supplies, and hence significantly more reliable beam extraction has been performed. Improved beam extraction has allowed greater use of both the instrumented copper beam dump, and visible cameras, to minimise the beam divergence through adjustment of the extraction voltage. Comparisons with the AXCEL-INP beam simulation software have allowed an estimation of the extracted beam current of approximately 9mA (6mA/cm^2) at 3.5kW RF power and a source pressure of 0.6Pa. On the source, diagnostic provision has increased, with a high resolution McPherson visible spectrometer and a Hiden Langmuir probe both being used to study the extraction region of the discharge. The spectrometer can provide data from the atomic Hydrogen Balmer series, as well as the molecular Fulcher transitions. Full details of all the characterisation work are given, along with the results and future plans for the facility.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 633053 and from the RCUK Energy Programme [grant number EP/I501045]. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

P2-25

Benchmark of numerical tools simulating beam propagation and secondary particles in ITER NBI

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Injection of high energy beams of neutral particles is a method for plasma heating in fusion devices. The ITER injector, and its prototype MITICA (Megavolt ITER Injector and Concept Advancement), are large extrapolations from existing devices. Therefore numerical modeling is needed to set thermo-mechanical requirements for all beam-facing components. As the power and charge deposition originates from several sources (primary beam, co-accelerated electrons, and secondary production by beam-gas, beam-surface, and electron-surface interaction), the beam propagation along the beam line is simulated by comprehensive 3D models.
This paper presents a comparative study between two codes: BTR has been used for several years in the design of the ITER HNB components; the SAMANTHA code was independently developed and includes additional phenomena, like secondary particles generated by collision of beam particles with the background gas. The code comparison is valuable in the perspective of the upcoming experimental operations, in order to prepare a reliable numerical support to the interpretation of experimental measurements in the beam test facilities.
The power density maps calculated on the Electrostatic Residual Ion Dump (ERID) is chosen as the benchmark, as they depend on the electric and magnetic fields as well as on the evolution of the beam species via interaction with the gas.
Finally the paper shows additional results provided by SAMANTHA, like the power deposition onto the Cryopumps due to secondary electrons accelerated by the ERID fringe-field.

P2-26

Development of a prototype negative ion source in KAERI

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A project to develop a negative ion based neutral beam source has been started to cope with the technological demand of the future NB heating in K-DEMO fusion reactor. NB sources will be still indispensable not only for the H&CD, but also for controlling the plasma profile in an advanced operation mode. It is well recognized that NB H&CD scheme now stands closer to the efficiency goal required for DEMO rather than other ways based on the RF technologies. However, there must be innovative ideas and breakthroughs for doubling the presently achieved efficiency, with improvements in the trasmission, neutralization, brightness and so on, and consequently for lowering the size and cost of NB devices. As the first step to provide an NNBIS test stand for developing a DEMO relevent NB source, a small scale facility composed of the KAERI prototype negative ion source, RF and HV power supplies, and basic diagnostics is being established. The ion source is composed of an RF plasma generator[1] and a beam extraction grid system. In this presentation, we will describe mainly the design concept and fabrication procedure of the beam extraction grid system of the prototype negative ion source. Two important requisites in the design of the negative ion beam extraction system are devices for maximizing the negative ion density near the plasma grid (PG), and for minimizing co-extracted electrons. To fulfill above requirements, elements generating a hybrid magnetic filter field (MFF) and a co-extracted electron deflection field (EDF) were carefully designed using 3D codes. To change both of the MFF strength and profile easily during beam extraction experiments, the PG current type MFF is adopted in addition to a pemanent magnet type. The stray field effect on the MFF by the current lead of the PG was took into account in the design. The co-extracted electron deflection field (EDF) is produced by permanent magnets inserted in the extraction grid.

