THE 10th INTERNATIONAL CONFERENCE ON ION SOURCES

Dubna, Russia, September 8-13, 2003

BOOK OF ABSTRACTS

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The 10th International Conference on Ion Sources

Dubna, 8 to 13 September 2003

Abstracts

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SCIENTIFIC PROGRAM

The scientific program includes invited (plenary) talks, selected oral and poster presentations on the following topics:

ECR
EBIS/T
Ionic Physics
Radioactive Ion Sources and Beams
Laser Ion Sources
MEVVA
Ion Extraction
Beam Emittance and Transport
Negative Ion Sources
Polarized Ion Sources
High Current, Novel and Miscellaneous Ion Sources
Ion Acceleration Systems
Fusion
Industrial Application

Paper code:	First letter	Session
	Second letter	**I** – invite (plenary) presentation **O** – oral presentation **P** – poster presentation
	and Progressive number	

Paper presentation conditions:

A total time of 35 minutes will be allotted for **invited** (plenary) **papers** and 25 minutes will be allotted for **oral papers.**
All presentation time includes 5 minutes discussion .

Poster presentation:

Poster board size: **85cm** wide and **140 cm** high.
The board site for the paper will be marked with the poster paper code
Posters have to be fasten on the board to 1 p.m. and taken off at 6.30 p.m. in the day of presentation.

OUTLINE OF SESSIONS AND PAPER PRESENTATIONS

Monday 8 September 2003:

Opening session

Session A – ECR 1,
Papers: **AI1** – Girard A., **AI2** – Lyneis C., **AO1** – Drentje A.

Session B – ECR 2,
Papers: **BI1** – Nakagawa T., **BO1** – Hitz D., **BO2** – Tinshert K.(not confirmed)
Session C – ECR 3,
Papers: **CO1** – Zhao H., **CO2** – Gobin R., **CO3** – Erukhimov V.

Session D (Poster 1) – ECR P,
Papers: **DP1 – DP46**

Tuesday 9 September 2003:

Session F – ECR 4,
Papers: **FO1** – Biri S., **FO2** – Celona L., **FO3** – Zelenak A., **FO4** – Pardo R.

Session G – EBIS/T,
Papers: **GI1** – Beebe E., **GO1** – Donets E.

Session H – Ionic Physics,
Papers: **HI1** – Ohtani S., **HI2** – Presniakov L.

Session J – Radioactive Ion Sources and Beams 1,
Papers: **JI1** –Leroy R., **JI2** – Panteleev V.

Session K (Poster 2) – EBIS/T, Laser, MEVVA, Radioactive Ion Sources and Beams, Ion Extraction, Beam Emittance and Transport
Papers: **KP1 – KP45**

Thursday 11 September 2003:

Session L – Radioactive Ion Sources and Beams 2,
Papers: **LO1** - Ames F., **LO2** - Sortais P., **LO3** - Alton G.

Session M – Laser Ion Sources
Papers: **MI1** - Laska L.

Session N – Ion Extraction, Beam Emittance and Transport
Papers: **NI1** - Gammino Santo, **NO1** - Spaedtke Peter, **NO2** - Stockli Martin P., **NO3** - Hatayama Akiyoshi

Session R – Negative Ion Sources 1.
Papers: **RI1** - Becker Reinard, **RI2** - Soloshenko Igor A.

Session S (Poster3) – Negative Ion Sources (P)
Papers: **SP1 – SP31**

Friday 12, September 2003:

Session T - Negative Ion Sources 2
Papers: **TI1** - Bacal Marthe, **TI2** - Belchenko Yuri I., **TI3** - Peters Jens P., **TO1** - Baksht F. G. (not confirmed)

Session U – Fusion and Industrial Application
Papers: **UI1** - Oka Yoshihide, **UI2** - Davydenko Vladimir I., **UO1** - Hanada Masaya

Session V – "Brightness Award" Ceremony

Session W (Poster 4) – Polarized Ion Sources, High Current, Novel and Miscellaneous Ion Sources, Ion Acceleration Systems, Fusion, Industrial Application
Papers: **WP1 – WP42**

Saturday 13, September 2003:

Session X – High Current, Novel and Miscellaneous Ion Sources, Ion Acceleration Systems
Papers: **XO1** - Derenchuk Vladimir P., **XO2** - Zhang Tianjue, **XO3** - Nikulin Sergey P. (not confirmed), **XO4** - Gebel Ralf H., **XO5** - Miyata Tomohiro

Session Y – Industrial Aplication 1
Papers **YI1** - Kanarov Viktor, **YO2** - Kawai Yoko

Session Z - Industrial Application 2
Papers: **ZO1** - Imanaka Masashi, **ZO2** - Tumey Scott

MANUSCRIPTS

Submission of Manuscript for Proceedings from RSI:

Deadline of Submission- **Monday 8 September 2003**
When the papers are not presented, they are not published.

Please inform to the Secretariat in advance if the author intend not to submit the manuscript.

Manuscript Length:	**Invited Papers – 5 pages** in Journal page from of RSI
	Contributed papers – 3 pages in Journal page from.

All the manuscripts must be reviewed by the referees. Therefore, authors are strictly requested to prepare the manuscript with clear stress on the originality and significance of the study together with new results comparing relevant research in the world. Otherwise, it takes too much time to review it, this may cause that the papers will not be published in the Proceedings.

Monday 8 September

AI1 **ECR PLASMAS AND ECR ION SOURCES: PHYSICS AND TECHNOLOGY**

A. Girard, D. Hitz, G. Melin

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Electron Cyclotron Resonance (ECR) Ion Sources are scientific instruments particularly useful for physics: they are extensively used in Atomic, Nuclear , and High Energy Physics, for the production of the beam. Moreover, these sources are also of fundamental interest for plasma physicists, because of the very particular properties of the ECR plasma. This article describes the state of the art on the physics of the ECR plasma related to multiply charged ion sources. In the first chapter we describe the bases of ECR Ion Sources. Physics related to the electrons is presented in the second chapter: we discuss there the problems of heating and confinement. In the next chapter the problem of ion production and confinement is presented. Some particular and important effects, specific to ECR Ion Sources, are discussed in chapter 4. Eventually, in the last chapter, technological aspects of ECR are presented and different types of sources are shown.

AI2

NEW RESULTS WITH VENUS

C.M. Lyneis, D. Leitner, S.R. Abbott, R.D. Dwinell, M. Leitner, C.S. Silver, C. Taylor

LBNL, CA 94720, USA.

The next generation superconducting ECR ion source, VENUS, has recently began operation at 18 GHz following six years of design and construction. The ion source and its closed cycle cryogenic system will be described along with the design of the 28 GHz 10 kW gyrotron system, which is scheduled for installation at the end of 2003. The low energy beam transport section includes a Glaser lens, a high transmission 90 degree analyzing magnet and a two axis emittance scanner to measure beam transport efficiency and emittance of the intense multi-charged ion beams. Results from the ongoing commissioning at 18 GHz are reported. Initial tests with gases such as helium, oxygen, argon and xenon have been performed with up to 2000 W of 18 GHz RF power. Promising performance has been measured in those preliminary beam tests. For example, 1100 eμA of O^{6+}, 180 eμA of Ar^{12+} and 84 eμA of Xe^{27+} were produced and the dependence of current versus RF power indicates more power is needed for optimum performance. Emittance measurements for various ion species have been performed and are discussed.

AO1 EXPERIMENTS WITH BIASED CYLINDER IN ECR ION SOURCE

A. G. Drentje[1], *A. Kitagawa*[2], *M. Muramatsu*[2], *H. Ogawa*[3] *and Y. Sakamoto*[2]

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[3] *Accelerator Engineering Corporation Ltd, 2-13-1 Konakadai, Inage, Chiba 263-0043, Japan*

The specific shape of the magnetic field of an ECR ion source gives rise to different particle fluxes to the end plates (mainly diffusion of electrons), and to the side walls (mainly ion diffusion). As was shown earlier, the electron fluxes to the injection end plate can be reduced by negatively biasing this plate (or so-called biased disk). This appeared to be a successful method of improving the confinement and thereby the output of highly charged ions (HCI). The situation at the side walls is somewhat complicated because the hexapolar field gives changing field directions (i.e. from one North pole to both adjacent South poles), always perpendicular to the axis. In addition there is a strong axial field. To first order, in the centre of the source electrons can hit the wall easier at the position of the six poles than at the areas between the poles. In all ECRISs these electron "leakage-lines" can be seen.

The particle fluxes could (externally) be influenced, e.g. by applying a voltage to the side wall. Recently, such an experiment was performed by the Frankfurt group. The effect was observed, but for the production of HCI the "traditional" configuration was the best. The aim of the present experiment is to again apply this method and thereby to try to bias either the areas corresponding to the poles of the hexapole magnet or the areas in between. The experiments have been performed with the Small Compact All Permanent-Magnet ECR Ion Source at NIRS (Kei-source).

A thin aluminum cylinder, coated on both sides with aluminum-oxide, was inserted into the Kei-source. In testrun C1 the coating was removed in the areas between the poles, so at these locations the plasma is facing conducting parts of the cylinder.
Currents of oxygen ions (q=6+) were measured for a range of cylinder voltages. Almost no effects were observed at low voltages, but for $V_{cyl} > 200$ Volt the O^{6+} current increased by more than 25 %. The total source output increased as well. The influence of the available biased disk reduced substantially for the optimized cylinder voltage setting.
In testrun C2 the cylinder was rotated over 30 degrees, such that the conducting areas were now coinciding with the poles of the hexapole magnet. From the measured O^{6+} output it appears that the source performance is much more sensitive to the cylinder voltage. A 25% increase was observed at $V_{cyl} > 42$ Volt, and a 25% decrease at $V_{cyl} < -18$ Volt. So in this situation particle fluxes clearly can be influenced more effectively.

One problem typical for this kind of experiments is the substantial outgassing of the inserted cylinder in conjunction with low pumping speed in the volume between cylinder and wall. For that reason, comparison with the source performance without cylinder is difficult. New measurements were started with a "comb-shaped" system, insulated outside while conducting inside, such that the "combteeth" cover the pole areas (as in C2 above).
First results show that the HCI output again strongly depends on the comb voltage. Example: the O^{6+} output increases from 45 to 122 μA due to an increase of cylinder voltage from 0 to 15 Volt. This highest current is substantially better than measured without the cylinder. The results may help to better understand the mechanism of higher HCI output in ECRIS with aluminum-oxide material on the side walls.

BI1 ECRIS DEVELOPMENTS IN RIKEN

H. Arai, G. Arzumanyan** Y. Higurashi M. Imanaka* M. Kidera, M. Kase, T. Nakagawa, G. Shirkov**, and Y. Yano*

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**Univ. Tsukuba, Tsukuba, Ibaraki, Japan*
***JINR, Dubna, Moscow region, Russia*

Last decade, we constructed and tested the various type of high performance ECRISs (RIKEN 10 GHz ECRIS, RIKEN 18 GHz ECRIS, liquid He SC-ECRISs (SHIVA and RAMSES) for increasing the beam intensity of heavy ions as an external ion source of accelerators. Especially, since 1995, we tried to increase the beam intensity of medium to high charge-state heavy ions for RIKEN radio isotope beam project (the final goal is 1pμA on target from proton to U beam). To meet this requirement, we are making further development of the performance of RIKEN ECRISs.

During these developments, we recognized that not only the magnetic field strength and frequency of the microwave, but also magnetic field configuration and geometrical effect of the plasma chamber play one of the essential roles to increase the beam intensity. Based on these systematic, we improved the performance and successfully produced 2mA of Ar^{8+}, 1mA of Ar^{9+} and 0.3 mA of Xe^{20+} at only 600~700W of RF power. It is noted that we only need 200W for producing 1mA of Ar^{8+} from RIKEN 18 GHz ECRIS.

To understand these effects on the beam intensities, we used the laser ablation theqnique to measure the density and temperature of the electrons and ion confinement time under the various conditions. (magnetic field configuration, RF power, biased electrode position and its voltage). In these experiments, we found that the magnetic field configuration strongly affects on the density and confinement time of the ions.

Based on these systematic studies, we started to make a design of new SC-ECRIS for production of U^{35+} beam (15 pμA) (RIKEN-U).

In this paper, we report how to produce such intense beam from ECRISs and its mechanisms and plasma diagnostics by using the laser ablation methods (the effect of the magnetic field configuration and biased disc (position and voltage) on the plasma parameters (ion confinement time, density and temperature of the electrons)). We also report the design of the new SC-ECRIS for production of U beam.

BO1 **PRODUCTION OF HIGHLY CHARGED ION BEAMS WITH THE GRENOBLE TEST SOURCE**

D. Hitz, A. Girard, G. Melin,
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Grenoble Test Source (GTS) is a room temperature Electron Cyclotron Resonance Ion Source whose purpose is to deepen the knowledge of this type of device. GTS was designed according to scaling laws determined with the SERSE source [1-2] while keeping enough flexibility in terms of magnetic confinement and RF heating to determine best conditions for the production of intense beams of high charge states. First results were presented a year ago [3-4]. Since then, some improvements have been performed mostly in beam extraction and analysis. Updated ion beam intensities will be presented: e.g. 0.4 mA of Ar^{11+} at 18 GHz and 18μA of Ar^{16+}, 1.8 μA of Ar^{17+} when GTS is operated at 14.5 GHz. On the other hand, CCD imagers have been installed to diagnose and monitor the ion beam; preliminary emittance measurements will be shown.

[1] D. Hitz, A. Girard, G. Melin, G. Ciavola, S. Gammino, L. Celona, Review of Scientific Instruments 73 (2002) 509.
[2] S. Gammino, G. Ciavola, L. Celona, D. Hitz, A. Girard, G. Melin, Review of Scientific Instruments 72 (2001) 4090.
[3] D. Hitz, D. Cormier, J.M. Mathonnet, 8th European Particle Accelerator Conference, Paris (2002) 1718.
[4] D. Hitz, D. Cormier, J.M. Mathonnet, A. Girard, G. Melin, F. Lansaque, K. Serebrenikov, L. Sun, Proc. of the 15th Workshop on ECR ion sources, Jyvaskyla, (2002) 53.

BO2 EXPERIMENTAL STUDIES OF THE AFTERGLOW MODE WITH XENON IN A CAPRICE ECRIS

K. Tinschert, R.Iannucci, J. Bossler, R.Lang

Gesellschaft für Schwerionenforschung mbH, Planckstrasse 1, D-64291 Darmstadt, Germany.

At GSI the CAPRICE-type ECRIS delivers ion beams to the High Charge State Injector (HLI). Following the demand of high flexibility the ECRIS is operated either in CW mode for high duty cycle beams or in afterglow mode to provide low duty cycle beams for the Heavy Ion Synchrotron (SIS) at low repetition rates in the order of several pulses per second. Especially for high Z ions the afterglow mode can provide higher intensities than CW mode in those charge states which are required for injection (A/q < 8.5). Besides sufficient beam intensity major demands of accelerator injection are good long time stability and good pulse to pulse reproducibility of the ion beam.

In order to find the best operating conditions for optimized afterglow performance systematic studies were performed with ^{136}Xe, the heaviest stable rare gas isotope. Different RF pulse conditions (pulse length, repetition rate, pulse shape, duty cycle) were investigated for different charge state distributions. The influence of the ion source parameters on the afterglow mode were studied in comparison to CW mode. The variation of the duty cycle allows to investigate the transition from pulsed afterglow mode to CW mode.

CO1 INTENSE HEAVY ION BEAM PRODUCTION FROM IMP LECR3 AND CONSTRUCTION PROGRESS OF SUPERCONDUCTING ECR SOURCE SECRAL

H. W. Zhao, Z. M. Zhang, X. Z. Zhang, X. H. Guo, W. He

Institute of Modern Physics (IMP), Chinese Academy of Sciences,
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Intense heavy ion beams have been produced from IMP 14.5 GHz LECR3 by optimization of the ion source condition and transmission efficiency. Highly charged stable beams, such as 95 eμA of Xe^{26+}, 7 eμA of Xe^{30+}, 145 eμA of Fe^{13+} and 75 eμA of Ni^{12+}, were obtained by 14.5 GHz rf power 800-1000 W. Furthermore, an advanced superconducting ECR ion source named as SECRAL is being constructed. SECRAL is designed to operate at rf frequency 18-28GHz with axial mirror magnetic fields 4.0 Tesla at injection, 2.2 Tesla at extraction and sextupole field 2.0 Tesla at the plasma chamber wall. The unique feature of this superconducting ECR source is that the sextupole is located outside of the three axial solenoid coils to reduce the interaction force and make the source more compact. Fabrications of the superconducting coils, cryostat, beam transmission line and other components are almost completed. The test results of the superconducting magnet with sextupole and solenoid coils together will be presented.

CO2 STATUS OF THE LIGHT ION SOURCES DEVELOPMENT AT CEA/SACLAY

R. Gobin, P-Y. Beauvais, A. Ben Ismail, D. Bogard, G. Charruau, O. Delferrière, D. De Menezes, A. France, R. Ferdinand, Y. Gauthier, F. Harrault, J-L. Jannin, P.A. Leroy, P. Mattéi, A. Sinanna,*
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SILHI (High Intensity Light Ion Source) is an ECR ion source producing high intensity proton or deuteron beams at 95 keV. It is now installed in the IPHI site building, on the CEA/Saclay center. IPHI is a front end HPPA's demonstrator. The source regularly delivers more than 130 mA of protons in CW mode and already produced more than 170 mA of deuterons in pulsed mode at nominal energy. The last beam characterisations, including emittance measurements, space charge compensation analysis and diagnostic improvements, will be reported. Taking into account the SILHI experience, new development are in progress to built and test a 5 mA deuteron source working in CW mode. This new source will also operate at 2.45 GHz and permanent magnets will provide the magnetic configuration. This source, of which the design will be discussed, will have to fit in with the Spiral II accelerator developed at GANIL to produced Radioactive Ion Beams. The H- test stand status will be presented in a companion paper.

CO3

2D MODELING OF ELECTRON DISTRIBUTION FUNCTION IN THE ECR ION SOURCE

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The paper discusses a recent development of a numerical model and corresponding computer code for electron distribution function dynamics which is an important part of ECR ion source modeling. ECR heating, collision processes, ionization and ambipolar losses through the plugs are taken into account. The model is based on a bounce-averaged kinetic equation together with an equation for ambipolar potential balancing electrons and ions losses. The model is applicable for both low plasma density regime when the loss cone is almost empty and high plasma density "quasigasodynamic" regime. The first results of simulations are presented. The traditional ECR heating models (fixed wave amplitude or fixed absorbed power) is compared with a recently developed model for self-consisting heating that takes into account the spatial structure of the heating wave. The latter model allows exploring the influence of the Doppler shift for energetic electrons on the electron distribution function. Also the formation of several groups of particles with different energy is demonstrated in the ECR discharge.

DP1 EXTRACTION OF SPACE-CHARGE-DOMINATED ION BEAMS FROM AN ECR ION SOURCE: THEORY AND SIMULATION

G. D. Alton and H. Bilheux

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P.O. Box 2008, Oak Ridge TN 37831-6368, USA

This report elucidates the problem of extracting high quality space-charge-dominated beams from plasma sources, in general, and high charge-state ECR ion sources in particular, *with* and *without* strong magnetic fields in extraction gaps, through both theoretical analysis and computational study of the problem. An all-permanent magnet, 6-GHz ECR source[2], equipped with a remotely positional extraction electrode system [3-5] for affecting changes in the extraction gap, was used as the basis of a series of simulations to give insight into the extraction process. From these studies we find that extraction of high quality space-charge-dominated ion beams constitutes an optimization problem centered about finding an optimal concave plasma emission boundary that minimizes half-angular divergence for a given charge-state, independent of the presence or lack thereof of a magnetic field in the extraction region[3-5]. Under minimum half-angular divergence conditions, the plasma emission boundary has an optimum curvature and the perveance, P, current density, $j+ext$, and extraction gap, d, have optimum values for a given charge-state, q. Optimum values for each of the independent variables (P, $j+ext$ and d) are found to be in close agreement with those derived from elementary analytical theory for extraction with simple two-electrode, parallel-plate or spherical geometry electrode systems, independent of the presence of a strong magnetic field in the extraction gap. This agreement enables the use of analytical expressions for predicting optimum extraction-gap settings that are crucially important operational parameters for extraction of highest quality, space charge-dominated beams. The action of strong magnetic fields, used to confine plasmas in the axial direction of these sources, modifies the character of beams during extraction through increases in angular spread and beam rotational effects. The emittances of individual charge-state beams, measured after M/q analysis, *with* and *without* strong magnetic fields in the extraction gap are essentially identical, suggesting that emittance growth due to aberrational and other non-linear effects attributable to magnetic field influences are small. In this report, the underlying theory is fully developed for extraction of space-charge dominated beams with parallel and spherical geometry extraction systems and compared with results derived from computational simulation studies for extraction of space-charge-dominated beams of varying mass, charge-state, and intensity.

1. Managed by UT-Battelle, LLC for the U. S. Department of Energy under contract DE-AC05-00OR22725.

2. Y. Liu, G. D. Alton, G. D. Mills, C. A. Reed, and D. L. Haynes, *Rev. Sci. Instrum.* 69 (1998) 1311.
3. H. Zaim and G. D. Alton, *Proceedings of the 2001 Particle Accelerator Conference*, IEEE: 01CH37268C, p. 2114.
4. G.D. Alton and H. Bilheux, Proceedings of the 15th International Workshop on ECR Ion Sources, ISBN 951-39-1342-2, Jyväskylä, Finland (2002) 169.
5. H. Bilheux, *Ph.D. Thesis*, Université de Versailles-Saint-Quentin, Versailles, France (2003).

DP2 INITIAL COMPARATIVE PERFORMANCES OF CONVENTIONAL "SURFACE"- AND "VOLUME"- TYPE, MINIMUM-*B* ALL PERMANENT MAGNET ELECTRON CYCLOTRON RESONANCE (ECR) ION SOURCES

G.D. Alton, Y. Liu, H. Bilheux and J.C. Cole

Physics Division, Oak Ridge National Laboratory[1], Oak Ridge, TN 37831-6368

It has been postulated[2,3] and subsequently experimentally verified[4-7] that the physical sizes and numbers of ECR zones in an ECR ion source play fundamentally important roles in the ability of the plasma to adsorb microwave radiation and consequently, to accelerate large populations of electrons to high energies, resulting in higher degrees of ionization, lower rates of charge-exchange and higher charge-state heavy ion populations within such plasmas. The physical sizes of the ECR zones can be enlarged in the spatial domain by configuring the central magnetic field so that it is uniformly distributed with magnitude in resonance with single frequency microwave radiation[2-4]. Additional zones can be added or physically enlarged in conventional ECR ion sources in the frequency domain by injecting multiple discrete[3,6,7], rapidly varying[3] or broadband frequency microwave radiation[3]. However, to date, no comparative measurements have been made that convincingly elucidate the advantages or disadvantages of single frequency "volume" ECR sources over their more conventional single frequency "surface" counterparts, as proposed in the original paper on the subject[2]. In this report, we seek to provide such information to help clarify the controversy of which design is superior. An all permanent magnet (6 GHz) ECR source, equipped with provisions for conversion into either magnetic field geometry was designed at the Oak Ridge National Laboratory for this purpose[8]. Details of the source design and operational parameters will be described, and charge-state and intensity distribution, along with companion *X*-ray spectral data, derived by operation of "volume" and "surface" forms of the source with selected noble gases without the use of gas mixing or biased probes, will be provided in this report. The present studies clearly show that, the "volume" configuration is superior to the "surface" configuration in terms of charge-state-distribution and intensity within a particular charge-state, under the same operating conditions9.

1. Managed by UT-Battelle, LLC for the U. S. Department of Energy under contract DE-AC05-00OR22725.
2. G. D. Alton and D. Smithe, Rev. Sci. Instrum. **65** (1994) 775.
3. G.D. Alton, *Proceeding of the 14th International Conference on Cyclotrons and their Applications*, Cape Town, South Africa (1995) 362.
4. A. Heinen, et al., *Rev. Sci. Instrum.* 69 (1998) 729.
5. L. Mueller, et al., *Proc. of 15th Int. Workshop on ECR Ion Sources* (University of Jyvaskyla, Finland, June 12-14, 2002).
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7. G. D. Alton, F. W. Meyer, Y. Liu, J. R. Beene, and D. Tucker, *Rev. Sci. Instrum.* **69** (1998) 2305.
8. Y. Liu, G. D. Alton, G. D. Mills, C. A. Reed, and D. L. Haynes, *Rev. Sci. Instrum.* **69** (1998) 1311.
9. H. Bilheux, *Ph.D. Thesis*, Université de Versailles-Saint-Quentin, Versailles, France (2003).

DP3

NEW DEVELOPMENTS IN ECR SOURCES AND ASSOCIATED EQUIPMENT

Claude BIETH - PANTECHNIK - France

Pantechnik is continuing to develop and improve the ECR ion sources with the collaboration of various laboratories, like GANIL (CAEN), 'Laboratoire de Physique Subatomique et Cosmologie' (Grenoble), Nuclear Science Centre (New Delhi) and in a near future, with some others. Pantechnik is working particularly on a new ECR source called PKDELIS, which will use High Temperature Superconducting coils. This new technique will reduce tremendously the total DC power of the source and will allow easily the possibility to use such a large source on a high voltage terminal. Pantechnik has also totally qualified the performances of Supernanogan for the use in Hadron therapy system, and is working on a very small and simple ECR source at 2.45 GHz able to produce 10 mA or more of proton, deuteron beams. The Phoenix charge breeder (Laboratoire de Physique Subatomique et Cosmologie - Grenoble), used for the production of RIB according to the process $1^+/N^+$ process, is now regularly produced. Various equipment like emittance meter, movable extraction system, beam profiler will also be presented.

DP4 **28 GHz 10 kW GYROTRON SYSTEM FOR ELECTRON CYCLOTRON RESONANCE ION SOURCE**

Yu. Bykov, G. Denisov, A. Eremeev, G. Kalynova V. Kholoptsev, A. Luchinin, I. Plotnikov

Institute of Applied Physics, Russian Academy of Sciences, Nizhny Novgorod, Russia
Gycom Ltd., Nizhny Novgorod, Russia

The 28 GHz gyrotron system (GS) has been purposely designed to meet present-day demand for a microwave source for powering an electron cyclotron resonance ion source (ECRIS) capable of producing both high total current and high average ion charge. Integral major parts of GS are a gyrotron oscillator operating at the second harmonic of the electron cyclotron resonance with the output microwave power smoothly regulated in the (0.1 – 10) kW range, an oil cooled focusing electromagnet, a microwave power transmission line, an integrated microprocessor and PC control system, and a water cooling subunit. A complete set of power supplies provides operation of GS in both continuous wave and pulse regimes.

As a whole the functional structure of GS follows the general method of design for feedback controlled microwave sources [1,2], whereas its technical specifications were dictated by the condition of compatibility with the ion source of the Institut National de Physique Nucleaire et de Physique des Particules, Grenoble, France. Meeting the particular requirements resulted mainly in a specific design of the microwave power transmission line. The overall power loss at both the conversion of the TE_{02} gyrotron operating mode to the TE_{01} mode applied to the ion source and at transport of the TE_{01} mode is less than 4 % in the built-up transmission line. The fast feedback loop consists of microwave power detector unit, a purposely developed PC control system, and a high voltage power supply, the regulated voltage from which controls the gyrotron output power. The feedback characteristic time is less than 1 second. The accuracy of a pre-set microwave power maintenance in continuous wave operation of GS is better than 100 W at an output power of 10 kW, and about 50 W at a power of 1 kW. In pulse operation the pulse length can be varied in the range of (1 – 200) msec with a repetition rate of (200 - 1) Hz. The leading and trailing edges of the microwave power pulse are 100 μsec and less than 10 μsec, respectively. The high voltage power supply is furnished with a fast electronic protective system to provide long-term trouble-free operation of gyrotron.

The developed PC microwave power control subsystem is supplied with LabWindows 6.0-based software. The subsystem makes it possible to control the microwave power in both manual and automatic mode. Along with the indication of the actual microwave power, the computer also displays the main operating parameters of the gyrotron power supplies such as the high voltage applied to the gyrotron, the electron beam current, and DC current in the main magnet. All the data received and generated by the control subsystem can be forwarded from the control computer of GS to user's computer via RS232 or RS485 interfaces, if necessary.

On trials the developed gyrotron system proved itself as versatile, reliable and user friendly tool applicable for long-term powering of ion sources.

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DP5 **DEVELOPMENT OF METALLIC ION BEAMS AT IMP**

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Many experiments and researches have been done to produce metallic ion beams since 1998 at IMP. We have designed a new high temperature oven it could reach more than 1300 degree using 110w electric power. Typical 70eμA of Ca^{12+}, 6eμA of Mg^{8+}, 17.5eμA of Pb^{27+}, 30eμA Zn^{15+} and 29eμA Ni^{10+} already have been achieved on the LECR2, and 74eμA Fe^{10+}, 40eμA Ni^{14+} in LECR3. We also have got some excellent results by MIVOC method in LECR3. For example, 210eμA Fe^{11+}, 74eμA Ni^{12+} etc. On the other hand plasma sputter method to produce ions of Ta and Cu also have been done in our lab, but not any good expected results were got.

DP6 EMITTANCE MEASUREMENT AT IMP LECR3

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We have designed and built an emittance scanner which was installed as the beam line of LECR3 . The emittance scanner measures the emittance of ECR ion source by the method of electric-sweep, typically named as Electric-Sweep Scanner (ESS). The horizontal and vertical emittances are both measured by two ESSs at the beam line. The relations between the beam emittance and the different conditions of the IMP LECR3 ,such as the mirror magnetic field .then extraction system and beam intensity with different charge states are experimentally studied. The detailed results and discussions will be presented.

DP7 OPERATION OF RF OVENS IN ECR ION SOURCES

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A 34. mm diameter radiofrequency (rf) oven system previously developed on bench [Cavenago, Kulevoy and Petrenko, Rev. Sci. Instrum., 73, 552] was inserted and tested into the ECR (Electron Resonance) Ion Source Alice, producing beams from natural Copper and Silver samples; charge range was typically *i=10-14* for Copper (with mass A=63 and 65) and *i=10-19* for Silver, which well compares to previous source yield for Xenon (charges 11-20). Taps on the coupling transformer improved flexibility of rf matching to different crucible materials (Tantalum or steel). Details of operating experience (cleaning the oven and replacing sample) as well as of clogging process are reported; sample duration was more than 100 h. Use of Osmium compounds for sample are discussed; to reduce clogging, a better thermal insulation of oven nozzle is under construction.

The ion source operation depending on both the oven distance from ECR plasma L_{oe} and the bias voltage V_B of the sample was investigated. Best conditions were found for small ($L_{oe}=60$ mm) or preferably intermediate position ($L_{oe}=100$ mm) and for sample negative respect to ECR chamber $V_B<-200$ V. Plasma channel formation protruding from ECR plasma back to sample is thus discussed. In this model, part of neutral vapor would be funneled on source axis, with evident benefit for source emittance, confirmed by preliminary observation; other neutrals penetrate farther (for about 200 mm). Final results of current for Silver [for example $I(^{109}Ag^{17+})$ about 800 nA] are well comparable to Xenon case [for example $I(^{129}Xe^{18+})$ about 500 nA] after correcting for isotopic abundance, which corroborates the injection model. Memory effect of metal ion generation was large and is discussed.

DP8 ANALYSIS TOOLS FOR MULTICHARGED AND MULTISPECIES ION SPECTRA

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In the development and operation of highly charged ion sources, in particular ECRIS (Electron Cyclotron Resonance Ion Sources), large amounts of data (spectra) on all the extracted ion currents are produced, depending on the source control variables (tunings, microwave and oven power, etc) and hystory (wall coatings); a sistematic analysis of the charge state distribution (CSD) of each element (or isotope) extracted as a function of control variables is fundamental both for theory and empirical optimizazion, but this analyis needs a properly automated tool(s) for CSD reconstruction. Some key features and experience of peak identification with the new program DAT2PEAK, without graphical or manual help from operators, are here discussed.

A preliminary phase to solve the dependence on source specific equipments is to produce a table of ion current I vs. analyzing magnetic field B for each spectra, with its timestamp; this is done a preprocessor LECR2DAT. The central phase, identifiying peaks, actually breaks in steps: filtering data; locating peaks; calibrating the measured B with the major element peak found; collating spectra of different dynamic ranges for I; listing superposed peaks (peaks common to a few elements) and singly identified ion peaks; fitting singly identified peaks with known models of CSD for each isotope and then distributing the current of superposed peak to related elements .

Differently from manual analysis, it is observed that any deviation from expected results in previous steps leads to numerical failures in following steps, so that robust (and typically simple) algorithms were developed and tuned for each step; for example, many fit models are tried; also, teslameter calibration drifts are corrected when comparing and collating different spectra.

For each measure processed (maximum 9999), a listing of found peaks and CSDs is produced, and DAT2PEAK updates the result database files (containing CSDs, extracted ion mass rate and average charge as a function of time and control variables) to make subsequent statistical analysis convenient.

Examples of evolution of charges and mass rate are given, finding good agreement with composition source feeding elements and expected trends.

DP9 A NEW VERSION OF THE TRIPS SOURCE OPTIMIZED FOR ADS PURPOSES

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A full set of measurements of the magnetic field has been carried out to define a different design of the TRIPS magnetic system, based on permanent magnets, in order to increase the reliability of the whole source.

The two coils of the source generate a maximum field of 0.15 T and the optimum field was determined around 95 mT. The OPERA-3D package was used to simulate the magnetic field and a new magnetic system was designed as a combination of three rings of NdFeB magnets and soft iron.

The high voltage insulation has been completely modified, in order to avoid any electronics at 80 kV voltage. The description of the magnetic measurements and the comparison with the simulations are presented, along with the mechanical design of the new version PM-TRIPS and the new design of extraction system.

Finally the modification of the low energy beam transfer line (LEBT), which now includes a 30° bending magnet, will be outlined, with a special regard to the accelerator availability improvement which can be obtained with the installation of two TRIPS sources or more on the LEBT.

DP10 A HIGH INTENSITY ECR ION SOURCE FOR HIGH CURRENT RFQ

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A high intensity ECR ion source for high current RFQ has been developed at China Institute of Atomic Energy(CIAE), China. The aim of the source is to produce up to 50 mA cw beams at 75 keV at the RFQ match point. A more uniform magnetic field of the source is produced by a electrical solenoids with the aid of permanent magnets. A hydrogen beam of more than 60 mA at 75keV can be extracted from a single 6.5 mm diameter aperture routinely. To measure reliability/availability of the source, continuous 120 hours run has been performed. This article will report the main features and the current status of the source.

DP11 RECENT RESULTS WITH THE mVINIS ION SOURCE

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The mVINIS Ion Source is a part of the TESLA Accelerator Installation, in Belgrade. It is an ECR ion source used as a stand-alone machine delivering multiply charged ion beams to a low energy experimental channel for materials modification (the L3A channel). In the future, it will be also used as a heavy ion injector for the VINCY Cyclotron. mVINIS had been constructed, assembled and tested in cooperation with the Joint Institute for Nuclear Research, Dubna, Russia, during 1996 and 1997. It was commissioned in 1998 and since that time it has been in routine operation, providing different ion beams for experiments at the L3A channel.

In this paper we present the recently introduced hardware and software changes resulting in an improved operation of mVINIS: the inlet system for precious gases, the improved control system of the microwave generator, a new power supply for the injection stage coil, the emittance measurement system and the improved program for recording and analysis of the ion beam spectra. This is illustrated with a few recently obtained results. Since mVINIS coupled with the L3A channel offers a unique possibility to irradiate and modify different materials using multiply charged ions, we present briefly some of the latest experiments for investigation of this kind of interactions.

DP12 PLASMA NUMERICAL MODELING IN AN ECR MINIMUM-B TRAP

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A plasma of a 14 GHz minimum-B source, which is based on the electron cyclotron resonance phenomenon, has been studied through a three-dimensional simulation code based on article in cell technique. In the code, the fast Larmor rotations are calculated with a time step equal to 1/250 of the microwave field period. The space geometry of the electron and ion components, as well as the ion spectra in both the core plasma and the charged particle fluxes, which reach the end walls, are visualized. The low frequency oscillations of the electron as well as the ion plasma components are discussed.

DP13 SELF CONSISTENT MODELLING OF ELECTRON CYCLOTRON RESONANCE ION SOURCES

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In order to predict the performances of ECRIS, it is necessary to perfectly model the different parts of these sources: (i) magnetic configuration; (ii) plasma characteristics; (iii) extraction system. The magnetic configuration is easily calculated via commercial codes; different codes also simulate the ion extraction, either in 2D, or even in 3D (to take into account the shape of the plasma at the extraction influenced by the hexapole). However the characteristics of the plasma are not always mastered. This paper describes the self consistent modeling of ECRIS: we have developed a code which takes into account the most important construction parameters: the size of the plasma (length, diameter), the mirror ratio and axial magnetic profile, whether a biased probe is installed or not... These input parameters are used to feed a self consistent code, which calculates the characteristics of the plasma: electron density and energy, charge state distribution, plasma potential. The code is briefly described, and its most interesting results are presented. Comparisons are made between the calculations and the results obtained experimentally. It is shown how this code can be used to predict the performances of ECRIS.

DP14 **EMITTANCE MEASUREMENT FOR INTENSE BEAM OF HEAVY IONS FROM RIKEN 18 GHZ ECRIS**

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Last decade, we tried to increase the beam intensity of medium charge-state of heavy ions, such as Ar^{8+}, Kr^{13+} and Xe^{20+}, for RIKEN radio isotope beam factory project (RI BF). Final goal of this project is to produce at least 1pμA on target from p to U beam. To meet this requirement, we had to make further development of the performance of the ECRIS. Last year, we successfully produced 2mA of Ar^{8+}, 1mA of Ar^{9+} and 0.3 mA of Xe^{20+} at 12~17kV extraction and 600~700 W of RF power by optimizing the plasma electrode position and the magnetic field configuration. It should be stressed that we only need 230W for producing 1mA of Ar^{8+}.

To increase the beam intensity from accelerator, it is obvious that the emittance is also important physical value for the ECRIS. The emittance of the intense beam, i.g. 2mA of Ar^{8+}, shoulde be enlarged by the space charge effect. To investigate this effect on the emittance and optimize the transmission coefficient of heavy ion beam from RIKEN 18 GHz ECRIS to the heavy ion linac, we measured the emittance of the intense beam under the various conditions. For test experiment, we used the Ar^{8+} and Xe^{20+} beams. We changed the beam intensity from several 10 μA to 1.5 mA. We also changed the bias disc voltage and its position to investigate the effect of negatively biased disc on the emittance of the heavy ion beam. To investigate the effect of the biased disc, we measured the emittance by changing the disc position and voltage without changing the beam intensity (we kept the beam intensity of Ar^{8+}~500μA). We observed that the biased disc did not change the emittance of the beam. In this systematic study, the emittance (~100 % of the total beam) of the Ar^{8+} beam increases from ~250 πmmmrad to ~380π mmmrad with increasing the intensity from 0.5 mA to 1mA. Such large emittance and the dramatic increases may be due to the space charge effect.

