ecris 2018

XXIII International Workshop on ECR Ion Source

INFN

September 10th – 14th, 2018

ecris18@lns.infn.it

ECRIS 2018

XXIII International Workshop on

ECR Ion Source

September 10th – 14th, 2018

Catania, Italy

Hosted by:

INFN
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Sud

PROGRAM AND ABSTRACTS

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WELCOME

Dear colleagues,

On behalf the Local Organizing Committee, we are glad to welcome you in Catania for the 23rd International Workshop on ECR Ion Sources, organized by the Istituto Nazionale di Fisica Nucleare-Laboratori Nazionali del Sud. The workshop is aimed to highlight the state of the art in ECR Ion Sources Science & Technology, and to reinforce the common ground and synergies among the different actors in the field.

The ECRIS workshop series have a long history (recently: 2012 Sydney, Australia; 2014 Nizhny Novgorod, Russia; 2016 Busan, South Korea), we want to encourage in this edition a stronger interaction by inserting three round tables on subjects that will cover a key role in the future evolution of ECR ion sources.

More than 70 contributions have been submitted from several countries showing that ECRIS science and technology has indeed literally spread all around the world. For the sixth successive time at the ECRIS workshop, Pantechnik awards the Geller prize. It rewards an exceptional contribution to the development of ECR sources and encourages young talented researchers.

The workshop will take place in the halls of the Catania Diocesan Museum, located in the heart of the old city with several archaeological and cultural attractions situated in the nearby. The venue is placed at the foot of the Etna Volcano - the highest and most active of Europe - in a city that is now experiencing its third millenium of history since its establishment in 730 BC.

The workshop includes a number of social events, which will enable participants to mix fertile cultural discussions with the state-of-art of our discipline enjoying the environment with natural and historical beauties.

Luigi Celona

Chair ECRIS 2018

ORGANIZATION

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GELLER PRIZE

We are very pleased to announce that **Pantechnick** will again be sponsoring the Geller prize for this conference. This prize will reward outstanding recent achievements in the field of ion source physics and technology made by young researcher.

This prize is awarded for the sixth time and it has been established by Pantechnik 10 years for the 18th ECRIS Workshop in Chicago (USA, 2008).

GELLER PRIZE SELECTION COMMITTEE

Santo Gammino	INFN-LNS
Takahide Nakagawa	RIKEN, Japan
Vadim Skalyga	IAP-RAS, Russia
Thomas Thuiller	LPSC, France
Mi-Sook Won, **Chair**	KBSI, South Korea
Daniel Xie	Lawrence Berkeley Lab, USA
Hong-Wei Zhao	IMP, China

WORKSHOP SCHEDULE

	Sunday 9 Sept.	Monday 10 Sept.	Tuesday 11 Sept.	Wednsday 12 Sept.	Thursday 13 Sept.	Friday 14 Sept.
08:30		Registration				
9:00 - 9:30		Opening session	Morning oral session Chair: Daniel Xie	Morning oral session Chair: David Mascali	Morning oral session Chair: G. Machicoane	Transfer to LNS
9:30 - 10:50		Morning oral session Chair: Santo Gammino Status reports and new developments	Status reports and new developments	Plasma Investigations	High Current	Morning oral session Chair: Klaus Tinschert Plasma Investigations
		Coffee Break	Coffee Break	Coffee Break	Coffee Break	Coffee Break
11:10 - 12:30		Morning oral session Chair: Hongwei Zhao Applications, Status reports and new developments	Morning oral session Chair: Takahide Nakagawa Plasma physics and techniques	Morning oral session Chair: Thomas Thuiller Plasma physics and techniques	Round table Chair: Peter Spaedtke Extraction and transport of intense ion beams	Morning oral session Chair: Sandor Biri Plasma Investigations Closing remarks
12:30 - 14:30		Lunch break	Lunch break	Light Lunch (provided)	Lunch break	Lunch break (provided)
14:30 - 16:30		Afternoon oral session Chair: Richard Vondrasek Charge Breeding	Geller prize session Chair: Mi-Sook-Won Co-Chair: Gabriel Gaubert (14:30-15:20) Poster session (15:20 - 16:50) (coffee break included)	Conference outing	Afternoon oral session Chair: Vadim Skalyga High Current	Tour of LNS
16:30 - 16:50		Coffee Break			Poster session (15:50 - 17:30) (coffee break included)	Bus to hotels
16:50 - 18:15		Round table Chair: Daniela Leitner Future Magnetic systems for ECRIS	Round table Chair: Hannu Koivisto Future of ECRIS, beyond the scaling laws?			
18:15 - 20:00	Registration					
20:00 - 22:30	Welcome reception				Conference Banquet	

GENERAL INFORMATION

Oral sessions:

All oral sessions will take place in the main hall. Authors are requested to keep the time of each talk leaving to the audience the time for discussion and questions. In detail: 39 talks of 20 min. each (15+5) and 6 talks of 30 min. each (23+7) have been allocated. Authors are requested to upload the presentations in PPT or PDF format through the JACOW repository or on the presentation laptop one session before the scheduled time.

Poster sessions:

Poster sessions will take place on Tuesday 11th and Thursday 13th. You are invited to upload poster in PPT or PDF format through the JACoW your repository. The poster must be displayed prior the beginning of the Tuesday session and we encourage you to leave it posted up till the end of the Thursday session.

Proceedings:

Proceedings will be published as usual on the JACOW repository along with the ones of the previous ECRIS Workshops editions. All papers must be submitted to the JACOW repository before September 14 (see Proceedings page on the website).

Moreover, in agreement with the International Advisory Committee, a peer reviewed journal interested in the publication of a special issue with the ECRIS18 papers has been identified.

Among the different choices The Journal of Instrumentation (JINST) has been chosen to guarantee visibility in publication and citation databases. Authors interested in the publication on JINST may contact the conference secretariat, the instructions are posted on the ECRIS'18 website.

Exhibitors:

The booths for exhibitors are installed in the same area of coffee breaks and of the poster sessions.

Welcome cocktail

Sunday 9th, 20:00 – 22:30 – Diocesan museum – Porta Uzeda terrace

Lunches

The lunch break is two hours long: the area around the workshop venue is plenty of several kind of restaurants, there is also a possibility to have a walk around the historical monuments in the nearby. The lunches of Wednesday 12th and Friday 14th will be provided.

Conference outing

Buses will leave from Diocesan Museum on Wednesday 12th at 14:00 riding you around the most important places and monuments in Noto (SR).

Banquet

Buses will leave from Diocesan Museum on Thursday 13th at 19:30.

LNS tour

The LNS tour will take place on Friday after the lunch break offered by the LNS Director.

PROGRAM – Oral Contributions

PROGRAM – Poster Contributions

Monday, 10th September 2018

Opening session: 9:00 – 9:30

Welcome of INFN-LNS director

Giacomo Cuttone

Morning oral session: 9:30 – 10:50

Chair: Santo Gammino

Development and status of 45 GHz FECR

Hongwei Zhao[1], Liangting Sun[1]

[1] IMP/CAS, Lanzhou

A 45 GHz superconducting ECR ion source FECR (a first Fourth generation ECR ion source) is being built at IMP. FECR will be the world first Nb3Sn superconducting-magnet-based ECR ion source with 6.5 Tesla axial mirror field, 3.5 Tesla sextupole field on the plasma chamber inner wall and 20 kW@45 GHz microwave coupling system. The biggest challenge for FECR is its Nb3Sn superconducting magnet with the maximum magnetic field 11.8 Tesla on the sextupole coils and 11.3 Tesla on the solenoid coils. Optimized design of FECR Nb3Sn superconducting magnet and detailed analysis of the shell-preloading-based mechanical structure illustrates that it is feasible for FECR to work stably at the designed 45 GHz operation fields. However, it is very challenging to manufacture such high field Nb3Sn magnet. A prototype magnet of FECR is being built to verify the magnet mechanical design. 20 kW@45 GHz microwave gyrotron system is ready for FECR ion source and was firstly tested with SECRAL-II ECR source to validate 45 GHz microwave coupling. This talk will present technical design and development of FECR focusing on the Nb3Sn magnet and its prototyping.

Exploring the potential of VENUS ion source

Daniel Xie[1], Janilee Yvette Benitez[1], Claude M Lyneis[1], Damon Todd[1], Wang Lu[2]

[1] LBNL, Berkeley, California
[2] IMP/CAS, Lanzhou

Exploration of the VENUS potential started a few years ago has led to greatly enhanced source performance. Improved cooling of the plasma chamber and a slightly modified 28 GHz microwave coupling have resulted in reliable operations, increased injected power of up to 10 kW, and a substantial enhancement in VENUS overall performance. VENUS has produced the following ion beams: 4 eμA of $^{40}Ar^{18+}$, 17 eμA of $^{78}Kr^{31+}$, 0.8 eμA of $^{124}Xe^{45+}$, 0.6 eμA of $^{197}Au^{58+}$ and 0.1 eμA of $^{209}Bi^{61+}$. Compared to prior performance, beam intensity has increased up to a factor of 6 for the same ion charge state and there has been an increase of five charge states upwards for Au and Bi beams where beam intensity is about 1 eμA. In addition, a number of higher charge state ion beams at lower intensities have been produced. With ion beams of $^{124}Xe^{47+}$, 48^{+}, 49^{+} injected from VENUS, the total beam energy has reached a new record of ~ 2.6 GeV for a K140 56-year-old cyclotron. Recent VENUS ion productions are rather significant and indicate that there may still be room for further improvements. This paper updates and discusses the source performance and the ongoing schemes to further explore the VENUS capability.

First Ion Beams Extracted from a New JYFL 18 GHz Ecris: HIISI

Hannu Koivisto[1], Taneli Kalvas[1], Risto Juhani Kronholm[1], Olli Tarvainen[1]

[1] JYFL, Jyvaskyla

A new 18 GHz ECR ion source HIISI is under commissioning at the Accelerator Laboratory at the University of Jyväskylä (JYFL). The main purpose of HIISI is to produce high-energy beam cocktails, e.g. Xe^{44+}, for radiation effects testing of electronics, and high intensity ¿ 5 MeV/u ion beams for international nuclear physics program with the K130 cyclotron. The initial commissioning results in 18+14 GHz operation mode using 24 segment sextupole (1.3 T) were performed in autumn 2017. In the beginning of 2018 a stronger 36 segment sextupole (1.45 T) was constructed. The first tests have been performed during the spring 2018 demonstrating improved performance of HIISI. As an example, the intensity of 0.5 mA was reached for the Ar^{12+} ion beam at the extraction voltage of 16 kV and total microwave power of about 2.5 kW. In this article we will present the latest development work, ion beam intensities of oxygen, argon and xenon, and future prospects of HIISI.