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P2-27

3D Model of a Matrix Source of Negative Ions: RF Driving by a Large Area Planar Coil

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The study is in the scope of the work on the matrix source of negative hydrogen ions: a matrix of small radius discharges with planar coil inductive driving. Determination of a manner of the rf power deposition into the dischages of the matrix, i.e. detemination of a suitable configuration of the coil, which would provide the same distribution of the plasma parameters or, equivalently, the same distribution of the induced currents in the separate discharges of the matrix, is aimed at. Former results [1] show that separate planar coil driving of each discharge as well as a construction of the matrix with a common, for all the discharges, bottom and single spiral coil driving of the whole matrix are satisfying decisions with respect to almost the same discharge driving efficiency in each tube of the matrix. Since rf driving of the matrix by a large area coil and discharge tubes starting from the position of the coil would be the most proper configuration, the continuation of the work presented here is in two directions: (i) rf driving by a single spiral coil of a block of tubes and (ii) rf driving by a single coil of the whole matrix. In the former case a block of four discharge tubes is considered whereas in the latter case a matrix consisting of nine discharge tubes, positioned in three columns and three rows, like in [1], is studied. In the case of a single coil driving of a whole matrix, the three configurations of the coil considered are: a coil with a **Ω**-shaped turn on the bottom of each tube and a coil formed by straight conductors which pass between or through the bottoms of the tubes. In both cases the models developed are 3D models based in their electrodynamical parts on solutions of the equation for the vector potential of the rf magnetic field in the discharges. However, in the case of a block of tubes the model is self-consistent providing results not only for the induced current density but also for the spatial distribution of the plasma parameters in the discharge tubes whereas in the case of a single coil driving of the matrix the model includes only electrodynamics with results for the spatial distribution of the induced current density, for given plasma parameters of the discharges. The results show that a single coil driving of a block of tubes is a suitable decision. For choosing a proper decision for a configuration of a coil driving a whole matrix further extension of the model to a self-consistent one is necessary.

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Experimental Verification of Negative Ion Density Prediction Based on Fulcher-α Spectroscopy Considering Non-Boltzmann Distribution

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Fulcher-α band spectroscopy is used for a convenient method to diagnose the vibrational distribution function (VDF) of electronic ground state for the hydrogen molecules to predict the volume negative ion production rate. However, its diagnostic characteristics is sensitive only for lower vibrational states(ν<5) whereas hydrogen negative ions are produced by dissociative attachment(DA) mostly with higher vibrational state molecules [1]. Thus, in order to correlate the vibrational temperature with the negative ion density, the Fulcher-α spectroscopy and laser photo detachment are conducted in the rf negative ion source at Seoul National University[2]. Interestingly, the vibrational temperature estimated from the Fulcher-α spectroscopy shows lower value despite of the higher negative ion density with higher electron temperature in the driver region. This opposite tendency between the negative ion density and the vibrational temperature can be explained by non-Boltzmann characteristics of the VDF in the analysis of the Fulcher-α spectroscopy[3]. In this study, realistic VDF is obtained by using a global model based on measured plasma source parameters such as electron density, temperature and neutral pressure. This result shows that the VDF may have non-Boltzmann distribution, where higher vibrational states are more populated than lower states as expected in the presence of energetic electrons. Also, the negative ion density calculation based on the non-Boltzmann VDF is well matched with the laser photo detachment result. Consequently, the non-Boltzmann VDF should be obtained by using plasma parameters when the Fulcher-α spectroscopy is utilized for the negative ion density prediction by estimating vibrational states from measured Fulcher-α band.