In this paper, we present the emittance of the intense heavy ion beam (order of mA) as a function of various parameters (RF power, bias disc voltage and position) and discuss the effect of the space charge on the emittance.

DP15 **FIRST BEAM RESULTS AND STATUS OF ECR PROTON SOURCE AT CAT**

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The Proton LINAC at 100MeV to be used as injector for 1GeV rapid cycling synchrotron at Centre for Advanced Technology (CAT) as a part of pulsed Spallation Neutron Source (SNS). An Electron Cyclotron Resonance (ECR) proton source operating at 2.45GHz producing 20mA proton current at 50keV beam energy will be used as an injector to 100MeV Proton Linac has been designed and constructed. The plasma chamber was excited with 300watts of microwave power at 2.45GHz microwave frequency with hydrogen gas. The microwave line was first characterized with glass load at its full magnetron rated power 2kW. The power supplies for the magnetron (4.6V AC, 19A for filament) and (anode supply 5kV DC, 1A) was designed and developed. The microwave power was coupled to the plasma chamber through ridged antenna. The plasma parameters, plasma density and electron temperature was studied with gas pressure, magnetic field and microwave power variation. The hydrogen plasma density $3.9 \times 10^{12} cm^{-3}$ and electron temperature 4.3eV is obtained. The extraction geometry (accel-decel type) was optimized using IGUN for the extraction of the proton beam. The 1mA proton beam current is measured at 4.5kV extraction voltage. This paper describes the first beam results and status of the ECR proton source at CAT.

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DP16 PRODUCTION OF MULTICHARGED IONS IN A 2.45 GHZ ELECTRON CYCLOTRON RESONANCE SOURCE DIRECTLY EXCITED IN A CIRCULAR TE01 MODE CAVITY RESONATOR

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Electron cyclotron resonance (ECR) ion sources have been widely used for production of high-intensity multicharged ion beams for accelerators, atomic physics experiments, and industrial applications as well as medical therapy of cancer. The design of the sources has reached a certain maturity, methods of fabricating ECR sources seem to be well understood. In contrast, the physical phenomena underlying the source performance and several empirical methods such as the biased disk, wall coating, low-Z gas mixing, pulse-modulated microwave and so on, are poorly understood.

In order to seek the upgrading feasibility of the low frequency ECR plasma by using 2.45 GHz microwaves for multicharged ion sources, we have conducted various experiments in the TAIKO device (Toyama Pref. Univ.). To investigate the production mechanism of multicharged ions, we have measured profiles of the electron temperature, density, and plasma potential by using the Langmuir probes [1]. The behavior of the hot electrons has examined by pulse height analysis of bremsstrahlung [2]. On the basis of these results, we have conducted the experiments which enhance production of multicharged ions by pulse-modulating the microwave to continuously add the afterglow phase [3]. And we have also investigated both experimentally and theoretically the optimized shape of the ECR zone [4].

In this article the experimental study concentrates on production of multicharged ions with respect to a microwave mode, especially, a circular TE_{01} mode, which is prospective for enhanced efficiency of electron cyclotron resonance. The electric field of the circular TE_{01} mode has only circumferential component in the same direction as electron cyclotron motion in the magnetic mirror field. We can assign the peak position of the electric field of the standing waves to the ECR zone in the cavity resonator, i.e., the vacuum chamber. The scenario in our experimental procedure is as follows: The diameter of the vacuum chamber is chosen to correspond to the guided wavelength which steeply depends on it as for the circular TE_{01} mode. The semi-dipole antenna is set at the sidewall, and directly excites the circumferential electric field. In order to suppress the other modes, i.e., the basic TE_{11} mode, other TE and TM modes, we install two circular metal plates insulated from the side wall at both of the end plates. A fixed plate is installed at the tip of the extractor. The distance between the fixed plate and the antenna is equal to a quarter of the guided wavelength of the circular TE_{01} mode microwave. The mobile plate is inserted from the opposite side along the geometrical axis to tune the TE_{01} mode cavity resonator. First we conduct simulated experiments and recognize the excitation of the TE_{01} single mode. Under the guideline obtained from the simulated experiments, we will newly construct the ECR source (TAIKO II). We will investigate the features of the plasma source in the cavity resonator of the circular TE_{01} mode microwave directly excited. We will mention the results of the simulated experiments, the guideline and the design of the new source in detail, and then preliminary results of the new source.

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DP17 PRODUCTION OF INTENSE ^{58}FE, ^{64}NI BEAM UISNG MIVOC METHOD AND NEW ANALYZING SYSTEM OF RIKEN 18GHZ ECRISS

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For request from the research group of super heavy elements, high intense beams of ^{58}Fe and ^{64}Ni ions were produced by the MIVOC method from RIKEN 18GHzECRIS. For production of these beams, we used the metallocene ($^{58}Fe(C_5H_5)_2$, $^{64}Ni(C_5H_5)_2$) made by the Chemical analysis division of RIKEN. The experiments using ^{58}Fe and ^{64}Ni beams were done about 1 week and 8 weeks respectively. Maximum intensities of the supplied ion beams were 20eμA at the extraction voltage of 15.9kV for $^{58}Fe^{13+}$ and 90eμA at the extraction voltage of 17.5kV for $^{64}Ni^{13+}$. The long term operation using MIVOC method have several problems, for example difficulty of stable gas production, because the vapour pressures of these materials are very sensitive to the temperature, contanimation of plasma chamber surface and increase of reflection micro waves etc.

For RIBF (Radio Isotope Beam Factory) and various requests of users group, we have a plan of double beam injector system of the two ion sources for RFQ and RILAC (Riken heavy Ion Linear ACcelerator). Two ion sources; RAMSES and 18GHz ECRIS, will be placed on August. Since we do not have enough space for setting the two analyzing magnet for two ECRISs and we would like to operate the two ECRISs simultaneously (one is beam production for accelerators and the other one is used for test experiment), special analyzing magnet is newly constructed. And new plasma chamber of 18GHz ECRIS was fabricated for use at the extraction voltage higher than 20kV.

In this paper, we present how to produce intense beam of ^{58}Fe and ^{64}Ni ions stably for long term operation. We also present the status of the new injection system and its structure.

DP18 STATUS REPORT ON ECR ION SOURCES AT HIMAC

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The Heavy Ion Medical Accelerator in Chiba (HIMAC) at the National Institute of Radiological Sciences (NIRS) is the first heavy-ion accelerator complex dedicated to cancer therapy[1]. We have started clinical trials in June 1994, and over 1500 cancer patients have already been treated with 140-400 MeV/u carbon beams. C^{2+} or C^{4+} ions are produced for the daily clinical treatment mainly by the NIRS-ECR ion source, which has a single closed ECR-zone with 10GHz microwave. The NIRS-ECR realizes good reproducibility and reliability with easy operation. The typical output currents of C^{2+} and C^{4+} are 300eμA and 280eμA, respectively. The NIRS-ECR also has a long operation time, and only requires maintenance (cleaning of electric insulators) after a running time of a half year. We summarize the successful experiences for this nine years.

HIMAC is not only dedicated to cancer therapy, but also offers beams with various ion species for basic experiments of biomedical science, physics, chemistry, etc. For the injection into the RFQ linac, the injection speed must be 8keV/u and the charge-to-mass ratio must be larger than 1/7. Another source, an 18GHz ECR ion source with High-voltage Extraction Configuration (NIRS-HEC), is available to produce such heavier ion species with medium charge state. The NIRS-HEC has two features. One is the high extraction voltage, since it prevents unwanted space charge effect at the extraction region which will occur at medium charged heavy ions. The maximum extraction voltage between the plasma electrode and the extraction electrode reaches to 60kV. The other is the optimized radial magnetic field to match a magnetic field-line flux with the beam-extraction configuration[2]. The maximum output ion currents are 1.1emA for Ar^{8+}, 180eμA for Fe^{10+}, 105eμA for $^{84}Kr^{13+}$, 95eμA for $^{132}Xe^{20+}$. Several applications realized by such ion beams are reported.

Developments for extension of the range of ion species and increasing the beam intensity for the NIRS-HEC are now in progress. The MIVOC technique is used for the production of ^{56}Fe and ^{57}Fe. In order to obtain desired evaporation rate and consumption rate, the temperature of the MIVOC oven is controlled. Ion species, such as B, Si, and Cl, are produced from the special gasses BCl_3 or $SiCl_4$. The gas feeding system with the safety interlock is installed. To produce metallic ions, a new gas supply method also has been developed. A metallic target rod at a high positive potential is heated by the electron bombardment technique. In addition, a high temperature crucible is also available by the same technique. The various metallic gasses with a maximum evaporation rate of 50 angstrom/sec at a distance of 5cm are supplied into the ECR plasma. The results of these recent developments are also reported.

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DP19 TUNABLE AND STRONG MULTIPOLE FIELD STRUCTURE FOR ELECTRON CYCLOTRON RESONANCE ION SOURCES USING PERMANENT MAGNETS

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The performance of the Electron Cyclotron Resonance Ion Source (ECRIS) increases in square with the microwave frequency used which gives a strong impetus towards the use of higher microwave frequencies. However, the higher frequency requires a stronger magnetic field for the efficient operation of the ECRIS. The rather complicated magnetic field configuration is provided by the combination of the solenoid and the multipole fields. As a result a so-called B-minimum structure is obtained. With the aid of permanent magnets the multipole field of around 1.2-1.4 T has been reached. That value makes it possible the efficient operation of the ion source at the microwave frequency of about 18 GHz. In this article we will describe a new multipole structure for any ECR-type ion source. According to our simulations the multipole field up to 2.3 T can be achieved by using permanent magnets. This allows the efficient operation of the ECRIS at the microwave frequency even higher than 28 GHz. In addition, the strength of the radial magnetic field can be changed continuously from the value of about 0.3 T to the value of 2.3 T. Hereafter, the abbreviation JYFL-IMPS is used for this structure (JYFL: Department of Physics University of Jyväskylä, IMPS: Improved MultiPole Structure).

DP20 **CPT METHOD OF MHD INSTABILITIES STUDYING IN PLASMA, CONFINED IN A MAGNETIC TRAP**

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Current trend in the development of electron-cyclotron resonance (ECR) sources of multiple charge ions (MCI) leads to increase of ECR pump frequency and, as a consequence, to increase in the magnitude of magnetic field in a trap. Traditional magnetic traps of ECR sources utilize "min B" magnetic filed configuration, which brings forth the need to stabilize MHD instabilities. Therefore further increase in magnetic field strength seems difficult. In [1] a new type of ECR source magnetic trap, not using "min B" configuration, was proposed and a possibility of high current generation of medium charge ions was demonstrated. One of the main limitations, which prevents these traps from producing ions with larger charge, is MHD instabilities leading to decrease in plasma lifetime. In our work we propose a method of MHD instabilities diagnostics based on the effect of coherent population trapping (CPT) via laser induced fluorescence (LIF). With this method one can obtain spatial distribution of magnetic field with good time resolution (about 100 ns) and particularly it would allow to trace field distortions caused by an instability.
The essence of CPT effect is the following. If there are two long-lived atomic or ionic states, for example two Zeeman sublevels, that are optically coupled to a common excited state, then resonant fluorescence and/or absorption are strongly suppressed at exact two-photon resonance. In the case of Zeeman sublevels, two-photon resonance condition is determined by the laser difference frequency and the local magnetic field strength. Thus CPT has clear potential for magnetic field probing. The CPT diagnostics method is developed and experimentally tested in IAP RAS. It has a number of advantages in comparison with probes and particle beams or other spectroscopic techniques (based on Zeeman or Faraday effects). Probes are invasive, so they disturb plasma, as well as beams. Spectroscopic methods based on absorption and phase shift are non-invasive, but give values integrated over the entire laser beam path. LIF is non-invasive and inherently a spatially resolved technique and is already used to measure magnetic fields via Zeeman shifts and electric fields via the Stark effect. Another advantage of LIF is that it can measure more than one physical quantity and produce 2D images, provided the fluorescence intensity is adequate to overcome the background glow of the plasma. In a model experiment [2] it was shown that magnetic field resolution of the order of 1 G and temporal resolution of the order of 100 ns are achievable. The special resolution of this method is primarily determined by the signal-to-noise ratio in the observed fluorescence and, according to our estimates, can be made of the order of 100 μm. CPT also does not require that the magnetic field direction be known in advance and works equally for large, intermediate and near-zero magnetic fields. In this work theoretical calculations demonstrating the feasibility of CPT-based diagnostics of plasmas of ECR MCI sources and possible experimental schemes are presented.

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DP21 MICROPHOENIX: INTENSE DEUTON BEAMS PRODUCTION FOR SPIRAL2

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The development of ECRIS at LPSC Grenoble (previously ISN) covers a wide range of applications.

MICROPHOENIX is a compact source whose magnetic confinement is fully generated by permanent magnets. The extraction geometry has been specially designed to manage high currents with a double electrode extraction system to improve the beam characteristics at high voltage. The ECRIS can accept a microwave power frequency from 10 to 18 GHz. It has been installed as a universal injector on the new charge breeder test bench in order to perform the widest range of experiments including mono or multicharged ion injections. To characterize the analyzed extracted beam, a new emittancemeter based on electrostatic deflection plates has been set up and permits to obtain online high resolution measurements. The first objective of the experiments was to fulfill the future SPIRAL2 requirements. After a technical description of the MICROPHOENIX ECRIS and its beam analysis system, the first experimental results obtained with a single puller electrode will be presented. Thus, a D+ intensity of 5mA@38kV is easily delivered within a normalized RMS emittance of 0.084 π.mm.mrad, which is well below the 0.2 π.mm.mrad limit assuring a 100 % RFQ transport efficiency as computed for the LINAG project. A more extensive study of emittance versus plasma parameters is in progress.

DP22 STATUS REPORT ON ECR ION SOURCE OPERATION AT GANIL

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The electron cyclotron resonance ion sources, ECR 4 and ECR 4M, provide high charge state ion beams to the compact injectors, Co1 and Co2, coupling alternately, with the main accelerator GANIL. Ions beam of various elements are demanded covering beam time periods from 8 to 11 weeks. A great part of them, intended for the production of radioactive ion beams on the SPIRAL facility, are produced from gaseous compounds. A high intensity is required at the source to obtain from 1 to 6 kW power beam on the target. However progress in metallic ions production remains a main objective. A recycling effect of $^{76}Ge^{13+}$, the sputtering method for $^{238}U^{31+}$ beam production and last results with $^{112}Sn^{22+}$ beams are reported. New ovens are under developments to improve the capacity and the performances of the standard micro-oven. Simulations and first measurements on test stand are presented.

DP23 THE NEW ECR ION SOURCE DECRIS-4 (PROJECT)

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A new ion source DECRIS-4 for the production of multiply charged ions is planned to be build at the FLNR JINR. The source can be used as an injector of heavy multiply charged ions for the U-400 cyclotron, as well as a "charge breeder" (the "1+ → n+" method) for the second phase of the DRIBs project. The main feature of the ion source design is the creation of the extended resonance zone in a comparatively compact ECRIS. For this purpose the axial magnetic field distribution is formed with a flat minimum. Superposition of the axial magnetic field with the field of the permanent magnet hexapole, made from NdFeB, allows one to create a large resonance volume. In this case the electrons can be heated more efficiently. The maximum of the plasma density is situated near the axis, where ions are mainly extracted from. For the plasma heating a microwave frequency of 14 GHz will be used. A preliminary design of the source is described. Also the features and prospects for the application of this source are discussed.

DP24 PERFORMANCE OF THE VENUS ECR ION SOURCE AT 18 GHZ

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The superconducting ECR ion source, VENUS, is currently operating at 18 GHz and work is underway for 28 GHz operation which is planned for the early part of 2004. Initial tests with low mass gases such as helium, oxygen and argon have been performed with up to 1200 W of 18 GHz RF power. For example, 810 μA of O^{6+} and 180 μA of Ar^{12+} were produced and the dependence of current versus RF power indicates more power is needed for optimum performance. We plan to extend the tests up to 2 kW of 18 GHz RF for a range of heavier elements from both gases and solids. The low energy beam transport section includes a Glaser lens, a high transmission 90 degree analyzing magnet and a two axis emittance scanner to measure beam transport efficiency and emittance of the intense multi-charged ion beams produced by VENUS. Systematic measurements can then be compared with beam transport simulations for the system, which include space charge effects.

DP25 **NUMERICAL SIMULATION MULTICOMPONENT ION BEAM TRANSPORT FROM ECR ION SOURCE**

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We are developing a multi-charged ion beams transport program. The program is dedicated to numerical simulation of the highly charged ion beam and optimization of beam dynamics in transport lines which is realized on the PC with Windows user interface of Microsoft Visual Basic. The capture of electrons between highly charged ions and low charged ions or neutral atoms are taken into account using classical Molecular Over-barrier Model and Monte Carlo method, the initial charged state distribution of ions is get from experimental data. The code also can give the change of charge state distribution along the transmission line. The main advantage of the code is simultaneous simulation of a number of ions with different masses and charge states, particularly, the loss of the highly charge ions caused by electron capture. Some simulation result for a transmission line of a highly charged ECR ion source will be presented. The simulation results are compared with experimental results achieved from IMP LECR3.

DP26 OPERATION OF THE TEXAS A&M 14GHZ, LARGE-VOLUME ECR2 ION SOURCE

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The lower-field 6.4 GHz ECR ion source (ECR2) at Texas A&M has been upgraded to a higher-field, 14.5 GHz ion source. The 8 liter volume of the plasma chamber is larger than that of most sources operating at this frequency, but equal to the volume of the Texas A&M high-B, 6.4 GHz source, ECR1. Operating in 14.5 GHz mode alone, ECR2 compares favorably to ECR1, but when ECR2 is operated in either 6.4 GHz mode or in dual frequency 14+6.4 GHz mode, the results are disappointing. Operating parameters, as well as results with sputtered metals are described.

DP27 FIRST OPERATION OF ECR ION SOURCE AT KUT

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To study atomic physics and nano scale manufacturing by using the ion beam, NANOGAN (10GHz), which is a ECR ion source developed by PANTECHNIK, has been installed in Kochi University of Technology (KUT). We have gotten the first beam extracted from ECRIS in January of 2003.

NANOGAN has been built with the beam transport system and the irradiation system at KUT. The voltage up to 30 kV and 100 kV are applied to extract and accelerate the ion beam, respectively. To perform mass analysis, a dipoler magnet was installed in the beam transport system.

To check the beam extraction, the beam extracted from NANOGAN into which Ar gas was fed was observed as a function of the voltage for the beam extraction. The power of RF (P_{RF}) applied to ECRIS was valid over the range 10 – 24 W and the beam current was measured by the Faraday cup. Since the beam current was measured without mass analysis in this measurement, all of ions extracted from NANOGAN were observed. The typical results are shown in Fig. 1. The solid line is the fitting results optimized by power function, $I = AV^B$. The index B = 1.61(10) is consistent with Child-Langmuir equqtion. And index B does not depend on P_{RF}. It is implied from this result that the extraction system works well.

To confirm the ionization, the mass spectrum of the beam extracted from NANOGAN was observed. Ar gas and the air were fed into NANOGAN and P_{RF} was valid over the range 8 – 24 W. The beam was analyzed by the dipole magnet and the beam current was measured by the Faraday cup. The mass spectrum measured at P_{RF} = 24 W is shown in fig. 2. Ar ions shown in fig. 1 with thick lines and other ions, C^{+1}, C^{+2}, N^{+1}, O^{+1}, were detected. Furthermore, molecular ions were detected. Ar ions and other ions are produced from Ar gas and air, respectively. It is confirmed that all of atoms and molecules, which are fed into NANOGAN as a gas, can be ionized.

It is concluded from the above results that the ECRIS system build at KUT works normally and has a possibility of an application to the various fields. In the next step, we will get the ion beams in higher charge states by applying more intense RF.

fig. 1

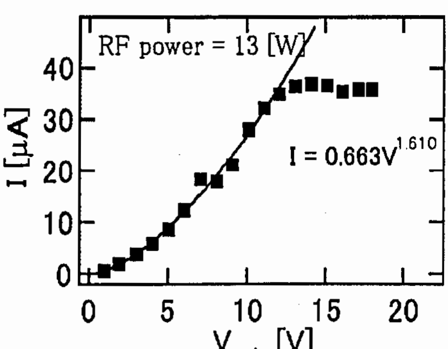
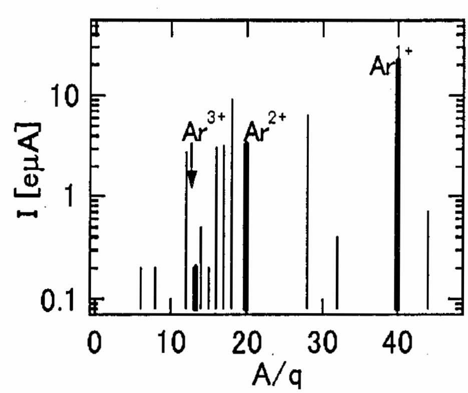


fig. 2



DP29 PARALLEL P3M CODE FOR ECR PLASMA SIMULATION.

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The there dimensional parallel P3M code for ECR plasma simulation is presented. Many-body classical systems where interparticle forces are central and conservative can be simulated usyning the presented parallel code library. ECR plasma is one of the systems with rapidly varying short-range forces and long-range Coulombic forces. The perfomed code is particularly effective for such systems.

DP30 **ACHIEVING SYMMETRIC SUFFICIENT CUSP FIELD FOR HIGH FREQUENCY ECR ION SOURCE**

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Related to plasma confinement in a cusp magnetic field, one can refer to a general theorem which states that an equilibrium state is macroscopically stable provided that the pressure everywhere decreases in the direction of the principal curvature of a magnetic field line. But the configuration in consideration has open cusps with confined plasma extending to infinity. So, it should be referred to a more refined treatment of equilibrium, which takes into account electric and magnetic mirror reflection of particles.

There has been a constant quest for better field configuration and magnetic well for confining plasma particles superbly. There has also been search for improving techniques and discovering new methods, for making conventional electron cyclotron resonance (ECR) ion source more powerful and compact in terms of giving high quality multi-charged heavy ion beams for various applications.

Some people used cusp modified minimum-B field configuration for designing ECR ion source for 2.45 GHz microwave frequency but very rarely. Later on, some source was converted into conventional one because of their poor performance. These sources were not very successful since plasma was probably created and heated asymmetrically [1] because of improper magnetic cusp field.

It has been successfully attempted to understand the problems of old cusp field ECR ion sources [2]. In this regard, cusp magnetic field is reconfigured using a pair of coaxial coils either at room temperature or low temperature. Discrepancy in magnetic field at the ring cusp position is mitigated using a highly permeable mid-iron disk. Yoke and plugs are properly added such that sufficient symmetric magnetic field for microwave frequency 18 GHz ECR ion source for working at high-B mode is achieved. Sufficient gap is created between the ECR surface and interior surface of the chamber in this mode of operation for uniform heating of electrons and plasma discharge around the centre. Achieved sufficiently symmetric magnetic field act as magnetic mirrors for escaping electrons and increase the plasma density and stability. Now, it is feasible to make more powerful and bigger ion device using the new cusp magnetic field for producing highly charged ions using only superconducting coils and millimeter wave high frequency gyrotrons.

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DP31 ROTATING MULTIPOLE FIELD ION AND PLASMA DEVICE

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The conventional type of magnetic well that is the minimum-B (Ioffe) field is formed by superposition of two types of static magnetic field: axial bumpy field and radial multipole field created often by coils and permanent magnet respectively. The magnetic well is used to contain plasma consisting of neutrals, ions and electrons. These particles are in constant motion in the well and energetic electrons create plasma by violent collisions with neutrals and ions. So it is imperative to simulate the motion of electrons in the magnetic well for visualizing how they are trapped.

When a magnetic field varies with time in magnitude, direction or both there is an induced electric field according to the Faradays law of induction. Here, it is attempted to rotate the multipole field theoretically, which is used in a plasma or ion device for confinement of plasma. Essentially, there is a natural induced electric field, which has been deduced and evaluated. The motion of electron in the rotating multipole field in presence or absence of the static axial field has been simulated for 1.0 μsec. It has been shown how its motion is influenced in terms of heating, confinement and azimuthal uniformity. Lastly the feasibility of practically achieving the rotating multipole field with reasonable magnetic field for a stand-alone plasma device is explored too.

DP32

DEVELOPMENT OF 13 GHZ COMPACT ELECTRON CYCLOTRON RESONANCE ION SOURCE

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An extremely compact, all-permanent-magnet electron cyclotron resonance ion source was designed and manufactured mainly for materials development. The ion source was installed to the 400kV ion implanter, and heavy ion beam in a MeV energy region with high beam current was available using multiply charged ions from the ion source.

The magnet size is 12 cm in the length, 3 cm and 11 cm in inner and outer diameter. The high magnetic field is formed with the unique permanent magnet structure in the plasma chamber. The maximum mirror field is achieved to 0.62 T and the B minimum is 0.40 T. The 13 GHz RF power up to 10 W was fed to the source by the solid state microwave generator, and the minimum B structure is formed in the plasma chamber.

In the preliminary result at the test stand, the Ar^{4+} beam of 80eμA and He^{2+} beam of 100eμA were available and the Ar^{12+} beam was obtained at the extraction voltage of 13.5kV with microwave power of only 8 W.

DP33 **OPTIMIZATION OF THE mVINIS ION SOURCE EXTRACTION SYSTEM**

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The ion-optical properties of the single gap extraction system of the mVINIS Ion Source are investigated. The pepper-pot method is used to measure the rms emittances of the space charge dominated ion beams extracted from the plasma. The emittances have been analyzed as functions of the extraction electrode position and the extraction voltage for various high charge state ion species.

DP34

NEW PROFILE-/EMITTANCE MONITORS AT THE FRANKFURT 14GHz ECRIS

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A device for measurements of beam profiles/emittances has been developed and tested at the Frankfurt 14GHz ECRIS. It consists of a standard moving slit system in combination with a new type of profile monitor that can easily be integrated into the diagnose boxes of the existing beam line. By utilizing essentially the standard Faraday cup measurements of the beam diagnosis as profile monitor, the system is permanently integrated into the beam line. This is in contrast to the device used so far, which always demanded for a major redesign of the existing beam line, merely for the case of emittance measurements. This device(s) will be introduced at certain diagnose boxes of the beam transport system to meet the increased need of an improved characterization of the beam quality during normal operation as well as for redesigning source parameters. It is also an important input for transport calculations of new beam lines. Such calculations are necessary to control the matching of the beam emittance to the acceptance of the (ve)-RFQ post accelerator. The system will be described and first results will be discussed.

DP35 ON THE PHYSICS OF METAL-DIELECTRIC STRUCTURES IN ECR ION SOURCES

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Previous research by the authors demonstrated the high capabilities of metal-dielectric (MD) structures to enhance the high-charge-state ion production in ECR Ion Sources [1,2.3]. In order to provide an explanation for this effect, dedicated experiments have been performed, in which, by testing changes of main plasma parameters in the presence of a MD structure, a viable scenario for the mechanism of this effect was given[4].

In this contribution we present a new experiment where we have concentrated on the question whether the effect of the high-charge-state enhancement by the MD structures is due to the presence of just a dielectric layer in the plasma chamber (e.g. working simply as a breaking of the non ambipolar wall currents) or whether details of the structure of the MD junction play an essential role (e.g. the strength of the electric field that builds up over a sufficiently thin MD structure (MD field effect). Ion charge state distributions (CSD), Bremsstrahlung radiation spectra are compared for two MD cylinders, of drastically different layer thicknesses (one very thin one and one quasi infinitely thick one) The experiment clearly demonstrates the importance of the MD field effect for the production of very highly charged ions.

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DP36 THE DESIGN OF A HIGH CHARGE STATE ALL PERMANENT ECR ION SOURCE

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In recent years, atomic physics researches have got great progresses in IMP, and with the broadening of the research fields, besides the present ECRIS (Electron Cyclotron Resonance Ion Source) in Lanzhou some extra high performance ECR ion sources are demanded. Now, an ECRIS put on a HV (high voltage) platform, which can be applied a HV up to 400kV, is now under construction. For the sake of high electric power consuming and some critical engineering requirements, an all permanent instead of a solenoid coil ECRIS is adopted. The axial magnetic mirror peaks are 1.46Tesla and 1.16Tesla at the injection and extraction side respectively. The ID of the plasma chamber is designed to be 67mm while keeping the radial magnetic field at the inner wall of the plasma chamber up to 1.2Tesla. Some interesting aspects on designing the hexapole as well as the parameters of the source will be given in the following chapters.

DP37 THE EFFECTS OF THE GAS MIXING AND PLASMA ELECTRODE POSITION ON THE EMITTANCE OF AN ELECTRON CYCLOTRON RESONANCE ION SOURCE

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Most of the recent development on the ECR ion sources [1] has been aimed to obtain higher ion beam currents and charge states. Consequently, high microwave frequencies are needed and therefore also strong magnetic field configurations are necessary. It has been found that the emittance of the ion beam increases with the magnetic field at the extraction [2]. Emittance should be as small as possible in order to produce more usable ion beams. In this work we have studied the effects of the gas mixing method [3] on the ion beam emittance and brightness. We have measured the emittance of different ion beams using helium, oxygen and argon with several gas feeding ratios by the JYFL 6.4 GHz ECRIS.

It has also been observed that the plasma electrode position has a strong effect on the extracted currents of different ion beams [4, 5 and 6]. In order to measure the effect of the plasma electrode position on the ion beam emittance we constructed a new extraction system for the JYFL 6.4 GHz ECRIS. The whole extraction system can be moved online and only the plasma chamber length changes when moving the plasma electrode. During the summer 2003 we are going to study the effect of the plasma electrode position to the emittance of different ion beams.

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DP38 **DIAGNOSIS OF PLASMAS IN COMPACT ECR ION SOURCE EQUIPED WITH PERMANENT MAGNET**

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For the precision isotope ratio measurement, Thermal Ionization Mass Spectrometer (TIMS) has been used because of the high stability of ion beam, i.e., the beam intensity is scarcely fluctuated in the brief time, and the fluctuation within the long time is also very moderate. However, the ionization for the elements with high ionization potential is difficult and its ion currents from the surface ionization ion source are very low. So we have proposed the compact size ECR ion source for the mass spectrometer, and a compact ion source has been developed [1]. Thesize of this compact ECR ion source is 22.5mm of the inner diameter (1-inch tube), and 56mm of length. The ECR plasmas in the compact ion source were discharged by the high frequency microwaves, 7-10 GHz. The microwaves were generated by the Gunn oscillator and amplified by the traveling wave tube (TWT). The ion source has an octupole magnet. In the present work, the permanent magnet, which was made of $Nd_2Fe_{14}B$, was introduced in order to generate the magnetic field for ECR region. The used magnet was the simple ring type. As a result of this equipment with permanent magnet, the total ion source system became more compact than one equipped with magnetic coil. The compact ECR ion source and the magnetic field generated by the ring type permanent magnet are shown in Fig.1. The argon gas was filled in this ion source and discharged. The plasma generations were confirmed at 10-150 mPa. The plasmas in this ion source were diagnosed by a Langmuire probe. The electron temperatures were 3-9 eV, and the plasma densities were in the order of 10^{16} -10^{17} m^{-3}. The effects of the input power on plasma generation in the ion source were investigated. A mode jump of plasma discharge was observed with increasing the RF power (see Fig.2). This mode jump shows that the conversion efficiency of electron kinetic energy to plasma density is low at the lower input power region, meanwhile at higher power region, the efficiency is high. In summary, the compact ECR ion source with permanent magnet was developed, and this ion source was characterized.

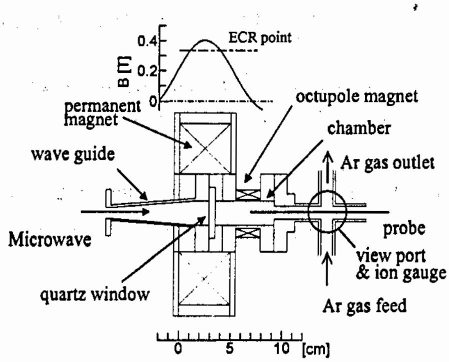

Fig. 1 Compact ECR ion source and magenttic field.

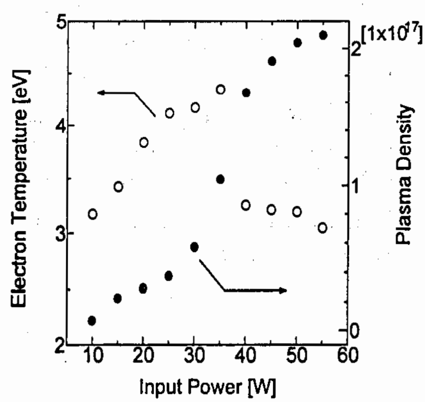

Fig. 2: Influence of input power on plasmas in the ion source. Open and solid circles are electron temperature and plasma densitiy, respectively. Ar pressure: 150 mPa.

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DP39 REDUCTION OF THE CARBON CONTAMINATION OF AN ELECTRON CYCLOTRON RESONANCE ION SOURCE

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ECR ion sources [1] are widely used for the production of highly charged ion beams. This type of ion source is highly versatile and ion beams from various elements can be produced. Many of the experiments in nuclear or material physics require production of ion beams from solid elements. At JYFL the MIVOC method [2] is used for the production of metal ion beams. The drawback of the method is the inevitable carbon contamination of the plasma chamber, which affects the performance of the ion source by reducing the number of secondary electrons emitted from the walls of the plasma chamber. The measurements [3] carried out in our laboratory have shown that the amount of the carbon contamination can be reduced significantly by gas mixing [4]. However, one cannot totally prevent the contamination. After the production of metal ion beams the plasma chamber has to be cleaned in order to achieve the maximum performance of the source. In this work the cleaning of the plasma chamber with the aid of oxygen has been studied. In addition, the result concerning the production efficiency of metal ion beams will be described.

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DP40 **ADVANCED MAGNETIC CALCULATIONS FOR HIGH MAGNETIC FIELD COMPACT ECR ION SOURCE**

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The design of the new advanced ECRIS requires relatively high axial and radial magnetic inductions to allow the ECR frequency increase and to take advantage of the subsequent density increase (scaling laws). The last improvements of the commercial rare earth magnets characteristics open new opportunities for ECRIS.

However, the dependence of the magnetic rigidity with respect to the temperature is a fundamental parameter which can be critical when using classical coils to produce the axial field. Taking in account these considerations, it is now possible to design very high hexapolar magnetic fields for next generation compact ECRIS.

Moreover, the High Temperature Superconducting wires allow designing reliable and compact axial field coils (30 K cooled) at a very effective cost. It is thus very relevant to study a compact hybrid ECRIS using high remanence magnet and HTS technologies. In such a design, the volume of the plasma chamber is a free parameter that can be adjusted to the user requirement.

It can be dedicated to very high ionic current production or high charge state production, pulsed or CW operations,. This paper presents the 3D overall design of a 3 Tesla axial magnetic field compact ECRIS with a high radial field hexapole composed with several magnet types. A particular care has been taken to the temperature magnet working point. This design will lead to the building of the 28-40 GHz A-PHOENIX source at the laboratory which will deliver its first beam by the end of 2004.

DP41 VISIBLE LIGHT SPECTROMETRY MEASUREMENTS FOR STUYING AN ECR PLASMA AND ESPECIALLY APPLIED TO THE MONO1001 ECR ION SOURCE

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At the GANIL facility and particularly at SPIRAL, we use and develop ion sources of ECR type to ionized radioactive atoms with an aim of forming Radioactive Ion Beam (RIB) as well multicharged as monocharged. The mechanism of production of ionized atoms from neutral elements (gas, vapor) must be well understood to provide the maximum particle intensity. One of the main difficulty encounters is the small number and the short life time of radioactive atoms. To achieve the best RIB, the ionization process which occurs inside ECR source must be as fast and as effective as possible.

Qualitative measurements have been made on the MONO1001 ECR source of the GANIL [1], especially on the ionization and excitation process of the Helium gas. The cylindrical geometry of the magnetic confinement allows us to measure radial characteristics of the working ECR plasma. The physical and the geometrical characteristic of the resonance surface inside the working ECR source have been quantified with the help of a visible light spectrometer. Hence, we have deduced a shape of the surface ECR resonance which corresponds closely to our magnetic calculations.

[1] P. Jardin et al., Rev. of .Sci. Inst., **73 (2)**, 789, (2002)

DP42 **MAGNETIC FIELD UPGRADE OF ARGONNE NATIONAL LABORATORY 14 GHZ ECR ION SOURCE**

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The magnetic structure of the 14 GHz ECR ion source at Argonne National Laboratory has been upgraded. The iron plugs on the injection side of the source have been modified to produce a 17% increase in the peak injection side field (at the biased disk). This brings the injection side maximum field in compliance with the scaling rule that $B_{inj} \sim 4\ B_{res}$. In conjunction with the iron upgrade, a new permanent magnet hexapole is to be installed which will increase the wall field by 10%. This will also bring the source magnetic structure more in line with the scaling rule of $B_{rad} \sim 2.2\ B_{res}$. Ion source performance characteristics and statistics will be presented.

DP43 **SOLID MATERIAL INTRODUCTION AT THE ARGONNE NATIONAL LABORATORY ECR ION SOURCES**

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The introduction of vapors from solid materials, particularly refractory materials, is of great importance to ECR ion source operation. Some of the ways for this introduction to be accomplished have been investigated at ANL – laser ablation, sputtering, high temperature ovens. Data will be presented regarding the performance of a recently constructed small high temperature oven with a self-supporting heating filament constructed of pyrolytic graphite. In addition, data from an induction oven will be presented. The oven is constructed of a 1/8" copper coil energized by a 1.0 kW power supply operating at 250 kHz. Material choices for the crucible and heat shielding will be discussed.

DP44 THE NEXT GENERATION OF SUPERCONDUCTING ECR ION SOURCES AT NSCL/MSU

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After more than 10 years of successful operation of the 6.4 GHz SC-ECR at NSCL/MSU [1], we decided to design and build a replacement for this ion source as well as an additional ECR ion source for off-line tests and developments. These ion sources will supplement ARTEMIS [2], a room temperature ECR ion source, used routinely in operations at NSCL.

Due to the requirements of intense, medium charge state ion beams, necessary for the Coupled Cyclotron Facility [3] operations (e.g., Ca^{8+}, Kr^{14+}, Xe^{19+}, U^{27+}) these ECR ion sources will be equipped, with a 80 mm inner diameter aluminum plasma chamber and they will use dual frequency heating at 18 + 14.5 GHz. This plasma chamber will have a considerably smaller size than the other plasma chambers in the existing or planned superconducting ECR ion sources (SC-ECR, SERSE, VENUS, SECRAL or Gyro-SERSE), which are optimized for highly charged ion production, requiring long confinement times.

The axial magnetic field will be produced by three superconducting solenoids, the center solenoid polarized oppositely. The maximum axial magnetic field intensities will be 4 T at the injection side, 0.5 T in the middle and 3 T at the extraction. The distance between the axial magnetic field maxima will be 400 mm.