Monday, 10th September 2018

Morning oral session: 11:10 – 12:30

Chair: Hongwei Zhao

Status of a New 28 GHz Gasdynamic Ion Source for Multipurpose Operation (GISMO) Development at the IAP RAS

Vadim Skalyga[1], Alexei Bokhanov[1], Mikhail Glyavin[1], Sergey Vladimirovich Golubev[1], Ivan Izotov[1], Mikhail Yurevich Kazakov[1], Roman L'vovich Lapin[1], Mikhail Vladimirovich Morozkin[1], Mikhail Proyavin[1], Sergey Razin[1], Roman Shaposhnikov[1], Alexander Tsvetkov[1]

[1] IAP/RAS, Nizhny Novgorod

The main latest activities in the field of ECR ion sources development at the Institute of Applied Physics (Nizhny Novgorod, Russia) are connected with transition from pulsed to continuous wave operation regime of a high-current gasdynamic sources. The main advantages of such devices in pulsed operation are extremely high ion beam current with a current density up to 600 ¿ 700 mA/cm^2 in combination with low emittance i.e. normalized RMS emittance below 0.1 ¿¿mm¿mrad. To continue development of a CW gasdynamic ion source a new experimental facility called GISMO (Gasdynamic Ion Source for Multipurpose Operation) was construction at the IAP RAS. The source utilizes 28 GHz/10 kW gyrotron radiation for plasma heating in a fully permanent magnet system with magnetic field configuration close to simple mirror trap. The first plasma in GISMO was ignited in the 2018. Status of the new source development will be presented.

The work was supported by Russian Science Foundation, Grant No. 16-12-10343.

Impact of ion source stability for a medical accelerator

Nadia Gambino[1], Szymon Myalski[1], Laurids Adler[1], Andrea De Franco[1], Fabio Farinon[1], Greta Guidoboni[1], Liviu Penescu[2], Christoph Kurfuerst[1], Mauro Torino Francesco Pivi[1], Claus Schmitzer[1], Ivan Strasik[1], Alexander Wastl[1],

[1] EBG MedAustron, Wr. Neustadt
[2] Abstract Landscapes, Montpellier

MedAustron is a synchrotron-based hadron therapy center located in Lower Austria. Accelerated proton beams with energies of 62-252 MeV/u are used to treat patients since 2016. The carbon ion beam is currently under commissioning and will provide treatment in 2019 with energies of 120-400MeV/u. Two of the four irradiation rooms are used for clinical treatment while the preparation of the Gantry beam line is ongoing. Proton beams of up to 800 MeV will be provided for non-clinical research. The Injector features three identical ECRIS from Pantechnik, two of which are used to generate the proton and the carbon beam respectively. The medical environment of the accelerator puts strict requirements on the ion source long-term stability operation. The extracted beam current from the source allow for maximum current fluctuations on the order of ±2.5% on continuous run. In this work we discuss the impact of the ion source performances on the characteristics and stability of the entire accelerator. Further, we discuss the latest progress on carbon commissioning and the future perspectives with particular emphasis on the source requirements.

Characterization of the AISHA Ion Source

L. Celona[1], S. Gammino[1], D. Mascali[1], G. Castro[1], F. Chines[1], O. Leonardi[1], M. Mazzaglia[1], L. Neri[1], G. Torrisi[1]

[1] INFN/LNS, Catania

The AISHa ion source has been designed to generate high brightness multiply charged ion beams with high reliability, easy operations and maintenance for hadrontheraphy applications. Aisha is a compact ECRIS whose hybrid magnetic system consists of a permanent Halbach-type hexapole magnet and a set of independently energized superconducting He-free coils. The present work shows the results of the ion source commissioning in SFH operational mode (18 GHz) for different ion species. Current status and further improvements will be highlighted.

Positive Ion Mass Spectrometry: A Novel Technique of Accelerator Mass Spectrometry Using Ecris.

Pierre Salou[1], Gabriel Gaubert[1], Thilo Michael Hauser[2], Kenneth Kearney[2], Mark Sundquist[2], Stewart Freeman[3], Cameron McIntyre[3], Richard Peter Shanks[3]

[1] PANTECHNIK, Bayeux
[2] National Electrostatics Corp., Madison, Wisconsin
[3] Scottish Universities Environmental Research Centre, East Kilbride

Accelerator mass spectrometry (AMS) for radio-isotope quantification, like radiocarbon dating, commonly uses negative ion sources (cesium sputter ion sources and cesium gas ion source) to eliminate nitrogen interference. This implies a low yield of ion production, maintenance and refill of cesium, beam intensity instabilities and a long preparation of sample in the case of solid target. A new technique of mass spectrometry, the so called PIMS for Positive-ion Mass Spectrometry, using electron cyclotron resonance ion source (ECRIS) producing positive ions coupled with a charge exchange gas cell, was developed. A PIMS prototype was built and tested. First tests showed comparable but easier results compared to the current AMS machine, within a smaller footprint (a few squared meters), lower potential (100 kVolts) and with the reliability of an ECRIS like stability of the beam, low maintenance, etc. Improvements of the ECRIS were done in order to fulfil the AMS requirements, for example by reducing the recovery time between two samples.

Monday, 10th September 2018

Afternoon oral session: 14:30 – 16:30

Chair: Richard Vondrasek

Challenges and Prospects of Electron Cyclotron Resonance Charge Breeding

Thomas Thuillier[1], Julien Angot[1], Maud Baylac[1], Bichu Subhash Bhasi bhaskar[1], Jean-Baptiste Cully[1], Josua Jacob[1], Thierry Lamy[1], Alexandre Leduc[1], Patrick Sole[1]

[1] LPSC, Grenoble Cedex

The Electron Cyclotron Resonance charge breeder (ECR CB) is one of the instruments used to boost the radioactive ion beam (RIB) charge state (from 1+ to N+) in isotope separator on-line (ISOL) facilities. The important parameters of a charge breeder are the 1+N+ conversion efficiency, the charge breeding time and the N+ beam purity. While the ECR CB can manage intense 1+ beam without difficulty, the present CB generation co extracts significant amounts of impurities which can be detrimental to the study of very low intensity N+ RIB in today facilities if no downstream high mass resolution separation is available. A status of the research activity on ECR CB is proposed underlining the last progresses and the limits of use. Prospects to develop a new generation ECR CB with a reduced impurity co-extraction is proposed. Such an instrument would make possible the use of the 1+N+ technique in next generation facilities like EURISOL.

Charge-Breeding of Radioactive Ions at the Texas A&M Cyclotron Institute

Donald Philip May[1], Juha Eerik Arje[1], Fred Abegglen[2], Gabriel Tabacaru[2]

[1] Texas A&M University Cyclotron Institute, College Station, Texas
[2] Texas A&M University, College Station, Texas

Singly charged, radioactive ions produced in an Ion Guide Isotope Separation On-Line (IGISOL) target cell have been charge-bred in an ECR ion source and subsequently accelerated to high energy by the K500 cyclotron at Texas A&M University. The 1+ ions were accelerated to near the extraction voltage of the ECRIS and then decelerated through the injection-end magnetic mirror field of the ECRIS. The charge-breeding efficiency was only at most 1%, and as a consequence another method of injection into the ECRIS is being attempted. As an experiment an alkali 1+ ion source was placed at the entrance of a 0.4 meter long rf-only sextupole ion-guide (SPIG) held near the extraction voltage of the ECRIS, and the exit end of the SPIG placed on axis near the maximum axial magnetic field at the injection end of the ECRIS. This arrangement resulted in good charge-breeding efficiency, perhaps as much as 10% into one charge-state, although this was difficult to quantify due to the difficulty of measuring the output from the SPIG. Direct injection of 1+ radioactive ions via a longer (2.5 m) SPIG transporting products from the IGISOL target cell is now being implemented and will be reported on.

Funding Agency: U. S. Dept of Energy Grant DE-FG02-93ER40773

Charge breeding time studies with short pulse beam injection

Julien Angot[1], Maud Baylac[1], Josua Jacob[1], Thierry Lamy[1], Naomi Preveraud[1], Patrick Sole[1], Thomas Thuillier[1], Olli Tarvainen[2]

[1] LPSC, Grenoble Cedex
[2] JYFL, Jyvaskyla

Investigations on the Charge Breeding (CB) time have been done with the PHOENIX ECR Charge Breeder. The traditional measurement method consists in generating a 1+ ion beam rise front and measuring the time to reach 90% of the final steady N+ ion beam intensity. In order to study the possible self-consistent effects of the accumulation of injected ions in the plasma and to better understand the 1+N+ process, short 1+ pulses were injected and the time resolved N+ beam responses were measured. Several experimental campaigns were performed with different elements and configurations. The effect of several parameters was studied like the amplitude and the width of the pulse. The measurements were also used to estimate the 1+N+ efficiencies in the case of radioactive species. The new short pulse CB time method and the experimental results will be presented.

SPIRAL1 charge breeder: performances and status

Laurant Manoury[1], Arun tejaswee Annaluru[1], Olivier Bajeat[1], Pierre Delahaye[1], Mickael Dubois[1], Romain Frigot[1], Stéphane Hormigos[1], Pascal Jardin[1], Omar Kamalou[1], Patrice Lecomte[1], Benoit Osmond[1], Guillaume Peschard[1], Ujic Predrag[1], Blaise-Maël Retailleau[1], Alain Savalle[1], Jean Charles Thomas[1], Ville Toivanen[1], Emil Traykov[2], Julien Angot[3]

[1] GANIL, Caen
[2] IPHC, Strasbourg Cedex 2
[3] LPSC, Grenoble Cedex

SPIRAL1 Upgrade hardware is now almost completed. The FEBIAD 1+ source has been tested for the production of new radioactive isotopes, PHOENIX Charge Breeder (CB) is in place reproducing nearly the charge breeding efficiencies measured at LPSC lab and the infrastructure is operational to welcome such new multifaceted devices. The commissioning phase started in the second semester of 2017. It has consisted of a stepwise process to test the upgrade of the SPIRAL1 facility from simple validation (operation of CB as a stand-alone source) up to the production of the first 1+/n+ Radioactive Ion Beam (RIB) with the $^{37}K^{9+}$. This contribution will summarize the different steps completed successfully and especially the measurements done to validate each of the commissioning stages. These include e.g. ionization efficiencies for CB; beam line optics for 1+/n+ and charge breeding efficiencies. The remaining effort required to ensure the reliability of the complete system for routine RIB operation is also presented. A section will be dedicated to a new feature of SPIRAL1 facility: combination of CB and CIME leads to deliver stable beams with energies never done until now.