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P2-29

Hydrogen Atom Temperature measured with Wavelength-Modulated Laser Absorption Spectroscopy in Large Scale Filament Arc Negative Hydrogen Ion Source

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Hydrogen atom dynamics in cesium seeded negative hydrogen ion source concerns with negative hydrogen ion prodoction. Energy distribusion of hydrogen atom is important paramenter to understand the mechanism from the production to beam extraction of negative hydrogen ion. We applied wavelength-modulated laser absorption spectroscopy to measure the hydrogen atom temperature in the vicinity of the plasma grid of large scale filament arc negative hydrogen ion source at NIFS[1]. A tunable diode laser with Balmar alpha line band wavelength was used. The laser frequency was slowly swept more than Doppler width (100 GHz / 1Hz) and simaltaneously fastly modulated at 600Hz with laser flequency width of 30 GHz. The spectrum of the second harmonic compornent of fast frequency modulation in transmitted laser agreed with a expected spectrum from the Doppler broadend Balmar alpha line. The estimated temperature was ~3000 K and independent on input arc discharge power and introduced hydrogen gas pressure, while the laser absorption increased with the input arc discharge power and the gas pressure.

This work is supported by the NIFS Collaboration Research Program NIFS13KLER021, NIFS Research Programs NIFS13ULRR008 and NIFS13ULRR702, and JSPS KAKENHI Grant Numbers 25800307, 25249134.

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P2-30

Polarized 3He- Ions Source with Hyperfine States Selection

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High beam polarization is essential to the scientific productivity of a collider. Polarized 3He ions are an essential part of the nuclear physics programs at existing and future ion-ion and electron-ion colliders such as the BNL RHIC and eRHIC and JLab's ELIC [1]. Ion sources with performance exceeding those achieved today are a key requirement for the development of these next generation high-luminosity high-polarization colliders.
Development of high intense, high brightnees arc discharge ion sources in the the Budker Institute of Nuclear Physics (BINP) [2,3] is open a possibility for realization of a new version of a polarized 3He- ion source. In this report it is discussed a polarized 3He- ion source based on the large difference in the lifetimes of the different 3He- ion hyperfine states relative to autodetachment. The highest momentum state of 5/3 has the largest lifetime of τ~350 μs while the lower momentum states have lifetimes of τ ~10 μs. By producing a 3He- ion beam composed of only the |5/2, +-5/2> hyperfine states and then quenching one of the states by an RF resonant field, 3He- beam polarization of 95% can be achieved. Such method of polarized 3He- production was considered in [4], but with a low intensity of existing He^+ ion sources were no hope to produce any interesting intensity of polarized 3He- ions.
The high-brightness arc-discharge ion-source developed in the BINP can produce 3He- beams with an intensity up to 2 A and up to ~1-4 mA of 3He- with ~90% polarization can be selected. A high gas efficiency of arc discharge source is important because 3He gas is very expensive. Some features of this PIS are considered in [5].

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Time	Monday, October 6th	Tuesday, October 7th	Wednesday, October 8th	Thursday, October 9th	Friday, October 10th
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9:00	Opening P. Sonato Yu. I. Belchenko	M. P. Stockli R. F. Welton B. X. Han	G. Fubiani S. Lishev S. Mochalskyy	Y. Takeiri G. Chitarin V. Antoni	P. Franzen U. Fantz R. Nocentini
10:00	Coffee M. Bacal A. Kojima G. Cartry L. Schiesko	Coffee J. Lettry D. A. Fink A. Ueno S. Lawrie	Coffee S. A. Veitzer T. Minea L. Caillault K. Miyamoto	Coffee C. Wimmer K. Ikeda M. Bandyopadhyay M. Wada	Coffee Laboratory Tour
11:00					
12:00	Lunch	Lunch	Excursion	Lunch	Lunch
13:00	U. Kurutz J. S. Vogel S. Briefi A. Simonin	V. Dudnikov H. P. L. de Esch M. J. Singh		C. Drag N. Umeda M. Yoshida M. Dehnel	
14:00		Group photo			D. Fiorucci T. Kalvas S. Peng
15:00	Coffee D. Faircloth M. Cavenago Y. H. Xie	Coffee Poster session 1		Coffee Poster session 2	Closing
16:00					
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18:00	Reception				
19:00				Conference banquet	