The optimum radial magnetic field ($2*B_{ECR} = 1.3$ T at the plasma chamber inner wall) for 18 GHz microwave frequency will be produced by six superconducting racetrack coils. The superconducting magnets will be cooled by a liquid-He free cryocooler. The advantage of the superconducting hexapole versus the permanent magnet hexapole is twofold: the radial magnetic field intensity is a tunable parameter and there is no danger of demagnetization of the permanent magnet.

The enhanced electrical insulation between the cryostat and the plasma chamber will permit extraction voltages up to 40 kV. The extraction will be performed with a 3-element accel-decel system, with remotely adjustable gap between the plasma electrode and the puller.

An ion source test stand will be constructed for off-line ion source R&D. This will be composed of two magnetic lens, a large gap 90° analyzing magnet, 2 sets of water cooled adjustable slit systems, 2 sets of X-Y steering magnets, 2 shielded Faraday cups, an optical beam view plate with CCD camera and two Allison-type transverse emittance scanners.

The total cost of this project is estimated at $2M. The first ion source and test stand is planned to be ready till the end of 2004, the second ion source will be constructed in FY05-06.

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DP45 **A 29.7 GHz ECR – PRIMARY PROTON SOURCE FOR THE RHIC OPTICALLY PUMPED POLARIZED H^- ION SOURCE.**

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A 29.7 GHz cw ECR source produces the primary proton beam in the RHIC optically pumped polarized H^-ion source. A proton beam of a 50 – 100 mA is extracted from the ECR plasma at 2.0 – 3.0 keV energy by a 120-hole, 3-grid ion extraction system. Since polarized beam injection to RHIC requires only ~ 500μs pulses at 0.2 to 6.7 Hz repetition rate, pulsed source operation was also studied. A significant current increase was observed at greatly reduced average microwave power and reduced hydrogen gas consumption. The molecular H_2^+ion beam component out of the ECR source causes polarization dilution, when H_2^0 molecular beam is dissociated and ionized in the sodium ionizer cell. These H^- ions, with half the energy of the main component, have lower polarization. An oxygen gas admixture to the hydrogen gas helps to reduce the H^+_2 beam component. While under non-optimum conditions the molecular component can be as high as 40%, it is reduced to less then 5% in the pulsed ECR operation. As a result of the ECR source optimization, the RHIC OPPIS intensity was increased up to 0.5 – 1.0 mA in routine operation (maximum current 1.5 mA). A polarization of 80% was measured in a polarimeter located at the end of the 200 MeV linac.

DP46 A NEW TECHNIQUE FOR DIAGNOSING MULTI-CHARGED ION BEAMS PRODUCED BY ECR ION SOURCE

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In order to study the transmission properties of multi-charged ion beams between the ECR ion source and the analyzing magnet, a new diagnostic system including three Wien-Filters with three single-wires was designed and installed on the IMP ECR source test bench. The single-wire is used to detect the beam profile and the beam density distribution, and the Wien-filter is used to measure the charge state distribution. By means of the diagnostic system, the beam profile, charge state distributions and beam losses along the transmission line from IMP LECR3 to the analyzing magnet are experimentally studied with different conditions of the ion source.

Tuesday 9 September

F01 IMAGING OF ECR PLASMAS WITH A PINHOLE X-RAY CAMERA

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In the ATOMKI a 14.5 GHz electron cyclotron resonance (ECR) ion source operates as a stand-alone device to produce both low- and highly-charged plasmas as well as low-energy ion beams. The investigation of different kinds of plasmas produced by the ECRIS is one of our long-term scientific projects. The motivation of this research is twofold: the first is to better determine the micro-parameters of the plasma and their relationship to external source parameter settings in order to improve source performance. The second point of interest is astrophysical. Most of the highly charged ions found in objects like the Sun, other stars, supernovae remnants, cometary halos, etc. can be produced in ECR sources. The information we can draw from laboratory plasmas can add to the understanding of these astrophysical phenomena.

ECR plasmas can experimentally be investigated by direct and indirect plasma diagnostic methods. Direct plasma diagnostics are performed by introducing small electrostatic probes into the plasma and current-voltage characteristic curves are measured in each position. This method gives detailed local information, however probes usually cannot be used in the hot regions of the ECR plasma and the full theoretical interpretation of these types of measurements is still lacking.

Indirect diagnostics is based on the fact that ECR plasmas emit radiation mainly in the UV, visible light, and X-ray regions of the electromagnetic spectrum. The measurements and the analysis of spectra are usually affordable tasks, the non-intrusive nature of this method is certainly an advantage, however the recorded information always arrives from a larger plasma volume or sometimes even from the whole plasma. Previous X-ray and UV imaging work done in other laboratories and modeling studies have shown that spatial imaging at different wavelengths give meaningful insight into the plasma structure and properties of the ECR plasma as well as the processes that create the radiation.

In this paper our results are presented by using a pinhole X-ray camera to image the ECR plasma. Our efforts focused on producing high spatial resolution images with simultaneous energy resolution for spectral filtering in the X-ray region. The 1152 x 1242 pixels CCD camera combined with a 70 micrometer X-ray pinhole provided us a spatial resolution of about 0.1 mm. In addition when operated with short exposure times, each pixel acted as a single photon detector with an energy resolution of about 180 eV. Using the large area camera to image the source allowed us to pinpoint the origin of different continuous and characteristic line features in the X-ray spectra. With the energy and spatial origin of each photon recorded, post detection spectral filtering of the images provided a capability for plasma diagnosis.

We produced and investigated Ar, Xe and Fe plasmas in low-charged and highly-charged states and recorded axial X-ray pictures together with extracted beam spectra. In particular we concentrated on the following effects: gas-mixing on/off, biased disk voltage on/off, magnetic field low/high, extraction on/off.

The paper will include details of these imaging studies, comparisons to model calculations, deduced properties of the ECR plasmas studied, and finally, relevance to astrophysical observations.

FO2 **STATUS OF THE TRIPS SOURCE AND EMITTANCE MEASUREMENTS**

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The TRASCO intense proton source (TRIPS) was installed at INFN-LNS in 2000 and it has been fully operational for two years. The proton beam intensity easily exceeds the current required for the ADS project, so that the extraction aperture was reduced from 8 to 6 mm. In these conditions, typical extracted current is 40 mA at 80 kV, corresponding to j=140 mA/cm^2, not far from the Child-Langmuir limit.

A set of emittance measurements was carried out for different source conditions and the results will be shown and discussed. Reliability tests and proton fraction measurements are under way and a short summary will be also given.

FO3 EMITTANCE STUDIES OF THE 2.45 GHZ PERMANENT MAGNET ECR ION SOURCE.

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During past several years different types of permanent magnet 2.45 GHz ECR ion sources were developed for production of singly charged ions [1]. Ion sources of this type are used in the first stage of DRIBs project, and planned to be used in MASHA mass-separator [2].

For above mentioned applications the emittance of the beam provided by the source is one of the important parameters.

For study the beam emittance characteristics the emittance scanner composed from a set of parallel slits and rotary wire beam profile monitor was used [3].

The emittance of helium and argon ion beams was measured with different shapes of plasma electrode for several ion source parameters: microwave power, source potential, plasma aperture – puller aperture gap distance, gas pressure. The results of measurements are compared with previous simulations of ion optics.

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FO4 HEAVY-ION BEAMS REQUIRED FOR THE RIA ACCELERATOR

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The proposed Rare Isotope Accelerator Facility (RIA) is planned to provide high intensity driver beams of heavy ions with beam power up to 400 kW in order to produce radioactive beams far from stability and address fundamental questions in nuclear physics and astrophysics. The exact mix of heavy-ion driver beams which will be needed by the facility will depend on the actual experimental programs undertaken, but will surely encompass a wide range of isotopes. We will explore some hypothetical facility operations models and identify the driver beams required in those scenarios. One example is an operations mix that seeks to optimally 'illuminate' the r-process path nuclei. Present ECR ion source performance for the identified mix of beams and assumed charge states will be compared to the requirements of the RIA facility needed to achieve the beam power goals of the facility. This work was supported by the U.S. Department of Energy under contract W-31-109-ENG-38.

GI1

THE RECENT ADVANCEMENTS OF MULTIAMPERE ELECTRON BEAM EBIS*

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An Electron Beam Ion Source (EBIS) that would satisfy RHIC requirements should be capable of producing intensities of e.g. Au32+ ions of about 3×10^9 particles/pulse in 10-40μs pulses. The total charge extracted (all charge states) would be 80nC, assuming 20% in the peak charge state. To achieve this at BNL, pulsed electron beam currents up to 10A, 100ms are being used. A test EBIS has been constructed, designed for the full electron beam power and having close to 1/2 of the trap length of an EBIS for RHIC. As a result of successful experiments on the test EBIS, we are confident that an EBIS meeting RHIC requirements can be built. Initial electron beam tests have demonstrated a 100ms, 8.6A electron beam through the EBIS trap. Stable operation of 10 A, 50ms electron beams through the EBIS trap have also been achieved. Gold spectra with a dominant charge state 34+ and total ion charge 55nC measured on a current transformer have been obtained at the EBIS exit after a 30ms confinement period. Recent studies with an in-line TOF spectrometer with measurement of charge on a Faraday cup have shown 83% of the >28nC extracted charge to be Au ions peaked at Au^{25+}, for a 7A electron beam and 10ms confinement period. Typical normalized rms emittance values using a 6.8A electron beam, 20-40nC total ion charge, and 1-3mA extracted ion current have been in the range of 0.08-0.1 π mm mrad. Energy analysis of the total extracted ion pulses >35nC has indicated a longitudinal energy spread of <2kV FWHM after 35ms confinement period using a 7A electron beam. Most design goals have been exceeded and much of the present work is geared towards improving reliability and providing larger safety margins. These include upgrading the electron gun, decoupling the electron beam launch energy from the electron collection energy, and tailoring the magnetic fields to reduce electron beam losses. Details of these measurements, tests in progress to improve performance, and plans for optimizing the design of the RHIC EBIS will be presented.

*This work is performed under the auspices of the U.S. Department of Energy

GO1 USE OF EBIS IN THE STRING MODE OF OPERATION ON THE NUCLOTRON ACCELERATOR FACILITY IN JINR

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The reflex mode of EBIS operation in certain conditions (a sufficient injected electron current for certain electron energy, the special construction of an electron gun and of an electron reflector, precise axial symmetry of a solenoid magnetic field and its strength and providing by all of these a sufficient density of multiply reflected electrons in a drift space) leads to formation of the so called electron string state of a pure one component electron plasma. It was shown experimentally, that electron strings are stable in broad enough regions to be used for production of highly charged ions in Electron String Ion Sources (ESIS) similar to electron beams in EBIS [1,2].

The EBIS "Krion-2" in the string mode of operation by means of which the electron string formation was first observed and majority of experimental information about its features has been obtained recently was used as the source of highly charged ions on the Nuclotron accelerator facility. During two runs in June 2002 and in June 2003 N6+, Ar16+ and Fe24+ ions, produced by this ion source have been accelerated to relativistic energies and used for several experimental physics studies.

To inject nitrogen and argon into the source electron string we used gas injection from the outside the source situated gas container while for iron the precisely heated container with 50 mg ferrocene was assembled on the 79 K injection section of the source drift tube structure.

The Nuclotron is a synchrotron with one turn (8 μs) injection. To meet this limitation the fast extraction of produced ions was developed for "Krion-2" source, so that usual output currents were about 300 μA for N6+, 200 μA for Ar16+ and 150 μA for Fe24+.

During the runs the ion source, situated on HV platform of the LINAC pre-injector and connected with a ground terminal via fiber optic links, worked mostly in the automatic mode of operation and showed high stability and reliability.

The work was supported in part by INTAS (Grants 96-0255, 01-2354), CRDF (Grants RP1-2110, PR1- 2417-DU-02) and by the Royal Swedish Academy of Science.

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HI1 ATOMIC PHYSICS EXPERIMENTS WITH AN EBIT

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The Electron Beam Ion Trap (EBIT) is a unique ion source for study of highly charged ions (HICs). It was developed at Lawrence Livermore National Laboratory initially for the in situ spectroscopy of HCIs,which was based on the Electron Beam Ion Soource (EBIS) concept invented by Donets at Dubna.

An EBIT confines ions more effectively than an EBIS with a shorter ion-trap length to limit plasma-like instabilities and hence to increase the residence time of trapped ions.

HCIs are created in the trap region by successive ionization processes through the interactions with the high-current-density electron beam. In principle,any charge stste of any element on the periodic table can be produced.

In addition to the ionization,other kinds of electron-ion interaction processes take place in the trap. Therefore,to analyze these processes,direct measurements of the cross sections for electron-impact excitaton,dielectronic recombination and radiative recombination are possible by observing emissions from trapped ions and intensities of extracted ions from the trap.

Here we review the research activities of the development of the EBIT device and of atomic physics experiments with it which have been performed so far.

HI2 **REARRANGEMENT REACTIONS AT ION-ION COLLISIONS IN CROSSED BEAMS**

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Collisions between ions belong to the elementary processes occurring in all types of hot astrophysical and laboratory plasmas. Compared to ion-atom collisions, experimental investigations of ion-ion collisions are quite scarce since the ion beams are very tenuous due to the mutual repulsion within both the projectile and target ion beams. Therefore, it is understandable that the theory should play an essential role in establishing the basic dependences on the physical parameters of the processes studied and in the reliable calculations of the differential and total cross sections.
In this overview, recent theoretical and experimental results are discussed for ionic collisions with large cross sections. Main attention is given to the joint efforts of the Giessen experimental group headed by E.Salzborn and the Lebedev Institute (Moscow) theoretical group. The most important topics are as follows:

- single- and double-electron detachment in collisions of H^- ions with multiply charged ions;
- mutual neutralization in collisions of two negative ions: single- and double-electron detachment;
- quasiresonant charge transfer between multiply charged ions;
- homonuclear and heteronuclear heavy-ion collisions;
- angular differential cross sections for charge transfer between a bare and a singly charged He ion;
- charged transfer in collisions of the fullerene ions.

The theoretical calculations are compared to the experimental data, good quantitative agreement is observed.

Some of the results are published in the joint papers (see reviews [1 – 3] and references therein).

The support from RFBR (grant 02-02-16274) is acknowledged.

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JI1 STATUS ON RADIOACTIVE ION PRODUCTION AT GANIL AND FUTURE PROJECTS.

R. Leroy, C. Barue, C. Canet, M. Dubois, M. Dupuis, F. Durantel, W. Farabolini, J-L. Flambard, G. Gaubert, S. Gibouin, C. Huet-Equilbec, Y.Huguet, P. Jardin, N. Lecesne, P. Leherissier, F. Lemagnen, J.Y. Pacquet, F. Pellemoine, M.G. Saint Laurent, C. Stodel, O. Tuske, D. Verney, A.C.C. Villari
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During the last ICIS in Oakland, we announced that the production of radioactive ion beams on the SPIRAL facility located at ganil will start before the end of 2001. The production has effectively started and numerous multicharged radioactive ion beams have been delivered for high energy nuclear experiments. This presentation will make an overview of the different beams that have been produced.
In the mean time, an important R and D research program is continued in oder to produce new species of radioactive elements. Different solutions are under studies like the monolithe principle that has been tested for radioactive alkalii production. Different sources have also been tested on line like minimono for monocharged ion production of radioactive noble gases. The results of these production tests will be presented.
At least, a new concept of multicharged radioactive production that couple a monocharged ion source, based on the monolithe concept, to an ecr ion source like nanogan3 is under developments and will be described
The development of monocharged ion sources with high efficiencies is also motivated by a new big project that is under studies at GANIL : the spiral 2 Project. The goal of this project consist in extending the disponible radioactive ion beams to very heavy elements created with a new method of production : while the spiral 1 facility uses the projectile fragmentation for radioactive nuclei production, the spiral 2 project is based on the fission of a Uranium carbide target induced by a neutron flow created by a high intensity deuton beam. The principle and a quick overview of the project will be presented.

JI2 RESENT ION SOURCE DEVELOPMENTS FOR PRODUCTION OF RADIOACTIVE BEAMS

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Presently worldwide radioactive ion beam facilities based on the separator on line are the main instruments for the nuclear structure study and solving many important questions of astrophysics. Investigations of short-lived neutron-rich and neutron-deficient nuclei far from stability give a unique possibility to test many aspects of modern nuclear structure theory. Therefore development of high efficient, selective and fast ion source-target systems (ISTS) for modern and next generation ISOL facilities is the crucial point for a future progress of nuclear science and experimental astrophysics. Last decade demonstrates a burst of new developments in the field of the ion source-target systems for ISOL installation use.

The main task of that review is to show the latest results obtained with different types of the ion sources, specially designed for short-lived isotope production, and to designate some directions of the ISTS development which can be noticed presently and very likely will be used in the nearest future.

KP1 AN ELECTRON BEAM ION TRAP TO BE SITUATED AT QUEEN'S UNIVERSITY, BELFAST

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Electron-beam ion traps (EBITs) [1] have been successfully used to study the physics of highly charged ions using both spectroscopic techniques and measurement of extracted ions. The EBIT is based on the principle of an electron beam ion source [2], while it has a shorter trap to suppress plasma instabilities to achieve a longer trapping time. An electron beam emitted from the electron gun cathode is accelerated by the electrostatic potential applied between the electron gun and the trap. In this period the electron beam is compressed by the magnetic field produced by the main magnets, resulting in a high current density electron beam. Ions are trapped radially by the space charge potential produced by the electron beam and at the same time ionized by electron impact caused by electrons from the beam. The magnetic field has usually been produced with a pair of super-conducting Helmholz coils, arranged to get direct sight to the trap region. More recently, permanent magnet EBITs have been also developed [3,4]. Although they have somewhat lower specification than those of a traditional EBIT in terms of the current density, beam energy and vacuum quality, they have some advantages such as decreased running cost and size.

We are designing a permanent magnet based EBIT, which uses a 100keV and 300mA electron beam and the central magnetic field of 0.62T, with higher specifications than those referenced above and also higher than some traditional EBITs except for the magnet field strength and current density. The magnetic field produced with permanent magnets is weaker than that with superconducting magnets, which results in the lower current density and therefore lower trapped ion density. However the device will be much smaller than traditional EBITs. The shorter trap-to-detector distance will give considerable signal enhancement for several experiments. Furthermore, by using the flexibility of a permanent magnet structure, the device will be particularly suitable for the study of electron-ion interactions. The permanent magnets will be bored along a horizontal plane containing the electron beam axis making the angular measurement of emitted photons possible. By making observation from 54.5 degrees with respect to the electron beam axis, we can make a measurement such as those in reference [5] without needing to consider polarized light emission. Indeed it will be possible to deduce polarizations from angular emission patterns. We can access the trap region easily and change the trap structure depending on the experiments being performed. We are also planning 'pop-in' and 'pop-out' trochoidal analyzers before and after the trap, which will be used as a low energy electron merger for recombination experiments and as an analyzer for product ions and electrons. Furthermore, the machine will be situated in a dedicated 'Ion Hall' with interconnecting beam-lines, user stations and a range of other ion sources.

At the conference we will present some of the capabilities and the design of the new EBIT with a view to making contact with potential future users.

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KP2 ELECTRON AND CHARGE SENSITIVE EVALUATED ION ENERGY DISTRIBUTIONS OF A VACUUM ARC PLASMA MEASURED WITH A 127° ELECTROSTATIC CYLINDER SPECTROMETER

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A new Mevva type ion source (VARIS) has been developed for the high current injector at the GSI accelerator facility for the production of uranium beams [1]. This ion source provides a high intense ion beam with a high fraction of four fold charged uranium ions for injection into the linear accelerator [2]. As part of the ion source development the ion and electron energy distributions are measured with an electrostatic cylinder spectrometer device. The energy spectrometer disriminates charged particles with different energy to charge ratio which -in case of different ion species within an extracted beam- allows a charge sensitive evaluation of ion energy distributions. Energy distributions are measured for various discharge parameters, i.e. arc current, magnetic flux densities close to the discharge region, and cathode materials. Different plasma parameters can be derived from these measurements: the plasma wall potential, charge resolved mean energy and the energy spread of ions, mean electron energy and electron temperature. The electron energy distribution may reveal the mechanism of plasma production and therefore may support the development of a plasma model of a vacuum arc plasma consisting of high charge states.

KP3 **ELECTRONICS FOR FAST ION EXTRACTION OF EBIS DEVICES**

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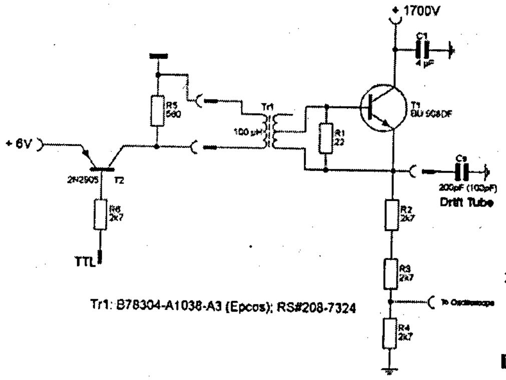
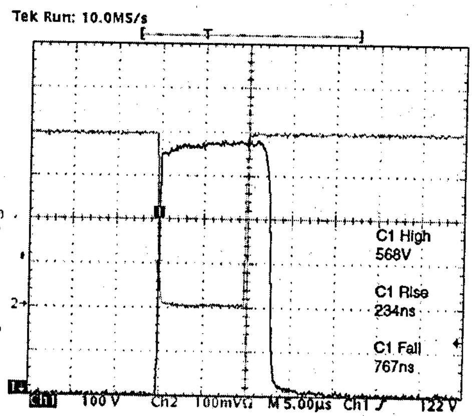
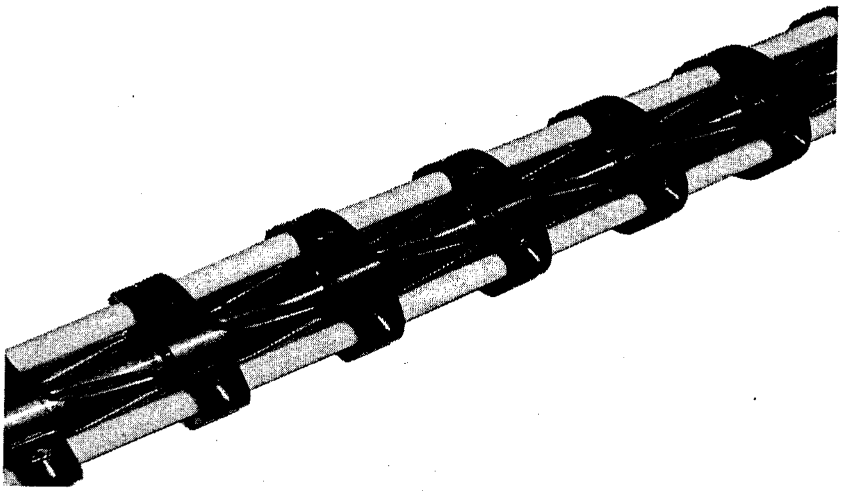
Future synchrotrons for cancer therapy could profit from single turn injection in terms of size, costs and easy operation. Short (~1.5 µs) and intense (~1.3 mA) pulses of highly charged light ions (C, N, O) are a requirement for these future therapy facilities which can be fulfilled using an EBIS as ion source. Such a MEdically Dedicated EBIS (MEDEBIS) has an electron beam of 400mA at 5keV and a ratio of beam to drift tube of 1/20. To obtain a 1.5µs ion pulse it is necessary to switch the drift tube potentials up to 1.6 kV in some 100 ns.





To avoid spreading out of the pulse due to the restoration of the full space charge depression at locations where ions have already been extracted, the potentials applied to the drift tubes are not held at constant voltage. They will be adjusted for each drift tube according to the transit time of the ion pulse. Furthermore the drift tubes are fully interpenetrating each other with tapered fingers in order to locally distribute the action of the applied potentials. This provides a potential wall, which is following the extracted ion pulse and results in a compressed short ion pulse for single turn injection.



KP4 DEVELOPMENT OF A VACUUM ARC ION SOURCE FOR INJECTION OF HIGH CURRENT URANIUM ION BEAM INTO THE UNILAC AT GSI

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To fill up the GSI heavy ion synchrotron (SIS) to its space charge limit with uranium ions a new vacuum arc ion source (VARIS), based on the GSI-MEVVA ion source has been developed and implemented into operation . The ion source has proven its capability in several long period beam times at the high current injector of GSI. With the new ion source it was possible to exceed the space charge limit of 16.5 emA U^{4+} ions at the entrance of the linear accelerator (UNILAC) for the very first time.

The reliability as well as he noise behaviour has been improved to such a degree, that this ion source can be used for injection into an accelerator without objection.

In the article we present the improvements of the ion source with the most important operational data.

The emission current density of the new ion source has been increased from 60 emA/cm^2 for the common used GSI-MEVVA to 170 emA/cm^2. This results in a full beam ion current of 156 emA at 32 kV with a fraction of four fold uranium ions of 67 %. The analysed U^{4+} ion beam after DC post acceleration amounts to 25 emA at 130.9 kV which is 1.5 times higher than the requested ion beam current at the entrance of the RFQ.

The reduced power density of the vacuum arc results in a higher efficiency and life time. Solenoids creating magnetic fields to enhance the charge state of the ions are no more placed inside the vacuum system. This results in a higher availability after ion source replacement at the injector, higher cost efficiency, and faster service time.

KP5 COMPARISION OF DIFFERENT EXTRACTION AND ACCELERATION SYSTEMS FOR A HIGH INTENSE PROTON BEAM FOR THE FUTURE PROTON LINAC AT GSI

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For the injection into the future proton LINAC at GSI [1] the ion source and LEBT system has to deliver a high intense proton beam with approximately 100 keV at the entrance of the RFQ within an acceptance (normalized, rms) of 0.2 π mm mrad. The proton yield provided by the ion source should be 90 % or higher, whereas the emittance should be as small as possible [2,3].

The article presents the results of computer simulations done with AXCEL-INP for three different extraction and acceleration systems: Pentode extraction system, compound system, and combination of triode extraction system followed by a separately screened dc acceleration system.

These systems will be discussed in terms of beam brightness and manageability for beam time operation.

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KP6 ELECTRON OPTICS SIMULATIONS FOR RHIC EBIS AT BNL*

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Based on the successful experience of the BNL test EBIS, the RHIC EBIS design utilizes a 10A electron beam to produce the required ion source the output intensity 3.4×10^{9} of Au^{32+} ions per 10-40 μs pulse. In order to provide increased cathode lifetime and reliability at the required 10A, and accommodate future upgrade of RHIC EBIS ion intensity, it is desirable to upgrade the electron gun. Simulations have been made for a new electron gun and an electron collector capable of generating and dissipating the electron beams with current up to 20 A. The method of forming the electron beam using magnetic compression and inverse magnetron structure of the electron gun are the same as has been tested successfully on EBTS. The new gun has higher perveance (2.9×10^{-6} A/V$^{3/2}$) and partially shielded spherical cathode. A bell-shaped radial current density distribution with reduced current density on a periphery of the beam, combined with a modified shape of the electron collector magnet shim, yields a simulated power density on the surface of the electron collector below 400 W/cm^2 for electron beam currents up to 20A.

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KP7

C^{4+} BEAM OPTIMIZATION OF LASER ION SOURCE FOR DIRECT INJECTION SCHEME

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The new acceleration system for high intensity heavy ion beam has been studied in RIKEN and Tokyo Institute of Technology (TITech) from 2001. Acceleration of high intensity heavy ion beam has the problem that the beam is mostly lost in low energy beam transport line (LEBT) due to strong space charge force. The acceleration system overcomes the problem by new injection scheme to accelerator. The new injection scheme is called "Direct injection scheme". In direct injection scheme, ion beam from laser ion source is injected directly to RFQ linac without LEBT. Concretely speaking, laser induced high density plasma has initial velocity, and in direct injection scheme the plasma goes to RFQ linac (~30cm) with the initial velocity. Space charge force leading to divergence of the beam does not work because what flies is plasma. High intensity beam is extracted in the injection section of RFQ linac and the high current beam acceleration realizes by trapping the beam by RFQ focusing field.

Proof of principle experiment was done by using RFQ linac in TITech (TIT RFQ). Very high intensity Carbon ion beam (25mA at peak, average of 8mA) was successfully accelerated

We manufactured ion source test bench and measured charge distribution and current density of the plasma to make analysis of the RFQ injection area of this experiment. The simulation of beam extraction was done by using this result. The result shows that beam is not effectively extracted. Part of extracted beam was lost by hitting the RFQ vane. And if the extraction system is optimized, more current will be accelerated.

We optimize the extraction system. Because the beam current density from laser ion source is much higher than that from ECR ion source, nonlinear effect is very big. Therefore we take the way to optimize the system from both sides of an experiment and simulation.

In simulation, we show it is possible that the high current beam is effectively injected to the inside of RFQ linac.

In experiment, we set the target ion to C^{4+} and optimize the laser power density to C^{4+} and measured plasma current density. And we manufactured ion extraction test bench designed by simulation and measured the extracted current and beam emittance.

KP8 LASER ION SOURCE BASED ON 100 J/1 HZ CO_2-LASER SYSTEM

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The laser system is a key element of Laser Ion Source (LIS), significantly influencing source stability and reliability. A 100 J/1 Hz Master Oscillator – Power Amplifier CO_2-laser system has been designed, built and tested for a Pb^{25+} LIS, with the aim of producing the ion beam parameters compatible with an injection chain for the Large Hadron Collider (LHC). The results obtained during commissioning of the laser at CERN are presented. LIS parameters based on 100 J/1 Hz CO_2-laser system and the use of such a source for ITEP-TWAC project are discussed.

KP9

DETERMINING THE ACCEPTANCE OF THE BROOKHAVEN EBTS FOR PRIMARY IONS BY SIMULATION.*

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We shall report on computer simulation studies to determine the acceptance of the Electron Beam Ion Source Test Stand (EBTS) at B.N.L. The results will be compared with estimates of the upper limits of the geometrical acceptance of EBISs. Knowledge of the acceptance is a useful guide in selecting a source of primary ions, and in designing a transfer line which best matches the primary beam to the acceptance ellipse.

*This work is performed under the auspices of the U.S. Department of Energy.

* This work is performed under the auspices of the U.S. Department of Energy.

KP10 GENERATION OF INTENSE BEAMS OF METALLIC IONS WITH A CHARGE STATE UP TO 10+ IN A LASER ION SOURCE

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Systematic studies have been carried out to test the yield and properties of Al, Au, Cu, Nb, Ni, Pb, Sn, Ta and W ions from the plasma produced by a 0.9 J/9 ns Nd:YAG laser. Changing either the laser pulse energy or the focal spot size, the laser power density on the target surface was varied from $1\text{x}10^9$ to about $1\text{x}10^{11}$ W/cm^2, i.e. from the threshold power density for the ion generation up to the maximum laser intensities, attainable with the setup used. Time-of-flight method (ion collectors) and cylindrical electrostatic ion energy analyzer were used for the diagnostics of produced ions.

An ion emission was strongly peaked along the normal to the target surface [1]. The ion velocities (ion energies) ranged from about $2\text{x}10^6$ to $2\text{x}10^7$ cm/s (100 eV - 10 keV) in dependence on the target element used and on the laser power density. Generally, one (Al, Ni, Cu) or two (Au, Nb, Pb, Sn, Ta, W) main ion groups were recorded for our experimental conditions. The proportion of ions (with respect to the neutrals), as well as the presence of their highest charge states, increase with the increasing laser power density. Ion current densities at a distance of 44 cm from the target for laser energy $E_L \leq 0.4$ J ($I_L \leq 1\text{x}10^{10}$ W/cm^2) ranged from about 4 mA/cm^2 for Au to 32 mA/cm^2 for Al. These results serve mainly for fundamental studies on hybrid ion source for a large accelerator injector, based on a coupling of LIS and ECRIS (project ECLISSE [2]), but also for a direct surface modification of solids (project PLAIA [3]).

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KP11 **OPTIMISATION OF THE CHARGE STATE DISTRIBUTION OF THE ION BEAM EXTRACTED FROM AN EBIT BY DIELECTRONIC RECOMBINATION**

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The Heidelberg Electron Beam Ion Trap (H-EBIT) facility allows both spectroscopic studies of trapped highly charged ions (HCI) and production of beams of HCI for external users. In particular, dielectronic recombination resonant process (DRR) is explored in detail for different elements with a high accuracy. Besides of its general interest for understanding the physics of HCI, DRRs can be used for effective optimization of HCI production by reducing the number of ions above certain charge state and concentrating them into the desired one, narrowing thus the charge state distribution of an ion beam.

We will present experimental results of DRR processes for krypton ions as observed through their characteristic x-ray emission and the intensity of the extracted ion beams. For this, the electron beam energy was swept slowly with a rate of 1 eV per second and with an amplitude of 1 keV around the resonance value needed to excite the KLL resonance at around 9 keV. After extraction and charge analysis, the beam of highly charged krypton ions was focused to a position sensitive detector placed directly after an analyzing magnet. The detector allowed measuring the intensity of the charge states from 32+ to 34+ simultaneously. It was found that at the resonance, the intensity of He-like krypton ions was reduced substantially, whereas the yield of Li-like krypton ions was correspondingly increased. At slightly higher energy of the electron beam, much more pronounced concentration was observed for Be-like krypton ions. The influence of electron beam current on the resonance conditions was examined and will be reported. From the experimental results, the ratio of rates of dielectronic recombination for He-like krypton ions and electron impact ionization of Li-like krypton ions was estimated and compared to theoretical value.

KP12 PERFORMANCE OF AN EBIS WITH HIGH-T_C BULK SUPERCONDUCTORS

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We have developed an electron beam ion source (EBIS)[1] utilizing a permanent current on a high-T_C superconducting material, which enables us to operate the EBIS at the liquid N_2 temperature with a sufficiently strong magnetic field. In this paper, the details and the status of the high-T_C EBIS will be presented.

The design of the high-T_C EBIS is given elsewhere[1]. Briefly, the EBIS mainly consists of three parts, an electron gun, a drift tube, and an electron collector. The electron beam emitted from the electron gun is accelerated toward the drift tube, compressed by the magnetic field produced by the high-T_C bulk superconductor, passed through the drift tube, and finally decelerated and collected by the water-cooled electron collector. Ions are confined within the center of the drift tube axially by an axial electrostatic well prepared by three successive electrodes and radially by the space charge potential of the compressed electron beam. Highly charged ions are thus produced by successive electron impact ionizations.
The high-T_C superconducting material used is YBa_2CuO_{7-x}, which has a high critical current density J_C[2]. It is noted that high-T_C superconductor is a kind of ceramic, and the wire is not flexible to make a solenoid with a small diameter. As an alternative method to prepare a superconducting solenoid, a high-T_C bulk material is machined as a ring shape with an outer diameter of 51 mm, an inner diameter of 15 mm, and a thickness of 12 mm. Three ring-shaped magnets are put in series and sealed in a stainless steel container which is in contact with the liquid N_2 reservoir wall. The bulk magnets are magnetized by so-called pulsed field magnetization (PFM) technique[3,4], where the magnetizing coil is installed in the liquid N_2 reservoir. By repeatedly applying pulsed magnetic field with a width of 11 ms and peak strength of several Tesla, we succeeded in magnetizing the bulk magnets up to 0.8 T at the liquid N_2 temperature.

In the first stage of test operations, the EBIS was operated in the DC mode[1] with electron beam parameters below 12 keV-50 mA. Ion extraction tests have been performed using Ar and Xe gases. The maximum charge state extracted so far was 17+ for Ar and 39+ for Xe. Currently, the high-T_C EBIS is used for highly charged ion-surface collision experiments. In the intervals of the physics experiments, further extraction tests are in progress, which will be presented at the conference.

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KP13 LASER SOURCE FOR DIRECT INJECTION SCHEME

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H. Kashiwagi, K. Yamamoto, J. Takano and T. Hattori, TITech, Japan.

A. Schempp and R. Becker, Johann Wolfgang Goethe-Universitaet, Germany

Generally, ion beam extracted from an ion source is transported in LEBT with focusing devices controlling beam divergence and then injected to a first stage accelerator. In case of high current heavy ion beams, however, non linear repulsion force due to space charge effect causes serious beam loss.

In order to overcome the beam loss at the LEBT, we had proposed new injection method called "Direct Plasma Injection Scheme". In this scheme, ion source can be attached to first accelerator, RFQ, and the LEBT is not needed. Heavy ion plasma induced by intense laser has initial velocity normal to target surface. The abrasion heavy ions can be transferred with the initial velocity as plasma state and is free from the space charge effect. After the plasma reaches to an entrance of the RFQ, the heavy ions are extracted and are directly injected into RFQ channel. We succeeded to accelerated 4 mA of Carbon 4+ beam using this new injection scheme. The obtained current agreed with results of computer simulations. Simultaneously we found that only the small portion of the ions in plasma captured properly by the RFQ. This means much more intense beam can be accelerated with the new injection scheme.

For the next step in developing the scheme, a dedicated laser source chamber is being fabricated for a new RFQ. To demonstrate the possibility of the Direct Plasma Injection Scheme, design goal was set to acceleration of 100 mA of C^{4+} which can be provided our existing CO_2 laser system. At the conferece, the datails of the new laser ion source and the new high intensity RFQ will be reported.

KP14 LASER-INDUCED FLUORESCENCE SPECTROSCOPY WITH HIGHLY CHARGED ION BEAM PRODUCED BY LASER ION SOURCE

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We designed and tested a beam line for transport of highly charged ions produced by laser ion source. The ion beam is prepared for a laser-induced fluorescence spectroscopy experiment. To measure atomic transitions precisely, the laser spectroscopy experiment is quite useful. So far, the researches of atomic spectral lines by the laser spectroscopic method have contributed greatly to not only atomic physics, such as the studies of the higher-order relativistic and QED effects to the atomic energy levels, but also nuclear physics [1]. However the experiment is limited by the energy oscillated by laser (less than 5 eV). We are now developing a new experimental technique which use synchrotron radiation X-rays (up to several hundreds eV) instead of laser lights to measure transitions of highly charged ions. Laser ion source is suitable for the new experiment, because it can supply high current beams of highly charged ions easily and is small-sized ion source; experimental apparatus requires to be moved instantly and easily at a public beam line, such as synchrotron radiation facility. Moreover laser ion source can be made at a moderate price.

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KP15 ELECTRON BEAM ION TRAP BY USING ANAC IONISER FOR STUDY OF FUSION REACTIONS WITH BARE BEAM AND TARGET

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The enhancement of cross section for charged particle fusion reaction due to the electron screening effects has been an entangled problem. We already proposed NARITA (Nuclear Astrophysics Researches in Ion Trap Apparatus) project to solve this problem by studying the fusion reaction with bare beam and target(1). It consists of various installation such as BeTa (Beam Target) apparatus by creation of the so-called electron string state of confining electrons(2). In order to store large amount of bare nuclei in an ion trap as a target or both projectile and/or target particles, other approach for ion traps than that has been extensively applied for atomic or nuclear physics studies is needed.