1 + / n + method: numerical simulation studies and experimental measurements on the SPIRAL1 charge breeder

Arun tejaswee Annaluru[1], Pierre Delahaye[1], Mickael Dubois[1], Pascal Jardin[1], Omar Kamalou[1], Laurent Maunoury[1], Alain Savalle[1], Ville Toivanen[1], Emil Traykov[2]

[1] GANIL, Caen
[2] IPHC, Strasbourg Cedex 2

In the framework of the SPIRAL1 facility, the R&D of charge breeding technique is of primary interest for optimizing the yields of radioactive ion beams (RIBs). This technique involves the transformation of mono-charged ion beams into multi-charged ion beams by operating an ECR charge breeder (CB). During the SPIRAL1 commissioning, experimental studies have been performed in order to understand the transport of the beam through the CB (shooting through mode) and to investigate the 1+ capture processes. Numerical simulations including ion optics and some ECR plasma features have been developed to reproduce the measurements. This article will also summarize the novel method, which has been executed by comparing the experimental results with SIMION 3D simulation output. The goal was to determine the importance of beam parameters which influence the transmission of the 1+ beam through the CB and plasma parameters (sheath and potential dip) which play a role on the 1+ capture.

Redesign of the GANIL GTS ECRIS for 1+/n+ Studies

Ville Toivanen[1], Pascal Jardin[1], Laurent Maunoury[1], Clement Michel[1]

[1] GANIL, Caen

More than half of the beams produced at GANIL are metallic elements, underlining the importance of their continuing development. Compared to the conventional techniques (oven, sputtering, MIVOC), the 1+/n+ method has demonstrated superior ionization efficiencies, suggesting the potential for improved metal beam production. Dedicated studies are required to assess the feasibility of this approach. The PHOENIX Booster charge breeder is now in operation at the GANIL radioactive beam facility SPIRAL1. Operation in high radiation area poses challenges for its future development. A separate test stand supporting charge breeder and metal ion beam R&D is thus desirable. The GTS 14.5 GHz ECRIS has been chosen as a platform for 1+/n+ studies. After the upgrade program of 2017-2018, the GTS provides good performance and versatility, making it well-suited for ion source R&D. A new injection module has been designed for 1+ injection into the GTS plasma to be used in the 1+/n+ studies. It can be easily replaced with the conventional system for normal ion source operation. The design of the new injection system will be presented in detail with ion optical simulations of the 1+ beam injection.

Monday, 10th September 2018

Round Table: 16:50 – 18:15

Future Magnetic systems for ECRIS

Chair: Daniela Leitner

Tuesday, 11th September 2018

Morning oral session: 9:00 – 10:50

Chair: Daniel Xie

Optimization of RIKEN SC-ECRIS performance for production of intense metal ion beam

Takahide Nakagawa[1], Yoshihide Higurashi[1], Takashi Nagatomo[1], Jun-ichi Ohnishi[1]

[1] RIKEN Nishina Center, Wako

To produce intense metal ion beams (e.g. Ti^{13+}, $V^{12+,13+}$, U^{35+}) for super heavy element search and RIBF experiments at RIKEN, we tried to optimize the RIKEN 28 GHz SC-ECRIS performance. Based on the scaling low and ¿high B mode¿ operation, we systematically measured the beam intensity of various heavy ions as a function of Binj, Br and Bext with 28 and 18 GHz microwaves. In these experiments, we observed that (1) optimum Binj>1.6~2 Bext, (2) optimum Br>1.2~1.4 Bext and (3) optimum Bext is dependent on the charge state and ion spices as described by scaling low. We also observed same tendency for 18 GHz liquid-He-free SC-ECRIS. Using this systematics, we obtained ~400microA of V^{13+} at the RF power of 2kW (28 GHz) and very low Bext (~1.4 T with 28 GHz). For long term operation (one month), we successfully produced very stable beam of 100~200 microA of V^{13+} ion. Following the success, we constructed new 28 GHz SC-ECRIS for super heavy element search experiments. In this contribution, we report the experimental results in detail and how to produce intense metal ion beams.

Present Status and Future Prospect of Heavy Ion Radiotherapy

Atsushi Kitagawa[1], Masayuki Muramatsu[1]

[1] QST-NIRS, Chiba

Heavy Ion Radiotherapy is one of important applications of an ECRIS. When the authors reported the status of heavy ion radiotherapy in the ECRIS 2012, only five facilities carried out the treatment worldwide. At present, ten facilities are under operation and eight are under commissioning or construction. All of them utilize ECRISs for the production of carbon ions, mainly. Heavy ion radiotherapy exponentially awakens worldwide interest. There are many construction plans in various countries. Heavy ion radiotherapy has been approved to cover by the National Health Insurance in Japan since 2016. In April 2018, fees for treatment in Japan are revised to 1,600,000 Yen for ¿prostate tumor¿ and 2,375,000 Yen for ¿bone and soft tissue tumor¿ and ¿head and neck tumor¿, respectively. The expectation of widespread use has accelerated sharply. On the other hand, the cost reduction for a facility has been urged too. We will summarize the present status and will speculate upon the future of heavy ion radiotherapy and related ECRIS¿s technology.

New 28-Ghz Superconducting Ecr Ion Source for Synthesizing New Super Heavy Elements of Z > 118

Takashi Nagatomo[1], Masaki Fujimaki[1], Nobuhisa Fukunishi[1], Yoshihide Higurashi[1], Osamu Kamigaito[1], Keiko Kumagai[1], Takahide Nakagawa[1], Jun-ichi Ohnishi[1], Naruhiko Sakamoto[1], Akito Uchiyama[1]

[1] RIKEN Nishina Center, Wako

To increase the intensity of heavy-ion beams such as V and Cr for synthesizing new super heavy elements (SHE), we started to construct a new 28-GHz Superconducting ECR ion source (SC-ECRIS) for RIKEN Linear Accelerator (RILAC) in 2017. The new SC-ECRIS consists of fully SC magnets and is designed to produce the beams of more than a hundred μA. RILAC is also currently being upgraded by adding superconducting (SC) rf cavities. The beam losses not only in the cavities but also in the beam pipes neighboring them must be avoided to keep the environment in the cold section as clean as possible. Thus, the high-intensity beam with well-controlled emittance is required for this SHE project. To meet the requirement, we use a triplet slits to limit the transverse emittance of the beam in the low energy beam transport (LEBT). In this contribution, we report the recent developments and the property of the first beam extracted from the new 28-GHz SC-ECRIS.

FRIB 28 GHz ECR ion source construction progress and commissioning status

Guillaume Machicoane[1]

[1] FRIB, East Lansing, Michigan; NSCL, East Lansing, Michigan

The Facility for Rare Isotope Beams at Michigan State University (FRIB) consists of a room-temperature front end and a Superconducting RF linac that will accelerate light to heavy ions up to Uranium to energies higher than 200 MeV and will be able to achieve a final beam power on target of 400 kW. Construction and installation of technical equipment is progressing rapidly. In particular commissioning of the Front End has already been completed successfully using a dedicated 14 GHz ECR Ion source and preparation for the acceleration of the beam through the first 3 linac cryomodules are underway. In the meantime construction and testing of a new superconducting magnet for a 28 GHz ECR Ion source was completed at Lawrence Berkeley National Laboratory (LBNL) and the cold mass delivered to FRIB in January 2018 with an overall completion of the ion source expected by August 2019. This paper review the progress on the 28 GHz ion source construction and the work done during the commissioning of the Front End.

Work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661

High Power Operation with SECRAL-II Ion Source

Liangting Sun[1], Xing Fang[1], Junwei Guo[1], Wei Huang[1], Jibo Li[1], Libin Li[1], Lixuan Li[1], Wang Lu[1], Hongyi Ma[1], Zhen Shen[1], Yao Yang[1], Wenhui Zhang[1], Xuezhen Zhang[1], Hongwei Zhao[1]

[1] IMP/CAS, Lanzhou

SECRAL-II ion source has been successfully developed with the experiences from SECRAL that is another superconducting ECR ion source in operation at IMP. Other than that, SECRAL-II has been intentionally optimized in structure so as to make it optimum for 28 GHz microwave operation. This ion source was available on the test bench in early 2016, and has been used for 28 GHz high microwave power commissioning and tests. With a maximum power 10 kW@28 GHz and 2 kW@18 GHz, very high microwave power density and dense hot plasma could be built in the 5-liter volume plasma chamber. Consequently, very high current density ion beams of high charge states are achievable, which have already exceeded the performance the 24 GHz SECRAL had made couple of years ago. However, there is also the intractable issues stemmed from the hot dense electrons inside the plasma, such as plasma chamber cooling, dynamic heat load to the cryogenic system, and so on. This paper will present the recent results of SECRAL-II operated with high microwave power. The typical consequent issues during the high power course other than high intensity high charge state ion beam production will be discussed.

Tuesday, 11th September 2018

Morning oral session: 11:10 – 12:30

Chair: Takahide Nakagawa

Perspective on High-Power Microwave Coupling in Gyrotron Frequency ECR Ion Sources

Junwei Guo[1], Xing Fang[1], Yucheng Feng[1], Libin Li[1], Lixuan Li[1], Wang Lu[1], Zhen Shen[1], Liangting Sun[1], Wenhui Zhang[1], Xuezhen Zhang[1], Hongwei Zhao[1]

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Better understanding of microwave power coupling is a key issue to enhance the performance of an ECR ion source in terms of higher ion beam intensity yield and critical in the design of the next generation ECRIS. For this reason, we investigated the impact on highly charged ion production using different microwave coupling modes and waveguide calibers with superconducting ECR Ion Source SECRAL, and some very encouraging results were obtained. Based on the comparison of ion source performance working at different coupling schemes, analytical studies on microwave power launching efficiency and the characteristics of electric field power distribution inside the ECRIS chamber have been made and some preliminary conclusions will be given in this paper. This paper will also provide a 45 GHz microwave solution for the next generation ECR ion source FECR (a Fourth generation ECR ion source). After off-line tests of microwave transmission efficiency and mode purity, the 45 GHz gyrotron microwave system has been commissioned with SECRAL-II (a superconducting ECR ion source optimized for 28 GHz operation), and some preliminary results have been achieved and will be given in this paper.

Plasma Heating and Innovative Microwave Launching in ECRIS: Models and Experiments

Giuseppe Torrisi[1], Giuseppe Castro[1], Luigi Celona[1], Santo Gammino[1], David Mascali[1], Maria Mazzaglia[1], Gino Sorbello[1], Eugenia Naselli[2]

[1] INFN/LNS, Catania
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Microwave-to-plasma coupling in ECRIS has been based on the classic scheme of waveguide-to-cylindrical plasma cavity matching. Optimization has been often obtained by empirical adjustments leading to an oversimplified model, obtaining however satisfying performances. In order to overcome the ECR-heating paradigm, on-purpose design of launchers¿ setup adequate diagnostics have to be developed. This paper describes three-dimensional numerical simulations and Radio Frequency (RF) measurements of wave propagation in the microwave-heated magnetized plasmas of ion sources. Moreover, driven by an increasing demand of high frequency ECR ion sources, innovative ideas for the geometry for both the plasma chamber and the related RF launching system - in a plasma microwave absorption-oriented scenario ¿ are presented. Finally, the design of optimized launchers enabling ¿single-pass¿ power deposition, not a¿ected by cavity walls e¿ects, are described.

A Possible Optimization of Electron Cyclotron Resonance Ion Sources Plasma Chambers

Carmelo Sebastiano Gallo[1], Alessio Galatà[1], David Mascali[2], Giuseppe Torrisi[2]

[1] INFN/LNL, Legnaro (PD)
[2] INFN/LNS, Catania

In the resonant cylindrical cavities of Electron Cyclotron Resonance Ion Sources (ECRIS), microwave fields are used to generate and sustain the plasma. Normally, resonant modes of a higher order than the fundamental one are excited, due to the high frequency used compared to the dimensions of the plasma chambers: this can lead to small electric fields on the resonant surface, translating in low electrons energy and poor source performances. In this paper, we propose a possible modification of the conventional plasma chambers, resulting from an electromagnetic study carried out on a Caprice-type full permanent magnet ECRIS. Such modification implies the excitation of a ¿length-independent¿ resonant mode, having an intense and homogeneous electric field on the plasma chamber axis. This characteristic makes the modification suitable to be applied to numerous ECR sources. The positive effect on the plasma electrons energy distribution will be also shown.

Manufacture of a 7.5 M Long Cryogen-Free Magnet System for Neutron Decay Studies

Roger Mitchell[1], Jeremy Good[1]

[1] Cryogenic Ltd, Acton, London

The design of a large purpose built cryogen-free magnet is reviewed. The system has been manufactured for the Fundamental Neutron Physics Beamline at the Spallation Neutron Source in Oak Ridge, Tennessee. The magnet system will house a custom spectrometer and be used to measure a, the electron-neutrino correlation parameter, and b, the Fierz interference term in neutron beta decay. The cryostat is cylindrical, 7.5 m along its axis and 1.43 m in diameter. It houses a complex set of niobium-titanium superconducting windings which provide a varying magnetic field profile along a 320 mm diameter gold-plated UHV bore. The bore tube extends along the full length of the cryostat and has orthogonal ports connected to the neutron beamline. A vacuum of $<3.10^{-10}$ mbar is achieved. The stray field generated by the magnet windings is compensated by a series of negatively wound co-axial windings which have approximately twice the diameter of the internal positive windings. The cryostat system will be housed in a passive steel shield to further compensate the stray field. No liquid cryogens are used for normal operation of the system.

Tuesday, 11th September 2018

Geller prize session: 14:30 – 15:20

Chair: Mi-Sook-Won

Co-Chair: Gabriel Gaubert

Tuesday, 11th September 2018

Round Table: 16:50 – 18:15

Future of ECRIS, beyond the scaling laws?

Chair: Hannu Koivisto

Wednesday, 12th September 2018

Morning oral session: 9:00 – 10:50

Chair: David Mascali

The Energy Distribution of Electrons Escaping Minimum-B ECR Plasma in Unstable Mode

Ivan Izotov[1], Dmitriy Mansfeld[1], Vadim Skalyga[1], Taneli Kalvas[2], Hannu Koivisto[2], Risto Juhani Kronholm[2], Olli Tarvainen[2]

[1] IAP/RAS, Nizhny Novgorod, [2] JYFL, Jyvaskyla

ECRIS plasmas are prone to kinetic instabilities associated with strong microwave emission and bursts of energetic electrons escaping the confinement*. It has been proven** that the instabilities restrict the parameter space available for the optimization of extracted beam currents of highly charged ions. Here we report the measurement of the electron energy distribution (EED) of electrons escaping axially from a minimum-B trap in unstable mode of operation where the Bmin/BECR-ratio exceeds a certain threshold value. The experimental data were recorded with 14 GHz ECRIS at the JYFL accelerator laboratory. The electrons escaping the unstable plasma through the extraction mirror of the ion source were detected with a secondary electron amplifier placed downstream from a dipole magnet serving as an electron spectrometer with 500 eV resolution. It was discovered that the EED is strongly non-Maxwellian. The comparison to EEDs acquired in stable mode, i.e. below the threshold Bmin/BECR-ratio, shows that a "hot" electron fraction with energies in the 200-300 keV range might be responsible for the development of periodic cyclotron instabilities.

* I Izotov et all, Plasma Sources Sci. Technol. 24 (2015) 045017 (9pp)

** O. Tarvainen et all, Review of Scientific Instruments 87, 02A703 (2016)

The work was supported by Russian Science Foundation, Grant No. 16-12-10343.

Bremsstrahlung Measurements with SECRAL II Ion Source

Jibo Li[1], Junwei Guo[1], Libin Li[1], Wang Lu[1], Liangting Sun[1], Xuezhen Zhang[1], Hongwei Zhao[1]

[1] IMP/CAS, Lanzhou

To investigate the hot electrons in highly charged electron cyclotron resonance (ECR) plasma, the bremsstrahlung spectra for X-rays between 10 and 300 keV were measured from SECRAL- II, a third-generation ECRIS at the Institute of Modern Physics. We focused on how the external source parameters, especially the magnetic configuration affects the axial bremsstrahlung and the resulting spectral temperature Ts. The experimental results have shown that Ts appears to be dependent solely on the minimum magnetic field Bmin rather than (Bmin/BECR) and the microwave frequency ¿. In addition, this investigation has shown that Ts is not sensitive to HV, bias and gas pressure, which implies that a more careful consideration into the heating mechanism of ECRIS is needed.

Plasma Instability Studies of the SuSI 18 Ghz Source

Bryan Christopher Isherwood[1], Guillaume Machicoane[2], Eduard Pozdeyev[2], Jeffry W. Stetson[3]

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[2] FRIB, East Lansing, Michigan
[3] NSCL, East Lansing, Michigan

Instabilities in magnetized plasmas, such as the cyclotron instabilities identified at JYFL*, can cause fast variations of the extracted ECRIS beams. In order to understand the effect of the radial component and longitudinal gradient of the magnetic field on plasma stability a series of measurements has taken place using the Superconducting Source for Ions (SuSI) at the National Superconducting Cyclotron Laboratory (NSCL). We present here the results from investigations into the instability characteristics of the beam current from SuSI at 18 GHz by varying longitudinal and radial magnetic field profiles, injected microwave power, and bias disk voltage. Our investigation shows multiple regions of beam variation within the magnetic field v.s. power phase space with multiple distinct modes of variance.

*O. Tarvainen, et al., Plasma Sources Sci. Technol. Vol. 23 (2014)

Funding Agency: National Science Foundation Grant 1632761

Time resolved X-ray measurements in a simple mirror trap

Tudisco Salvatore[1], Giuseppe Castro[1], Luigi Celona[1], Santo Gammino[1], Gaetano Lanzalone[1], Frazia Litrico[1], David Mascali[1], Maria Mazzaglia[1], Annamaria Muoio[1], Giuseppe Torrisi[1], Eugenia Naselli[1-2], Rosalba Miracoli[3]

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The time-resolved characterization of the X-ray emission represents an innovative technique to investigate the heating mechanism of the worm/hot electron component in ECRIS devices. In this paper, the technique has been described and the results of an experimental campaign of measurements in order to characterize the X-rays emission of an axis-symmetric simple mirror trap has been showed. Particular attention has been paid to the ignition and turning off phase. This approach has permitted to estimate confinement time of the warm/hot electron population and put in evidence eventual instability effects during the critical phases. Further developments and perspectives of the technique will be highlighted.

Effect of the two-close-frequency heating to the extracted ion beam and to the X-ray flux emitted by the ECR plasma

Richárd Rácz[1], Sándor Biri[1], Zoltán Perduk[1], Alessio Galatà[2], Giuseppe Castro[3], Luigi Celona[3], Santo Gammino[3], David Mascali[3], Maria Mazzaglia[3], Eugenia Naselli[3], Giuseppe Torrisi [3], József Pálinkás[4]

[1] ATOMKI, Debrecen, [2] INFN/LNL, Legnaro (PD)
[3] INFN/LNS, Catania, [4] University of Debrecen, Debrecen

Multiple frequency heating has been used since the '90 in ECR ion sources as heating schemes able to improve current intensities especially for highly charged ions. More recently, "Two Close Frequency Heating", where the frequency gap is comparable with the scale-length of the resonance, has been proposed, expected also to be sensitive to the relative waves' phase relationship. At ATOMKI - Debrecen a dedicated experiment has been carried out for exploring the effects of the combined frequencies and their relative phase-difference in an argon plasma. The second frequency was finely tuned between 13.6-14.6 GHz with respect to the first one (fixed 14.25 GHz). An optimal frequency gap (in terms of Ar^{11+}/Ar^{6+} beam currents ratios) has been experimentally found, in agreement with the theory; the optimal power balance (total RF power was 200 W) between the two frequencies has been determined empirically. A weak but clear effect of the relative phase shift has been observed. Each configuration has been characterized by a multi-diagnostics set-up: HPGe and SDD detectors were used for the X-rays, a RF probe was introduced inside the plasma chamber to detect the radio-emission from the plasma.