We constructed the test bench by using ANAC ionizer as an apparatus for the reflex mode of EBIS with an axial ion injection system for storing nucleus generated with 2.45 GHz ECR ion source. We have a plan to investigate the amount and lifetime of stored ions in this warm bore EBIT by observing the extracted beam with several diagnostic devices.

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KP16 **FORMATION OF HIGH INTENSIVE POSITRON STRINGS**

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The possibility of an intensive positron string formation is discussed in this report. A Positron String Source (PSS) is proposed to be based on principles and technology of the Electron String Ion Source (ESIS) [1-2] developed in JINR few years ago. This ion source is used for generation of extremely highly charged ions of various elements [1-2]. In this source electrons captured in the Penning trap immersed in guiding magnetic field of 3-5 T. A special electron gun and electron reflector was constructed to accumulate multiply reflected electrons. The transition from the state of multiply reflected electrons to an electron string is realized when injection electron current reaches a critical value.

The positron string source is considered for storage of positron strings cooled to cryogenic temperatures of 0.05 meV. The positron flux at an energy of 1- 5 eV is injected into a positron string source which has a similar construction to ESIS [1-2]. The low energy positrons are captured in the PPS Penning trap placed in the magnetic field of 5-10 T. The low energy positrons are cooled down caused by synchrotron radiation in the strong magnetic field. The positron string source permits to store and to cool to cryogenic temperature up to 10^{10} positrons.

The intensive positron string cooled to cryogenic temperature can be used as for applied investigations, so for antihydrogen atom production [3].

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KP17 STATUS-REPORT ON DEVELOPMENT OF A TUBULAR ELECTRON BEAM ION SOURCE (TEBIS)

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The theoretical estimations and numerical simulations of tubular electron beams in both the beam and reflex mode of source operation, as well as off-axis ion extraction from the TEBIS, will be presented.

It is well known that the upper limit of the ion output for the linear EBIS, working in the reflex (electron string) mode of its operation (ESIS), appears because of a virtual cathode formation at certain perveance in the electron drift space, which does not allow to increase in the number of stored electrons. There only way to increase it is to use a tubular electron string in a system with the internal and external tubular walls. In such a system the limiting perveance increases linearly with the tubular string radius, hence such Tubular Electron String Ion Source (TESIS) could provide 2 to 3 orders of magnitude increase in ion output compared to a linear electron string ion source. Very recently the technical solution of TEBIS and TESIS sources with off-axis ion extraction was proposed [1], which provides a conservation of very small ion beam emittance, peculiar to EBIS and ESIS, that solves the problem of effective injection of ion beam, produced by TESIS/TEBIS, into accelerators.

Based on the theoretical estimations and numerical simulations, reported previously in the Ref.[2] the conceptual design and main parameters of new Tubular sources, which are planned in JINR, MSL and BNL at existing EBIS test stands, will be discussed.

The work is supported in part by the EU INTAS – 01-2354 and by the USA CRDF RP1-2417—DU-02 Grants.

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KP18 RECENT DEVELOPMENTS IN PRODUCTION OF RADIOACTIVE ION BEAMS WITH THE SELECTIVE LASER ION SOURCE AT THE ON-LINE ISOTOPE SEPARATOR ISOLDE

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The resonance ionisation laser ion source (RILIS) of the ISOLDE on-line isotope separation facility is based on the method of laser step-wise resonance ionisation of atoms in a hot metal cavity. Using the system of dye lasers pumped by copper vapour lasers the ion beams of many different metallic elements have been produced at ISOLDE with an ionization efficiency of up to 27%. The high selectivity of the resonance ionization is an important asset for the study of short-lived nuclides produced in targets bombarded by the proton beam of the CERN Booster accelerator. Radioactive ion beams of Be, Mg, Al, Mn, Ni, Cu, Zn, Ga, Ag, Cd, In, Sn, Tb, Yb, Tl, Pb and Bi have been generated with the RILIS.

To extend the range of laser-ionized beams a series of experiments on laser spectroscopy of highly excited atomic states of antimony, scandium and yttrium has been carried out using the ISOLDE mass separators in off-line mode. As a result of this study the optimal three-step ionization schemes of Sb, Sc and Y have been defined. The absolute values of ionization efficiency were measured by evaporating small samples of the studied elements.

Setting the RILIS laser in the narrow line-width mode provides conditions for a high-resolution study of hyperfine structure and isotopic shifts of atomic lines for short-lived isotopes. The isomer selective ionization of some Cu, Ag and Pb isotopes has been achieved by appropriate tuning of laser wavelengths.

KP19 LAST RESULTS OBTAINED AT GANIL WITH NEW TARGET-SOURCE SYSTEMS DEDICATED TO THE RADIO-ACTIVE ION PRODUCTION

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GANIL. Bd Henri Becquerel. BP 55027. F-14076 CAEN cedex

During the last year, two new target-source systems dedicated to radio-active ion production have been designed at GANIL (Grand Accélérateur National d'Ions Lourds). The goal is to provide efficient singly-charged ion sources for the production of some radio-active ions in the frame of projects like SPIRAL II, which will use the charge-breeding concept. After their characterization with stables ions, in term of response time and ionization efficiency, the target-sources were used on the SIRa test bench to perform radio-active ion production. The results obtained with these singly-charged ECRIS (Electron Cyclotron Resonance Ion-Sources) are presented and compared to the previous results obtained using multi-charged ion sources.

KP20 COMMISSIONING THE TRIUMF/ISAC ECR ION SOURCE FOR RADIOACTIVE ION BEAMS

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A radiation hard 2.45 GHz ECR source has been installed in the ISAC target station. The ion source with its 8-60 kV extraction system is coupled to the radioactive isotope production target via a short transfer tube. The volatile radioactive isotopes produced by bombarding a target with a 500 MeV proton beam are ionized and accelerated at the ECR source system. The whole assembly is located beneath a 2 m thick steel shielding structure. Commissioning and initial results including the yield measurements are presented.

KP21 **LASER ION SOURCE FOR THE LEUVEN ISOTOPE SEPARATOR ON-LINE (LISOL)**

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An element selective laser ion source has been developed at the Leuven Isotope Separator On-Line (LISOL) for the production of purified beams of short-lived isotopes of refractory elements. The operational principle of the ion source is based on multi-step selective resonant laser ionization of nuclear reaction products that are neutralized and thermalized in a high-pressure noble gas. The separator is coupled on line to the cyclotron accelerator at Louvain-la-Neuve. Exotic radioactive nuclei were produced in a light/heavy-ion induced fusion-evaporation reactions and in a proton-induced fission of uranium-238.

The interactions of ions with impurity molecules, with noble gas atoms, with electrons and with electrical fields have been investigated in order to specify the requirements for the gas cell as a source of radioactive rare isotopes for the next generation radioactive ion beam facilities.

A gas cell can be used eventually after in-flight separator to stop nuclear-reaction products from heavy-ion fusion or fragmentation. High-energetic beam with large transversal and longitudinal divergence can be converted into a low energetic one for precision experiments or for the consequent injection into a post-accelerator. This concept is considered now days within the EURISOL, RIA, RIKEN and SHIPTRAP projects. The ions will be guided towards the exit hole of the gas cell by the combination of DC and AC electric fields. Since the primary/secondary beam induces a high degree of ionization of the buffer gas, the intensity of the outgoing radioactive beam is limited by space charge effect inside the cell. On expense of evacuation time, much higher intensities can by obtained by using laser ionization in the gas cell. In order to get a more quantitative idea of the performance of the laser ion source, the conversion of a 185 MeV nickel-58 beam from the cyclotron accelerator into a low energetic mass separated beam was studied. After thermalization and neutralization the nickel atoms are re-ionized by laser light via a selective two-step resonant process and are extracted for further mass separation. Efficiencies, defined as the ratio between the mass separated beam intensity and the primary beam intensity, up to 10% have been obtained. .

KP22 ECRIS CHARGE BREEDING : HIGH RESOLUTION SPECTRA AND EMITTANCE

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The charge breeding process, consisting in a low charge state ion beam (1+) plasma capture followed by a multi-ionization process, has been developed for more than 10 years in LPSC Grenoble (previously ISN) using ECRIS.
The challenge has been to optimize the 1+ capture and then the re-extraction of the multicharged ions produced, keeping a "reasonable ECRIS working". There are now 3 ECRIS PHOENIX Booster in the world (LPSC-Grenoble, CLRC-Daresbury, and TRIUMF-Vancouver). The LPSC one has recently been set up in a completely renewed test bench equipped with a high resolution N+ mass spectrometer and a high resolution emittancemeter. The CLRC one is dedicated to online experiments[1] with radioactive ions at REX-ISOLDE and the TRIUMF one will soon be ready to undergo a validation process.
We will present the results obtained with the new setup of the LPSC PHOENIX Booster with a special attention to the n+ emittance and the characterization of the unwanted beams (usually called "impurities" by the RIB production specialists) present in a spectrum of a non UHV ECRIS

[1] Under EU contract nb. HPRI-CT-1999-50003

KP23 **MECRISOL, A COMPACT ECRIS FOR IONIZATION OF NOBLE GAS RADIOISOTOPES AT ISOLDE**

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A very compact ECRIS for ionization of singly charged radioactive ions has been developed at ISOLDE/CERN. The radioisotopes are produced mainly by fission, spallation and fragmentation reactions induced via high-energy protons impacting on a thick target. During this process, radiation showers generate dose rates of up to 50 kS/h at 10 cm distance where the ion-source is located. The often short-lived radioactive elements required for ISOLDE physics [1] diffuse out of the target, effuse through a cold transfer tube providing selectivity for highly volatile elements, and eventually reach the ionizing volume. An efficient ionization process is mandatory in view of the very small production cross-sections of radioactive elements far from stability and fast ionization is desired to minimize decay losses.

The MECRISOL (Mono ECR ISOLDE) is mainly intended for light noble gases (He, Ne, Ar and Kr), which have low ionization efficiency in ordinary plasma ion sources, but also for gaseous molecular compounds of C, N and O isotopes. The source fits within a standard ISOLDE target unit and its lightness enables handling with the target robot. No maintenance is possible once the target is irradiated; it is a consumable which lifetime is determined by the ion-source and the release out of the target material. Thus, a simple and cheap design was chosen. Special attention has been paid to the radiation robustness of the components of the system. As a unit will be exposed to a high neutron dose, permanent magnets were avoided and instead the magnetic confinement field is formed by two water-cooled coils in Helmholtz configuration. An innovative cavity design with opposite stems forcing the cavity to resonate in TE111 mode assures an optimum heating of the electrons. The RF field is inductively coupled to the cavity via a loop antenna. The plasma region is confined by a quartz tube to minimize the ionization volume, and thereby also the hold-up time in the source.

We will report on the design and construction of the device, including magnetic field calculations and RF simulations. Results of the first tests performed with stable ion beams are presented.

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KP24 DEVELOPMENT OF A BE-7 BEAM : NOVEL TECHNIQUES FOR THE IONISATION OF RADIOACTIVE METALLIC ELEMENTS

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The Louvain-la-Neuve ECR ion source is used to ionise metallic radioactive elements like Be-7 ($T_{1/2}$= 53d) for post-acceleration in its radioactive beam facility.

Because of the minute quantities of primary material available, dedicated techniques had to be developed to inject the radioactive atoms in a controlled manner and to recycle the atoms lost on the plasma chamber walls. For this purpose, a heated plasma chamber has been constructed which allows the use of "on-line chemistry in the source" to effectively recycle the deposited material. The presence of a radioactive tracer proved to be a strong diagnostic tool to locate the material loss in the different parts of the source.

This development resulted in the production of a post-accelerated beam of Be-7 in 1+ and 2+ charge states. Up to 110 hours of continuous beam have been provided with primary material quantities of a few ng. The total efficiency of the source reached a few percent.

These beams were initially developed for experiments in nuclear physics. The implantation of Be-7 is now also used as a powerful tool to measure the wear properties of various materials like ceramics and amorphous carbon layers. This will be illustrated with a few examples.

KP25 MASS-ANALYZER MASHA HIGH TEMPERATURE TARGET AND PLASMA ION SOURCE

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Plasma ion source with electron bombarding (FEBIAD B2) was installed and investigated in the FLNR JINR. It will work together with high temperature thick Uranium carbide target and the thermo-gradient tube in between target and source.

The scientific program of Mass-analyzer MASHA includes of an accurate masses measurements of synthesized super heavy atoms and determining the modes of their decays.

The high temperature target with thermo-gradient tube and high efficiency ion source is one of important part of the setup. The material of the target is porous graphite with a thickness of 1 mm. The target will have the Uranium carbide in the beam side surface with a density of 15 mg/cm^2. The working temperature of the target will be up to 2700 K. This temperature conditions will allow us transportation of the volatile elements at this temperature with high speed from the target to the transportation tube.

The changing of the temperature of thermo-gradient tube shall allow us to make primary separation.

High temperature FEBIAD ion source provide as to produce ion beams of many elements with the evaporation temperature up to 2000K with a charge state 1+, which were crossed the thermo-tube. The supposed efficiency of ion source for noble gases such as Kr and Xe reaches to 36% and 50%, correspondly. The efficiency of ionizing of Hg atoms reaches to 70%.

The results of investigation of efficiency of MASHA ion source will be presented. The ways of increasing of efficiency of the target-thermo-tube-source complex is discussed.

KP26 MEVVA ION SOURCE OPERATED IN PURELY GASEOUS MODE

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We have operated a vacuum arc ion source in such a way as to form beams of purely gaseous ions. The vacuum arc configuration that is conventionally used to produce intense beams of metal ions was altered so as to form gaseous ion beams, with only minimal changes to the external circuitry and no changes at all internally to the ion source. In our experiments we formed beams from oxygen (O^+ and O_2^+), nitrogen (N^+ and N_2^+), argon (Ar^+) and carbon dioxide (C^+, CO_2^+, O^+ and O_2^+) at extraction voltage of 2 to 50 kV. We used a pulsed mode of operation, with beam pulses approximately 50 milliseconds long and repetition rate 10 pulses per second, for a duty cycle of about 50%. Downstream ion beam current as measured by a 5 cm diameter Faraday cup was typically 0.5 mA pulse or about 250 μA time averaged. This time averaged beam current is very similar to that obtained for metal ions when the source is operated in the usual vacuum arc mode. Here we describe the modifications made to the source and the results of our investigations.

KP27

EXTRACTION DESIGN AND LEBT OPTIMIZATION OF SPACE CHARGED MULTISPECIES ION BEAM SOURCES

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In all accelerator projects, the low energy part of the accelerator has to be carefully optimized to match the beam characteristics requirements of the higher energy parts. Since 1994 with the beginning of IPHI project (Injector of Protons for High Intensity) and SILHI (Source of Light Ions with High Intensities) ECR ion source development at CEA/Saclay, we are using a set of 2D codes for extraction system optimization (AXCEL, OPERA-2D), beam transport (MULTIPART), and also 3D code for beam selection and mass analysis (TOSCA).

The 95 Kev SILHI extraction system optimization has largely increased the extracted current, and improved the beam line transparency. From these good results, a 130 mA D^+ extraction system for IFMIF project has been designed in the same way as SILHI one. We are also now involved in SPIRAL 2 project for the building of a 40 KeV D^+ ECR ion source, continuously tunable from 0.1 to 5 mA, for which a special 4-electrode extraction system has been studied.

In this paper we will describe the 2D design process and present the different extraction geometries and beam characteristics. The 3D simulation of the Wien filter associated with the SILHI emittance measurement unit will be presented too. Simulation results of SILHI H^+ beam emittance will be compared with experimental measurements.

KP28 THE LOW-FIELD, PERMANENT MAGNET, ELECTROSTATIC PLASMA LENS

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We describe here the status of ongoing research and development of the electrostatic plasma lens as used for the manipulation of high current broad beams of heavy ions of moderate energy (10-100 keV). In some collaborative work at LBNL the lens was used to good effect for carrying out high dose ion implantation processing [1]. In the process of this work a very narrow range of low magnetic field was found for which the ion-optical characteristics of the lens improve markedly. Subsequent theoretical analysis and computer modeling has led to an understanding of this phenomena. These serendipitous results open up some attractive possibilities for the development of a new compact and low cost plasma lens based on permanent magnets rather than on current-driven field coils surrounding the lens volume. Preliminary results of our research into permanent magnet plasma lenses have been reported previously [2]. The development of this kind of lens to include both very low noise and minimal spherical aberration effects, may lead to a tool suitable for use in the injection beam lines of high current heavy ion linear accelerators.

Here we briefly review the lens fundamentals, the peculiarities of focusing heavy ion beams at low magnetic fields, and summarize recent theoretical and experimental developments, with emphasis on the relevance and suitability of the lens for accelerator injection application.

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KP29 PHASE SPACE MEASUREMENTS AT NON-ACCESSIBLE POINT ON THE BEAM PATH OF AN ACCELERATOR FACILITY

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The optimization of beam lines for extracted particles from accelerator facilities requires the knowledge of beam parameters. A method for the measurement of phase space and beam intensity distribution is represented. This method depends on the setting of quadrupole lenses that allows the imaging of beam profiles at arbitrary positions along the beam path on the same multi wire proportional chamber, where the intensity distribution can be evaluated. The necessary focusing powers for a certain imaging task are calculated in a thin lens approximation. A comparison of the calculated focusing powers for thin and thick lenses reveals deviations at the highest field strengths, due to saturation effect. The position of the beam waist in normal and angular space is directly calculated and visualized. The horizontal and vertical waist positions are found to be rather independent of the beam energy. The effect of a reduced aperture of the extracted particles shows that the maximum emittance depends on the waist distant and the aperture diameter.

KP30 ELIMINATION OF ABERRATIONS IN CASE OF INTENSE LARGE-APERTURE ION BEAM FOCUSING BY MOROZOV'S PLASMA LENSES

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The problems of intense ion beam focusing are important for nuclear physics, accelerators, beam technologies, etc. The essential feature of intense ion beams is that they should be charge compensated during the focusing to prevent their destruction. In this case, the application of Morozov's plasma lenses [1] is expedient. In such lenses the magnetic surfaces are equipotentials of the electrical field. Due to extrinsic charges in the focusing space, the lenses have some advantages such as great focusing force, correction of various types of aberration, focusing of intense non-paraxial ion beams. Experimental researches [2] basically confirm the initial theoretical model [1], however the further studies of eliminating rather significant aberrations are necessary.

In this work a computer modeling of such lenses is considered. Numerical codes elaborated can efficiently optimize some existing and planned experimental devices. Results of simulation of intense, large-aperture ion beam focusing are given in view of their longitudinal, radial, and azimuthal motion. Besides of geometrical and chromatic aberrations; in Morozov's plasma lenses the moment aberrations, and aberrations connected with discrete distribution of the external focusing potential must be considered. The moment aberrations obey the conservation law of the moment of ion generalized momentum, and they disappear when an ion source is placed into a zero magnetic field. The geometrical aberrations are removed by choice of the optimal electric field intensity distribution that has been calculated. As a result, the beam compression can achieve a value up to 10^5. The influence of discrete potential distribution on ion focusing was simulated, and corresponding aberrations have been investigated. To the aim of the aberrations decreasing, it is proposed more perfect scheme of the focusing potentials input into Morozov's plasma lens. An example of a two-lens achromatic system has been proposed and investigated as well.

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KP31 TEST RESULTS OF 18GHZ ECR CHARGE BREEDER FOR KEK-JAERI RNB FACILITY

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We made an 18GHz ECR charge breeder (ECRCB) for KEK-JAERI radioactive nuclear beam (RNB) facility [1]. In the facility, the charge breeder (CB) is required to convert singly charged radioactive ions from the JAERI-ISOL [2] to more highly charged ions of A/q<7 for the acceleration of RNB. Tests of the CB are in progress at KEK test bench. During the conference, after a brief introduction of the present status of the facility, we will present two test results as follows.

(1)Charge breeding experiments: We have measured charge-breeding efficiencies for stable ions. The singly charged ions were injected to the plasma of the ECRCB. The ECR plasma consisted sorely of residual gases, such as O and C ions. The charge-bred ions were extracted and their charge distribution was measured. The global efficiency was typically about 50%. The maximum observed at Xe^{20+} reached about 6.5%, for example.

(2)Selective reduction of residual ion species in the plasma of ECR charge breeder: Under a typical operational condition of the source for charge breeding, we have observed ions of about several tens nA in the region of interest, e.g. 6<A/q<7, presumably associated with the gases primarily existing in the plasma chamber and out-gassing from the surface of the inner wall of the chamber in the operational condition of the source. In the application of the ECRCB for RNB facilities, such a background in the ion spectrum would be an intolerable problem due to the very low RNB intensities as compared to those of stable beam. Although a part of them could be certainly reduced by an improved performance of the beam analyzing system, we have rather tried, at the test bench, to selectively reduce the residual gas components in the source. We have investigated the possibility of the selective reduction by covering the inner wall of the plasma chamber with a NEG (Non-Evaporable Getter), whose surface is activated by the microwave power used for heating electrons in the normal operation of the souce. The activated surface of the NEG reacts to gas molecules consisting of C, O and N, forming refractory compounds that diffuse into its bulk. We will present the preliminary results, and discuss the possibility and limitation of the method.

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KP33 NONLINEAR DISTORTION OF MULTICOMPONENT HEAVY ION BEAM EMITTANCE CAUSED BY SPACE CHARGE FIELDS

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The beam of ^{48}Ca ions is obtained in ECR-ion source with helium as supporting gas. The current of helium ions is often greater than calcium one. The influence of the helium ions self-fields on emittance of calcium beam during the common transportation from ECR-ion source to analyzing bending magnet is investigated by macro-particles simulation. For big magnitude of helium current the calcium ions have a holed-beam shape just after analyzing magnet and beam emittance is strongly increased. The possibilities of elimination of this effect are discussed.

KP34 OPTIMIZATION METHOD TO REDUCE THE NON-LINEAR EFFECTS IN SPACE CHARGED LIMITED EMISSION DIODE

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We have studied the evolution of electron or ion beams in axially symmetric extraction systems dominated by space charge. At first, electric and magnetic field components induced by a high voltage diode and an external magnetic focusing are respectively computed using analytical formulas. This new approach allows a better insight into the individual effects of the three non-linear forces (electric, magnetic and space charge) on the emittance evolution. Indeed, the optimization method acts on the rms emittance minimization. More complicated extraction geometries can be handled thanks to numerical simulation codes using this method.

KP35 MOMENT METHOD APPROACH TO SIMULATION OF LOW ENERGY ION BEAMS.

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At present the beam space charge problem for the low energy ion beams has been studied using the PIC methods and RMS envelope equation (second order moment equations). The second approach is connected with using of an effective linear self electric field.

In this report we discuss the problem of nonlinear beam simulation on the base of the method of moments of particle distribution function. The polynomial approximation of a charge density of a beam with circular cross section has been fond using time varying moments. The self electric field deconstructed with the help of the density approximation and used in the system of moment equations. In such a way one obtains the approximate solutions of Vlasov self consistent problem. The new simulation method is demonstrated on the examples of free expansions of beams with nonuniform space charge density. Nonlinear effects such as emittance growth, varying density profile, asymptotic behavior of a beam etc. are under discussion.

KP36 STATIC AND DYNAMIC CHARACTERISTICS OF PLASMA LENS WITH MODIFIED MAGNETIC FIELD GEOMETRY

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The first results of investigations of the focusing features of high-current wide-aperture plasma lenses (PL) based on permanent magnets and developed in Kiev are described in [1]. The magnetic field line configuration in these lenses was similar to those, created by current-driven coils. In such case the conditions exist for excitation of nonlinear vortices-like structures that worsen characteristics of the lens [2]. In this work we present some results of investigations of static and dynamic characteristics of PL with modified configuration of magnetic field lines. In central region of the lens axial and radial field gradients are minimized. It should promote the suppression of mentioned structures and the decrease of spherical aberration.

We investigated PL characteristics under passing through it the beams of Cu and Pb ions accelerated by 6-16 kV voltage, having up to 0,4 A current and ~6 cm beam diameter. PL with aperture of 7,4 cm diameter had 13 ring-shaped electrodes fed by dc or pulsed voltage source (up to 5 kV). Magnetic field induction in PL center comprised 9-70 mT.

In a range of small beam currents (up to 50 mA) current density compression coefficient reaches value ~30 in the focus and decreases at higher currents. Besides, focusing features of the lens differ significantly at pulsed and dc power supply to the electrodes. In the last case it is due to developing self-maintained low-current (up to 1 mA) discharge in PL, even at the lowest working pressure of residual gas (10^{-5} Torr). It appeared also that in given magnetic field configuration the lens properties change significantly at small perturbation of the plasma medium. Particularly, presence in PL the probe with external dielectric cover having 2 mm diameter decreases beam compression coefficient in the lens focus by several times. Studying PL properties in range of small magnetic fields (up to 13 mT) has shown that under these conditions the focusing possesses non-stationary character, and regular decrease of the lens strength is observed, which is due to short-time ejections of electrons from the lens volume. Possibility of such ejections is also demonstrated by the results of computer modeling. At the same time, for this range of magnetic fields presence of regimes is determined with the absence of focusing breakdowns and the absence of growth of noise component of ion beam focused by the lens.

This work was supported in part by the STCU, project #1596.

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KP37 METHOD FOR THE SIGN-ALTERNATING STRONG ELECTROSTATIC FOCUSING OF INTENSE BEAMS OF CHARGED PARTICLES AND THE DIRECT ACCELERATING OF THOSE PARTICLES

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Starting from the principles of the mass-spectrometric in-flight-capture trap of type [1], a feasibility analysis [2, 3] has been carried out of accumulation of low-energy light charged particles (p, d, t, ^{6,7}Li ions) in a combined trap with crossed solenoidal magnetic and quadrupole electric fields. It was shown that under certain conditions, in mutual collisions in a vacuum of the accumulated equilibrium beams, for example deuteron and triton beams, as a result of fusion reactions, neutrons will be generated in numbers sufficient for neutron researches and practical applications.

Intense ion beams are supposed to be produced with an ion source of type [4]. The ion source of this type has a wide ring emission slit that is adequate to the acceptance of the storage collider and a ring electron emitter of a large area that enables the extraction of emitted electrons with a high perveance. Ionizing electrons are strongly contracted by the fringe magnetic field of the solenoid. Ions are extracted along magnetic lines through a narrow emission hole of a large diameter.

Deuterons and tritons are accelerated with a direct action accelerator with a constant potential of 50 – 100 kV generated by a one-stage step-up transformer and a rectifier circuit. The high-current (up to 10 A) tubular ion beam of a moderate density (up to 0.1 A/cm^2) is focused with a time-constant electric field, using the principle of a sign-alternating quadrupole focusing and accelerating action. This principle, which lies at the basis of Russian patent [5] granted for *The method for accelerating and focusing charged particles with a constant electric field and a device to realize this method* was developed as a result of the reverse solving of electrostatic problems [6].

The proposed method for generating neutrons in ion collisions in a vacuum is considered by the author as an alternative to the known methods for generating neutrons based on irradiation of a massive target with accelerated charged particles and the fusion of light nuclei in hot plasma.

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KP38 MASS SEPARATION OF ION BEAMS USING TRANSVERS RADIO FREQUENCY ELECTRIC FIELD

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Broader ion beams are required to fabricate large area display devices. One method to realize a large area exposure of ion beams is to produce an ion beam with the cross section long in one direction,[1] and move the target in the direction perpendicular to the long side of the beam cross section. Mass separation of the ion beam having a long cross section utilizing a linear magnetic field becomes more difficult as the longer distance between the magnetic pole pieces is required. Methods to realize mass separation using radio frequency(RF) electric field can be the alternatives to achieve broad ion beams with reasonable ion beam purities. An experiment was made to test the mass separating capability of the RF field applied in the direction of the beam extraction,[2] and the separation of the target ions from the impurity ions in the beam was demonstrated. In this study, the results of the mass separation performance of the RF electric field applied in the direction perpendicular to the extracted beam are reported.

A 0.7 mm diameter beam was extracted from a 6 cm diameter 6 cm long magnetic multicusp ion source with a single gap extraction system. Four pairs of 4 mm diameter cylindrical electrodes were arranged 8 mm apart at the extractor downstream to realize a spatially sinusoidal RF electric field strength. All four electrodes on one side of the beam were set at the ground potential, while a RF voltage was applied to the electrodes on the other side. The spatial distribution of the beam was measured by moving the position of a Faraday cup having a 1 mm wide entrance slit.

For fixed amplitude of the applied RF voltage, a peak of the ion beam current was recorded by changing the extraction voltage as the Faraday cup was positioned at the center of the beam axis. The extraction voltage at which the ion beam showed the maximum increased as the applied RF power was increased. The spatial distribution of the beam current density showed a sharp profile as the RF power was tuned to realize the maximum current at the center of the electrode pairs for fixed voltage of the beam extraction. These characteristics agreed qualitatively with a simple mathematical model. The results showed that the mass separation of a thin long beam can be achieved by applying a RF field in the direction perpendicular to the beam propagation. An improvement in the mass separation capability of the system is expected by increasing the number of electrode pairs.

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KP39 PROGRAM FOR CALCULATIONS OF ABERRATIONS IN SOLENOIDAL LENS

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The algorithms within the matrix formalism to obtain the solution of nonlinear equations of charched particle motion by Green' function method, are described.

The Fortran program is written for analitical and numerical solutions. There is the code block for calculations of magnetic field map.

For some application the results of calculations are presented.

KP40 DESIGN AND SIMULATION OF ION OPTICS FOR ION SOURCES FOR PRODUCTION OF SINGLY CHARGED IONS

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During the last two years different types of singly charged ion sources were developed for FLNR (JINR) new projects such as DRIBs (Phase I and Phase II), production of tritium ion beam, MASHA mass-separator. The ion optics simulations for 2.45 GHz ECR source [1], RF source [2], and plasma ion source [3] were performed. In this article the results of design and simulations of optics of new ion sources are presented. The results of simulation are compared with measurements data obtained during the experiments.

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KP41 **ION BEAM FORMATION WITH HIGH ION CURRENT DENSITY**

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The possibility to obtain dense plasma containing multi-charged ions in mirror magnetic trap with ECR pumping by powerful gyrotron radiation has been demonstrated in [1]. The ion current densities in trap plug about 200 mA/cm^2 have been reached in these experiments thus significantly exceeding current densities obtainable in the traditional ECR sources. Ion beam formation at such high current density is a complicated problem.

This work presents the results of the experiments on optimization of two-electrode system of ion extraction from dense plasma and emittance measurements for generated ion beam.

The experiments were carried out at SMIS 37 setup [1]. Plasma was generated in a simple mirror magnetic trap with magnetic field in plugs up to 3.5 T by means of gyrotron radiation with frequency 37.5 GHz, maximum power 100 kW, pulse duration 1.5 ms. Two-electrode quasi-Pierce extraction system was used for ion beam formation. The extractor was placed either into the plug or on a certain distance from the plug beyond the trap. Extracted beam was analyzed and collected by two removable Faraday cups. Removable plate with holes 1 mm in diameter was used for emittance measurement.

The possibility to control current density of multi-charged ions due to the motion of extraction system from the plug to the area of lower magnetic field on the outside the trap was demonstrated.

The ion extraction system has been optimized experimentally. Minimum angular beam divergence equal to 3° was obtained at strong difference between diameters of holes in plasma and puller electrodes.

An ion beam with emittance not larger than $100\pi \cdot mm \cdot mrad$ has been obtained at the extraction of ions from plasma with ion current density 50 mA/cm^2.

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KP42 **HIGH TEMPERATURE ELECTRON BEAM ION SOURCE FOR ON-LINE PRODUCTION OF ISOTOPES OF HARD VOLATILE ELEMENTS**

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Results of on-line tests of a high temperature ion source with a working temperature up to 3000°C which has been developed for production of single charge ions of most elements of the Periodic table are presented. That kind of source was specially designed for ionizing of atoms of hard volatile elements such as Fe, Co, Ni, Rh, Pd and others. For isotope production of pointed out elements the ion source was coupled with uranium carbide target of a high density [1]. The measured yields of Fe, Co, Rh and Pd isotopes have been compared with calculated ones, making use of experimentally measured cross-sections [2]. The overall production efficiency which is the product of release and ionization efficiencies was obtained as a ratio of the measured and calculated yields.

A new designed and off-line tested version of the ion source with the electron emitting cathode placed from the side of the extraction electrode has been described.

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KP43 THE ENHANCEMENT OF IONIZATION EFFICIENCY OF SURFACE AND LASER ION SOURCES BY AXIAL MAGNET FIELD APPLICATION

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Effect of an axial magnet field influence on the ionization efficiency of surface and laser ion sources has been observed.

The axial magnet field applying in the range 500 - 800 G gives an increase of the ion current of all elements those are ionized in a hot cavity of the surface or laser ion source [1]. Moreover, if for ionization of elements with low potentials of ionization such as K, Rb and Cs the magnet field applying effect is negligible, for elements with ionization potentials higher then 6 eV, such as Gd, Tm, Yb, Lu, and others it reaches value about 20 in the temperature region of 2100 - 2500°C.

The results of on-line experiments are presented confirming the influence of the axial magnet field on the ionization efficiency rise of neutron deficient isotopes of rare-earth elements [1] produced in the ionizing target and Eu isotopes resonantly ionized in the laser ion source [2].

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KP44 ACCEPTANCE OF THE CHANNEL FOR MODIFICATION OF MATERIALS (L3A) OF THE TESLA ACCELERATOR INSTALLATION

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The channel for modification of materials (L3A) of the TESLA Accelerator Installation at the Vinča Institute of Nuclear Sciences consists of the mVINIS ECR ion source, a beam transport line and a target chamber for ion beam assisted deposition (IBAD). The 12.8 m long beam transport line, starting at the analyzing slit after the analyzing magnet, contains two electrostatic quadrupole triplet lenses, a 90° bending magnet and an electrostatic beam scanner. Maximal beam transmission through this line, achieved for 250 keV Xe^{17+} ion beam, has not exceeded 25%. At the time the beam line has been designed, the mVINIS ion source has not been commissioned yet, so that the beam emittances were underestimated. This is the main reason for low transmission performance of the beam transport line. In this paper, the results of the beam transport line acceptance calculations are presented, and compared with the measured ion beam emittances [1]. The calculations are based on the transfer matrix formalism, with no space charge taken into account. Suggestions for improving the ion beam transmission are given.

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KP45 CHARGE-ENERGY DISTRIBUTION OF Ta IONS FROM PLASMAS PRODUCED BY 1ω AND 3ω FREQUENCIES OF THE HIGH-POWER IODINE LASER

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The high-power iodine laser system PALS ($\lambda_0 = 1.315$ μm, $E_L \leq 1$ kJ, $\tau \sim 400$ ps at the fundamental laser frequency, 1ω, and $\lambda_{1/3} = 0.438$ μm, $E_L \leq 500$ J, $\tau \sim 400$ ps at the third harmonic frequency, 3ω), with a maximum attainable laser intensity I_L of up to about $3x10^{16}$ W/cm^2, was used to generate highly charged Ta ions. The properties of the ions emitted from the laser-produced plasma were measured in the far expansion zone using ion collectors and a cylindrical electrostatic ion energy analyzer. The focus position with regard to the target surface (and the focus spot size) determines not only the laser power density deposited and the amount of ions produced, but it also directly influences the mechanisms of ion generation.

Maximum ion charge states above z = 50+ were recorded and the maximum energy of emitted ions (with no external acceleration) exceeded E_i = 10 MeV [1,2]. Charge-energy distributions, evaluated and compared at various experimental conditions, are presented for both the 1ω and 3ω laser frequencies. Ion current densities, recalculated to a distance of 1 m, reached tens of mA/cm^2, depending on the group of ions produced. At least seven different ion sub-groups, the origins of which are not yet fully understood, have been distinguished at long distances from the target (~ 2m) at high laser intensities [2]. The existence of an "optimum focus position", found to lie in front of the target surface, suggests that the interaction of a long (τ_L > 100 ps) laser pulse with the plasma produced by the beam itself actually improves the conditions for ion acceleration by ponderomotive forces and by relativistic self-focusing [3].

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Thursday 11 September

LO1 REXEBIS OPERATION AND DEVELOPMENTS

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B.H. Wolf, Johannes Gutenberg-Universität Mainz, Germany and the REX-ISOLDE collaboration.

In 2002/03 REXEBIS[1] delivered charge bred ions for accelerator tests and experiments most of the time. The focus was on stable operation of the ion source. Radioactive ions, $^{9}Li^{2+}$, Sodium isotopes 24 to 29 and $^{30}Mg^{8+}$, have been delivered to experiments after the linac. After an upgrade of the linac top energy to 3.2 and 4.5 MeV/u, heavier elements (with $A/q < 4.5$) will be requested from REXEBIS. With Cesium charge state 32 could be produced as the maximum of the charge distribution using an extended breeding time of 160 ms. In addition $^{138}Ba^{26+}$ and $^{153}Sm^{28+}$ have been produced using breeding times of 18 ms and 38 ms respectively. The Samarium ions ($A/q = 5.46$) have been accelerated in the RFQ for ion implantation into Silicon Carbide as radiotracers. All ions have been bunched and cooled prior to the injection by the Penning trap REXTRAP. Cs ions were injected into the trap from a test ion source, all other ions from the ISOLDE separator. Until now the efficiency from the exit of the trap to the end of the analyzer magnet (in front of the RFQ) is between 5% and 10% for one charge state.
The electron current determines the efficiency especially for the high charge states. It was limited to 300 mA due to extensive electron losses above this value. Alternative cathodes and gun designs are investigated for improved performance.

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LO2 **ECRIS DEVELOPMENT FOR STABLE AND RADIOACTIVE PULSED BEAMS**

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The latest 28 and 37.5 GHz developments show that very intense pulsed beams of medium charge states can be produced with an ECRIS. We will present latest results obtained with PHOENIX 28 GHz in afterglow mode operation and specially the capacity of the source to produce high current of medium charge states despite a relatively low radial magnetic confinement system.

Initially, these developments have been made for Pb^{n+} ion production for the LHC. A new program is now underway by using a very strong ionic pumping effect in order to produce new highly bunched beams of radioactive ions suitable for synchrotron acceleration for the CERN Beta-beam project.

The purpose of this program consists in producing about 10^{12} of ^{6}He or ^{18}N ions/bunch within 100 μs pulse durations and with a 10 Hz repetition rate. This development must use two ECRIS advantages: the gas efficiency and the bunching capability.