Wednesday, 12th September 2018

Morning oral session: 11:10 – 12:30

Chair: Thomas Thuiller

Simulations of ECRIS Performance for Different Working Materials

Vladimir Mironov[1], Sergey Bogomolov[1], Andrey Evgenyevich Bondarchenko[1], Andrey Efremov[1], Konstantin Igorevich Kuzmenkov[1], Vladimir Loginov[1]

[1] JINR, Dubna, Moscow Region

Free parameters of Numerical Advanced Model of ECRIS (NAM-ECRIS) are selected such as to reproduce the experimental charge-state-distribution of the extracted argon ions for the DECRIS-PM source tuned to produce the maximized Ar^{8+} currents. Using these fixed parameters, we calculate the extracted currents for Kr, Xe and Bi ions in mix with oxygen, for Ca in mix with helium, and for pure O and He plasmas. Comparison is made with the experimental data; good correspondence is observed.

Ca production and strategy with the Phoenix V3 ECR ion source

Alexandre LEDUC[1], Christophe Barue[1], Frederic Lemagnen[1], Laurent Maunoury[1], Josua Jacob[2], Patrick Sole[2], Thomas Thuillier[2]

[1] GANIL, Caen
[2] LPSC, Grenoble Cedex

In the framework of the Spiral2 project, the PHOENIX V3 ion source upgrade has been developed to optimize the production of ion beams with charge over mass Q/A=1/3. The ion source aims to produce mainly metallic ions. For such beams, the atoms are often trapped into the plasma wall chamber leading to a poor global ionization efficiency. In order to study the wall capture and improve the atom to ion conversion, a temperature controlled liner is designed and under construction to test the atoms re-emission from the wall as a function of temperature in PHOENIX V3. In parallel, a hybrid particle in cells (PIC) code is under development to study the metallic ion dynamics in the plasma chamber and its extraction as an ion beam. A low temperature oven has been designed and tested leading to a global efficiency for Ca beam of above 20%. The oven was simulated and coupled to the hybrid PIC code to study the calcium atom capture from the oven to the plasma. Comparison between simulation and experience is proposed.

High temperature oven development for intense metal beam production at IMP

Wang Lu[1], Wei Huang[1], Cheng Qian[1], Liangting Sun[1], Xuezhen Zhang[1]

[1] IMP/CAS, Lanzhou

As the main injector of heavy ion accelerator, ECR ion sources need to provide more and more intense highly charged refractory metallic ion beams at Institute of Modern Physics. This requires the performance of high temperature oven to be further improved so that the crucible can operate at ultra-high temperature for a long time without deformation. In order to meet these requirements, an inductive high temperature oven with ~200 kHz of heating frequency has been proposed and fabricated. The very preliminary off-line test results show that this oven can reach up to about 1800 ¿ at 0.5 kW of AC power. In this contribution, we will discuss the structure of this high temperature oven and analyze the testing results as well.

Practical Use of High-Temperature Oven for 28 GHz Superconducting ECR Ion Source at RIKEN

Jun-ichi Ohnishi[1], Yoshihide Higurashi[1], Takahide Nakagawa[1]

[1] RIKEN Nishina Center, Wako

In order to accelerate uranium beams at the RI-beam Factory (RIBF) at RIKEN, U^{35+} ions are extracted from a 28 GHz superconducting ECR ion source by using a high-temperature oven. Our high temperature oven uses a tungsten crucible joule-heated with a large DC current. The crucible is heated to a temperature of approximately 2000°C to achieve a UO_2 vapor pressure of 0.1-1 Pa. We encountered the following problems since 2013: 1) the ejection hole of the crucible was blocked with UO_2, 2) local over-heating in the upper and lower rods supporting the crucible, and 3) the supporting rods were bent and broken by an electromagnetic force because of the reduction of tungsten strength in the long-term operation at high temperature. We overcame the above problems, and moreover by doubling the volume of the crucible, the high-temperature oven has been used for the ion source operation for the RIBF experiments since the first use in the autumn of 2016. In this contribution, we report the design changes in the new crucible, and the results of the long-term operation. Moreover, we also present the practical use of the high-temperature oven for vanadium beams for the super heavy element search.

Thursday, 13th September 2018

Morning oral session: 9:00 – 10:50

Chair: Guillaume Machicoane

High intensity proton source and LEBT for the European Spallation Source

L. Celona[1], L. Neri[1], S. Gammino[1], O. Leonardi[1], A. Miraglia[1], G. Torrisi[1], F. Chines[1], G. Calabrese[1], G. Manno[1], G. Castro[1], D. Mascali[1], M. Mazzaglia[1]

[1] INFN-LNS, Catania, Italy

At the Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud (INFN-LNS) the beam commissioning of the high intensity Proton Source (PS-ESS) and the Low Energy Beam Transport (LEBT) line for the European Spallation Source (ESS) has been completed. The official project schedule was satisfied and the source has been installed in the ESS accelerator tunnel on January 2018. Due to the high flexibility of the magnetic system, and to the innovative approach developed for the commissioning, we were able to test a huge amount of configurations (more than 400'000). The optimum source configuration that satisfy all requirements at the same time has been identified. The source is able to produce a stable total current between 40 and 125 mA (90 mA requested) through an 8 mm extraction aperture, with a proton fraction of up to 87%. At the end of the LEBT the beam characteristics fully satisfy the ESS requirements: more than 70 mA of proton beam with 99% normalized beam emittance of 2.25 π.mm.mrad have been transported with intra pulse current fluctuation below ±1.5% and long term current fluctuation below ±3%. Results and used strategy are shown in details

Point-like Neutron Emission Observation Using a Neutron Generator Based on a Gasdynamic ECR Ion Source

Sergey Vladimirovich Golubev[1], Ivan Izotov[1], Roman L'vovich Lapin[1], Sergey Razin[1], Roman Shaposhnikov[1], Alexander Sidorov[1], Vadim Skalyga[1]

[1] IAP/RAS, Nizhny Novgorod

One of the interesting applications of ECR ion sources is their use as a part of neutron generators. The use of high-current gasdynamic sources with plasma heating by high-frequency gyrotron radiation allows to increase neutron yield, and obtain a point-like neutron emission by sharp focusing of a high-quality deuterium ion beam on a target. Such point-like neutron source could perspective for neutron tomography. In the first experiments at SMIS 37 facility the high-current deuterium ion beam was focused by a simple magnetic coil (magnetic field strength up to 2 T) placed behind two-electrode extraction system on a titanium target saturated with deuterium. It was demonstrated that in such system a weakly descending 60 mA ion beam with the convergence of 50 could be focused in 1 mm spot resulting in 8 A/cm^{-2} of current density at the focal plane. Measured neutron yield from the target placed in the focal region under conditions of the beam energy of 80 keV reached a value of 10^{10} neutrons per second in 1 ms pulse.

The work was supported by Russian Science Foundation, Grant No. 16-19-10501.

Strategic Management for Delivery and Installation of Ion Source and Low Energy Beam Transport for ESS Project

Andrea Miraglia[1], Gaetano Agnello[1], Giuseppe Calabrese[1], Luigi Celona[1], Francesco Chines[1], Antonino D'Agata[1], Santo Gammino[1], Ornella Leonardi[1], Giovanni Manno[1], Salvatore Marletta[1], Antonio Maugeri[1], Lorenzo Neri[1], Riccardo Papaleo[1], Angelo Seminara[1], Davide Siliato[1]

[1] INFN/LNS, Catania

At the Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud (INFN-LNS), the delivery and installation of the high intensity Proton Source for the European Spallation Source (PS-ESS) was completed in February 2018. All planned activities were performed successfully in time without unexpected events and additional costs. The analysis of the environment in which the INFN-LNS operates and the goals to be achieved, allowed to formulate a series of strategic decisions to be undertaken. The next step was the implementation of these decisions on the organization's resources. The paper summarize the day-to-day process and actions adopted for a safe transfer of the equipment and of the knowledge needed for the next operations and for the maintenance the Ion Source.

Development of LECR4 ion source for intense beam production and LECR5 for SESRI Project

Cheng Qian[1], Xing Fang[1], Yucheng Feng[1], Junwei Guo[1], Wei Huang[1], Zehua Jia[1], Xixia Li[1], Wang Lu[1], Liangting Sun[1], Hui Wang[1], Yao Yang[1], Xuezhen Zhang[1], Hongwei Zhao[1]

[1] IMP/CAS, Lanzhou

Several intense highly charged heavy ion beams have been produced from Lanzhou ECR ion source No.4 (LECR4) since 2014. Recently an attempt to generate intense light ion beam was tested by High-B mode of LECR4 ion source. We firstly produced 8.72 emA of 4He2+ beam with 1.7 kW of 18 GHz microwave power at 30 kV extraction voltage. According to the experience of LECR4. A new room temperature ECR ion source (named LECR5) has been designed to deliver multiple charge ion beams for the Space Environment Simulation Research Infrastructure (SESRI) at Harbin Institute of Technology. It aims to produce almost all ion beams from H2+ to 209Bi32+. This article reviews the latest result of LECR4 and preliminary design of LECR5 in detail.

Gasdynamic ECR Tandem Ion Source for Negative Hydrogen Ion Production

Roman L'vovich Lapin[1], Sergey Vladimirovich Golubev[1], Ivan Izotov[1], Sergey Razin[1], Roman Shaposhnikov[1], Vadim Skalyga, Olli Tarvainen[2]

[1] IAP/RAS, Nizhny Novgorod
[2] JYFL, Jyvaskyla

H- ion sources are in great demand for beam injection into cyclotrons and storage rings utilizing charge exchange extraction or injection. The efficiency of proton beam production with the use of gasdynamic ECR ion source based on ECR discharge in a simple mirror trap has been recently demonstrated. It was then suggested to use the gasdynamic discharge as the first part of a tandem source for volumetric negative ion production. Experiments were performed with 37 GHz / up to 100 kW gyrotron power. Plasma was confined in a dual-trap magnetic system consisting of two equal simple mirror traps. The first trap was used for plasma production under the ECR condition. Dense hydrogen plasma flux from the first trap was allowed to flow into the second trap through a perforated conductive plate, which prevented propagation of the heating microwaves into the second one thus preventing plasma heating in the second chamber and allowing cold electrons to accumulate there. We present recent experimental results on this topic after optimization of the facility. We achieved a negative ion current density of 80 mA/cm^2 with a 1 mm plasma electrode aperture.

The work was supported by Russian Science Foundation, Grant No. 16-12-10343.

Thursday, 13th September 2018

Round Table: 11:10 – 12:30

Extraction and transport of intense ion beams

Chair: Peter Spaedtke

Thursday, 13th September 2018

Afternoon oral session: 14:30 – 16:30

Chair: Vadim Skalyga

Development of 2.45 GHz ECR ion source at IMP

Qi Wu[1], Liangting Sun[1], Hongwei Zhao[1]

[1] IMP/CAS, Lanzhou

The Ion Source Group at IMP has undertaken series of high intensity ion beam R&D projects. The first project is the development of the intense proton source and low energy beam (LEBT) for China Initiative Accelerator Driven Sub-Critical reactor (CiADS). The specific characteristics of the proton source are long term operation reliability and beam manipulation for the commissioning needs of the SRF accelerator. The 2nd project is the development of the intense ion source for Jinping underground Nuclear Astrophysics experiments (JUNA). The ion source was requested to provide 10 emA H^+, 10 emA He^+ and 2.5 emA $He2^+$ beams for the study of (p, ¿), (p, ¿),(¿, p) and(¿, ¿) reactions in the first phase of the JUNA project. Other projects mainly include the development of pulsed intense proton source and LEBT for Compact Pulsed Hadron Source (CPHS) at Tsing Hua university and the commissioning of an intense $H2^+$ ion source. In this paper, the studies of this intense beam injector system, for instance, beam intensities, species and ratio, beam transmission efficiency in LEBT and also the beam matching to the downstream accelerator system will be presented.

Development of test bench of 2.45 GHz ECR ion source for RFQ accelerator

Sudhirsinh J Vala[1], Mitul Abhangi[1], Mainak Bandyopadhyay[1], Rajesh Kumar[1], Ratnesh Kumar[1]

[1] Institute for Plasma Research, Bhat, Gandhinagar

The optimization of beam quality at the entrance of RFQ system requires a test bench for the optimization of ion source and ion beam parameters. The aim of this test bench is to produce the 5 mA proton beam with rms normalized emittances lower than 0.2 pi.mm.mrad for the 5 MeV RFQA. This bench consists of an indigenously developed permanent magnet based 2.45 GHz ECR ion source with three electrode ion extraction system and a LEBT to match the beam for the injection in to the RFQ. The LEBT system has been designed using TRACEWIN© code. The LEBT parameters have been optimized in order to maximize the beam transmission through the RFQ. The ECR ion source test bench has been setup and operated up to 50 kV. The plasma parameters of the ECR ion source have been measured using optical emission spectroscopy technique system. The electron temperature and electron density are typically 3.6 eV to 1.3 eV and 1-6 x 10^{13} cm^{-3} at chamber pressure in rang of 10^{-4} torr to 10^{-5} torr respectively. Deuterium ion beam of 10 mA is extracted from the test bench. This paper present the design of the test bench, results of latest extracted ion beam and plasma parameters.

Compact High current H+ ECR Ion Source with Fast Pulse Gas Valve

Yoshihisa Iwashita[1], Yusuke Takeuchi[1], Hiromu Tongu[1]

[1] Kyoto ICR, Uji, Kyoto

A compact H+ ECR ion source is under development. For reduction of the gas load to vacuum evacuation systems, the gas injection into the plasma chamber is chopped by a piezo- electric gas valve. To achieve the enough short time constant of gas flow, a small plasma chamber with 50 cm^2 is adopted and the chamber is operated in 6 GHz TE111 mode. The magnetic field is generated by permanent magnet for reduction of the required volume. The ECR volume is maximized by a multi mirror magnetic field in a limited plasma chamber volume.

Development of Compact 2.45 GHz ECR Ion Source for Generation of Singly-Charged Ions

Sergey Bogomolov[1], Andrey Evgenyevich Bondarchenko[1], Andrey Efremov[1], Yurij Kostyukhov[1], Konstantin Igorevich Kuzmenkov[1], Vladimir Loginov[1], Dmitriy Pugachev[1], Riyaz Fatkullin[2]

[1] JINR, Dubna, Moscow Region
[2] ITEP, Moscow

2.45 GHz ECR ion sources are widely used for production of single charged heavy ions and secondary radioactive ion beams. This paper describes the development of a compact ECR ion source based on coaxial quarter wave resonator. The first results of extracted current measurements at different resonator configuration as a function of UHF frequency, power and gas flow are presented. At the extraction voltage about of 10 kV and UHF power about of 100 W more than 500 μA of He^{+} ions were produced with the extraction hole of 3 mm in diameter that corresponds to the current density of 7.5 mA/cm^2.

Friday, 14th September 2018

Morning oral session: 9:30 – 10:50

Chair: Klaus Tinschert

High Resolution Spectrometer Development for Ecris Plasma Spectroscopy

Risto Juhani Kronholm[1], Taneli Kalvas[1], Hannu Koivisto[1], Olli Tarvainen[1]

[1] JYFL, Jyvaskyla

Spontaneous de-excitation of electronic states of atoms and molecules, present in Electron Cyclotron Resonance Ion Source plasmas, enables studying them non-invasively through optical emission spectroscopy (OES). A high resolution spectrometer (10 pm FWHM at 632 nm) with lock-in data acquisition setup has been developed at JYFL specifically for the diagnostics of weak emission lines characteristic to ECRIS plasmas. In this presentation the development process and considerations will be discussed in detail. Methods to analyze emission spectrum will be presented and different particle species and charge states will be identified from the argon plasma spectrum. Densities of low charge state ions, neutral atoms and the temperature of the cold electron population play a major role in determining different reaction rates such as ionization and charge exchange. A method to study these plasma parameters with high resolution OES will be presented. By using this method, the temperature of cold electron population was found to change from 20 to 40 eV when the extraction voltage is switched on. The high resolution of spectrometer allows also the broadening of emission lines to be studied.

Simulation and experimental studies of biased disc behavior in the superconducting ECR ion source VENUS

Damon Todd[1], Janilee Yvette Benitez[1], Claude M Lyneis[1], Daniel Xie[1]

[1] LBNL, Berkeley, California

The use of a biased disc in place of a first stage injector in an ECR ion source was first reported at the 1990 ECRIS workshop. The improvements in both charge state distribution and beam current were significant: so much so that almost all ECR ion sources built since use biased discs instead of a first stage injector. Though now ubiquitous, exactly how a biased disc is affecting the plasma is not well-understood. The superconducting ECR ion source VENUS provides a good test bench for further studies of the biased disc as VENUS¿ flexibility allows for the production of moderate current, high current, and highly charged ion beams, and the biased disc operation can be vastly different for each of these operation modes. We present experimental results from varied biased disc operation with VENUS, and also for modifications to the biased disc such as decreasing its size and boring a hole in its center to inject additional electrons from a thermal cathode. Additionally, we have developed a code to investigate electron heating in VENUS. We will discuss results from these simulations which, when coupled with experimental results, will provide a better understanding of the biased disc.

High Resolution Spectropolarimetry: from Astrophysics to ECR plasmas

Marina Giarrusso[1]

[1] INFN/LNS, Catania

Electron Cyclotron Resonance (ECR) plasmas with high density and high temperature are required by the injectors for the Accelerators and by interdisciplinary studies in Astrophysics and Nuclear Astrophysics. The magnetic traps need a very fine analysis of plasma conditions in terms of density, temperature and ionisation state, not allowed by the present diagnostic methods (imaging, low resolution spectroscopy not spatially resolved). We here describe the results routinely obtained in Astrophysics with high resolution spectroscopy, largely used to analyse astrophysical plasmas in the visible range, which allows to determine physical parameters of stars as surface gravity, effective temperature, chemical abundances. In addition, we show that polarimetry is the only technique to derive the morphology of stellar magnetic fields, whose knowledge is necessary for a correct interpretation of spectra from magnetised plasmas. An application of these non-invasive methods to minimum-B ECR plasma concerning optical emission is discussed in view of a better comprehension of the plasma structure, magnetic confinement properties and heating processes.

Friday, 14th September 2018

Morning oral session: 11:10 – 12:00

Chair: Sándor Biri

Axial X-Ray Cutoff in Small, Dense Plasma in the VENUS ECR

Janilee Yvette Benitez[1], Claude M Lyneis[1], Damon Todd[1], Daniel Xie[1]

[1] LBNL, Berkeley, California

The coil structure of the superconducting ECR ion source VENUS allows for considerable control over the plasma-confining magnetic field while investigating axially-emitted x-rays from the source. Generally, it is found that axial x-ray intensity increases with input RF power. However, when the minimum field at the source center is relatively high this increase with power is only over a limited range. Past this range there is a sudden decrease in x-ray intensity followed by a complete disappearance of axial x-rays for any further input heating. As ion beams are still extracted, it is clear that plasma is still present. We will present measured data in the forms of x-ray spectra, extracted beam currents, and transmitted and reflected microwave power to explore the possibility that the plasma may have reach critical density on axis and effectively turned off RF heating in this region.