We will present a new concept showing how we can bunch and ionize the radioactive gas injected in a CW operation source. Experimental data will be presented to illustrate this new approach. To match the ionizing time to the time structure of the synchrotron used for the post acceleration we have to imagine a pulsed device using 60 GHz RF power and above; this is the purpose of this presentation

LO3 A UNIVERSAL METHOD FOR EFFUSIVE-FLOW CHARACTERIZATION TARGET ION SOURCE/VAPOR TRANSPORT SYSTEMS FOR RIB GENERATION

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Worldwide interest in the use of accelerated radioactive ion beams (RIBs) for exploring reactions important in understanding the structure of the nucleus and nuclear astrophysical phenomena has motivated the construction of facilities dedicated to their production and acceleration. Many facilities utilize the Isotope-Separator-On-Line (ISOL) method in which species of interest are generated within a solid or liquid target matrix. Experimentally useful RIBs are often difficult to generate by this technique because of the times required for diffusion from the interior of the target material, and to effusively transport the species of interest to the ion source following diffusion release in relation to its lifetime. Therefore, these delay times must be minimized. We have developed an experimental method that can be used to determine effusive-flow times of arbitrary geometry target/vapor transport systems[2,3]. The technique utilizes a fast valve to measure effusive-flow times as short as 0.1 ms for any chemically active or inactive species through any target system, independent of size, geometry and materials of construction. In this report, we provide theoretical basis for effusive flow through arbitrary geometry vapor transport systems, describe a universal experimental apparatus for measuring effusive-flow times and provide time spectra for noble gases through prototype RIB target/vapor-transport systems.

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MI1 REVIEW OF LIS DEVELOPMENTS IN PRAGUE AND PRODUCTION OF q OVER 50+ IONS AT PALS

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Laser Ion Sources (LIS) have proved to be very efficient sources of highly charged ions. Depending on the kind and parameters of the used laser, ions with charge states from 1+ up to more than 50+ can be produced, with ion energies ranging from hundreds of eV up to hundreds of MeV, with no external acceleration. Ion current density yields tens of mA/cm^2 at a distance of 1 m from the target (tens of kA/cm^2 in its vicinity). Any solid material can be evaporated and ionized. Such ions can be used for the preinjectors of large colliders, for hybrid ion sources based on a combination of LIS and ECR ion source principle, for a direct ion implantation, and also are of interest in the laser space propulsion revived quite recently. Different demands on the kind, energy, and number of ions influence the laser choice, and, on the contrary, parameters and properties of the laser determine properties and parameter limits of generated ions. Most applications of LIS are based on production of a large number of ions. Thus, high repetition lasers are preferred for technical applications while single shot lasers are used mainly for fundamental research [1].

Investigation of ion emission from laser produced plasma in Prague was initiated by H. Haseroth (CERN) [2] with the aim to compare performance limits of CO_2 and iodine lasers as LIS drivers. An international collaboration with the laboratories mentioned above made possible an additional comparison with the lasers of different parameters (Nd:glass - ns, subns, ps), as well as an extension of the experiments in the direction of hybrid ion sources and/or ion implantation. The high-power iodine laser systems PERUN and PALS ($\lambda_0 = 1.315$ μm, $E_L \leq 1$ kJ, $\tau \sim 400$ ps at the fundamental laser frequency, 1ω; possible conversion to 2nd and 3rd harmonics, 2ω and 3ω), with a maximum attainable laser intensity I_L of up to about 3×10^{16} W/cm^2, were used to generate highly charged ions of various elements (Al, Co, Ni, Cu, Ag, Sn, Ta, W, Pt, Au, Pb, Bi). The properties of ions were investigated mainly on the basis of time-of-flight method using ion collectors, cylindrical electrostatic ion energy analyzer and Thomson parabola spectrometer. Simultaneous X-ray and/or interferometric measurements were also implemented. Maximum ion charge states above z = 50+ were recorded and the maximum energy of emitted ions exceeded $E_i = 20$ MeV. Some typical results, both earlier and more recent, will be presented.

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NI1 HIGH INTENSITY BEAMS FROM ELECTRON CYCLOTRON RESONANCE ION SOURCES – A STUDY OF EFFICIENT EXTRACTION AND TRANSPORT SYSTEM

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A study for the design of extraction and transport system for high intensity beams that will be produced by next generation Electron Cyclotron Resonance Ion Sources (ECRIS) was carried out in the frame of an European collaboration devoted to the definition of the main parameters of 3rd generation ECRIS. High intensity production tests carried out in the previous years at INFN-LNS have put in evidence the need to review the main concept of the beam analysis and transport when high currents of low energy beams are extracted from the source. It is demonstrated that the transport of low energy beams and the injection in the cyclotron becomes critical as soon as the current exceeds a few mA.

The study is based on the calculated parameters for the GyroSERSE source and the calculations have been carried out to obtain a relatively low emittance for the beams to be produced. The design of the extraction system was carried out by means of the KOBRA (3 dimensional) code.

The following study of the analysis magnet and of the related beam line has been carried out by taking into account both the phase space growth due to space charge and to the aberrations inside the magnets. The description of the different beamline options along with a few details on the proposed diagnostics will be also given.

NO1 SOPHISTICATED COMPUTER SIMULATIONS OF ION BEAM EXTRACTION FOR DIFFERENT TYPES OF PLASMA GENERATORS

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Various plasma generators are used to generate the necessary particle density for extraction of an ion beam with required performance. For the simulation the distribution of ions and electrons in real space and momentum space has to be taken into account to get a realistic description of ion beam formation. In addition, the charge state distribution does influence the quality of the extracted beam with undesired space charge effects if magnetic fields are acting on the ions.
Examples will be presented to demonstrate the influence of these parameters. The different boundary conditions for filament driven volume ion sources, mevva ion sources, laser ion sources, Penning ion sources, H^- sources, and ECR ion sources will be compared.

NO2 **SELF-CONSISTENT, UNBIASED, EXCLUSION-BASED EMITTANCE ANALYSIS**

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The emittance of low-energy, charged particle beams is mostly derived from current signals measured with a double slit device and resulting in locally resolved angular distributions. The small acceptance of such devices reduces these signals to a small fraction of the total beam intensity, which makes the data more susceptible to noise and bias. This is especially evident when measuring pure background that normally dominates the data field. This background can cause a significant problem when calculating the rms-emittance from the raw data, where a bias of 0.01% can change the result by a factor of 5. Such small residual biases are common, even with bias-corrective acquisition systems.

The common practice of thresholding the data yields more consistent results, but the results tend to underestimate the rms-emittance because the threshold removes background as well as the small signals found in the wings of the distribution. Exclusion boundaries, however, can be selected to include all real signals while excluding only pure background. Exclusion boundaries reduce the bias sensitivity, but do not completely eliminate it.

We have developed the Self-Consistent, Unbiased, Elliptical Exclusion Method, SCUBEEx, which uses the data outside an ellipse to estimate the bias. This estimate is subtracted before calculating the rms-emittance from the data within the ellipse. The size of the ellipse is varied to reveal the minimum ellipse that includes all real signals and thus yields the most reliable rms-emittance estimate. Quasi-random background variations encountered during this minimization process lead to variations in the rms-emittance estimate that can be used as an estimate for its uncertainty.

All methods will be illustrated by analyzing measured emittance data.

SNS is a collaboration of six US National Laboratories: Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), Thomas Jefferson National Accelerator Facility (TJNAF), Los Alamos National Laboratory (LANL), Lawrence Berkeley National Laboratory (LBNL), and Oak Ridge National Laboratory (ORNL). SNS is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy.

NO3 NUMERICAL ANALYSIS OF NEGATIVE ION TEMPERATURE IN A NEGATIVE ION SOURCE

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The negative ion temperature is an important parameter of the negative ion source, since it affects the beam optics and determines the lower limit of the negative ion beam emittance. Extensive experimental measurements of H^- ion temperature have been made in Ref.[1]. In addition, energy relaxation processes by elastic collisions with various background particles, such as H^+ ion, H atom and H_2 molecule, were discussed to explain the experimental results. Recently, to understand good beam optics observed in the tandem type H^- ion source[2], numerical simulations by a 3D Monte-Carlo H^- transport code were done in our previous paper[3]. Trajectories of surface-produced H^- ions were followed by solving 3D equation of motion. The Monte-Carlo BCM (Binary Collision Model)[4] has been used to simulate Coulomb collision. It has been shown that the temperature of H^- ions relaxes toward the background H^+ ion temperature T_{H^+}. The energy relaxation by Coulomb collision with H^+ ions plays an important role in good beam optics.

In the present paper, we have developed a numerical model for elastic collisions with H atoms. The model has been implemented in our code to investigate the effects of collisions with neutrals. In the model, we employ a semi-classical approach[5], in which the interaction potential obtained by quantum mechanics has been used, to determine the differential cross section. By using the differential cross section, the total cross section and the mean free path are calculated to obtain the spatial point of the collision event by Monte-Carlo method. Also, the scattering angle of each collision event can be calculated from the cumulative probability density function of the differential cross section. By taking account of both Coulomb collisions with H^+ ions and elastic collisions with H atoms, preliminary calculations have been done for energy relaxation of surface produced H^- ions in the tandem type H^- ion source. The result shows that the effect of Coulomb collision is still dominant, at least, for the parameters; $T_{H^+} = 1eV$, $n_{H^+} = 10^{18} m^{-3}$, $T_H = 0.5eV$, and $n_H = 10^{19} m^{-3}$.

Based on theses preliminary results, detailed analysis of energy distribution of H^- ions and also analysis of the energy relaxation process of volume-produced H^- ions in the large hybrid type H^- ion source (Camembert III) are now under way by taking into account the realistic geometry and the birth profile of H^- ions calculated by the neutral transport code[6].

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RI1 A SELF CONSISTENT SHEATH THEORY FOR THE EXTRACTION OF NEGATIVE IONS

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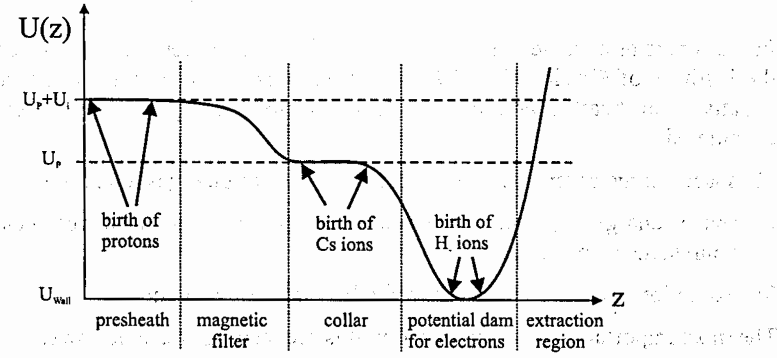

Fig. 1 Electrostatic ion source model for volume production of H^-

A simple electrostatic model of an H^- ion source (see Fig.1) is used to develop a self-consistent sheath theory. It is based on the simplest mathematical description of a 2-component plasma and includes the space charge of negative ions and those of many different positive ones. The problem of creation of a virtual cathode in the extraction region by reflected positive ions in free space is solved by applying results of decelerating electrons in an EBIS. The saddle-point problem associated with the axial minimum of the potential function is overcome by assuming sufficient negative space charge of H^- ions in the vicinity of the wall electrode. Solutions for the resulting implicit and non-linear equation for the plasma potential become restricted in parameter space by the requirement of a positive plasma potential, a modified Bohm criterion and by discarding axial potential functions in the extraction region, which correspond to the build-up of a virtual cathode. The potential function in the extraction region is used to find the proper shape of the plasma-wall electrode for an aberration free ion beam boundary at low velocities (see Fig. 2). This clearly shows, that computer programs for the simulation of positive ion extraction must fail for the determination of electrode details at low ion energies.

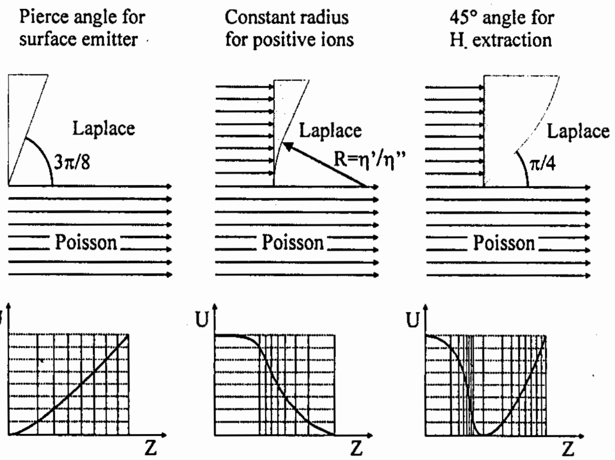

Fig. 2 Comparison of electrode shapes for rectilinear flow

RI2 PROBLEMS OF INTENSE NEGATIVE ION BEAM TRANSPORT

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In the report brief review is presented, which considers results of the researches performed in the Institute of Physics NAS Ukraine on physics of the processes that take place in intense negative ion beams, and on problems of their transport. The following processes are considered:

1) space charge compensation at the expense of residual gas ionization;
2) space charge dynamic decompensation arising in result of beam modulation by nonresonance oscillations;
3) excitation and developing collective (resonance) oscillations.

The most important results presented in this proceeding are, as follows:

1. The process of space charge compensation of negative ion beam possesses principal peculiarities in comparison with the case of positive ion beam. Particularly, in such case overcompensation of the space charge is possible. This effect is used for creation of space charge lens, which provides efficient focusing of negative ion beam.
2. Ion-ion instability of the beam at low gas pressure may result in practically total decompensation of the beam and to impossibility of its transport for long distances.
3. The way of stabilization of ion-ion instability is proposed and realized. The method consists in injection of electrons, that shorten oscillation wavelength, into the beam volume.

SP1

SIMULATION OF NEGATIVE HYDROGEN ION PRODUCTION AND TRANSPORT IN BATMAN ION SOURCE

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Negative hydrogen ion production and transport in BATMAN ion source has been simulated by means of a combination of three 3-D Monte-Carlo codes. These are (1) neutral transport code, (2) negative hydrogen ion production code and (3) negative hydrogen ion transport code. The first code has been used to estimate the spatially resolved density n_v and spectrum of the vibrationally excited H_2 molecules. With the second code, the production and the distribution of H^- ion density n_- in the discharge volume has been calculated. And with the third code, the calculation of the survival probability of H^- ions up to the extraction grid has been carried out. In all the codes, the experimentally observed plasma parameters as well as background gas density and temperature profiles are considered as inputs during trajectory calculation. It is found that the effective negative ion density is almost uniform from the driver to the grid. Only those H^- ions, which are produced within a few centimeters from the grid, are able to reach the extraction hole. To validate the code calculation, a zero-order particle balance equation is also solved. In the case of volume production mechanism, both the code calculation and particle balance equation solution show that n_- near the grid strongly depends on the local n_v only. The balance equation shows that the negative ion density n_-, is increased nearly a factor of two, as a consequence of reduction of the electron temperature T_e from 5ev to 1eV. But the simulation does not show any considerable effect due to the same electron temperature reduction close to the grid, considering the experimentally observed electron temperature and density profile. The H^- ion density near the grid increases almost linearly with the local electron density n_e till n_e becomes equal to n_v. After that, n_e dependency vanishes slowly.

SP2 NIGUN©: A 2D-SIMULATION PROGRAM FOR THE EXTRACTION OF H^- IONS

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So far the simulation of H^- extraction from plasmas has been done with computer programs, which have been written for positive ion extraction. By reversing the polarity and adding the space charge of co-extracted electrons to the space charge of ions, quite reasonable results have been obtained. For those simulations, however, which needed careful design of the plasma-wall electrode, this procedure could not be successful, because the physics of the plasma-beam interface is completely different from positive ion extraction.

The new theory for a multi-particle plasma sheath in case of H^- extraction recently provided the basis to modify the well established 2D computer program IGUN© for this task. As in the case of IGUN, stability of convergence is obtained for the very non-linear sheath region by directly inserting the analytical space charge according to the Poisson equation for each mesh point above the wall potential. For 3-component plasmas (e, p, and H^- or Cs^+) only the relation of proton birth potential to electron energy and H^- energy to electron energy is needed to obtain all parameters – besides the densities. For 4-component plasmas (e, p, H^-, and Cs^+) additionally the density and the energy ratios between protons and Cs^+ ions is required as input for the calculations. Up to 10 different positive ion species may be declared, requiring also input of the corresponding ratios for density and energy. Then the actual field strength in the extraction gap is used to determine the proper densities of all particles by the program. Like in IGUN, it is also possible to specify a certain current and make the plasma-beam interface to react on it: For too high currents the equipotential line on wall potential will bend out of the extraction aperture, making a divergent beam, and vice versa.

A few examples will be given to demonstrate the difference in beam formation by IGUN and NIGUN and the numerical "proof" will be given that – as predicted by theory – an angle of 45° between the beam boundary and the wall electrode will provide rectilinear flow, once the density is matched to the field in the extraction gap.

SP3

NEGATIVE ION SOURCE IMPROVEMENT BY SHUTTER MASK INTRODUCING

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Multicusp sources with cesium seed are widely used for negative ion production. Study of large multicusp source was done recently at National institute for fusion science by plasma grid masking. Large external-filter-type multicusp source with directly heated filaments and the triode beam extraction/acceleration system was used. The movable molybdenum shutter musk was attached to plasma grid at the plasma side. A complete opening or closing of emission apertures was obtained with the shutter musk fast moving. H^- beam production with current of about 3 A, energy up to 90 kV and pulse duration 0.6-1.3 s was studied.

Maximal H^- ion yield is about 1.4 times larger for the shutter musk case, than that for source operation without shutter mask. The emission apertures closing by shutter musk during the interval between the beam extraction pulses produces an essential decrease of cesium escape to accelerator and an improvement of injector high voltage conditioning and operation. Duration of injector high voltage starting conditioning was decreased 2 times. Number of shots with breakdowns in the accelerated circuit was 30% less in the operation with mask shuttered for 3 sec, as compared with the opened mask case. An increased thickness of composite plasma grid + shutter musk structure (3+2 mm) provides the better suppression of extracted accompanying electron flux. It permits to operate with the negative plasma grid biasing and produces an increased ion beam in this case.

No cesium deposition to the vicinity of plasma grid emission apertures takes place at the shutter mask closed position. It permitted to separate the income of plasma grid emission apertures area and of the shutter mask surface to the H^- surface production. Negative ion current evolution during the first cesium seed to the plasma chamber evidenced that about 60% of negative ions are produced on the shutter musk surface, while about 30% – on the edges of plasma grid emission hole, exposed by cesium only after the start of mask shutting.

SP4 **STUDY AND PRELIMINARY RESULTS FOR A NEW TYPE OF ECR H^- IONS SOURCE**

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With the passing of the years, the need has been growing to be able to build a high current source with a long lifetime. An H^- ion production code has been developed to improve the understanding on this ion production. At the same time promising experimentation are going on at CEA-Saclay on an ECR H- ion source. This code is split in two parts. A PIC 2D MCC 3D (Particle In Cell in 2D Monte Carlo Collisional in 3D) is in charge to establish the electron energy distribution function (eedf), which is later use in the fluid code. This second code, calculates the chemistry of the H^- ion production. The 2D configuration of the study obliges to choose a PIC code instead a Boltzmann one. Two important difficulties were considered. The first one is due to the very low pressure (under 10 mtorr) as it is common in H^- production experiments. The second difficulty is to accurately inject the high power discharge (tenth kW) usually demanded for such sources. This condition often carries divergences in PIC code. This code is able to decrease the pressure down to 6 mtorr with discharge few tenth of kW with a good reliability. This paper describes the solution used in the codes and their results useful to bring the development to a new type of long lifetime H- ion source.

SP5 COMPACT SURFACE- PLASMA SOURCES FOR HEAVY NEGATIVE ION PRODUCTION

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Features of several versions of a Compact Surface Plasma Source designed for Heavy Negative Ion Beam production are presented. Discharge in crossed field with Hollow Cathodes has been used for plasma generation. Cylindrical and spherical focusing emitters made of different materials are used for heavy negative ion beam production in surface-plasma interaction with cesium catalysis. Dynamics of emitter's activation in pulsed and DC modes of operation are discussed.

SP6 ELECTROMAGNETIC MODELLING OF THE EXTRACTION REGION OF THE ISIS H^- ION SOURCE

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The ISIS Penning surface plasma source, which routinely produces 35 mA of H^- ions during a 200 μs pulse at 50 Hz for uninterrupted periods of up to 50 days, is regarded as one of the leading operational sources in the world. The ISIS source should provide an excellent starting point for a development programme to produce H^- ion sources with performances exceeding those achieved today, which will be a key requirement for the next generation of high power proton accelerators. One goal is to produce 60 mA of H^- ions from the source without large departures from the optimum conditions for source lifetime or increased emittance. It is predicted that an increase in extraction potential from 17 to 25 kV should be sufficient to achieve this, and a suitable pulsed power supply for the ion source extraction electrode has been manufactured. An understanding of how extract geometry changes affect beam transport is essential for operation at higher extraction potential. An examination has been undertaken of the electromagnetic fields in the extract electrode region using MAFIA finite element analysis (FEA) software. The effects of changing the extraction potential, gap and electrode geometry are described.

SP7 THERMAL MODELLING OF THE ISIS H^- ION SOURCE

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The development of H^- ion sources with performances exceeding those achieved today is a key requirement for the next generation of high power proton accelerators. The ISIS Penning surface plasma source, which routinely produces 35 mA of H^- ions during a 200 μs pulse at 50 Hz for uninterrupted periods of up to 50 days, is regarded as one of the leading operational sources in the world, and should provide an excellent starting point for a development programme. One goal is to produce pulse widths of 1.2 ms at 50 Hz and 2.5 ms at 50/3 Hz, thereby increasing the duty factor from 1% to as much as 10%. Increasing pulse widths will necessitate an improved cooling system to offset increased heating. The most effective cooling strategy will be determined by thermal finite element analysis (FEA) modelling of the ISIS source. This modelling will then be extended to find an optimal means of offsetting increased heat loading, and will minimise the amount of engineering required to produce an effective solution. Modelling of the ISIS source has established the temperature profiles of the source components. At the specific locations where temperatures are measured in operation using thermocouples the model values match those seen in practice. Transient modelling has been used to provide temperature variations for the source during the 20 ms period of the 50 Hz cycle.

SP8 DEVELOPMENT OF AN H- ION SOURCE BASED ON ECR PLASMA GENERATOR AT CEA/SACLAY.

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ECR plasma generator have already demonstrated for a long time their efficiency, reproducibility and long life time, for the production of light positive ions like protons or deuterons. These sources generally work in CW mode. A new 2.45 GHz ECR test stand based on pure volume H^- ion production is currently under development. This negative ion source is working in pulsed mode, routinely 1ms at 10 Hz. The first H^- ions have been observed at the beginning of 2002 with a very poor efficiency. Only few µA were produced. To avoid negative ions destruction by non absorbed microwave close to the extraction aperture, a stainless steel grid was installed in the rectangular plasma chamber. As a result, the chamber is now effectively separated in 2 zones, the ECR plasma generator and the negative ion production zone. By plotting the extracted current versus the production zone length, the H^- ion intensity reached more than 100 µA with the grid located at 25 mm from the aperture. A voltage difference of few ten volts can be applied between both part of the plasma chamber in order to modify the energy of the electrons entering in the production zone. In parallel, a fundamental approach has been undertaken to improve the knowledge on electron and gas interaction. A 2D PIC 3DMCC associated with a fluid code is necessary to overcome the non-isotropic configuration problem. It simulates the effect of an electron beam interacting with hydrogen gas where more than 40 processes are involved. Most important processes are included as: e-V, E-V, V-T, V-V, molecular dissociation, H^- destruction and wall recombination respecting the Miles conditions.

This work is supported by the European Commission under contract n°: HPRI-CT-2001-50021.

SP9 **EFFECTS OF NOBLE GAS MIXING AND GAS INJECTION POSITION IN TCP H- ION SOURCE**

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The addition of noble gases into plasma discharges has been reported to control plasma parameters such as plasma density and temperature. Argon and xenon gases are known to enhance H- production significantly by increasing electron densities while decreasing electron temperatures. On the other hand, helium gases are known to increase predominantly electron temperatures instead of electron densities, which has negligible effects on H- production. Local plasma parameters are controlled to see the effect on H- production by adding various noble gases at different gas feeding positions such as plasma heating region and ion extraction region. Gas injection position of hydrogen itself has also shown different plasma characteristics in H- TCP (Transformer Coupled Plasma) ion source. Electron densities and temperatures are measured in the ion source by combining measurements with both Langmuir probes and optical emission spectroscopy. H- beam currents are correlated with these plasma parameter changes.

SP10 CONTROL OF NEGATIVE ION BEAM UNIFORMITY BY USING MULTI POWER SUPPLIES FOR ARC DISCHARGE

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It is well know that imbalances of arc plasmas are observed in large scaled ion sources with elongated arc chambers; such sources are utilized for NBI in nuclear fusion. Improvement of the plasma uniformity is needed to increase beam power and also to obtain better perviance matching in whole beam extraction area. We, therefore, adopted a filament and an arc power supplies divided into twelve in order to increase a uniformity of the arc discharge. The high-power plasma heating is done by three NBI systems with six negative ion sources in the Large Helical Device. The specification of the injection hydrogen-beam is 180 keV and 5 MW on each beam line. Our negative ion sources have a rectangular arc plasma chamber (1450 mm in height and 350 mm in width) for arc discharge. The produced plasma is surrounded by the line cusp and external filter magnetic fields. Every two filaments are connected to the separated 12 filament and arc power supplies for discharge in the third NBI system. The plasma tends to shifts on the upper side of the arc chamber when the same arc voltage is applied to all filaments. We applied an individual arc control for each pair filaments to improve the uniformity. The arc discharge current became uniform as a consequence of the individually voltage control. The beam profile is optimized controlling the arc current distribution as shown in Fig. 1. The beam also depends on the choice of a pair of filaments. The beam production efficiency is improved by the arc discharge control.

A negative ion beam profile is observed by many methods along the beam line. We measured a heat loading of five segments of the extraction grid and the ground grid by using the water-calorimetric method. An electron component in a beam can be estimated by this measurement. The electron increases in an early stage of the beam conditioning with a cesium seeding in the upper side of the arc chamber. An image of Hα emission is observed by using the optical filter and the CCD detector at 2.2m downstream from the ground grid. The spatial distribution of the beam spectrum shows the extracted negative ion distribution well. The beam, which comes out from the central three grids has the good uniformity. The beam distribution is also measured by a beam calorimeter at the 8.5m downstream near the injection port. The beam profile, which measured by an IR camera, is maintaining the initial rectangle form on the beam armor tiles at the 22m downstream in the LHD vacuum vessel. We also compared these measurements with the beam distribution calculation by using the model function of the initial beam profile. The beam component from center three segments occupies 73% of the whole detected negative ion beam. The beam divergence is evaluated to be 10 mrad.

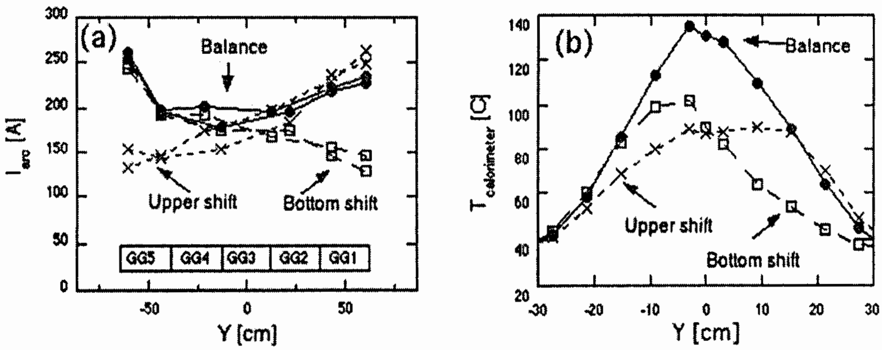

Fig. 1. The beam profile (b) is optimized controlling the arc current distribution (a).

SP11 EFFECT OF ARGON ADDITIVE ON H- DENSITY AND TEMPERATURE IN VOLUME NEGATIVE ION SOURCE

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Various plasma parameters were measured for several hydrogen-argon mixtures in multicusp H- ion source Camembert III, equipped with tantalum filaments. The density and the temperature of electrons were measured with the Langmuir probe situated in the centre of the source and associated with the photodetachment diagnostics. The two-laser photodetachment diagnostics was used to obtain the curve of the recovery of negative ion density. The new methodology of the treatment of these experimental data [1] was used to determine the temperatures of the two H- populations and their fractions.

At low hydrogen pressure (0.8 mTorr) a small concentration of argon additive enhances the hydrogen negative ion density (by approximately 60%), which confirms the earlier work [2], it also increases the electron density.

The population fractions having the high- and low- temperature values behave differently when varying the total pressure in pure hydrogen and in hydrogen with argon additive. In pure hydrogen the population fractions having the high- and the low- temperature values are roughly constant when the pressure is varied. In hydrogen with argon additive the population fraction with high temperature abruptly goes down when argon is added, and correspondingly the fraction with low temperature abruptly goes up. This seems to be the main effect of the argon additive.

Several possible explanations of this drastic change of the relative ratio of negative ion populations are proposed.

Another interesting phenomenon observed during the experiments is the decrease with time of H- density in the presence of argon. After adding the argon during the time interval of ~ 1 hour the H- density goes down and finally saturates. The final H- density is lower than the H- density in pure hydrogen plasma before adding argon. This Ar "poisoning" takes place also in other sources.

The proposed explanation is that during the poisoning the atoms of Ar take the place of the hydrogen at the walls and/or filaments and prevent vibrationally excited H2(v) from forming at the walls, thus diminishing H- density.

Acknowledgement. The support of EEC (Contract HPRI-CT-2001-50021) is gratefully acknowledged.

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SP12 **H^- PRODUCTION IN ECR DRIVEN MULTICUSP VOLUME SOURCE**

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We have used the existing magnetic multicusp configuration of the large volume H^- source Camembert III [1] to confine the plasma created by seven elementary multi-dipolar ECR sources as described in [2]. Each ECR source consists of a permanent magnet mounted at the extremity of a coaxial feedthrough. The ECR resonance at 2.45 GHz takes place for the magnetic field intensity of 875 Gauss. The pressure varied from 1 to 4 mTorr, the total power of the microwave generator was varied between 500 W and 1 kW. We studied the plasma created by this system and measured the density and temperature of the hydrogen negative ions in this plasma by laser photodetachment techniques.

The results are compared to the data obtained in the same source operated with filaments and those obtained in a system with ECR sources without multicusp magnetic confinement. The ECR-driven discharge turns out to be much more stable, the temperature of negative ions at the same pressure is lower than in the case of filament discharge. Another interesting phenomenon we have observed is the presence of double overshoot on the curve of recovery of negative ions after laser irradiation.

When the pressure is in the range 2 to 4 mTorr and the microwave power – 1kW, the electron temperature is optimal for H^- ion production (0.6 - 0.8 eV).

The electron temperature is lower than that obtained with similar elementary sources in the absence of multicusp field. This could indicate that the multicusp configuration effectively traps the fast electrons produced by the ECR discharge.

Acknowledgement. The support of EEC (Contract HPRI-CT-2001-50021) is gratefully acknowledged.

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SP13 **TWO NEGATIVE ION GROUPS IN VOLUME H- SOURCES: ORIGIN AND MEASUREMENT OF THEIR TEMPERATURES**

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The two-laser photodetachment technique has been used to measure the dynamics of the recovery of negative ion density in the center of the multicusp H- ion source Camembert III. The source was equipped with tantalum filaments. The measurements of the electron density and temperature were performed by the Langmuir probe associated with the photodetachment diagnostics. Several series of experiments in pure hydrogen and hydrogen-argon mixtures for the pressures ranging from 0.85 mTorr to 3 mTorr were performed.
The curve of the dynamics of H- return serves to determine the temperature of negative ions. The single-temperature fits of the experimental curves were not satisfactory, so several changes were introduced into the process of treatment of the experimental data. As a result two negative ion populations with different temperatures were identified both in pure hydrogen and in hydrogen with argon additive. This identification was done by fitting the experimental data with a theoretical curve including two H- groups. The same new treatment was also applied to older experiments where tungsten filaments were used.
There are two H- populations – with a relatively low (~ 0.1 eV) and high (~ 1 eV) temperatures. These populations are formed as a result of the existence of two H^- production regions with different plasma potentials, as pointed out by modeling by Hatayama *et al* [1]. The low temperature population (0.03 to 0.25 eV) corresponds to the ions formed in the central source region, where the plasma potential is flat and H- temperature is measured. The higher temperature population corresponds to ions formed near the walls or filaments (driver region). This group is then accelerated by the plasma potential into the central plasma region. Thus the well-known difficulty [2] of too high negative ion temperature values obtained with a single parameter fit, was resolved.

Acknowledgement. The support of EEC (Contract HPRI-CT-2001-50021) is gratefully acknowledged.

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SP14 CONTRIBUTION OF H$^-$ DENSITY NEAR A PLASMA GRID SURFACE IN AN H$^-$ BEAM EXTRACTED FROM A CS ADDED VOLUME PRODUCTION TYPE ION SOURCE

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The amount of beam current of negative hydrogen ions (H$^-$) extracted from a volume production type negative hydrogen ion source is increased three to four times by addition of Cesium (Cs) into the ion source plasma. To use this type ion source for neutral beam injection (NBI) of fusion plasma heating device, understanding of key factors influential upon the ion source operation under Cs added condition is indispensable. However, the precise mechanisms causing the enhancement of H$^-$ current due to Cs addition have not been understood yet. In particular, the contribution of H$^-$ assumed produced at the plasma grid (PG) surface of the ion source by hydrogen reflection or desorption was not quantified.

In this study, H$^-$ density near a PG surface is measured with ion beam assisted photodetachment method, which utilizes the temporal decrease of the extracted H$^-$ beam current due to destruction of H$^-$ inside of the plasma by the incidence of pulsed laser beam. The method does not require the insertion of a Langmuir probe into the plasma, and can directly show how large the contribution due to the local H$^-$ in laser irradiated region is to the overall H$^-$ beam current.

Waveform of the photodetachment current signal obtained from this method showed the duration of about 30μsec, and the current peak height as large as about 20% of the DC beam current. When the position of the laser injection was moved away from the PG, the signal became small and showed the influence due to collision of H$^-$ with plasma particles. In this report, the result of the investigation on the difference in photodetachment current signals between the plasma with Cs and that without Cs is given.

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SP15 NUMERICAL ANALYSIS OF PLASMA SPATIAL UNIFORMITY IN NEGATIVE ION SOURCES BY A FLUID MODEL

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In the tandem-type negative ion source, a spatial non-uniformity of plasma profile in the perpendicular direction to both the ion source axis and the filter magnetic field was experimentally observed in the extraction region [1]. It is very important to analyze plasma profiles and to underatand their underlying physics for improving plasma uniformity in negative ion sources.

For this purpose, we are developing a new 3D plasma fluid model. In the extraction region Lorentz force by the filter field is important for both ions and electrons. However, their dynamics are completely different. For typical plasma parameters in the filter region, electrons are magnetized, while ions are not magnetized, because the following inequalities, $\omega_{ce}\tau_e >> 1$ and $r_{Le}/L << 1$ for electons, and $\omega_{ci}\tau_i < 1$ and $r_{Li}/L < 1$ for ions (ω_{cj}, τ_j and r_{Lj} are cyclotron frequency, collosion time and Larmor radius of *j*-th species, respectively, L is typical scale length), are satisfied. Also, quasi-neutrality $n_i \approx n_e$ is considered to be valid, since Debye length is much smaller than L in most of the filter region by simple estimate.

Taking into account these important features in the filter region, and starting from the usual set of plasma two-fluid equations (density, momentum, and energy balance equations for ions and electrons), we have derived a system of plasma model equations in the filter region. The resultant model equations consist of the following equations; i) continuity equation for ions, ii) momentum balance equation for ions, iii) generalized Ohm's law, iv) continuity equation for plasma current, and v) energy balance equation for electrons. The density and velocity of ions and electrons can be obtained by solving equations i), ii) and iii). Current continuity equation iv) is used to obtain the plasma potential, which is important for the electron $\boldsymbol{E}\times\boldsymbol{B}$ drift motion. Electron temperature is calculated by the equation v), while ion temperature is assumed to be very low and is not significant for the total energy balance in the filter region. The system of model equations is solved simultaneously to obtain self-consistent profiles of plasma parameters.

Before starting full 3D analysis, we have done the simple 2D analysis in the perpendicular direction by assuming that the motion of ions and electrons is uniform in the parallel direction to the magnetic filter. The result shows that a possible cause of spatial non-uniformity is the ion flow rather than $\boldsymbol{E}\times\boldsymbol{B}$ drift motion of electrons. This flow of ions is caused by synergetic effect of the force by electric field, Lorentz force and inertia force.

To verify the above results by 2D analysis and more quantitative comparisons with experiments, full 3D analysis is needed. Because the electron loss along the field line is important for the plasma potential and the electric field in the filter region. Full 3D analysis is now under way.

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SP16 **HIGH PROTON RATIO PLASMA PRODUCTION IN A SMALL NAGATIVE ION SOURCE**

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Negative ion beams of high current density ($\geq$ 200 A/m^2) are required for various application fields such as high intensity proton accelerator and fusion. The negative ion sources of such application utilize surface production process that produces hydrogen (or deuterium) negative ions from proton or atomic hydrogen on a low work function surface. Hence, high proton yield ion sources are required for the high current negative ion production. Generally, a large volume plasma generator with strong plasma confinement operated at low pressure is suitable to achieve high proton yield. The JAERI Kamaboko source which has a large discharge volume of 30 liter surrounded with strong cusp magnets produced a high current density H^- ion beam of 300 A/m^2 at low operating pressure of 0.1Pa. On the contrary, it has been considered that production of high proton ratio plasma is not easy in small sources, since dissociation of hydrogen molecules are not effective due to poor confinement of primary electrons. However, in a small source (3.5 liter), high current negative ion beam of 800 A/m^2 was obtained[1] at a high source filling pressure of 1.0-1.5 Pa.

Present paper describes experimental and analytical studies to increase the proton ratio in a small ion source (1.4 liter). The study includes effects of a transverse magnetic field applied as the magnetic filter in the source. Figure 1 shows the proton ratio in the extracted positive ion beam measured with and without the filter. The proton ratio drastically increased from 40% to 90% even in such a small source by applying the magnetic filter.

Coupled rate equations were numerically solved to estimate particle (H^+, H_2^+, H_3^+, and H^0) densities in the source by varying scales of the ion sources. In the large source (30 liter, 0.13 Pa), more than 80% of proton is estimated in the driver region. A major process of proton production was identified as the reaction (A) $H + e \rightarrow H^+ + 2e$, and was comparable or higher than (B) $H_2^+ + e \rightarrow H^+ + H + e$. The dissociation and ionization of molecules proceed in the large ion source, thus the high proton ratio is achieved at the low filling pressure.

In the small source (1.4 liter) with high pressure (1 Pa), the calculated proton ratio is 40-60% in the driver region. The major process of proton production is reaction (B) due to the low degree of dissociation. However with the magnetic filter, flow of primary electrons through the magnetic field is restrained, resulting in suppression of H_2^+ production in the extraction region. Molecular ions coming from the driver region are easily dissociated or neutralized by thermal electrons in the extraction region. In addition, the proton production reaction (B) is still active due to the large cross section with low temperature electrons. Thus the proton ratio is enhanced by applying the magnetic field in the small sources even in the high operating pressure. Consequently negative ions of high current density can be obtained at the high pressure in the small sources.