Impact of the two close frequency heating on ECRIS plasmas stability

Eugenia Naselli[1-2], Sándor Biri[3], Zoltán Perduk[3], Richárd Rácz[3], József Pálinkás[4], Alessio Galatà[5], Giuseppe Castro[2], Luigi Celona[2], Santo Gammino[2], David Mascali[2], Maria Mazzaglia[2], Giuseppe Torrisi[2]

[1] Catania University, Catania, [2] INFN/LNS, Catania
[3] ATOMKI, Debrecen, [4] DU, Debrecen, [5] INFN/LNL, Legnaro (PD)

Several experiments have recently demonstrated that plasma instabilities are powerful limiting factors to the flux of highly charged ion beam extracted from ECRIS. One of the methods for damping the instabilities is to feed the plasma in two frequency heating mode. Since the fundamental physical mechanism is still unclear (diffusion in velocity space? additional confinement?), a deeper experimental investigation is necessary, using multi-diagnostics setups. At ATOMKI-Debrecen the effect on the plasma instabilities of an argon plasma in a “Two Close Frequencies” scheme has been explored. Spectra of radio-emission from the plasma have been collected for different frequency gaps and relative power balances. The measurements show the plasma self-emitted radiation comes out from the internal plasma (i.e. around the lower frequency) but the instability damping can be effective for some specific combinations of frequency-gap and power balance. Radiofrequency spectra have been collected simultaneously to time-resolved X-ray measurements, triggered by RF bursts produced by the instabilities and detected via a microwave diode connected to a plasma-chamber-immersed multi-pin RF probe.

Friday, 14th September 2018

Closing remarks: 12:00 – 12:30

Atsushi Kitagawa

Poster sessions:

Tuesday, 11th September 2018

15:20 – 16:50

Thursday, 13th September 2018

15:50 – 17:30

An Irradiation Test Facility at INFN-LNS: Status and Perspectives

Giuseppe Gabriele Rapisarda[1], Vincenza Piera Bonanno[1], Roberto Catalano[1], Giuseppe A. Pablo Cirrone[1], Luigi Cosentino[1], Giacomo Cuttone[1], David Mascali[1], Mario Salvatore Musumeci[1], Giada Petringa[1], Sebastiana Maria Regina Puglia[1], Danilo Rifuggiato[1], Tudisco Salvatore[1]

[1] INFN/LNS, Catania

In the framework of ASIF "ASI Supported Irradiation Facilities" project some beamlines available at Laboratori Nazionali del Sud-INFN (LNS) Catania have been dedicated to irradiation test. These beamlines have been recently upgraded in order to meet the ESA specifications about radiation hardness testing of devices suitable for space applications. The Superconducting Cyclotron K800 installed at LNS can provide protons up to 80 MeV for integrated dose tests and a number of heavy ion beams for Single Event Effect (SEE) studies. The beamlines are equipped with detectors that allow beam diagnostic in term of spatial uniformity, purity and energy measurement, including on-line monitoring of flux and fluence received by the device under test. Upgrades activities are now ongoing, especially to broaden up the number of available beams, both in terms of ion species and energy, to optimize the switching times from one beam to another. The paper will present an overview of the developed facility, which will take benefit of the ongoing SERSE (the superconducting ECR ion source) revamping: the new gas-box system, plasma chamber and controls system are ready to be installed within autumn 2018.

Production of various ion species by gas pulsing technique for multi ion irradiation at NIRS-HEC ion source

Masayuki Muramatsu[1], Atsushi Kitagawa[1], Fumihisa Ouchi[2], Toshinobu Sasano[2], Tadahiro Shiraishi[2], Taku Suzuki[2], Katsuyuki Takahashi[2], Taku Inaniwa[3], Yoshiyuki Iwata[3], Kota Mizushima[3]

[1] QST-NIRS, Chiba [2] AEC, Chiba INFN/LNS, Catania
[3] NIRS, Chiba-shi

High-energy carbon-ion radiotherapy is being carried out at Heavy Ion Medical Accelerator in Chiba (HIMAC). Over 11000 cancer patients have been treated with carbon beams having energies of between 56-430 MeV/u since 1994. At present, multi ion irradiation method by various ion species is being studied for optimization of LET and dose distribution. An ion source has to produce the helium, carbon, oxygen and neon at pulse by pulse for this method. Requirement currents for He^{2+}, C^{2+}, O^{3+} and Ne^{4+} are 500, 150, 230 and 300 euA, respectively. We obtained beam current of 482, 151, and 270 euA for He^{2+}, C^{2+} and O^{3+} with mixed helium and CO_2 gases under the extraction voltage of 27 kV. Beam current of 27 and 15 euA for C^{5+} and O^{7+} ions were also obtained in this time. He^{2+} beam include full striped ion such as C^{6+}, N^{7+} and O^{8+}. We have to increase the purity of He^{2+} beam. The gas feed system was modified for making pulsed gas by using a solenoid valve for switching different gas. Some experimental results of various ion productions will be described.

Initial beam commissioning for the RISP injector

In-Seok Hong[1]

[1] IBS, Daejeon

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

This work was supported by RISP which is funded by Ministry of Science and ICT(MSIT) and National Research Foundation (NRF) of Korea.

Progresses in the installation of the SPES-Charge Breeder beam line

Alessio Galatà[1], Judilka Bermudez[1], Giovanni Bisoffi[1], Andrea Conte[1], Mauro De Lazzari[1], Paolo Francescon[1], Marco Oswaldo Miglioranza[1], M. Francesca Moisio[1], Carlo Roncolato[1], Massimo Rossignoli[1]

[1] INFN/LNL, Legnaro (PD)

Since fall 2017, the ADIGE (Acceleratore Di Ioni a Grande carica Esotici) injector of the SPES (Selective Production of Exotic Species) project entered the installation phase. The injector includes an ECR-based charge breeder (SPES-CB) and its complete beam line, as well as a newly designed RFQ, to allow the post-acceleration of the radioactive ions produced in the so-called Target-Ion-Source system. The injector has different peculiarities, deriving from particular needs of SPES: a complete electrostatic beam line equipped with a 1+ source for test purposes, and a unique Medium Resolution Mass Spectrometer (MRMS, R~1/1000), mounted downstream the SPES-CB, to clean the radioactive beam from the contaminants induced by the breeding stage. This contribution reports about the status of the installation of the injector, describing the various technical solution adopted, and giving a realistic planning for the commission and following operation of its main parts.

POSTER

Next Generation Magnet Technology for ECR Ion Sources Operating at 28Ghz and Above

Tengming Shen[1], Diego Arbelaez[1], Laura Garcia Fajrado[1], Daniela Leitner[1], Soren Prestemon[1], GianLuca Sabbi[1]

[1] LBNL, Berkeley, California

Novel superconducting magnet systems for ECR ion sources (ECRIS) operating at frequencies of 28 GHz and above is a core technology to be developed over the next many years. Current state-of-the-art magnet systems are based on Nb-Ti technology at 4.2 K and have become the bases for next generation heavy ion beam facilities injector sources. However, increasing the frequency beyond 28 GHz will further advance the performance of high charge state ECR ion sources. Nb3Sn provides an immediate option for reaching higher frequencies, but Nb3Sn designs would ultimately be limited to about 56 GHz. A versatile longer-term option is the use of high-temperature superconducting magnet technologies, which can enable possible operations of >37.5 GHz ECR ion sources at >20 K. The ultimate limit of HTS magnet systems is not limited to 37.5 GHz but in principle could even attain 84 GHz, due to the greater than 100 T magnetic field limit of several HTS materials. The paper will discuss the conceptual design options for such a magnet systems and R&D steps towards realizing such a system.

Operation of the phoenix V3 ecris applying double frequency heating

Fabio Maimone[1], Ralf Lang, Jan Maeder[1], Patrick Tedit Patchakui[1], Klaus Tinschert[1], Daniel van Rooyen[1], Julien Angot[2], Laurent Bonny[2], Josua Jacob[2], Alexandre Leduc[2], Patrik Sole[2], Thomas Thuillier[2]

[1] GSI, Darmstadt
[2] LPSC, Grenoble Cedex

PHOENIX V3 is an upgraded version of the V2 ECRIS to be installed on the heavy ion injector at SPIRAL2. The source is under commissioning at LPSC since 2016. One of the main upgrades of the V3 concerns the new microwave injection system including two WR62 waveguide apertures. This new plug having two waveguide ports allows running the ECRIS with the double frequency heating mode by connecting two different high power microwave sources. For the investigation of this plasma feeding regime a klystron generator at 18 GHz proving up to 2 kW microwave power was used together with a traveling wave tube amplifier with a 12.75-14.5 GHz bandwidth and 650 W maximum output power. Several experiments were carried out in order to verify the performance increase with respect to the single frequency operation. Different ion source configurations were investigated and different frequencies and power combinations were analyzed with the aim to maximize the high charge state ion production and to reduce the ion beam instability. The measurement results are reported here.

X-Ray Investigation on the Superconducting Source for Ions (SuSI)

Derek Elwin Neben[1], Guillaume Machicoane[1], Jeffry W. Stetson, Larry Tobos[1], Daniela Leitner[2-3], Bryan Christopher Isherwood[4]

[1] NSCL, East Lansing, Michigan, [2] LBNL, Berkeley, California
[3] NSCL, East Lansing, Michigan, [4] MSU, East Lansing, Michigan

Heavy ion facilities such as the National Superconducting Cyclotron Laboratory (NSCL) often use ECR Ion Sources (ECRIS) for the production of highly charged ions to increase the efficiency of accelerating structures. Axial bremsstrahlung emission was studied on the Superconducting Source for Ions (SuSI) at the NSCL for 18 GHz and 13 GHz operation with oxygen. The hot electron temperatures were estimated from the bremsstrahlung high energy tail and seem to depend only on magnetic minimum in the same way as was found on VENUS [1], even in the case where 18 GHz and 13 GHz frequencies were compared for similarly sized ECR zones. Additionally, the time independent x-ray power increased at a significantly larger rate when operating the source in known regions of instability such as where the magnetic minimum approaches the ECR zone [2]. The results are discussed in the context of electron losses due to magnetic confinement.

*J. Benitez, et Al., in Proc. ECRIS'16, paper MOCO04.

**O. Tarvainen, et Al., Plas. Sourc. Sci. Technol., vol. 23, pp. 025020, 2014.

This work was supported by Michigan State University and the National Science Foundation: NSF Award Number PHY-1415462.