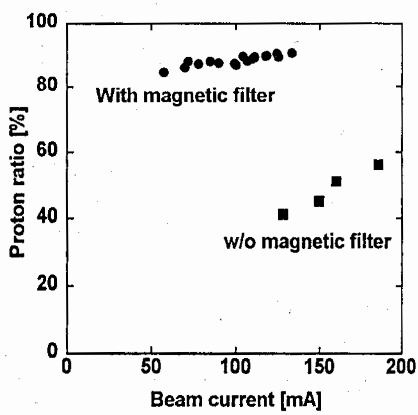

Fig. 1 proton ratio of the extracted beam with beam current in a 1.4 liter small ion source with 1 Pa.

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SP18 INVESTIGATION OF GENERATION OF NEGATIVE IONS IN CUSP PLASMA ELECTROMAGNETIC TRAP WITH PENNING PLASMA SOURCE OF ELECTRONS WITH HOLLOW CATHODE

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A new method of generation of negative ions in cusp plasma electromagnetic trap [1] with Penning plasma source of electrons with hollow cathode [2] was experimentally investigated. The schematic of an experimental set-up is shown in Fig.1. The process of dissociative attachment of cold electrons to molecules of a working gas excited on a high vibration level [3] was used for production of negative ions in volume of the trap. An energy spread electron beam with maximal energy with up to 300 eV emitted from a Penning plasma source of electrons with hollow cathode was injected along magnetic force lines into plasma electromagnetic trap with cusp magnetic configuration. The low energy component of injected electron beam was confined within working volume of the plasma electromagnetic trap and the trap was filled up with a partially uncompensated low – temperature plasma with electron temperature of T_e = 0.1–2 eV and plasma density of $n_o \sim 10^{11}$ cm^{-3}. The magnetic configuration was created by subtractive polarity of magnetic coils for confining of the low - temperature plasma. The high energy component of injected electron beam with energy in range of 70-120 eV [3] produced the vibrational excitation of working gas molecules in a working volume of the trap. As results of spatial combining of generation regions of cold electrons and vibrationally excited molecules it was realized a single-chamber scheme of negative ion generation.

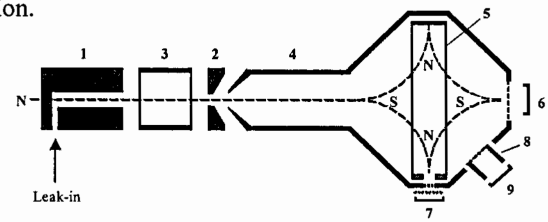

Fig.1. Schematic of an experimental set-up.

1 – hollow cathode, 2– reflective cathode, 3 – anode of plasma electron source, 4 – working chamber, 5 – closing electrode, 6, 7 – collectors of electrons, 8 – negative ion extracting grid and graphite insert, 9 – collector of negative ions.

In run of preliminary experiments the influence of working gas pressure and parameters of the injected electron beam on extracted negative ion currents was studied. The negative hydrogen current of 300 mkA with current density of 0.7 mA/cm^2 was obtained at injection of electron beam with current of 300 mA under operating conditions far from optimal. The further gain in efficiency of negative ion generation in the trap can be obtained by an increasing of extraction potentials as well as injected electron current.

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SP19 DEVELOPMENT OF ACCELERATOR MASS SPECTOMETRY METHOD AT THE TANDEM ACCELERATOR IN ALMATY ON THE BASE OF THE NEW HEAVY ION SOURCE

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During nuclear tests at the territory of Kazakhstan there were made about 30 nuclear explosions in salt domes. Destruction of the cavities and penetrating of radionuclides into underground water can cause serious ecological troubles. Taking into consideration that the regions where the explosions were carried out place near to inhabitant settlements, the continuous monitoring of radio-ecological situation is necessary in areas adjoined to the underground cavities formed by nuclear explosions. Presence of large quantity of salt NaCl in the explosion epicenter area predetermines accumulation of the isotope ^{36}Cl (~130 g) from reaction $^{35}Cl(n,\gamma)^{36}Cl$ possessed high migration properties owing to its good water dissolving ability. Measurement of isotope content ^{36}Cl in water samples taken from the test wells can serve a reliable indicator of radioactive nuclei migration and allows realizing long-range forecast of radio-ecological situation in the places remote from the explosion epicenter. In that case the high requirements are made of choose analytical method sensitivity.

The method of accelerating mass-spectrometry (AMS) is nowadays more sensitive for analysis of isotopic samples composition. Currently we are upgrading the heavy ion tract for development on its basis the method AMS.

More significant part of the AMS system is heavy ion source. Ion current obtained from the source determines the sensitivity of the accelerating mass-spectrometry technique at the analysis of isotope ^{36}Cl trace concentrations in samples. Besides, for carrying out of precise analysis the source is to be multi-cathode for quick change between different cathode without opening the ion source. Therefore, the new heavy ion source MC-SNICS manufactured by National Electrostatic Corporation firm was purchased in 2001.

The MC-SNICS source uses accelerated cesium ions striking a cold cathode to produce a negative ion beam of cathode material, provided the material can form negative ions. Cesium ions are produced by a conical tantalum ionizer immersed in a cesium vapor. Cs^+ ions are accelerated into the cathode which sputters negative ions of the cathode material away. The MC-SNICS incorporates a cesium focus electrode that focuses Cs^+ onto the cathode. This focusing lens produce a cesium beam spot at the cathode from 1.5 mm to 0.2 mm depending on what voltage the focusing lens is set at. A thin layer of cesium condensed on the cathode surface enhanced negative ion production. In general, negative ion beam currents are a function of cathode composition, cathode potential, cesium ion density and cathode temperature controlled by cooling fluid.

SP20 EFFECTS OF THE WEAK MAGNETIC FIELD AND ELECTRON DIFFUSION ON THE SPATIAL POTENTIAL AND NEGATIVE ION TRANSPORT IN THE NEGATIVE ION SOURCE

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In the experiments[1][2], the extraction of negative ions (H^-) is greatly improved by the weak magnetic field. The plasma grid (PG) has a pair of magnets which create a transverse magnetic field strong enough to suppress electrons. Electron near the PG can be easily magnetized by the stray magnetic field (a few tens of Gauss) and lost along the field line, while positive ions (H^+) cannot be magnetized because of the larger Larmor radius. This difference of the dynamics between electrons and H^+ ions perturbs the plasma neutrality in this region and lead to the positive electric potential. This modification of the plasma neutrality and the resultant electric potential due to the weak magnetic field are considered to be very important for the H^- transport and their extraction.

The purpose of this study is to verify this idea by a numerical simulation. A particle-in-cell (PIC) model is used which simulates the motion of the charged particles in their self-consistent electric fields. The trajectories of the particles are calculated by numerically solving the equation of motion. To examine the effects of the weak magnetic field, the following two cases, (A) with the weak magnetic field and (B) without the weak magnetic field, are simulated. For the case (A), since electrons hardly can reach the PG due to the weak magnetic field, H^- ions are balanced with H^+ ions instead of electrons. On the other hand, for the case (B), the balance between positive and negative charge consists of the three kinds of the particles. These simulation results make certain the reasonableness of the idea that more H^- ions arrive in the region close to the PG in order to ensure the plasma neutrality. In addition, the presence of the weak magnetic field produces important modifications in the positive ion flow, and, as a result, in the structure of the spatial potential which collects H^- ions. In this paper, we focus our attention mainly on the effects of the electron diffusion across the weak magnetic field on the spatial potential and the H^- extraction.

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SP21 SPACE CHARGE LENS FOR FOCUSING NEGATIVE ION BEAM: THEORY AND EXPERIMENT

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The report is devoted to theoretical and experimental study of space charge lens proposed earlier by the authors for focusing negative ion beams. Focusing field in the lens is created by the space charge of positive ions formed due to gas ionization by ion beam itself. The electrons formed at that are moved out of the lens volume by longitudinal electric field.

Numeric calculations performed by means of particle-in-cell method allowed obtaining spatial concentration distributions for plasma ions and electrons, electric field values and, finally, trajectories of the beam ions. In result of the calculations it was shown that concentration distributions for the plasma particles possess complex character, however, concentrations of electrons in any point of the lens are lower than those of positive ions by factor of 1-3 orders of magnitude. Exactly this circumstance enabled obtaining electric fields ~ 100 V/cm, required for creation of efficient lens.

The experiments were accomplished with hydrogen negative ion beam having 10 keV energy and 30 mA current. Heavy gases (argon, krypton, xenon) possessing big inertia and relatively large ionization cross section were used as plasma generating media. The lens was composed of cylinder with 10 cm length and 5 cm diameter, and two rings with approximately the same diameter placed at 1 cm distance from ends of the cylinder. Potential of –2 kV relatively to that of the rings was applied to the cylinder. It has been shown that at reaching sufficiently high pressure in the lens (~ 10^{-3} Torr) focusing fields ~ 100 V/cm are realized in the system, and efficient beam focusing is provided (focal length ≤ 20 cm). Results of the experiments are in a good agreement with the calculations.

SP22 NUMERICAL MODELING OF EXCITED HYDROGEN ATOMS AND THEIR TRANSPORT IN HYDROGEN NEGATIVE ION SOURCES

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In hydrogen negative ion sources, neutral particles play a key role to control plasma parameters and to produce negative ions. To calculate the neutral density distribution, a 3D Monte Carlo transport code[1][2] in negative ion sources has been developed. The PCA (Pseudo-Collision Algorithm)[3] is used to follow the neutral particle trajectories in a given background plasma and is very efficient to reduce the computation time. Each vibrational exited level (v=0,1,...) of hydrogen molecules is treated as a different species. And their trajectories are followed separately. However, excited levels (n=1,2,...) of hydrogen atoms have not been included.

In this study, we have improved this 3D Monte Carlo transport code. Not only the ground state, but also the excited states of hydrogen atoms have been taken into account by the QSS-CR (Quasi-Steady-State Collisional Radiative) model[4]. The following important atomic and molecular processes related to excitation of hydrogen atoms are taken into account,

(1) $H_2(v)+e \rightarrow H(n)+H(1s)+e$: (dissociateve excitation),

(2) $H_2^+(v)+e \rightarrow H(n)+H(1s)$: (recombinative excitation),

(3) $H^+ +e+e \rightarrow H(n)+e$: (three-body recombination),

(4) $H^+ +e \rightarrow H(n)+hv$: (radiative recombination),

(5) $H(n)+e \rightarrow H(n')+e$: (collisional excitation and de-excitation),

(6) $H(n)+e \rightarrow H(n')+hv$: (spontaneous emission).

In addition, the following processes are included; (7) ionization, (8) vibrational excitation and de-excitation, (9) dissociative attachment, for H_2, and (10) ionization, (11) charge exchange, (12) surface H^- production, (13) surface recombination, for H, respectively.

By using this code, test calculations have been done with the model geometry[1] of a negative ion source. Density profiles of these atoms have been successfully calculated with typical plasma parameters of negative ion sources. Additionally, the emission intensity distribution of H-alpha in the model geometry has been calculated according to exited-atom density. Based on these preliminary results, it will be necessary to compare simulation results with spectroscopic measurements to evaluate the validity of the model. And the code will be a powerful tool for the analysis of the experimental measurements.

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SP23 TRANSPORT VELOCITY OF DC LASER INDUCED PHOTODETACHED ELECTRONS IN A H$^-$ ION SOURCE

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Transport of photodetached electrons in a negative hydrogen(H^-) ion source plasma was investigated by injecting 808 nm semiconductor laser beam and detecting the probe signal produced from the photodetachment reaction. A hydrogen plasma was produced with the combination of a linear magnetic field and a multiline cusp magnetic field. The power of the semiconductor laser was amplitude modulated and the probe current due to the photodetachment was detected using a Lock-in amplifier to distinguish the photodetachment current from the plasma noise. The distance between the laser beam and the probe was varied and the transport velocity of the photodetached electrons was calculated by the phase difference between the photodetachment current and the modulated laser beam.

Typical sensitivity of the photodetachment signal for the system was about 0.8 $\mu A/cm^2$ W for 60 W, 0.4 Pa and 500 cm^3 H_2 plasma. In this experimental condition, the electron density increased from 0.4×10^{11} cm^{-3} to 1.6×10^{11} cm^{-3} against increasing pressure from 0.4 Pa to 1.2 Pa while the electron temperature decreased from 2.0 to 1.0 eV. The transport velocity of the photodetached electrons was measured to be 1.5×10^5 cm/s, and was nearly independent of the gas pressure. This value of the measured transport velocity was much slower than the one close to the ion acoustic speed observed in the experiment using a pulse laser photodetachment method.[1] The transport velocity for the photodetached electrons did not show any dependence upon the electron density, the electron temperature nor the density of the neutral atoms. However, it was experimentally confirmed that the transport velocity of the photodetached electrons had a strong correlation to the magnitude of the linear magnetic field. The transport velocity decreased from 1.5×10^5 cm/s to 0.5×10^5 cm/s against the increasing magnitude of the linear magnetic filed from 0 to 50 Gauss.

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SP25 OPTIMIZATION OF A CS-FREE H⁻ ION SOURCE FOR HIGH INTENSITY AND HIGH ENERGY PROTON ACCELERATOR

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A Cs-free negative hydrogen ion source driven by pulsed DC-arc plasma with a LaB_6-filament was under operation for the beam test of the J-PARC (Japan Proton Accelerator Research Complex) linac. A peak H^- intensity of 38mA, which exceeds the requirement for the first stage of the J-PARC, is stably extracted from the ion source with a beam duty factor of 0.75% (300μs*25Hz, slightly smaller than the required value of 1.25% for the first stage of the J-PARC) by optimizing the plasma electrode, the LaB_6-filament and the distributions of filter, plasma confinement and electron suppression magnetic fields. The sufficiently small emittance of the beam was proven by high transmission efficiency (around 90%) through the following 324MHz-3MeV-RFQ. The empirical optimization of the ion source is presented in this paper.

SP26 COMPUTATION DESIGN STUDIES FOR AN H^- ION EXTRACTION SYSTEM

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At the University of Frankfurt, a high current H^- source has been developed and tested. The ion source is of volume type with four tungsten filaments. It consists of a cesium seeded multicusp plasma generator with a variable filter magnet. An H^- beam current of 120 mA @ 35 kV has been extracted using an emission opening radius of 5 mm [1].

This source is equipped with a diode extraction system. Thus, the extraction voltages determine the beam energy, which depends on the plasma density. In order to adjust independently the extraction voltage from the beam energy, a new 65 kV extractor is being designed. It consists of a compact four electrode (tetrode) system. The electron dumping will be performed behind the tetrode system.

For the design a new code called NIGUN [2] has been used. This code, which is a further development of IGUN, takes into account a new model of negative ion extraction. A magnetic field can be added in NIGUN. For computing 3D magnetic fields the code Amperes [3] was used. So the influence of the magnetic fields on the angle of the H^- beam and the position of the electron dumping system could be taken into account.

The paper presents the layout of a compact 65 kV extractor for 120 mA H^- and the electron dumping system. A comparison of the calculations of NIGUN and IGUN is presented.

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SP27 ATOMIC FRACTION OF HYDROGEN PLASMA IN A NEGATIVE HYDROGEN ION SOURCE

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Several ion source models have been presented to calculate extractable negative hydrogen ion (H^-) current from the sources.[1-3] Source plasma parameters including H^- density, H^- temperature[4] and the temperature of hydrogen molecules[5] in the plasma are currently being investigated to compare these parameters with theoretical predictions. The atomic hydrogen density in plasma of an H^- source can play an important role in determining the beam current. In this study, the dependence of atomic hydrogen flux upon the discharge power density measured for a small H^- source is reported.

A 6 cm diameter 6 cm long cylindrical ion source of multi line cusp type was used as a test ion source. A tungsten filament serving as the cathode was biased at -60 V with respect to the chamber wall serving as the anode. The discharge power was controlled by adjusting the discharge current. Neutral particles effused out of the ion source through a 3 mm hole into a chamber pumped down by a 500 l/s turbo molecular pump. The neutral particle flux should pass through another collimator to be detected in the other chamber independently pumped down with 230 l/s turbo molecular pump. The flux of hydrogen atoms was measured using a high resolution quadrupole mass analyzer operated in the second stability zone of the Mathieu's diagram.

When the discharge was turned on, both signals from atomic and molecular species increased. In accordance with the increase of discharge power, the atomic hydrogen flux increased while the molecular hydrogen flux decreased. The flux ratio of atoms to molecules was about 0.5 at the discharge power of 300 W when the H_2 pressure in the ion source was 0.4 Pa. When the H_2 pressure was increased to 1 Pa, the flux ratio of atoms to molecules at the same discharge power was about 0.2 and was substantially lower than the values obtained for lower pressures. The atomic flux decreased at lower pressure and higher discharge power operation, which can be interpreted as the reduced efficiency of the ionizer and the higher degree of ionization for the ion source gas. Determination of the density fraction of atomic hydrogen to molecular hydrogen is attempted from the measured velocity distributions of the hydrogen species

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SP28 **ALTERNATIVE PLASMA GENERATION SCHEMES IN RF MULTICUSP H⁻ ION SOURCES**

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RF-driven, multicusp, H^- ion sources used for injection of high brightness beams into particle accelerators have traditionally produced inductively coupled plasmas created by the application of many kilowatts of pulsed RF power to a helical antenna immersed in the plasma. In recent years, antenna coating technology has improved dramatically allowing these sources to operate with reasonable lifetimes at the beam currents and duty factors demanded by modern accelerator facilities. In order to insure long source lifetime at the beam currents (~45 mA) and duty factors (6%) which will be required during the operational phase of the US Spallation Neutron Source (SNS) we are exploring alternative plasma generation schemes. This report discusses four alternative plasma generation schemes: an inductively coupled plasma produced using an external, water-immersed antenna; a high-density helicon plasma created using an external antenna; a plasma produced using a circularly polarized wave launched from a spiral antenna; and an over-dense plasma created by microwave excitation coupled through a resonance zone located at the injection surface of the plasma. The physics of each technique is discussed along with main design considerations for each concept. Ion source designs are presented as well as preliminary results of experimental investigations of H^- production for systems that have been tested.

SP29 CESAITION IN THE SNS H$^-$ ION SOURCE

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The ion source for the Spallation Neutron Source (SNS) is a radio-frequency, multicusp source designed to deliver 45 mA of H$^-$ with a nominal duty factor of 6% and a normalized rms emittance of less than 0.2 π mm mrad to the SNS accelerator. The ion source—designed, constructed, and commissioned at Lawrence Berkeley National Laboratory (LBNL) has now entered routine operation commissioning the SNS accelerators. The use of Cs is required to produce H$^-$ beams greater than 15 mA and is dispensed by heating Cs_2CrO_4 cartridges contained in a collar, which surrounds the outlet aperture of the source. Understanding source cesiation is essential to the delivery of long, sustained beams required for accelerator operation. This report provides a theoretical description of the cesiation process as well as measurements of H$^-$ yield resulting from various collar heating profiles. H$^-$ yields are correlated to Cs vapor densities measured using an in-line conductivity sensor.

SP30 A PIG ION SOURCE PRODUCING O^- ION BEAM

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A pocket penning ion gauge (PIG) source for producing O^- ion beam has been developed, in which the magnet field was excited by a SmCo permanent magnet, and its outline is 8 cm in diameter and 8.5 cm in height. The source can produce mA grade of O^- ion beam at several tens watts of discharge power normally. In order to increasing O- ion intensity, we have been doing some researching work as following:
At first we studied the mechanism of O^- ion producing in this kind of source, and found that the negative ion formation both on the cathodes surface and in the discharge volume, and more than 80% O^- ion producing on the cathode surface. So the cathode material should be adopted with those as low as work function. And multi-crystal LaB6 cathodes with work function 2.7eV are the best one for producing O^- ions in our experiments up to now. Secondly, we tested the effect of magnet field variation for O^- ion current, and the experiments showed that when the SmCo magnet size was changed from 2.0 x 1.8 cm to 3.0 x 3.0 cm, the O^- ion current can increase 100% at fixed other experimental conditions. Thirdly, the extraction geometry was optimized. Now 2 ma O^- ion beam can be easily extracted at 80 mA discharge current and 10 kV extraction voltage from this source. The dependence of extracted total beam on extraction voltage V_{ex} can be expressed by $I_t=KV^a_{ex}$, and in which a=1.4—1.6.This means that under certain experimental conditions the dependence of I_t and V_{ex} is accord with the 3/2 langmuir-law in this source.

SP31

NUMERICAL INVESTIGATION FOR HIGH INTENSITY H^- BEAM INJECTION TO A 100 MEV COMPACT CYCLOTRON

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As a part of the Upgrade Project of Beijing Tandem Accelerator Laboratory[1], a 100 MeV compact H^- cyclotron was designed for the generation of high intensity proton beam. Comparison the beam intensity injected into the cyclotron central region of the 30 MeV medical used cyclotron developed at CIAE 8 years ago, those injected into the 100 MeV machine will be 4 times higher. So, the axial injection optics was investigated numerically again by means of taking the space charge effect into account and the old layout based on the ES (Einzell Lens and Solenoid) system is modified.

From our operation experience, we know ES system is able to control effectively the envelop during beam injection. However, as the beam intensity increasing, the envelop become bigger and the emittance is deteriorated. So as to inject intense beam into the spiral

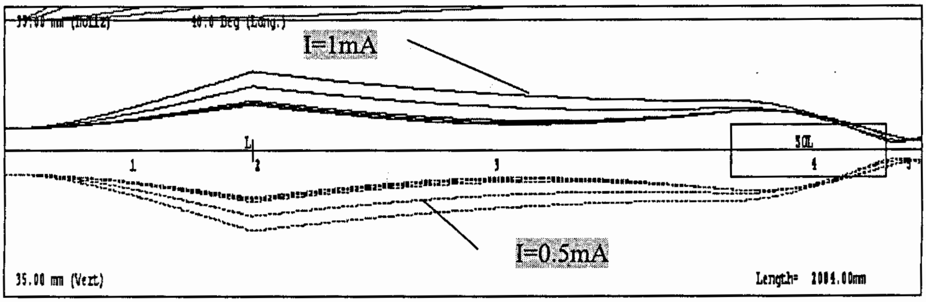

Fig. 1 The beam injection with various intensities by ES system

inflector with an inlet of 8 mm x 16 mm, adjusting ε_x and ε_y is needed to match the acceptance of cyclotron central region better. The TRIUMF's experience[2] show us that the SQQ(Solenoid and Doublet) system has a high beam handling capability. It suggests us to modify the injection line by using ESQQ (Einzell Lens, Solenoid and Doublet) system. The results from numerical investigation and a test stand of the injection line will be described in this paper.

[1] Tianjue Zhang et al., "Research Activities Related to Low Energy Accelerators in CIAE (Invited)", Proc. of 2001 APAC, pp 54-58

[2] T. Kuo, R. Baartman, L.Root, et al., "A Comparison of Two Injection Line Matching Sections for Compact Cyclotrons", Proc. of 1995 PAC, pp 1858-1860

Friday 12, September

TI1 CONTRIBUTION OF WALL MATERIAL TO THE VIBRATIONAL EXCITATION AND NEGATIVE ION FORMATION IN HYDROGEN NEGATIVE ION SOURCES

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The study of the VUV spectrum from a hydrogen negative ion source plasma showed that the enhancement, due to recombinative desorption, of the density of molecules with low v'' (possibly v''< 2) is important since these molecules can serve as the initial species in the E-V singlet excitation (vibrational excitation to higher v'' through the singlet states B and C).

The experiments were performed in a multicusp ion source equipped with two filaments. After annealing and heating these filaments and operating the discharge for 30 minutes before starting the experiment, the wall was covered with filament material. Tungsten, tantalum and rhenium filaments were tested. We will denote the situation when tungsten filaments are used, as one with 'tungsten covered wall'.

The VUV-visible spectrophotometer has been connected to the plasma chamber. In order to detect the VUV radiation we used a film of sodium salicylate deposited on glass to convert this radiation into visible one.

We compare the experimental spectra with the synthetic spectrum convoluted by Dr. Xianming Liu (Ref. 1) with our apparatus function, for our plasma conditions (gas temperature 500 K and electron energy 100 eV). The synthetic spectrum is generated assuming that 100 eV electrons collide with hydrogen molecules in the initial states v'' = 0. The agreement is fair. The computations of Dr. Xianming Liu (Ref.1) give us also the contributions of the molecules with v'' = 1 and 2 initial state. We were able to improve greatly the fit taking the vibrationally excited molecules into account, in generating the synthetic spectrum. These initial densities simulate the molecules generated by recombinative desorption on the wall. From the fit of the experimental spectrum with the synthetic one, we can estimate the density of initial molecules with v'' = 1 and 2.

Acknowledgement. The support of EEC (Contract HPRI-CT-2001-50021) is gratefully acknowledged.

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TI2 CW H^- ION SOURCE FOR MEDICINE ACCELERATOR USE

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A compact cw hydrogen negative ion source having reliable operation and a simplified maintenance is developed at Budker Institute of nuclear physics for tandem accelerator of boron capture neutron therapy installation. The source uses a Penning discharge with a hydrogen and cesium feed through the hollows in the cathodes. Discharge voltage is about 60-80 V, current up to 8 A, hydrogen pressure 4-5 Pa, magnetic field 0.05-0.1 T, cesium seed <1 mg/hour. Negative ion are mainly produced on the cesiated anode surface due to conversion of hydrogen atoms. An optimal anode temperature 250-350 C. Negative ion beam current is directly proportional to the discharge current and to the emission hole area. The triode system for the beam extraction and acceleration system is used. The flux of accompanying extracted electrons was decreased by filtering in the transverse magnetic field. This electron flux was intercepted to the special electrode, biased at 3 kV potential with respect to the anode.

Source stable cw operation for several hour runs was multiply tested. H^- ion beam with current up to 8 mA, beam energy 23 keV was produced regularly. Negative ion current of heavy impuruties had value of about 3% of the total beam current. Beam normalized emittance is about 0.3 π mm·mrad, emission current density - 0.1 A/cm^2. A build-in cathode heater provides the operation quick start.

TI3

NEW DEVELOPMENTS IN RF- AND FILAMENT-VOLUME ION SOURCES

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Since M. Bacal first found volume-produced negative ions in 1977 in France, H^- volume sources have been in development in North America, Europe and Asia. There are now sources in operation with cw, high (5%) and low (0,01%) duty factors. Currents up to 120 mA have been reached.

Several techniques have been applied. The optimizations of source designs have involved much experimentation and theoretical studies. Plasma heating has first been done with filaments. Later rf power was also used, with design studies and measurements over a wide rf frequency range and with different types of rf coupling. Also gas mixing, cesiation and several extraction methods have been tested and the designs optimized.

This report gives a survey of the design of Hminus volume sources with emphasis on the newest developments.

UI1 **STUDIES OF H⁻ SOURCE FOR LARGE HELICAL DEVICE-NEUTRAL BEAM INJECTOR**

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A beam system using high current (about 26A) negative hydrogen ion sources has been operated since 1998 for the Large Helical Device-Neutral Beam Injection System in the National Institute for Fusion Science, NIFS. The design goal of the system is 15 MW of neutral beam power at a beam energy of 180 keV for tens of seconds, and 3 MW for 30 minutes. These operations have established the usefulness of negative-ion-based neutral beams as a powerful heating system in NIFS. Taken with the operations of negative ion neutral beams at the Japan Atomic Energy Research Institute, they validate this technology for future applications on larger fusion devices such as ITER. The three LHD beam-lines use six ion sources, i.e., two per beam-line. In this paper, we describe mainly the following three studies of the LHD-NBI H^- source: (I) Present status of the ion source during 6^{th}-LHD experimental cycle, (II) Measurement of cesium weight loss and filament weight loss of tungsten during the cycle, and (III) Doppler shift spectroscopy system and energy spectrum measurements to study the stripping loss of H^- ions in the accelerator.

-(I) Recently the injected power has increased to ~10.4MW totally with a new accelerator[1] and improved plasma[2] uniformity as well as an increased number of conditioning shots.

-(II) At present it is necessary to introduce cesium vapor to efficiently produce H^- ions[3], so it is meaningful to measure cesium consumption in a full size ion source, as this was investigated previously in the case of a $1/3^{rd}$ scale source[4] on a test stand. The cesium introduction system consists of a cesium oven, on/off valve controlled remotely at the operation desk, and front cesium-diffuser. Three ovens were installed on each source, of which the dimensions are ~35 x ~35 x ~145 cm^3. The measured weight loss of cesium was ~10.60gram. in one ion source for half a year NBI-operation with an average negative ion current level of about 26A. The lifetime of the filaments (24 per source) was about three months. As a result of this, the filament lifetime dictates how often we must open the source to air or argon during the experimental cycle. Distribution of the weight loss of 24 filaments also was measured.

-(III) Experimentally-guided improvements were made to the Doppler-shift spectroscopy system, which consisted of a Grating / CCD 25cm-spectrometer. The spectrum was observed at the ion source vacuum vessel. These enabled us to get the first measurement of the velocity spectrum of the LHD beams, strongly peaked at the full acceleration energy, although the instrumentation does not permit a qualitative analysis nor systematic observation.

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UI2 NEUTRAL BEAM INJECTORS FOR PLASMA DIAGNOSTICS

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Narrow, low-divergent neutral beams are often applied in modern magnetic fusion devices as a diagnostic tools providing unique information about plasma parameters. Series of injectors of focused neutral beams with beam energy ranging from 5 to 50 keV, equivalent beam current of 1-20 A, angular beam divergence of ~ 10^{-2} rad, equivalent current density in focus of beam more than 1 A/cm^2, pulse duration of 10^{-4}- 10 s is developed in Budker Institute of Nuclear Physics.

A specific approach to formation of high brightness ion beams is used in short pulse versions of the injectors. The low transverse ion temperature of plasma emitter is achieved by use of plasma emitter formed by the collisionlessly expanding plasma jet. The highly ionized plasma jet is produced by a cold cathode arc discharge plasma generator. Ion beams are extracted from the plasma emitter by precise multi-aperture four-electrode ion optics systems.

Two methods of beam focusing have been tested and successfully applied. In the first one the formed ion beam is focused by a magnetic lens and partially neutralized in a pulse gas target. The second method is based on geometrical focusing of the beam by spherically bent electrodes of an ion optics system. To profit better use of the nonuniform plasma jet, the developed ion optics systems with geometrical beam focusing have gaps extending with radius that ensures optimal beam formation from enlarged surface.

To provide a beam for active beam emission spectroscopy measurements in large fusion devices the injector was developed to be operated at energy 50 keV, equivalent beam current (for hydrogen) up to 1 A, pulse duration of up to 10 s and capability of beam modulation with frequency of up to 500 Hz. In the injector ion source the emitter plasma is produced by an inductively exited RF discharge. Distinctive feature of the ion source is that in order to simplify injector design, a thermal inertia-type ion optics system with "thick" electrodes [1] is used. With grids formed to focus the beam 4m downstream from the source the integral angular divergence of the beam, measured at 1/e level in the focus, of 10^{-2} rad was obtained.

[1] V.I.Davydenko et al., Rev.Sci. Instrum., **68** (1997)1418

UO1 EXPERIMENTAL COMPARISON BETWEEN PLASMA AND GAS NETURALIZATION OF HIGH-ENERGY NEGATIVE ION BEAMS

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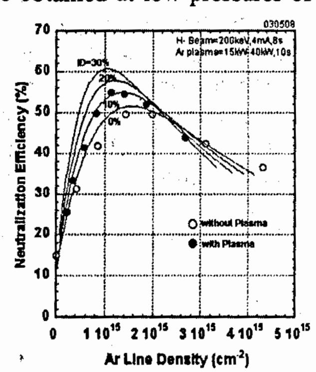
Future fusion plant requires a neutral beam (NB) injector that can drive plasma current at high system efficiency of >50%. The NB system efficiency is determined mainly by a neutralization efficiency. The neutralization efficiency of a conventional gas neutralizer presently used in the NB injector is limited to 60%, resulting in the system efficiency of about 40%. A prediction of the neutralization efficiency analyzed from cross-section data shows that a plasma neutralizer increases the neutralization efficiency up to 80% at relatively low line density. Based on the analysis, the R&D[1] on the plasma neutralizer has been mainly concentrated on a production of dense plasma with high ionization degree. However, the accuracy of such cross section data is ±20 %, and hence, it is inevitable to confirm the neutralization efficiency in an actual neutralizer with high-energy negative ion beams as a proof-of-principle test of plasma neutralization.

This paper reports neutralization of 100-300 keV H^- ion beams by Ar arc plasmas produced in a large plasma neutralizer of 2 m in length and 0.6 m in diameter. The neutralizer wall is surrounded with 36 magnetic cusp lines, except for openings of 0.2 m in diameter on the beam path. The magnetic field on the central axis of the neutralizer, i.e., on the beam path, is as low as 1 Gauss. In the initial experiment with Ar discharge of 15kW-40 kW, it was found that the plasma density cannot be increased at low operating pressure due to leakage of the primary electrons through the openings. The electron leakage was suppressed by installing a pair of magnets to form a transverse magnetic field perpendicular to the beam path. By this magnetic configuration, plasma densities of 10^{11}-10^{12}cm^{-3} were obtained at low pressures of 0.002 Pa-0.03 Pa.



The H^- ion beams of 4mA, 200 keV were produced, and then injected into the neutralizer. Emerging beams of residual H^+, H^- and neutrals were deflected by a solenoid coil, and dumped on three beam dumps. From the temperature rises of each beam dump, power loadings were measured separately for each species. The Ar gas line density along the beam path was measured by four ion gauges distributed on the beamline. Figure shows the neutralization efficiency of 200 keV H^- ion beam as a function of Ar gas line density (LD). The closed and open circles indicate neutralization efficiencies of plasma and gas, respectively. Analyzed neutralization efficiencies for the ionization degrees of 0-30% are also indicated in the figure. The neutralization efficiency of the gas neutralization was maximized at 1.5 x 10^{15} cm^{-2}. When the Ar plasma was fired in the neutralizer, the neutralization efficiency was increased at a low line density of < 1.5x 10^{15} cm^{-2}. At 0.8 x 10^{15} cm^{-2}, the neutralization efficiency of plasma neutralization was about 8% higher than that of gas neutralization. An optimum LD for maximizing the neutralization efficiency was reduced by plasma neutralization. Neutralization efficiencies in the plasma and the gas as functions of the LD were in good agreement with those analyzed from the cross-sections. Thus, it was experimentally verified that plasma can increase neutralization efficiency at lower line density as predicted from the analysis. The similar analysis for a 2 MeV D^- ion beam required for future NB systems predicts that neutralization efficiency of 80% are to be achieved by producing a hydrogen plasma of 7.8 x10^{18} m^{-3} over 3 m, which is the target plasma in the on-going experiment of ref.1.

1. V.A.Zhiltov, E. Yu. Kilmenko, P.M.Kosarev, and et al., IAEA-F1-CN-69/ITERP2/04(1998).

WP1 **A RADIOACTIVE ION BEAM TARGET/ION SOURCE FOR MATERIAL REASERCH**

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A radioactive ion beam target/ion source for material reaserch has been developed at China Institute of Atomic Energy,China. With the ion beam from HI-13 tandem as pramary beam, the low intensity radioactive ion beam can be generated on line. The first aim of the source is to produce radioactive ion beam of $^{62}Zn^{+}$ which will serve as nuclear probe in material reaserch. The main features and current status of the source will be presented in this report.

WP2 CHARACTERIZATION OF A COMPACT FILAMENT-DRIVEN MULTICUSP ION SOURCE FOR LOW ENERGY TIME-OF-FLIGHT RBS APPLICATION

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Because of the limited pulse height energy-resolution of a detector, conventional Rutherford backscattering spectrometry (RBS) requires an energy of the incident alpha particle to be in the MeV region. Here at Chiang Mai University we have researched the possibility of utilizing a 280 keV nanosecond pulse of helium ion for the RBS application. We have chosen a compact filament-driven multicusp ion source of 5 cm in diameter and 10 cm in length being investigated for the time-of-flight RBS applications. In this paper, we present the general ion source performance using helium, nitrogen and argon for generating the discharge plasma. The general ion source characteristics have been measured and analyzed. The measurement also includes extractable ion current and ion beam emittance. We have performed beam extraction calculation with a computer simulation code, KOBRA. Results of the measurements and calculation will be presented and discussed.

WP3 HIGH POWER HYDROGEN INJECTOR WITH BEAM FOCUSING FOR PLASMA HEATING

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High power neutral beam injector is developed with the atom's energy 25 keV and beam current 60 A. The 6 or 8 of such injectors will be used for modernization of the atomic injection system at Gas Dynamic Trap (GDT) device. The purpose of modernization is: increasing of the injecting power; increasing pulse duration from 1 to 5 ms and provide the possibility of beam focusing. The power injector includes the arc discharge plasma source, expansion chamber with peripheral multipole magnetic wall and 4-electrodes ion optical system (IOS).

The 1 kA arc discharge channel of 1 cm in diameter generate a plasma flow which spread in expansion chamber and forms the plasma emitter of 200 mm in diameter. The multipole magnetic wall with permanent magnets is used to increase the efficiency of plasma source and to provide the uniform emission at the 1st grid of the IOS. The homogeneity of ±15% is obtained over the extraction region of 200 mm in diameter.

The molybdenum grids of the IOS has more than 3000 holes of 2.5 mm diameter, the holes form the regular hexagonal structure which manufactured with the accuracy of 10 mcm. The grids have spherical curvature for geometrical focusing of the beam. The optimal IOS geometry and electric fields were calculated. The measured beam divergence is ≈0.8°, the focal length was 110-350 cm depending on the radius of the grid curvature. The measured beam profile has the 1/e radius 2.5 cm at focal point. The neutralizer efficiency was ~73%. A good reliability is sufficient requirement for injector, which operates in a system of many injectors. The required probability of failure ~ few percent was demonstrated at test.

WP4 SIMULATION OF BEAM-PLASMA DISCHARGE AT BEAM CURRENT, EXCEEDING LIMITING VACUUM CURRENT.

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Simulation results of spatial-time dynamics of beam-plasma discharge at beam current, exceeding limiting vacuum current, are presented. It is found that process of the discharge development passes three characteristic stages: stages of immovable virtual cathode (VC), stages of VC progressive motion and stages of ordinary beam-plasma discharge. It was also found that in the second stage ions ensemble is separated into two parts – plasma ions and ions, captured into collective acceleration by moving VC.

WP5

PECULIARITIES OF COMPACT SURFACE-PLASMA SOURCES OPERATION (PRACTICAL ASPECTS)

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Operation Experience of Compact Surface-Plasma Sources (CSPS) under operation in different laboratories around the World, will be considered. Features of CSPS are small volume, small gaps between electrodes, high plasma density and high emission current density. These features have complicated the long time operation of CSPS with high beam parameters, because a sputtering rate, flakes formation, deposition of insulators surface and probability of short circuit of electrodes should be high. But in many versions of CSPS was reached a very long operation time. Features of CSPS important for long time operation will be considered.

WP6 COLD-CATHODE SOURCE OF RIBBON GASEOUS ION BEAMS

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A source of ribbon gaseous ion beams, which is based on a low-pressure glow discharge in a magnetic field, is described. The electrode system of the source comprised 4 series discharge chambers of the inverse magnetron type with rod anodes and a screen grid whose perforated part was 440×30 mm in size. The cross-sectional area of the chambers was 100×60 mm in the plane transverse to the screen grid. Common cathode walls of the chambers had communication holes. Magnetic coils, which were mounted on the earthed casing of the source, produced a magnetic field transverse to the ion extraction direction. Electrodes of the multi-slit ion optics were 80% transparent.

The source operated at the gas (argon) pressure of $1.5\text{-}3\cdot10^{-4}$ Torr and the magnetic field of 2-6 mT. The discharge operation voltage was 300-550 V at the glow-discharge current of 0.15-1 A. The beam current of argon ions was 20-100 mA at the accelerating voltage of 5-20 keV. The ratio between the ion beam current and the discharge current or the efficiency of ion extraction from the plasma, α, changed from 0.1 to 0.14. Large α values corresponded to smaller discharge currents and low pressures, weak magnetic fields and high accelerating voltages. The energy efficiency of the source was 0.25-0.3 A/kW at the discharge current from 0.3 to 0.6 A.

The distribution of the current density along the ion beam cross-section (440 mm) had a maximum in the center at high gas pressures. When the pressure decreased, a minimum of the current density appeared in the center of the distribution. The profile of the beam current density became more uniform with growing magnetic field. An accelerating voltage of 15 keV provided a beam whose current density profile was nonuniform to within ±15% of the average current density at a pressure of $1.7\text{-}2.3\cdot10^{-4}$ Torr and a magnetic field of 3.5-5 mT. The current density profile nonuniformity did not exceed ±7% at a 5-keV voltage.

Further studies will deal with optimization of conditions for joint operation of a greater number of magnetron chambers with the aim of making the profile of the beam current density more uniform. The effect of ion extraction from the plasma on the beam current density distribution will be analyzed.

WP7 OCEANS CIRCULATION AND ECR SOURCES: MEASUREMENT OF THE AR-39 ISOTOPIC RATIO IN SEAWATER

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The radionuclide ^{39}Ar is produced in the atmosphere by cosmic rays and has an isotopic abundance of 8.1×10^{-16}. Because its half-life (T1/2= 269 y) is well matched to the time periods involved in the oceanic currents around the Earth, the measurement of the ^{39}Ar isotopic ratio is an ideal tool to date ocean water from different depths. It would complement the information gained by the ^{14}C measurements ($T_{1/2}$= 5730y).

However, the measurement of the isotopic ratio $^{39}Ar/^{40}Ar$ is a technical challenge: one liter of modern ocean water contains ~6500 atoms of ^{39}Ar, and produces ~17 decays per year. Although it has been possible to detect the ^{39}Ar decays in large volumes of sea water by using the low level counting technique, the possibility to measure the number of ^{39}Ar atoms faster and in smaller samples using the Accelerator Mass Spectrometry (AMS) technique, would be a major breakthrough for this type of measurements.

The development of a viable AMS method for ^{39}Ar has been underway for several years at Argonne National Laboratory, and is presently hampered by the presence of stable ^{39}K ions coming from the ion source. Although the intensity of this isobaric contaminant is low (~pA extracted from the source), it has to be compared with the ^{39}Ar beam intensity (atoms per minutes). In order to separate these two beams (whose mass difference is only 1.6×10^{-5}), the intensity of the ^{39}K beam coming from the ion source has to be reduced by several orders of magnitude. This reduction has been investigated both at Argonne National Lab and at Louvain-la-Neuve. Two techniques have been tried out. In the first, a quartz liner is used to provide a clean surface, while in the second these impurities are buried in a SiO2 layer formed "in situ" by running the source with a mixture of silane and oxygen. The ^{39}K background has been reduced by a factor of 100 with these treatments. These techniques and their results obtained both at Argonne and Louvain-la-Neuve will be presented. The ion source specific requirements for this type of application will also be discussed.

WP8 A GLOW-DISCHARGE-DRIVEN BUCKET ION SOURCE

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Characteristics of a broad-beam gaseous ion source with a glow-discharge-based plasma cathode have been studied. The first stage of the ion source discharge system was a 13-cm diameter hollow cathode of the glow discharge. The second stage was a cylindrical bucket-type chamber, in which an end-plate 13 cm in diameter simulated the screen electrode of the ion optics. The chamber was surrounded by 12 longitudinal rows of permanent samarium-cobalt magnets to form a multicusp magnetic field. Electrons were supplied to the anode stage through a 10-mm diameter outlet aperture of the hollow cathode. Two operating modes of the plasma cathode were analyzed. They included (1) the mode of an open-hole constricted glow discharge [1] and (2) the electron injection mode [2] when the inlet aperture of the second stage was covered with a fine-mesh grid.. Uniform (~10%) plasma was generated in the magnetic-field-free space (dia. 8 cm) in both modes of the glow discharge operation.

In the electron injection mode, the inlet aperture grid, which was electrically connected to the screen electrode, had a negative potential of 0-200 V relative to the anode of the second stage. The glow discharge current was adjusted within 0.2 to 1 A. The discharge operating voltage was 400 to 450 V. The current in the screen electrode circuit increased with growing negative potential of the screen electrode, the glow discharge current, and the argon pressure ($1\text{-}3\cdot10^{-2}$ Pa). As the potential difference between electrodes of the second stage increased, the injected electron current approached the current in the hollow cathode circuit, while the current to the anode of the second stage was nearly equal to the sum of the injected electron current and the ion current in the screen electrode circuit. The maximum ion current (250 mA) accounted for up to 40% of the injected electron current (600 mA). Thus, considering the ion losses at the periphery of the screen electrode and the screen grid transparency, the ion beam current could account for 10-15% of the glow discharge current. In other words, taking into account the main loss of power in the glow discharge, the predicted value of a total energy efficiency of the ion source may be within 0.25-0.35 A/kW. Thanks to a low voltage applied to electrodes of the second stage, this type of ion sources has a low content of metal ions in the ion beam. The cold cathode provides a long-term operation of the ion source with reactive gases.

The energy of injected electrons is determined by the controllable voltage drop in a space charge layer localized near the fine-mesh grid. The rate of ion generation in the second stage depended on the number and energy of injected electrons, efficiency of the electron confinement by a multicusp magnetic field, and the gas pressure, which influenced the ratio of the full path of electrons in the plasma and their mean-free ionization path. If the magnetic field induction at the poles is increased over 0.1 T used in this study, it will be possible to improve confinement of injected electrons and raise the ion current. The working gas pressure decreases by reducing the size of the outlet aperture of the hollow cathode.

In the constricted discharge mode, the ion current was 2 to 8 times lower if all other factors were equal. Larger currents corresponded to lower gas pressures. This was due to a rise of the voltage drop across the double layer of the space charge in the outlet aperture of the hollow cathode.

1. N.V. Gavrilov, A.V. Ponomarev, Proceedings, II All-Union Conference "Modification of materials with charged particle beams" (Sverdlovsk, Russia, 1991, vol.1, p. 30-32).

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WP9

RADIO-FREQUENCY GAS DISCHARGE PLASMA CONFINED IN A MAGNETIC QUADRUPOLE FIELD

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A new concept for the generation of gas discharge plasmas as has been proposed recently by J. Christiansen [1] and is now under investigation in Frankfurt. A high frequency discharge embedded in a magnetic quadrupole produces a cylindrical plasma column which is actively confined towards the axis of the cylinder. The basic effect of this confinement is well known in accelerator physics as the "principle of strong focusing", where an ion beam is guided in alternating quadrupoles fields. The focusing is achieved in an accelerator due to the radial increasing field strength which applies a stronger focussing to outer ions in comparison to the defocusing force acting on the inner ions at lower field strength. In this radio-frequency plasma the confinement is caused by the focussing and defocusing force acting on the electrons due to the alternating electron movement during the discharge.

In this concept the basic discharge configuration consists of a glass cylinder within a quadrupole magnetic field. The energy is inductively coupled into the plasma with a coil using frequencies between 13 and 16 MHz. The adjustment of the resonant circuit was performed by a tuneable external capacity. First test experiments have been carried out with argon gas. The adjusted gas pressure in the cylindrical tube was in the range of 1 Pa only. As energy feeding source a tuneable high frequency amplifier with a maximum power of 600 W was used. During the experiments an external magnetic quadrupole field was applied in the range from 0 to 1.5 T. For the determination of the ionisation degree an additional spectroscopic measurement of Ar (I)- and Ar (II)-lines was performed. With this preliminary spectroscopic investigations a high ionisation degree of singly charged argon ions has been verified.

One possible application of this new radio-frequency plasma is an efficient argon ion laser. A second promising application of this highly ionised and dense plasma is the use as a reproduceable DC-high-current-ion-source. Further exerimental investigations are directed to study the beam production depending on discharge parameters like pressure, magnetic field and the shape of the antenna.

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WP10 ACCELERATION OF 1 MeV, 100 mA CLASS H^- ION BEAMS IN A PROOF-OF-PRINCIPLE ACCELERATOR FOR ITER

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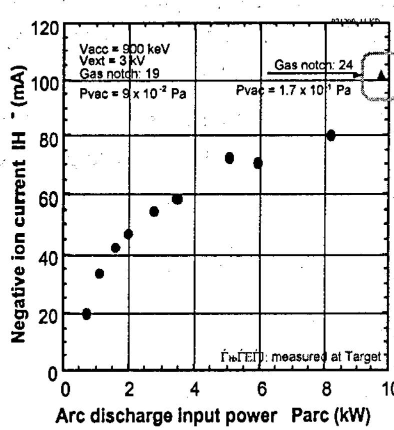
ITER requires heating and current drive by a neutral beam (NB) system that provides NB power of 16.5 MW/injector to the plasma. The primary source of the NB is a large negative ion source and accelerator, which generates 40 A D^- ion beams at 1 MeV. However, it has not been achieved to accelerate any charged particles of ampere class current up to MeV range energy for a substantial period ($\geq$ 1 s). Within the framework of ITER Technology R&D, development of an electrostatic accelerator has been carried out in Japan Atomic Energy Research Institute (JAERI) toward acceleration of 1 MeV, ampere class H^- ions, as a Proof-of-Principle demonstration for the ITER NB accelerator.

The accelerator is an electrostatic type, consisting of an extractor and 5 acceleration grids (every 200 kV potential difference). Each grid has 49 apertures drilled in 7 x 7 lattice pattern to extract/accelerate high current ions. The apertures were masked at the plasma grid to allow extraction of ions from 3 x 3 or 5 x 5 apertures in the present experiment. There is a vacuum gap of 50 mm wide all around the grids support, which allows direct line of sight from -1 MV potential to the ground. A stack of five FRP (fiber reinforced epoxy) insulator rings (1.8 m dia., each 0.33 m high) surrounds the accelerator grids as the vacuum boundary. Thus the accelerator main structure is immersed in vacuum, and hence, the accelerator is called as a vacuum insulated beam source (VIBS). The highest beam performance achieved by the VIBS was 971 keV, 20 mA[1] H^- ion beam. However, the voltage near 1 MV was sustained only for ~15 minutes, and thus, the beam acceleration by the VIBS has been limited due to poor voltage holding, typically less than 800 kV.

The voltage holding of the accelerator was improved[2] drastically by lowering the electric field strength at the triple junction, i.e. an interface of FRP insulator, metal flange and the vacuum. This was achieved by installing a large stress ring (120 mm radius instead of original 22.5 mm one) inside vacuum near the inner surface of FRP insulator rings. As the result, the accelerator sustained 1 MV stably for more than 2 hours. Glow discharge has not been observed in the accelerator even during the source operation with gas flow into the accelerator (the H_2 gas pressure in the accelerator: 0.08 ~ 0.2 Pa). The H^- beams of 100 mA were accelerated up to 900 keV for 1 s, and also 70 mA H^- ion beams up to 1 MeV (current measured calorimetry at downstream target). Since the current density was still low (18~48 A/m^2), more than a half of ions extracted from the source were lost in the accelerator due to direct interception of diverging beam, which could generate stray electron and then Bremsstrahlung, followed by (probably) photoelectron production in the insulator. However, the beam acceleration was quite stable for 6 days, and 130 shots of the beam were obtained at this level. An attempt to increase the H^- ion current is in progress by seeding Cesium in the ion source for enhancement of negative ion production.



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WP11 **CHARACTERIZATION OF ION SPECIES MIX OF THE TEXTOR DIAGNOSTIC HYDROGEN BEAM INJECTOR WITH AN RF AND ARC-DISCHARGE PLASMA BOX**

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The hydrogen diagnostic beams are now widely exploited in magnetic fusion devices [1] to provide the local plasma parameters. In particular, the diagnostic neutral beam injector of TEXTOR device is envisaged to measure the ion temperature and impurity profiles via active charge-exchange recombination spectroscopy [2]. As well as the beam angular divergence and current density, the beam species mix is critically important for this diagnostic. The ion specie fractions of the beam have been determined by making use of a H_α -light Doppler shift spectroscopy [3,4]. This spectroscopic technique has been first applied to neutral beam for plasma heating [3,5], and recently to the diagnostic neutral beams [6,7]. In the data analysis we followed the standardized procedure, which is described in [5]. It has been adopted that observed intensities of the light emitted by the beam species are governed by a Corona model. Alternatively, the beam species mix was measured by using magnetic mass-spectrometer. Both methods provided similar quantitative assessment of the ion species mix. The measurements have been done for the fixed beam energy of 50keV and beam current variable upto 2.5A. In these experiments, the ion source was alternatively operated with two different type of plasma boxes. Namely, an RF and arc-discharge based plasma boxes have been used, which operated at the same ion current density. According to the measurements, the full energy beam component for the RF plasma box amounts to ~50% by the particle density and to more than 75% for arc-discharge plasma box. Optimal conditions, for which the full energy specie is maximal for both plasma boxes studied, have been thus determined.

This work was supported in part by WTZ (Bilateral Scientific and Technological Collaboration) under research project #RUS-01/582.

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WP12 DEVELOPMENT OF A COMPACT HELICON ION SOURCE FOR NEUTRON GENERATORS

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A compact Helicon ion source has been designed for a neutron generator. Energetic deuterium beams of 120keV from this ion source will be headed onto Ti-coated copper target where D-D nuclear fusion reactions may occur and generate 10^8 n/sec of neutron. High-density plasma sources such as a helicon plasma source, known for its highest efficiency of generating high-density plasmas, are chosen for the high-current density compact ion source. Plasma densities of up to $10^{12}cm^{-3}$ are obtained with 2kW RF power at the frequency of 13.56MHz. Different magnetic field configurations are provided with both electromagnets and permanent magnets, and are compared to generate efficient hydrogen/deuterium plasmas operating in high-density modes. With the protoype helicon ion source, hydrogen beam currents of up to 44mA at 23kV have been extracted in cw operations. Characteristics of the ion source will be presented in detail.

WP13 PRODUCTION OF MULTICHARGED IRON IONS BY USING PYROLYTIC BORON NITRIDE CRUCIBLE AND APPLICATION TO MATERIAL PROCESSING

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Multiply charged ions of iron are produced from solid material in a 2.45 GHz electron cyclotron resonance (ECR) ion source. In the TAIKO device (Toyama Prefectural University), the ECR plasma is confined in the mirror field superimposed by the octupole magnetic field. Microwave of 2.45 GHz frequency is normally launched by using a rod antenna. The ECR zone is formed around the bottom of the magnetic mirror trap.

In our previous experiments, the multicharged iron ions have been produced by both directly sputtering the pure material and evaporating it in form of filament in the ECR plasma. [1, 2] We try to produce multicharged Fe ions by using a crucible made from the pyrolytic boron nitride (pBN) with several shields suppressing radiation. The evaporator is mounted on the tip of a coaxial copper pipe, and inserted into the ECR plasma from the mirror end plate along the geometrical axis of the mirror field. The ac voltages transformed by the ring transformer are applied to the Ta heater for the crucible. Vaporized Fe atoms are introduced and ionized in the ECR plasma. Argon gas is usually chosen for supporting gas, and the working pressure is about 10^{-4}~10^{-3} Pa. The multicharged ions are extracted from the opposite side of mirror end against the target or the evaporator of the iron, occasionally, and then multicharged ion beam is formed. Extraction voltage is normally 10 kV, the sector magnet separates mass/charge, and the ion beams are collected by the Faraday cup. The optimum conditions for production of multicharged iron ions are investigated experimentally. The ratio of total multicharged Fe ion to the total ion current attains to about 11% at the maximum.

The Faraday cup is removed off from the beam line, and then the ion beams can be introduced to a newly constructed part for the ion irradiation of the substrate installed on the beam line. This part is separated by the gate valve from the upstream beam line and independently evacuated. In this part, we use a steering coil and an einzel lens to control profile of beams after mass/charge separation. The beam profiles can be measured both vertically and horizontally by wire probes, and the current density and the required dose can be estimated.

After improvement of ion extraction and beam transport [3], we try to form iron silicides and to enhance light catalytic performance of titanium-dioxide thin films by applying the multicharged iron ion beams. The Si wafer is chosen for the substrate in the formation of silicides. As for TiO_2 substrate, we use thin films (350~400nm) produced on the glasses by reactive sputtering in our different equipment. [4] The substrates for ion beam irradiation are set on the beam line at about 0.3 m downstream from the wire probes, and about 0.7 m from the einzel lens. Therefore we recognized formation of β-$FeSi_2$ by x-ray diffractometer with thin-film optics in the high dose implantation. We also recognized enhancement of photo-catalytic performance, i.e., contact angle of the distilled water on TiO_2 thin films, in visible light region without degradation in UV light region.

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WP14 BEAM EMITTANCE MEASUREMENTS OF TRANFORMER COUPLED PLASMA ION SOURCE FOR FOCUSED ION BEAM

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The medium energy ion scattering (MEIS) spectroscopy equipped with an focused ion beam (FIB) promises a large improvement of the lateral resolution for nano-scale measurements. However, FIB with conventional liquid metal ion source (LMIS) is not suitable as a microprobe for the MEIS because gallium ions can cause contamination or damage to the structure of objects. As a result, to develop a high brightness ion source capable of producing light ion beams (H+, He+) is of great significance in the successful development of FIB systems for nano-MEIS. A transformer coupled plasma (TCP) ion source has been evaluated for FIB, which can generate hydrogen ion beams focused in nano scale. One of the most important parameters of the ion source for the FIB application is sufficiently low beam emittance. Beam emittances are measured with Allison-type scanning device for various plasma parameters and extraction conditions to see the feasibility of a high brightness TCP ion source for the FIB system.

Acknowledgment:
This work was supported by the Korea Ministry of Science and Technology

WP15 HIGH INTENSITY ALKALI ION SOURCE FOR PLASMA DIAGNOSTICS.

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Alkali ion source, based on solidstate thermoionic emitters (aluminosilicates of Li, Na, K, Cs, and Tl) may give up to 10 mA of alkali ion current in a stationary mode for plasma beam diagnostics. It may be used in heavy ion beam probing (HIBP) [1] or beam emission spectroscopy (BES) [2].

This ion source consists of emitter heating unit, which guaranteed the emitter surface temperature in a range of 800 – 1500^{0}C, emitter cup with aluminosilicates crystalloid structure and quasipierce extracting system. The calculations and experimental optimization of the ion extracting system were carried out in Institute of Plasma Physics of National Scientific Center "Kharkov Institute of Physics & Technology". The quasi-pierce extracting gap geometry works without ion current losses to the extracting electrode.

Alkali ion emitters also elaborated in Institute of Plasma Physics of NSC "KIPT" have high emission rate, only Child-Lengmour law limits ion current. In a pulse mode with infrared laser heating of the emitter surface were obtained emission rates up to 100 mA/cm^2 for Tl^+ and 2A/cm^2 for Li^+ [3]

In HIBP diagnostic injectors are used 8 mm diameter emitters (K, Cs, Tl) with ion capacity 2 –3 mA hour, in BES diagnostic – 15 mm diameter emitters (Li, Na) with ion capacity up to 9 mA hour. These emitters may be manufactured from natural minerals or from artificial components [4]. For Li emitters can be used spodumen and euqriptit, feldspars for Na and K, pollucs for Cs and Li, Na, K, Tl emitters can be fabricated from artificial components. Ion beam mass purity for Li, Na, K emitters is about 98%, for Cs and Tl is 85 – 90%.

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WP16 DIAGNOSTIC NEUTRAL BEAM INJECTOR FOR LARGE PLASMA DEVICES.

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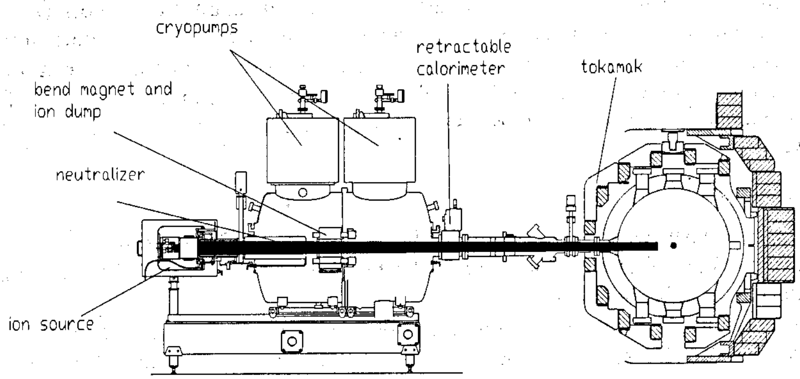
A diagnostic beam system has been developed for the Alcator (MIT, Boston). The system is primarily used for measurement of the ion temperature in plasma by charge-exchange recombination spectroscopy (CHERS) and for magnetic field measurements via motion Stark effect (MSE). The system consists of ion source, vacuum pumps and various diagnostics of the beam. The ion source creates 50 keV, 5A hydrogen beam. Ions are extracted from a plasma created by an arc discharge source and, after accelerating and focusing, neutralized in gaseous target. A low ion perpendicular temperature at the plasma emission surface, achieved via plasma expansion cooling, results in low (0.01 rad) intrinsic beam divergence. The spherically curved electrodes of the ion optic system provide geometric focusing of the beam on distance 4 m with beam current density up to 100 mA/cm^2 in focus. Arc discharge plasma source provides high content (85%) of the main fraction (protons of full energy) in the beam. The injector provides 50 msec duration pulse each 5 min. In order to increase the signal to noise ratio the beam can be modulated with a frequency variable up to 250 Hz.



WP17 **PROGRESS IN THE DEVELOPEMENT OF RF DRIVEN NEGATIVE ION SOURCES FOR NEUTRAL BEAM INJECTION**

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For the neutral beam injection system of ITER, a powerful large area RF source could represent an attractive alternative to an arc discharge source. The main advantage of the RF source is the lack of filaments, removing the requirement for their replacement about every six months by remote handling. Additionally the RF source relieves certain problems in the transmission line and offer cost savings because of the inherent simplicity of its mechanical and electrical design.

IPP is presently developing a 40 1 RF source in the framework of an EFDA contract, operating at 0.9 MHz with up to 150 kW RF power. The goal is to demonstrate a H^- current density of 28 mA/cm^2 over an extraction area of 390 cm^2 for pulses up to 3600 s. This represents the first milestone towards a full size source (0.6 x 1.5 m^2) for the NBI system of ITER.

The present source design is based on the concept of small RF driven cylindrical sources, mounted onto the back plate of a magnetically confined expansion volume. The configuration of the confinement magnets has been calculated in order to optimize the plasma confinement and to improve the operation at low pressure. This low pressure (< 0.4 Pa) is necessary, because to minimize stripping losses in the grid system.

In order to reach the H^-current density goal an optimization of the Cs evaporation procedure together with the admixture of Argon is being carried out.

The influence of the strength, localization and shape of the magnetic filter field on the H^- current are being studied. With a new internal electromagnetic coil, which produces a very uniform, localized magnetic field very encouraging results have been obtained. An internal coil has the advantage being scalable to an arbitrary size.

The initial results of a number of new diagnostics, that have been implemented in the test stand, are presented:

- Laser detachment
- Plasma spectrometry
- New calorimeter
- Janus probe
- Ion beam spectroscopy

First experiments have been carried out in parallel on a second testbed, which enables long pulse negative ion beam extraction with the entire extraction area of 390 cm^2.

WP18 THE BEAM INJECTOR SYSTEMS FOR FUSION PLASMA DIAGNOSTICS

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The Beam Probing Diagnostics are widely used methods for no perturbing investigations of the plasma in existing fusion devices [1].

These methods allow obtaining the space and temporal characteristics of main plasma parameters. Despite the difference of the detection principles, the common to all probing beam methods is an atomic or ionic beams injection in plasma under study [2].

Ion and neutral beam injection systems developed for tokamaks or stellarators strongly differ in ranges of both beam intensity of specific probing particles (10mkA – 10mA) and energy (20 – 500 keV), determined by the experimental and operational conditions of each plasma device.

This paper describes the recent heavy ion injection systems, elaborated in the Kharkov Institute of Plasma Physics NSC "KIPT" and used in the experiments on T-10 tokamak (Moscow) and TJ-II stellarator (Madrid).

It includes the characteristics of the ion sources, beam extracting systems with transport ion optics, beam control and testing systems and a high stability (no worse than 10^{-5}) accelerator power supplies [3].

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WP19 **NEW OPERATIONAL BEAM FOR THE CERN HEAVY ION PROGRAMME**

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After 9 years of delivering lead ions to the SPS fixed target physics programme,a new beam was requested for the last physics period, namely indium. The operational requirements and present status of the source will be presented together with the solutions to some of the problems experienced. Comparisions with lead beam operation will be made.

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WP20 HIGH CURRENT DENSITY BEAMLETS FROM AN RF ARGON SOURCE FOR HEAVY ION FUSION APPLICATIONS

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In our approach to develop high current beams for heavy ion fusion, beam current at $\approx$ 0.5 Ampere per channel is obtained by merging an array of high current density beamlets, of 5 mA each, produced from a plasma source. We have done computer simulations to study the transport of high current density beamlets and the emittance growth due to this merging process.

At present we are conducting experiments with a 33 cm diameter (ID) RF multicusp source. Our goal is to produce a cluster of 61 high current density argon beamlets using minimum gas flow. With an RF power of $\approx$ 10 kW (at $\approx$11 MHz), gas pressure $\approx$ 2 mTorr, and beam pulses length $\approx$ 20 ms, we have achieved a current density of $\approx$100 mA/cm^2. After extraction, the beamlets are transported through a series of Enizel lens for a precursor study before doing the merging experiment. The Enizel lens has a compact design that relies on the use of high gradient insulators. Our interest is to demonstrate the high voltage limits that can be applied to the Enizel lens in order to determine the maximum transportable current density for future designs.

This work has been performed under the auspices of the US DOE by UC-LBNL under contract DE-AC03-76SF00098 and by UC-LLNL under contract W-7405-ENG-48, for the Heavy Ion Fusion Virtual National Laboratory.

WP21 MONO1001 : A SOURCE FOR SINGLY CHARGED IONS APPLIED TO THE PRODUCTION OF MULTICHARGED FULLERENE BEAMS

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It is the aim of this paper to present recent studies about the production of beams of (multiply charged) fullerene ions. Indeed, there is an increasing demand for multiply charged C_n^{q+} beams linked to actual studies of different fundamental properties of carbon clusters, as for example, the dissociation energy of $C_{70/60}^{q+}$ clusters with respect to C_2 emission. The collaboration, which has been initiated between the Århus University, the CIRIL and the GANIL at the beginning of this year, consists in testing the production of multiply charged fullerene and carbon cluster ions with the MONO1001 ion source. The production test has been held on the ELISA facility [1] in Århus University where the analysis dipole magnet allows a broad mass separation until a maximum mass over charge ratio of ~ 1500 at an extraction voltage of 22 kV. The measurements have shown that, under specific conditions, intense beams of multiply charged fullerene ions can be produced with an ECR type ion source as already demonstrated in Ref.[2].

The ion source, called MONO1001 derived from the MONO1000 ion source [3], has been developed and designed at GANIL for the production of radioactive beams. We have tested this source at the ELISA facility with powders of C_{60} and C_{70}, then the extracted beams have been used for collision studies. Typical measured mass spectra (see figure 1) will be presented and the influence of the gas support and other parameters (HF-power, pressure,...) on the condition necessary for an optimum source operation will be discussed.

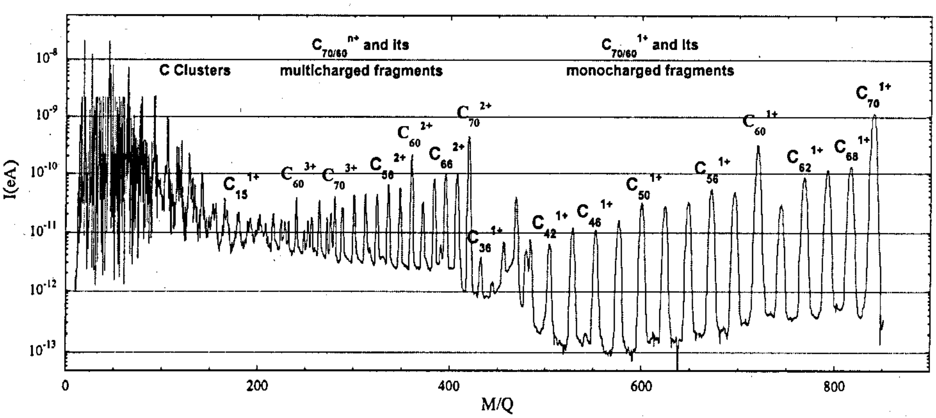

Figure 1 : Typical mass spectrum from C_{70} powder at 22 kV of extraction voltage

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WP22 MICROWAVE PLASMA SOURCE AS AN ION BEAM NEUTRALIZER

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A 13.56 MHz radio-frequency driven multicusp ion source has been developed[1] at Fast Neutron Research Facility. An argon ion current density of 29 mA cm^{-2} can be obtained for argon gas at a pressure of 3 mTorr, RF power of 500 W and extraction voltage of 3 kV. For such a low energy and high current ion beam, additional low energy electrons are needed to keep the beam from blowing up too fast. This can be achieved by producing electrons and deliver them into the beam.

An in-wave-guide microwave plasma source, operating at a frequency of 2.45 GHz, has been constructed based on the design of Korzec *et al.*, at Wuppertal[2]. It is composed of a 40 mm diameter and 30 mm long quartz tube located in the middle of a tapered WR340 waveguide. An electron current of up to 250 mA can be extracted from the source, at an absorbed microwave power of 90 W, pressure of 5.8×10^{-4} Torr, and the extraction voltage of 50 V. The neutralization source is installed down stream, in the vicinity of the beam line so that the beam potential will pull the electrons into it.

To investigate the neutralization effect, the ion extractor is modified to produce a parallel beam. A multiwire beam profile monitor is used to measure the beam size at different distances down stream in both cases; with and without the neutralizer. The profile of the beam can give information about the degree of neutralization. Ion beam potentials and beam currents at different distances from the neutralization source are also measured in order to see the effect of charge and current neutralization in the beam. Results of the measurements will be presented and discussed.

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WP23 **SOME EFFECTS OF A MAGNETIC FIELD ON A HOLLOW CATHODE ION SOURCE**

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Hollow cathode discharges are well known as a simple means for producing relatively dense gaseous plasmas. Electrons can efficiently ionize the working gas due to their pendulum motion in the plasma between opposite cathode sheaths. A variety of plasma, electron, and ion sources have been developed based on this type of discharge. The introduction of a magnetic field leads to further enhancement of the plasma density without increase of the discharge power. In fact, experimental work has shown that plasma density enhancement can be achieved at even reduced power input. In the present work, a hollow cathode ion source was equipped with an exchangeable magnetic field coil. The hollow cathode had a diameter of 6 cm and a length of 8 cm; the exit hole toward the extractor had a diameter of 1 cm. The magnetic field coils had a length of 4 cm and 18 cm, producing a non-uniform or rather uniform field up to 0.1 Tesla, respectively. Ions were extracted via a multi-aperture extractor grid at a voltage up to 5 kV. Current-stabilized power supplies enabled simple, stable operation. Parameters of the discharge, plasma, and ion beams were measured as a function of magnetic field strength and uniformity. At constant discharge current, the discharge voltage and hence power is reduced when a magnetic field is present. The extracted ion current shows a non-monotonic behavior as function of the magnetic field strength but the magnetic field distribution had only little influence on the current-voltage characteristics and on all other, derived plasma and beam parameters.

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WP24 HIGH BRIGHTNESS RF ION SOURCE FOR ACCELERATOR-BASED MICROPROBE FACILITIES

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The paper discusses possible ways of increasing beam brightness in RF ion source. The characteristics of RF ion sources with different permanent magnet systems are investigated. Experiments was performed with argon and helium gas. Beam brightness of ~ 100 A/(m^{2}rad^{2}eV) was obtained at plasma density $3*10^{11}$ cm^{-3} for argon and $1*10^{11}$ cm^{-3} for helium. The ion current density inside an emission hole with diameter of 0.6 mm was 10 mA/cm^2 for RF power input into the plasma of 40 W (f_{RF}=27.12 MHz). Measurements of the beam current value and emittance were performed with ion source testing equipment which permit measurements of current, emittance, mass composition, ion beam energy spread, and RF power input into the plasma.

WP25

COMPACT ECR ION SOURCE WITH PERMANENT MAGNETS FOR CARBON THERAPY

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High-energy heavy-ion cancer treatment is being carried out at Heavy Ion Medical Accelerator in Chiba (HIMAC) with 140-400 MeV/u carbon ions. Ion sources for the medical facilities should have characteristics of easy maintenance, low electric power, good stability and long operation time without maintenance (one year or more). The 10 GHz compact ECRIS with all permanent magnets is developed since 2000. The beam intensity and stability for C^{4+} are 300 eμA and better than 6% during 20 hours with no adjustment of any source parameter. These results are acceptable for the medical requirement.

In addition, in order to realize various applications, beam intensities of the highly charged ions such as oxygen and argon were increased by the following improvements; 1) biased disk method, 2) additional vacuum pomp at the injection side, 3) gas mixing method, 4) biased cylinder. Output currents of O^{6+} and Ar^{8+} are more than 120 eμA and 140 eμA, respectively.

Recently, many plans were developed for the construction of the next generation treatment facility. For such facility we have designed a new all permanent magnet ECRIS. Higher magnetic field is chosen than the previous one for increasing beam intensity. The maximum mirror magnetic field on the beam axis are 0.58 T at the extraction side and 0.87 T at the gas injection side. The minimum B strength is 0.25 T. The source is 30 cm diameter and 29 cm in length. Details of the design are reported.

WP26 LARGE VOLUME ICP SOURCES FOR PLASMA ION IMPLANTERS

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Plasma ion implanters require large volume, dense, uniform plasma for high efficiency and conformal treatment of 3-dimensional workpieces. A series of large volume inductively coupled plasma (ICP) sources for plasma immersion ion implantation and deposition (PI^3D) facilities have been developed. All the sources operate in CW mode at frequency of 12.56 MHz or 13.56 MHz and RF power up to 3 kW. Volume of the processing chambers, which are to be filled with plasma, is in the range of 18 liters to 1000 liters. Dense and spatially uniform plasma is produced at the working gas pressure of 0.05 - 2.0 mTorr using immersed RF antenna and multicusp magnetic field around the cylindrical wall of the chamber. The antenna design provides significant reduction of capacitive coupling with plasma, which is essential to reduce contamination caused by antenna sputtering due to its self-biasing. Using a termination capacitor in a matching circuit results higher plasma density and lower amplitude of RF voltage at the antenna terminals, which further weakens the antenna sputtering. The plasma density of up to 10^{11} cm^{-3} has been achieved even in the largest chamber. Plasma parameters were measured with RF-compensated Langmuir probe and ion mass analyzer. Design and characteristics of the sources as well as their performances in the developed PI^3D systems will be presented and discussed.

ACKNOWLEDGEMENT

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CHARACTERISTICS OF MULTI-ANTENNA RF ION SOURCE

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A key issue for a long operation of Neutral Beam Injection (NBI) in fusion experiments is a prolongation of the lifetime of cathode filament in arc discharge ion sources. In H^- ion source for Large Helical Device-NBI at National Institute for Fusion Science, the filaments are exchanged typically every three months during the experimental periods. The exchange causes an interruption of the NBI experiments and results in re-conditioning of the source. Radio frequency-discharge ion source for NBI has been developped[1,2,3] to improve the issues of the lifetime of filaments as well as tungsten vaporization.

In this paper, we report the characteristics of multi-antenna rf-driven ion source for NBI. One- and multi-turn antenna system, instead, are used to put the high rf power into plasmas. The new multi-antenna system[4] is designed to reduced rf voltage on the antenna compared to that of conventional loop antenna, which can reduce high voltage rf breakdown and lower both electron temperature and plasma potential. The effect of the reduction of impedance in multi-antenna system on plasma production, and ion extraction by installing single hole extraction electrode in the ion source were studied.

Rf antenna was set in $1/6^{th}$ scale negative hydrogen ion source of LHD-NBI with external magnetic filter. The dimension of the plasma source is 35 x 35 x 21 cm^3. The antenna was attached by extant filament feed-through on the back plate of the multi-cusp plasma source. Three rf generators of maximum powers of 1kW, 30kW, and 75kW (2 to 28MHz) were used to study the rf power and frequency dependences on the plasma characteristics. Pulse width and duration of the rf power are 10ms and 1s, respectively.

Depending the number of antennas, dependence of the ion density on the rf power was investigated. In case of single antenna, the ion saturation current measured by Langmuir probe tended to saturate around 10kW but that for the multi-antenna increased up to 12kW. The rf voltage on the antenna was larger for the one turn antenna but the rf current was larger for the multi-antenna. Higher frequency tended to produce larger ion saturation current below 2kW. Experiments with rf power of more than 50kW is now under the operation

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WP28 STUDY OF LARGE H^- ION SOURCE WITH DISTRIBUTED PLASMA INJECTION FROM SEVERAL CESIATED HOLLOW CATHODES

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Large negative ion sources are developed and operated for the high-power neutral beam injection to the experimental fusion devices in the National Institute for Fusion Science and Japan Atomic Energy Research Institute[1]. The operated sources use the hot filaments for primary electron emission, and the filament lifetime limits an experimental cycle. It is needed to develop the durable ion source with multisecond pulse length or cw operation. Possible decision is to use the distributed plasma injection to the large source from the several hollow cathodes. The cesiated hollow cathode with the small orifice, exploring the hydrogen and cesium seed was developed at Budker Institute of Nuclear Physics, and the multicusp source operation using one hollow cathode was tested for the plasma and negative ion production in the NIFS[2].

The first results of distributed plasma production from simultaneously operated several hollow cathode units are presented in this paper. The operation of $1/6^{rd}$ scale source with two hollow cathodes and of $1/3^{rd}$ scale source (plasma chamber volume 35W x 62H x 20L cm^3) with up to four hollow cathodes were tested on the test stand facility of the National Institute for Fusion Study. The hollow cathode units were installed through the filament feedthrough port on sidewalls of the plasma chambers. Two different designs of hollow cathodes, developed at BINP, were tested, including the novel one, having an isolated cathode body and a cascade discharge structure. The independent hydrogen, cesium and power supply systems for every cathode were used. Power supplies and discharge parameters were controlled by the data acquisition system. The reliable discharge ignition and operation with current up to 50 A per hollow cathode unit and pulse duration up to 5 s was tested. H^- beam production with multi-aperture extraction and acceleration from the source driven by several hollow cathodes was studied.

The authors would like to acknowledge the Director-General Prof. O. Motojima for his continuous support of this collaboration in NIFS.

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WP29

MULTIPLE IONIZATION OF METAL IONS BY ECR HEATING OF ELECTRONS IN VACUUM ARC PLASMAS

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A joint research and development effort has been initiated, whose ultimate goal is the enhancement of high ion charge states in vacuum arc metal plasmas by a combination of a vacuum arc discharge and an ECR system. Experiments have been carried out at IAP using a single mirror magnetic trap with ECR plasma heating. Metal plasma was generated by a special vacuum arc mini-gun located on the axis, outside the magnetic trap close to the bottom of the magnetic mirror. The results have demonstrated substantial multiple ionization of metal ions. Thus, for example, for a lead plasma, ECR heating increased the maximum attainable ion charge state from Pb^{2+} up to Pb^{6+}. High power, high frequency microwave radiation (gyrotron-generated, 37.5 GHz, 50 kW, 1.5 ms) provided the high plasma electron temperature that is needed for multiple ionization at the plasma density produced (up to 10^{14} cm^{-3}). The critical parameter describing the efficiency of multiple ionization, $n\tau$, was as high as ~10^9 cm^{-3}.s. Further increase of the ion charge states will be attained by increasing the vacuum arc plasma density and optimizing the ECR heating conditions.

WP30 A ION SOURCE Gas/Me ON GLOW DISCHARGE OF LOW PRESSURE

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The source mixture ions of type Gas/Me on glow discharge of low pressure was developed. A mixed positive ion beam is useful to the modification of properties surface. The stationary beam with circular ∅ ~ 60 mm are extracted from gas-metal plasma of two-step shaped arrangement designed in coaxial geometry [1].

The external ring chamber with cold cathodes serves as an source of penetrating gas plasma. The cooling ring anode and poles – cathodes – symmetrical arranged about ring builds up discharge spacing. A glow discharge of low pressure in crossed E x B fields is initiated by the autoelectronic emission from sharp edges of cathodes [2]. A tolerant discharge run for pressure (10^{-2} – 1) Pa, low current power sufficient to heat the sharp edges of poles – cathodes to emission temperature. A arc – shaped magnetic field in discharge spacing produce external regulating electromagnet. The dense gas plasma discharge for current (0,1 – 1) A by voltage ≤ 1 kV concentrates in gap between magnetic poles.

The internal cylindrical chamber with axial sputtered electrode serves to creating gas-metal plasma. The gas plasma enters via slit gap between poles – cathodes into sputtering chamber. A penetrating gas plasma for density $n_i \sim 10^{18} - 10^{19}$ under potential on sputtering electrode $U_s \sim$ (1-3) kV is initiated forced glow discharge. Sputtering and sublimation atoms of target produce high concentration particles of Me in arrangement with regulating removal heat. A attractive ionization neutral particles. Me in internal chambers is attained because of injection in plasma secondary accelerated electron in discharge an open type.

The free of separator non drop beam charged particles with total currents I = 20 mA and energy E = 40 - 45 keV was obtained stoichiometric composition ions titanium / nitrogen ~ 1.

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WP31 PRELIMINARY EXPERIMENTS ON LASER COUPLED TO ELECTRON CYCLOTRON RESONANCE ION SOURCE FOR TRACE ELEMENT ANALYSIS

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We have developed the laser coupled to electron cyclotron resonance (ECR) ion source for the detection of heavy elements by accelerator mass spectrometry (AMS) at University of Tsukuba. A compact Nd: YAG pulsed laser at 1064 nm wavelength with the pulse width of 8 ns and the maximum energy of 50 mJ is employed to evaporate the sample materials as a means of introducing solid samples into the ECR plasma. This method has a number of advantages. The spot size of the laser beam can be focused in the range of 100 μm therefore we can choose the precise position on the sample to analyze trace element. We have the aim of using this system to apply for *in situ* microanalysis of geological samples. All rocks or minerals are composed by a mixture of mono-mineral grains typically in the range from μm to mm. The efficient production of highly charged ions in the ECR ion source ensures the elimination of molecular ions or micro-particles produced by the laser ablation. The combination of a velocity-matching accelerator and the magnetic beam transport system acts as a mass separator for background suppression.

The 14.5 GHz superconducting ECR ion source (SHIVA) is operating for the production of multiple ionized clusters with soft peripheral collision of highly charged ions with metal clusters at University of Tsukuba. The laser ablation system is designed to couple on to SHIVA for the first step of this project. Ions and neutral particles evaporated from the different sample materials by the laser ablation are measured. The design of this system and the results of the preliminary experiments will be reported.

WP32 EFFECTIVE CHARGED AND NEUTRAL PARTICLE BEAMS SOURCE ON THE BASE OF DISCHARGE WITH HOLLOW CATHODE

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In wide applied plasma sources of electrons and ions on the basis of the reflective discharge with cold hollow cathode energy given to the discharge interval basically is allocated on electrodes and is removed by the appropriate system of cooling. Use of this energy for increase of efficiency such plasma emission structures becomes possible due to accommodations on an axis of the discharge of the not cooled rod cathode, thus the electrode structure of the reflective discharge with hollow cathode will be transformed to the structure of electrodes of magnetron discharge with hollow cathode [1]. In the Fig. 1 the electrode structure of magnetron discharge with hollow cathode is schematically submitted, in which the cathode electrode is heated in the discharge up to temperatures, sufficient for thermion emission. The circuit of electrodes consists of the cathode 3 with box cavity. On the axis of box cavity the cathode rod 2 is located with diameter of 0.25-4 mm, which is electrically isolated from hollow cathode 3, and forms a backlash with an aperture in the cathode 5. The rod is covered by the cylindrical anode 1 with diameter 18 and length 12 mm. The axial magnetic field is created in the anode cylinder by a ring magnet 6. Through an aperture in the reflective cathode 5 the working gas is pumped out. It also can serve as the emission channel of the plasma source.

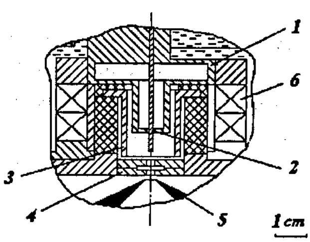

Figure 1. Discharge chamber of magnetron discharge with hollow cathode: 1 – hollow cathode; 2 – rod cathode; 3 – anode 4 – cathode insert; 5 – accelerating electrode; 6 - magnets

The electron and ion beam source was developed on the base of magnetron discharge with hollow cathode. Its general view is shown in Fig. 2. Such source allows to generate electron beams with power efficiency (up to ~15 mA/W), discharge burning voltage is of 85-180 V, discharge current 2 A, ion beam current 0.1-0.15 A, electron beam current 1 A. This device was entered into a design of a vacuum post VUP-5, reconstructed for thin films deposition [2].

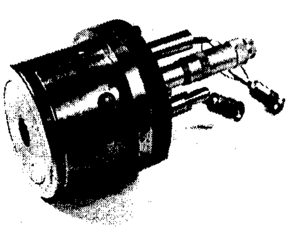

Figure 2. General view of discharge plasma source

Technology of charge particle beams generated in discharges with cold cathode based on sputtering of graphite and processing of carbon film by ion or electron beam allows growing of diamond and diamond-like thin films at low temperatures and pressures.

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WP33 **RESULTS OF UPGRADE OF THE DIAGNOSTIC NEUTRAL BEAM INJECTOR FOR THE TCV TOKAMAK**

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The diagnostic neutral beam injector (DNBI) [1,2,3] has been developed at BINP for beam emission spectroscopy measurements in the TCV tokamak. The DNBI has been commissioned at the tokamak in 1999. It operates with the beam energy up to 50 keV, equivalent neutral beam current (for hydrogen) up to 1A and pulse duration up to 2 s. Plasma in the ion source is produced by inductively-coupled 4.6 MHz RF discharge. Ions are extracted and accelerated by a four-grid ion optical system with 163 circular 4 mm i.d. apertures.

The DNBI is to provide local measurements of plasma ion temperature, velocity and impurity densities through active charge exchange recombination spectroscopy (CXRS). The beam parameters of the diagnostic injector enabled to carry out the measurements at plasma density in tokamak up to 5×10^{19} m^{-3}.

In order to further increase the active to passive signal ratio of the CXRS measurements and extent the operational density up to 10^{20}m^{-3}, the diagnostic injector has been upgraded in 2002. The technical upgrade was undertaken to obtain an increase of the neutral beam current density in observation region of the CXRS diagnostic by a factor of ~1.5÷2. A new ion source was installed on DNBI with corresponding changes in the power supplies. The diameter of RF cylindrical plasma box was increased from 10 to 12 cm, an extraction area was increased from 7.2 to 9.2 cm in diameter. Correspondingly, the number of apertures was increased from 163 to 241.

This paper describes the results of the beam parameters measurements after upgrade.

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WP34 VERY HIGH-TEMPERATURE ION SOURCE.

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The design of the effective high-temperature ion source with operating temperature of discharge chamber walls more than 1600 °C are continued. It is supposed to use the well recommending itself the combined method of the discharge chamber heat (infrared radiation + electron bombardment + ion bombardment). The chamber sizes and its material are optimized so that as much as possible to reduce the heat losses by radiation.

At that some its characteristics, first of all – the ignition and stability of discharge were unsatisfactory.

Now the ion source design is the subject to the significant constructive changes directed on the improvement of its operational characteristics.

The design estimations of the thermal mode of ion source's discharge chamber, the influence on such mode the various types of heat and the different ratios of discharge chamber sizes are spent. Also the different ways of thermal flow reduction from discharge chamber walls are estimated.

The positive influence of the made constructive changes on the stability of discharge and the stability of its characteristics is experimentally confirmed.

Works on the system perfection of the operating vapor feed in ion source's discharge chamber is realized for the reduction of operating vapor losses and the increase of its utilization efficiency. But for all that a high solubility of the platinum-palladium group metals in the majority of the constructional materials with formation of the eutectic melts is the main problem as usual.

WP35 ZINC ISOTOPE DISCRIMINATION EFFECT IN INDUCTIVELY COUPLED PLASMA MASS SPECTROMETER

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Inductively coupled plasma mass spectrometry is used for many purposes of elemental analysis, trace analysis, isotope ratio analysis, etc. The part of mass spectrometer is changeable according to the purposes, quadrupole, high-resolution double focused type mass spectrometer, and multi collector type. The multi collector type ICP-MS is most popular for the isotope ratio analysis, but the quadrupole type ICP-MS, which is the less expensive one than MC-ICP-MS, has been also used. The isotope effects, the isotope fractionation effects and discrimination effects, in the mass spectrometer are important problem for the precise and accurate isotope ratio analysis. The isotope effects in ICPMS are collectively called the isotope discrimination effects generally, although the isotope fractionation and discrimination effects are apparently distinguished essentially. The degree of isotope effects is known to be varied according to the kind of ion source. The mass spectrometer with surface ionization ion source, i.e. the thermal ionization mass spectrometer, TIMS, has the least isotope effect in all mass spectrometers. However, it is difficult to measure the isotope ratios of elements with high ionization potential, e.g. zinc, by using TIMS. Thus, ICP-MS is used to measure the isotope ratios. In the present work, the isotope discrimination effects in the ICP-MS are investigated by using a quadrupole mass spectrometer, Jarrell-Ash X7. The zinc was used for estimation of the isotope discrimination effects. The zinc isotope ratios measured by ICP-MS and TIMS, FINNIGAN MAT 261, were compared. We used zinc samples, which the isotope ratios were fractionated by an ion exchange chromatography [1]. The isotope ratios, $^{66}Zn/^{64}Zn$, are shown in Figure. This figure shows that the relative variation of isotope ratios measured by ICP-MS approximately corresponds with results by TIMS, but the measurement by using ICP-MS overestimates the ratios of heavy isotopes. It was deduced that this overestimate is mainly due to the nozzle effects; a kind of diffusion isotope effect derived from the differential pumpings. The influences of the rf power, the extraction voltage, the zinc sample concentration, and matrix on isotope ratios were also investigated, and the discrimination effects were confirmed, respectively.

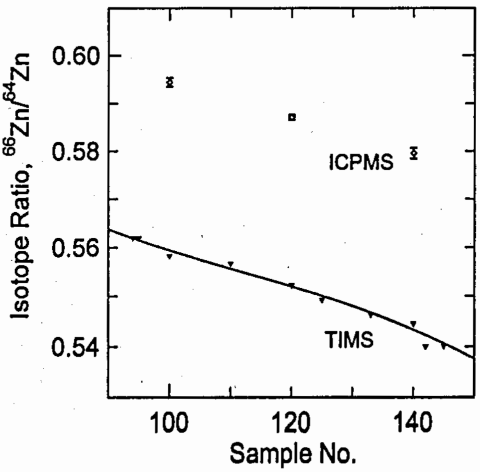

Fig. Isotope ratios measured by ICP-MS and TIMS.

The present work was performed as a part of Innovative and Viable Nuclear Energy Technology Development Project, The Institute of Applied Energy, Japan.

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WP36 DEVELOPMENT OF A HIGH-CURRENT MICROWAVE ION SOURCE FOR PROTON LINAC APPLICATION SYSTEMS

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A microwave hydrogen ion source was developed to improve reliability, and to increase operation time of proton linac application systems based on industrial high-current microwave ion source technologies and low emittance beam production techniques for nuclear fusion. The ion source needs no filament in the discharge chamber, which lead to reliability improvement and less maintenance time. The developed source produced a maximum hydrogen ion beam current of 70 mA (high current density of 360 mA/cm2, beam energy of 30 keV) with a 5 mm diameter extraction aperture and 1.2 kW microwave rf power. The proton ratio was increased with an increase in rf power and reached around 90 % at 1 kW. The extraction grid design was optimized with beam trajectory simulations. Measured 90 % beam normalized emittance was 0.42 π mm mrad. This will meet acceptance of proton linacs. Rise times of rf power and beam current to 90 % of the final value were about 30 and 35 us respectively at a pulse operation mode with 400 us pulse width and 100 Hz repetition rate. The dynamic range of beam currents was enlarged (3-63 mA) in the pulse mode by a modified rf waveform to assist ignition of microwave discharge. These performance parameters will be desirable for pulse operation accelerator applications like proton therapy systems. A long time operation stability (150 hr) was confirmed with beam current of 51 mA and change in the current of 2%.

WP37 HIGH POWER BEAM INJECTION USING AN IMPROVED NEGATIVE ION SOURCE FOR LHD-NBI

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In the Large Helical Device (LHD), neutral beam injection is one of the most powerful and promising methods to heat plasma, to increase the plasma parameters, and also to generate the target plasmas. Increasing the injection power can be expected to expand the experimental area and to support the achievement of the target values for LHD-NBI. These target values are the beam power of 5MW/beam line, the energy of 180 keV and the pulse duration of 10 s.

A new negative ion source was researched and developed to increase injection power and to partially achieve the target values. The ion source consists of an arc chamber with hexagonal cross section and a set of new beam accelerator whose grounded grids has been replaced form the multi-aperture to the multi-slit grids. In previous accelerator, deflection of H^- beam-lets is corrected by displacing the aperture axes of the grounded grid. It is not avertable for slit grid to steer the beam-lets in a long side direction of the slit, and additional steering grid with apertures is set between the extraction grid and the slit grounded grid. The steering grid is applied extraction voltage. The beam energy and power has previously saturated near 170 keV and 3.6 MW, respectively. In the case of the new accelerator the maximum injection power goes up to 4.4 MW and the maximum beam energy attained to180 keV, which is the target energy value of LHD-NBI. Beam conditioning time gets drastically shorter; the beam energy reaches 181 keV within 5 days after starting to dose cesium into the arc chamber.

Electron and widely spread H- beams in acceleration gap collide with grounded grid and the beams carry heat to the grid. The heat load is measured by means of water-calorimetric method. In the same beam power, the load on the multi-slit grounded grid is reduced half as much as that onto the multi-aperture grounded grid. The dominant reason for the heat reduction is an increase of the transparency of the multi-slit grid. The beam interfering area of the slit grid is about 60% of the aperture grid. The increase of maximum beam energy is considered due to the decrease of acceleration breakdowns whose triggers are gas releases and sputtered ions form grounded grid as a result of irregular beams colliding and heating up the grid.

The two-dimensional beam profiles are measured by a calorimeter array installed in the neutral beam line. Large influence of slit could not be detected and the beam width along the long side of slit is rather narrower than the width by using multi-aperture grid. Beam profile has the narrowest widths at a certain ratio of acceleration voltage to extraction voltage. Although horizontal and vertical beam widths should have the minimums at the same voltage ratio, there is a mismatch for the ratio in present and the mismatch is expected to induce the beam injection loss. The problem is being settled by further investigation of the beam optics for slit grid.

WP38 HIGH POWER ION BEAM GENERATION AND ITS MEASUREMENT VIA NUCLEAR ACTIVATION TECHNIQUES

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The preliminary research results for generation and diagnostics of high power ion beam (HPIB) on the FLASH accelerator are reported. The equation of parapotential flow is corrected for the reduction of diode A-C gap due to the motion of cathode and anode plasmas. The HPIB peak current of ~100kA is obtained with a peak energy of ~600keV. The current of HPIB is experimentally determined by monitoring delayed radioactivity from nuclear reactions induced in a target by the protons. The delayed radioactivity on ^{12}C target was measured by using the high purity germanium sensitivity semiconductor detector and the target mass loss due to blow-off was corrected. The cross section and yield for $^{12}C(p,\gamma)^{13}N$ and $^{12}C(d,n)^{13}N$ nuclear reaction were calculated. The radioactive nuclei ^{13}N, Ion number and energy deposition profile were also calculated.

WP39 SIMPLE STRUCTURE HOLEY-PLATE ION SOURCE

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Recent studies have demonstrated that a surface-wave plasma source can be used to produce uniform high-density plasma.[1-4] We have developed a new surface-wave plasma source using a holey-plate (HP) and have reported that a partial-coaxial cavity-type HP plasma source (CHPPS) can produce high-density plasma under low pressure.[5] The CHPPS is designed to determine the most efficient method of coupling between the plasma and the surface wave. This source converts microwave power at 2.45 GHz into a surface wave as an evanescent electric field on the holey-plate, and efficiently couples the plasma and the field. Moreover, we have already reported that a CHP ion source (CHPIS) is very useful for producing high-density ion beams.[6] However, this ion source has an 18-mm-diameter ion beam, which is too small to be used for a variety of industrial applications.

Drawing from the research already conducted on the CHPPS, we have built a rectangular waveguide type HP plasma source (RHPPS) for large wafers. The holey-plate is placed on an H-plane located at one end of the rectangular waveguide. We have already reported that the plasma uniformity of the RHPPS is higher than that without the holey-plate called a dielectric-plate surface-wave plasma source.[7] We also presented the operational characteristics of this source applied to a broad-beam ion source.[8] A 150 mm X 150 mm argon ion beam is extracted from the ion source. The ion current densities are in excess of 2 mA/cm^2 at an extraction voltage of 1 kV. The RHPPS is not easily scalable to larger plasma sources because the glass becomes larger and heavier, which becomes a significant loss material for microwaves.

In order to scale this source to a large area, we have designed a parallel-plate type holey-plate plasma source (PHPPS) [9] without using glass as a dielectric coupler. The plates have a 100 mm X 140 mm area and are separated by 10 mm. In an experiment, the entire body of the parallel plate is placed in a vacuum chamber. Dense plasmas are produced only on the holey plate. The electron density is 1×10^{11} cm^{-3} at an Ar gas pressure of 9 Pa and at a microwave power of 120 W at a 10 mm distance over the holey plate. The electron temperature is 3 eV. Uniformity is approximately ±22% within the area of the plate. In this work, we present the operational characteristics of this source applied to a high-efficiency, lightweight, and low-cost ion source. A 78 mm X 108 mm argon ion beam is extracted from the ion source. The ion current densities are in excess of 1.2 mA/cm^2 at an extraction voltage of 500 V.

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WP40 A PERMANENT MAGNET MICROWAVE ION SOURCE

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A 2.45 GHz microwave ion source with permanent magnet was developed. The discharge chamber size, microwave window, magnet field distribution and so on were optimized. Now the plasma chamber of the source is 48 x 50 mm only. In which the magnet field is larger than 930 Gauss, and produced by NdFeB permanent magnet ring. The source can operate in both CW and pulse mode. And in pulse mode, the pulse duration is 4-5 ms, repetition rate is 50 Hz usually. At hydrogen discharge, pulse mode and 45 kV extraction voltage, 25 mA average current of hydrogen was extracted from 5 mm emit aperture in plasma electrode, i.e. macro pulse current can research 100 mA.

WP41 **HIGHLY UNIFORM AND COLLIMATED ION BEAMS GENERATED BY RF INDUCTIVELY COUPLED PLASMA**

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In this article we describe the recent development of an advanced RF inductively coupled plasma (ICP) ion source, ARIS, designed for Ion Beam Etch (IBE) applications requiring both extremely high beam collimation and etch rate uniformity. Typical requirements are: maximum beam divergence angle $\theta < 3°$, etch rate uniformity $U_s < 3\%$ on a static wafer and $U_r < 1.5\%$ on a rotated wafer, and etch rate and uniformity repeatability within 1%. As will be described in the article, conventional low-pressure ICP generators are not able to provide ion beam extraction and formation conditions satisfying these stringent process parameters. In particular, the static wafer etching uniformity is extremely sensitive to both the plasma density distribution uniformity and beam divergence and directionality. To meet both static and rotated wafer IBE requirements a novel configuration of an electrostaticly shielded ICP generator with a dynamic magnetic field is proposed. A new flat grid assembly with improved thermal and mechanical stability is designed and fabricated for this application. Experimental data on plasma density distribution measured by an array of flat Langmuir probes, ion beam density distribution measured by two dimensional array of Faraday cups, beam divergence distribution obtained by a pepper-pot emittance measurement technique, and etching rate distribution measured on different material wafers is also presented to demonstrate the designed ion source static and rotated wafer IBE performance.

ION GENERATION VIA RESONANTLY-ENHANCED TWO-PHOTON PHOTOIONIZATION

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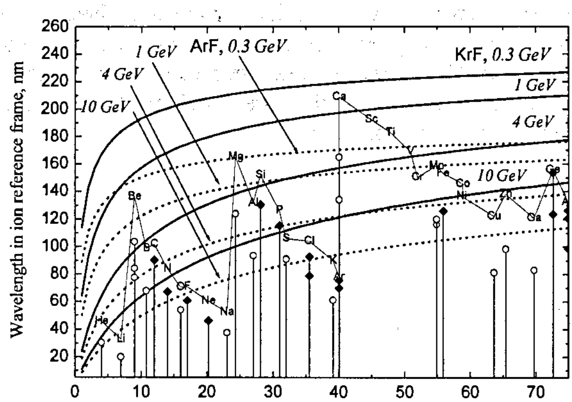
Charge-exchange or stripping method of ion injection into accelerators and storage rings has essential advantages compared to other conventional methods as this technique has no restrictions imposed on the storage ions on orbit by Liouville's theorem. Ion injection by means of the charge-exchange on a material target has been developed by A. J. Dempster [1], L. Alvarez [2], and G. I. Budker, G. I. Dimov et. al. [2]. At present, charge-exchange injection is widely employed on many accelerators and storage rings. In particular, the charge-exchange injection is a subject of special interest for projects of heavy ion driven inertial confinement fusion (see, *i. e.* [4]). A non-Liouvillean injection technique based on ion stripping by hard vacuum ultraviolet radiation via direct photoionization [5] or through an autoionization state [6] has been recently proposed by Rubbia and Hofmann. Implementation of this method requires using an HVUV-laser that does not exist yet.



We suggest a resonantly enhanced two-photon photoionization (RETPI) as a technique for stripping ions, moving on an equilibrium orbit, to the next charge state. An intense UV laser beam crosses at some angle a high-energy singly charged ion beam. Varying ion beam energy and the angle, one can match photon energy ε_φ in the ion beam reference frame (solid and dotted lines in the figure) to the energy of one of the ion resonance transitions $E^* = \varepsilon_\varphi > I/2$ (circles and diamonds in the figure). Wavelengths corresponding to half of the ionization potential I for the lightest elements are shown in the figure with a thin line. Intermediate excited state is populated to saturation and then is ionized by following photons. For most elements this technique can be realized with conventional excimer lasers and employed for ion injection, stacking, or diagnostics. High ionization efficiency, rather low photon flux (0.01-2 J/cm^2 for KrF and ArF lasers), which is necessary for complete ion beam ionization, as well as absolute selectivity are advantages of this method. Detailed description of the technique is provided in Ref. [7].

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XO1

A CW MICROWAVE PROTON SOURCE AND LEBT FOR THE IUCF CYCLOTRONS

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A proton injector for a 20 keV to 750 keV CW RFQ has been constructed and installed [1] to supply beam for acceleration by the Indiana University Cyclotron Facility (IUCF) cyclotrons for use in the Midwest Proton Radiotherapy Institute (MPRI) [2]. The injector includes a microwave ion source based on the LEDA design [3,4]. Two solenoids match the 20 keV, few milliampere beam to the RFQ with an additional pulsed solenoid for modulating the beam intensity out of the cyclotrons. An electrostatic chopper operates at 17.79 MHz to select beam that will match the RF phase acceptance of the 35.58 MHz cyclotrons. This paper will describe details of the injector construction and operation.

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XO2 # H^- CUSP SOURCE DEVELOPMENT FOR 100 MEV COMPACT CYCLOTRON AT CIAE

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As a part of the Upgrade Project of Beijing Tandem Accelerator Laboratory[1], a 100 MeV compact H^- cyclotron was designed for the generation of high intensity proton beam. Due to the limit of acceptance by the cyclotron central region, a new H^- cusp source was developed at CIAE. The design of this new source is based on the TRIUMF's experience[2]. More than 10 mA H^- beam with an emittance ~100 mm mrad are got at a voltage of 28 kV from an extraction hole of 11mm in diameter. In this paper, the structure of the source, the magnetic filed configuration of multi-cusp and virtual filter, the extraction optics, the test result and the improvement next step will be described.

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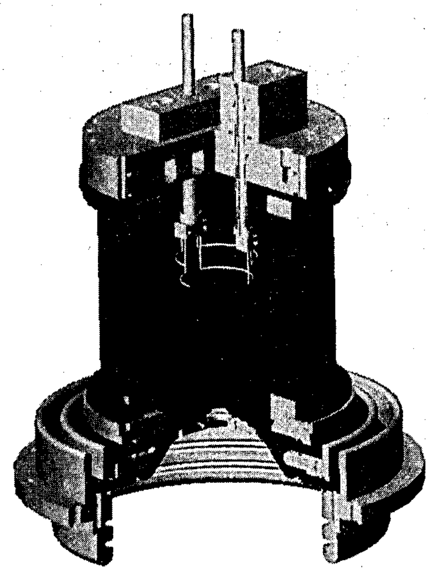

Fig. 1 The body of H^- cusp source at CIAE

XO3 GENERATION OF BROAD ION BEAMS IN SOURCES BASED ON PENNING SYSTEM WITH NONEQUIPOTENTIAL CATHODE

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The use of cold cathode discharge systems for the development of technological ion sources is preferable in comparison with thermocathode ones due to their higher life-time. One of the well – known discharge systems with cold cathode used in ion sources is Penning one. Earlier it was used for generation of narrow beams due to sharp radial nonuniformity of generated plasma in the system. In our experiments it was shown that it is possible to obtain uniform plasma in the system at the use of nonequipotential cathode, i.e. at the use of several cathode elements being at different potentials. This enables the development of broad beam ion sources based on the modified Penning system.

Two variants of ion sources have been developed. The first source is destined for ion cleaning. It generates low energy (~1 keV) ions. In this variant acceleration of ions is realized directly in cathode fall, and the treated target plays role of one of the cathode of the system. More than 50 % of ions generated in the discharge system reach the target. The required level of ion energy is ensured by applying of corresponding voltage between the target and the anode.

The second source generates ion beams with higher (several tens of keV) energy. It is destined for ion implantation and other ion technologies. Accelerating - decelerating ion optics is used in this variant. The extraction efficiency defined as ratio of beam and discharge currents is equal to 30%. The obtained level of extraction efficiency is several times higher in comparison with obtained one in known ion sources. So energetic efficiency increases significantly also, that make it perspective the use of the source in different ion technologies.

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XO4

ION SOURCES AND LOW ENERGY BEAM TRANSPORT FOR THE NEW SUPERCONDUCTING LINAC FOR COSY/JÜLICH

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The Institut für Kernphysik of the Forschungszentrum Jülich GmbH is in the process of designing and developing a new injector for the cooler synchrotron COSY.
To serve efficiently the projected linac injector new ion sources have to be provided. The ion sources will deliver polarized or unpolarized H^- or D^- beams in the mA range with an energy of 25 keV and pulses of up to 500 μs width and up to 2 Hz repetition rate.
Alternative arrangements of the ion sources and the LEBT system are under investigation. Selected results and the status of this part of the project will be presented.

XO5

IMPROVEMENT OF THE YIELD OF HIGHLY CHARGED IONS BY GAS PULSING AND CURRENT STATUS OF NIRS-PIGIS

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The NIRS-PIGIS can produce highly charged ions due mainly to the "ion pumping effect"[1], which is followed by a pulsed arc-discharge. When producing light ions, however, much gas-flow rate (~10 cc/min) is required both to keep the discharge stable and to obtain a sufficient ion yield. In such case the pressure in the beam line should be deteriorated.

There are three ion sources in the HIMAC[2] injector; PIGIS, 10GHz-ECRIS and 18GHz-ECRIS. We have employed a "time-sharing" technique[3], which allows us to accelerate different ion species from the different sources by every 1s order. In this case, the beams from PIGIS and ECRIS go alternatively through the common beam line. When producing highly charged ions in the ECRIS with very low gas–flow (~0.01 cc/min), the effects of high gas-flow in the PIGIS bring some loss of ECRIS.

To overcome this problem, the gas pulsing system has been proposed, which will allow us to improve not only the intensity of ECRIS but also the transmission efficiency of the PIGIS beams.

In this article we report the preliminary result of the gas pulsing system and the status of the NIRS-PIGIS.

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YI1 INVESTIGATION OF BROAD ION BEAM DIVERGENCE AND LOCAL ION INCIDENCE ANGLE DISTRIBUTION FUNCTION

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In commercial applications of broad ion beams, such as ion milling (etching), cleaning, and surface modification of thin film devices, the quality and reproducibility of device microstructures processed over the entire surface of the substrate strongly depends on the local ion incidence angle distribution function (ADF). The shape of the ADF is defined by many factors, among which are the ion beam plasma generation method, ion beam optics structure and parameters, and beam neutralization and transport conditions. In this paper we present the results of investigation of the incidence angle distribution function for a 35 cm diameter gridded RF ion source and two types of three-grid ion optics. The investigation is carried out for Ar ions in the energy range of 150-1000 eV. The current density distribution of ions and charge exchange neutrals at the selected wafer positions is obtained by linear and round pepper-pot beam emittance measurement techniques. The temperature-controlled version of the linear pepper-pot probe is used for local beam steering angle estimations. A simple analytical model is proposed for the ADF reconstruction from the beam density distributions at the image plane of the pepper-pot. The individual beamlet density profile in the downstream region of the grid optics is also investigated and correlated to the local ion ADF shape. Differences between the two profiles in the "tail" regions of the distributions are mainly a function of the beam radial and longitudinal coordinates and ascribed to the ion interaction with the beam plasma particles and space charge field. It is also found that for highly collimated low energy (<500 eV) beam parameters, individual beamlet divergence angle and the ADF are sensitive to the electron temperature of the neutralizing electron source.

YO1 HIGHLY STRIPPED ION SOURCES FOR MEV ION IMPLANTATION

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A joint research and development effort whose ultimate goal is to develop an intense, high charge state, ion source for MeV ion implanters has been initiated. Present day high-energy ion implanters utilize low charge state (usually single charge) ion sources in combination with rf accelerators. Usually, a MV LINAC is used for acceleration of a few mA. It is desirable to have instead an intense, high charge state ion source on a relatively low energy platform (dc acceleration) to generate high-energy ion beams for implantation. This dc acceleration of ions will be far more efficient (in energy utilization). This endeavor is continuation of an earlier research, which resulted in generating ions like Pb^{+7} & Bi^{+8} and ion currents exceeding 200 mA. The natural next step is to convert and optimize ion charge state enhancement techniques to generate B, P, As, and Sb ions, and adapt them to a dc implanter. A number of schemes are to be pursued simultaneously. The most promising approach is to be developed into a commercial ion source.

YO2 SELENIUM CLUSTER FORMATION USING A NEW CORONA DISCHARGE ASSISTED CLUSTER ION SOURCE

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Cluster ions of metal and semiconductor elements are of interest because of the possibilities for using the clusters as new materials, and because these clusters offer a new understanding of reactions. The cluster ions of metal and semiconductor elements have been generated as follows: neutral clusters are first formed by evaporation from an oven or laser ablation chamber, often followed by cooling with inert gas, and then the neutral clusters are ionized by an electron beam or laser. The ionization by electron beam makes the internal energy of the cluster high, which leads to the dissociation of the cluster. Ionization by laser can solve this problem, but the cluster ion sources supplied with laser ionization systems are expensive, and require a large space for installation. A simple and less expensive cluster ion source that generates cold cluster ions is needed.

In the present study, we developed a new simple cluster ion source which utilizes a corona discharge. It is a characteristic of our new cluster source that the target element, which is evaporated, is ionized by primary ions generated by the corona discharge. The secondary ions of the target element are expected to promote the nucleation to form the objective cluster ions. The new cluster source, in which cluster growth follows the ionization process, may be more effective in generating clusters than the conventional cluster sources, in which the ionization process follows cluster formation. The following supersonic expansion induces further cluster ion formation and the cooling of the cluster ions.

Schematic of the cluster ion source is shown in Fig. 1. The cluster ion source is composed of a corona discharge chamber and a cluster generation chamber. In the present case, we used nitrogen for the corona discharge. Nitrogen ions generated by the corona discharge were introduced into the cluster generation chamber through orifice 1. Ions easily diffused into the cluster generation chamber, because the pressure at the corona discharge chamber was higher than that in the cluster generation chamber. The cluster generation chamber was filled with selenium (Se) vapor, formed by placing Se in a crucible and heating it to evaporate. The cluster chamber was separately heated to control the pressure of the Se vapor, and to avoid the deposition of the Se vapor on the chamber wall. The nitrogen ions can ionize the Se atoms by the charge transfer process. Selenium clusters, Se_n, were expected to be formed by the ion induced nucleation process and supersonic expansion. The cluster ions were extracted through orifice 2, which can be biased against the rest of the source. The cluster ions were observed through a quadrupole mass spectrometer.

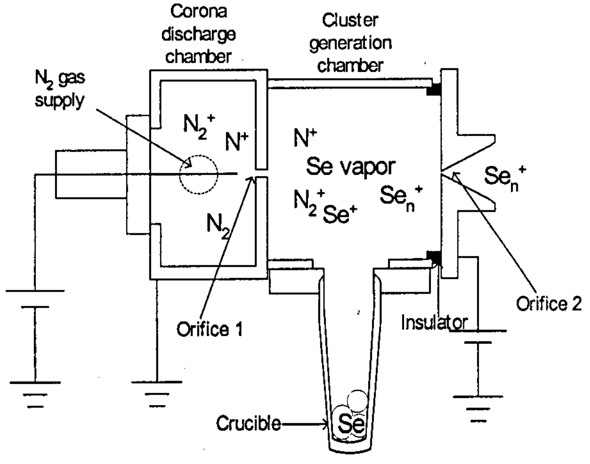

Fig. 1. Schematic of the cluster ion source.

ZO1 NANOCLUSTER ION SOURCE BY PLASMA-GAS-AGGREGATION

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Science of nano-scaled structures is now a frontier of the solid-state physics, and electronics. The global goal common to most scientist in the field is the attempt to understand the evolution from atoms or molecular to bulk properties with increasing cluster size. The field of such clusters science is strongly dependent on the development of the cluster ion source. Very often the development of the new techniques of the ion source gives rise to a quantum leap in the progress of the field.

Furthermore, nano cluster beams have several attractive features for applications in the field of electronics, thin film production and so on. One of the attractive features is that the cluster process supplies particles for deposition that are energized to the level of few eV per atoms. Using such low energies, deposition carried out at low temperature and high packing density. For these applications, we need the source, which can produce the intense beam of nano-cluster ions.

For these reasons, we are constructing and developing a new cluster ion source and a detection system. The new cluster ion source consists a large area plasma ion source and gas aggregation cell instead of present cluster ion source configuration (magnetron ion source and gas aggregation cell). This feature allows us to produce intense beam of cluster ions stably compared to the present ion source.

In this paper, we report the design of the ion source and the TOF system for measurement of mass of cluster produced from the ion source. We also report the present status of this system.

ZO2 DEVELOPMENT OF A COMPACT CESIUM-SEEDED MAGNETICALLY-CONFINED PLASMA ION SOURCE FOR ACCELERATOR MASS SPECTROMETRY

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Accelerator Mass Spectrometry (AMS) is an ultra-sensitive analytical tool with a wide range of applications, the most common being radiocarbon analysis where measurements of isotope ratios to one part in 10^{15} are routine. Cesium sputter ion sources are the primary type used in most AMS systems to produce the required negative ions. However, there is interest in the AMS community to develop an ion source that allows direct injection of gaseous samples. Such an ion source would circumvent the lengthy graphitization process required with a traditional cesium sputter source, resulting in a dramatic increase in sample throughput. It could also increase sensitivity due to the potential reduction of sample contamination. Several attempts have been made to develop a gas injection ion source for AMS applications, but have thus far been limited by memory effects and marginal negative ion yield. Cesium-seeded multi-cusp ion sources have been used extensively to drive thermonuclear fusion reactors (e.g. the tokamak type reactors) because of their ability to produce very intense, high-quality beams of H^-. Due to their relatively high gas efficiency, these ion sources seem well suited for AMS applications. Traditionally, these ion sources use a cylindrical array of permanent magnets with alternating polarities to produce a multi-cusp pattern of magnetic field lines which confines the plasma to a small volume. Recently, an ion source using a symmetric rather than alternating arrangement of magnets has demonstrated an order of magnitude more effective plasma confinement. This design yielded positive ion beams of similar intensity to the traditional multi-cusp arrangement, with a factor of forty decrease in discharge power, and extended filament lifetime. In this paper we will compare the potential for using an alternating or symmetric magnet geometry for a negative ion source, and describe our progress to develop such a compact ion source for radiocarbon AMS. In particular, we will characterize the plasma conditions for different support gases at various pressures, a variety of filament materials, and different source configurations. We will then study the relationship between the source plasma characteristics and the properties of extracted negative ion beams.

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Abstracts

10 международная конференция по ионным источникам

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