POSTER

Multi Diagnostic Setup at the Atomki-Ecris to Investigate the Two-Close-Frequency Heating Phenomena

Sándor Biri[1], Zoltán Perduk[1], Richárd Rácz[1], Alessio Galatà[2], Giuseppe Castro[3], Luigi Celona[3], Santo Gammino[3], David Mascali[3], Maria Mazzaglia[3], Eugenia Naselli[3], Giuseppe Torrisi[3], József Pálinkás[4]

[1] ATOMKI, Debrecen, [2] INFN/LNL, Legnaro (PD)
[3] INFN/LNS, Catania, [4] University Debrecen, Debrecen

While the mechanism is still not clear, the beneficial effect (higher intensity of highly charged ions, stable plasma conditions) of the second microwave injected to the ECR plasma was observed in many laboratories, both with close and far frequencies. Due to the complexity of the phenomena (e.g. interaction of resonant zones, damped instabilities) complex diagnostic methods are demanded to understand its mechanism better and to fully exploit the potential hidden in it. It is a challenging task since complex diagnostics methods require the arsenal of diagnostic tools to be installed to a relatively small size plasma chamber. Effect of the injected second 13.6-14.6 GHz microwave to the 14.25 GHz basic plasma has been investigated by means of soft and (time-resolved) hard X-ray spectroscopy, by X-ray imaging and by probing the rf signals emitted by the plasma. In order to separate the source and position of different X-ray photons special metallic materials for the main parts of the plasma chamber were chosen. A detailed description and explanation of the full experimental setup and the applied non-invasive diagnostics tools and its roles are presented in this paper.

The first measurement of plasma density by means of an interfero-polarimetric setup in a compact ECR-plasma trap

Eugenia Naselli[1-2], Giuseppe Castro[2], Luigi Celona[2], Santo Gammino[2], David Mascali[2], Maria Mazzaglia[2], Giuseppe Torrisi[2], Gino Sorbello[1-2]

[1] Catania University, [2] INFN/LNS, Catania

This paper presents the first measurement of plasma density by a K-band microwave polarimetric setup able to measure the magnetoplasma-induced Faraday rotation in a compact size plasma trap. The polarimeter, based on rotating waveguide OMTs (OrthoModeTransducers), has been proven to provide reliable measurements of the plasma density even in the unfavourable conditions λp ≈ Lp ≈ Lc (being λp, Lp and Lc the probing signal wavelength, the plasma dimension and the plasma chamber length respectively) that complicates the measurements due to multi-patterns caused by reflections of the probing wave on the metallic walls of the plasma chamber. An analysis method has been developed on purpose in order to discriminate the polarization plane rotation due to magnetoplasma Faraday rotation only, excluding the effects of the cavity resonator. The measured density is consistent with the previous plasma density interferometric estimations. The developed method is a powerful tool for probing plasmas in very compact magnetic traps such as Electron Cyclotron Resonance Ion Sources and for in-plasma β-radionuclides' decay studies.

Characterization of ECR plasma by means of radial and axial X-ray diagnostics

Rosalba Miracoli[1], Giuseppe Castro[2], Luigi Celona[2], Santo Gammino[2], David Mascali[2], Maria Mazzaglia[2], Giuseppe Torrisi[2], Eugenia Naselli[2-3]

[1] ESS Bilbao, Zamudio, [2] INFN/LNS, Catania
[3] Catania University, Catania

This work presents the X-ray characterization of the plasma generated in simple mirror axis symmetric trap as a function of magnetic field profile. A Si-Pin detector has been used to characterize warm electron population either in axial than in radial direction at two different operating frequencies: 4.1 GHz and 6.8 GHz. Moreover, the hot electrons emitted by axial direction has been measured by means of a HyperPure Germanium (HpGe) detector. Results show that X-ray emission is not homogenous and homogeneity and temperature depends strongly on the magnetic field profile.

Status Report on the AECR-U Ion Source at KVI-CART

Herman R. Kremers[1], Johannes P.M. Beijers[1], Sytze Brandenburg[1], Brian Jones[2]

[1] KVI, Groningen
[2] KVI-CART, Groningen

Due to the growing demand for pure heavy ion beams at KVI-CART, there is a motivation to improve the intensities and quality of these beams. A new hexapole, equipped with a pole tip field of 0.86 T on the plasma chamber wall, has been installed in the AECR ion source to improve the performance of the source, which includes an observed enhancement in all charge state distributions. For the xenon charge state distribution this resulted in a significant increase of the higher charge states that now allows for the production of an 129Xe32+ beam with intensities of 2 μA (un-collimated beam) that can be used for regular operations. Beams of 12C, 16O, 20Ne, 40Ar, 84Kr and 129Xe were developed to demonstrate a high purity of the beam on target. For 129Xe we achieved a beam with impurities at the 10^{-5} level. With these improvements KVI-CART intends to offer heavy ion irradiations to the scientific and radiation hardness test community.

ESS ion source and LEBT installation and commissioning

Øystein Midttun[1], Ryoichi Miyamoto[1], Aurélien Ponton[1], Alejandro Garcia Sosa[1]

[1] ESS, Lund

A 2.45 GHz microwave discharge proton source was installed at ESS by INFN-LNS in January 2018. The complete system, including a two-solenoid low energy beam transport (LEBT), was pre-commissioned at INFN-LNS during 2017 showing promising results by producing a stable 74 mA, 3 ms, 14 Hz proton beam within an emittance of 0.25 mm mrad. The commissioning at ESS will take place during the autumn 2018 with the goals of reproducing the previous ion source performance, studying optimized injection into the RFQ, and establishing the capability of manipulating beam parameters to produce different beam modes. This paper presents the installed ion source and LEBT at ESS together with the preparatory work and simulation studies for the beam commissioning.

Study of the Lead Evaporation from the Oven of the GTS-LHC Ion Source

Toke Koevener[1], Detlef Kuchler[1], Ville Toivanen[2]

[1] CERN, Geneva
[2] GANIL, Caen

The GTS-LHC ECR ion source at CERN provides heavy ion beams for the chain of accelerators from Linac3 up to the LHC and the SPS fixed target experiments. During the standard operation the oven technique is used to insert lead into the source plasma to produce multiply charged lead ion beams. Many years of experience show that some of the source instabilities can be linked to the oven performance. The evaporation seems not to be constant and when the oven reaches its maximum power, an indication that a refill is required, often half of the original lead sample is still present inside the oven crucible. A dedicated study of the oven using an offline test stand as well as thermal and gas dynamics simulations intends to help to identify the reasons for these experimental observations. The goal is to find design modifications to stabilize the evaporation rate and to prolong the oven runtime. This contribution presents the latest results of the study.

The Design Study of In-situ Material Research Equipment

Byoung Seob Lee[1], Jonggi Hong[1], Seong Jun Kim[1], Jin Yong Park[1], Mi-Sook Won[1]
[1] Korea Basic Science Institute, Busan

The Implantation beam-line using 28GHz ECRIS, in Busan, has been studied for overcoming limitation of conventional ion injection system. From this results, the new system designed carrying out in situ system on mass spectrometer. This implantation system can be employed in novel applications such as a metal, polymers, ceramics, new materials and irradiation tests of structural and fabrication of functional materials for nuclear material and future fusion reactors. For in-suit material research, the new system includes variable accelerator system, heat treatment chamber, beam monitoring system and SIMS (Secondary Ion Mass Spectrometer). In this paper, we will report results of feasibility design study.

The Current Status of Kbsi-Sc-Ecr Ion Source

Mi-Sook Won[1], Jonggi Hong[1], Seong Jun Kim[1], Jung-Woo Ok[1], Jin Yong Park[1]

[1] Korea Basic Science Institute, Busan

The 28 GHz superconducting electron cyclotron resonance (ECR) ion source has been developed to produce a high current heavy ion for VIBA. VIBA (Versatile Ion Beam Accelerator) is a compact linear accelerator facility using 28GHz ECR ion source at KBSI (Korea Basic Science Institute). Recently, ECR ion source was overhauled to improve the performance of ion beam extraction. We modified some components of the system. One more cryocooler was installed to cryostat for increasing the cooling efficiency of the cryostat. And, we replaced the stainless steel bore with tantalum bore to shield the cryostat from radiations. This report describes the effect of upgrade on ECR ion source.

Operation of the GTS-LHC ECR ion source in afterglow with varying klystron frequency

Detlef Kuchler[1], Michael O'Neil[1], Ville Toivanen[2]

[1] CERN, Geneva
[2] GANIL, Caen

The GTS-LHC ECR ion source delivers lead ions for the CERN heavy ion programme at the LHC and the SPS fixed target physics. The source is normally operated with a main microwave frequency of 14.5 GHz in the afterglow mode. As part of the consolidation the microwave generator was replaced with a klystron based generator that allows free variation of the operating frequency in a range of 14.0 ¿ 14.5 GHz. The aim of this study was to see how the lead charge state Pb29+, which is the main ion species produced for experiments, is influenced by the different frequencies. Variations in performance were observed (beam intensity and beam stability), but no frequencies were found that would provide significant performance improvements compared to normal operation at 14.5 GHz. The results in general suggest that for the GTS-LHC ion source the optimal operating frequency depends on the overall source tuning and the influence of varying the main frequency is comparable to adjusting the other tuning parameters.

Production of Intense Metal Ion Beams at the Dc-60 Cyclotron

Vladimir Loginov[1], Sergey Bogomolov[1], Andrey Evgenyevich Bondarchenko[1], Vladimir Mironov[1], Vitaliy Viktorovich Alexandrenko[2], Igor Ivanov[2], Mikhail Koloberdin[2], Sergey Kozin[2], Alisher Kurakhmedov[2], Daulet Mustafin[2], Yernaz Kajratovich Sambayev[2], Maxim Zdorovets[2]

[1] JINR, Dubna, Moscow Region
[2] INP NNC RK, Almaty

In 2017-2018, research program of the DC-60 cyclotron (Astana Branch of the Institute of Nuclear Physics, Kazakhstan) requests acceleration of intense ion beams of solid elements. Beams of B and Fe ions are produced in ECR ion source by using the volatile compounds, while ions of Li, Mg, P and Ca are produced by evaporation from an oven. Beams of $56Fe10^{+}$, $7Li1^{+}$, $24Mg4^{+}$, $31P5^{+}$, $40Ca7^{+}$, and $11B2^{+}$ ions were accelerated up to energies of 1.32-1.75 MeV/u.

This work was supported by MES RK IRN under grant number AP05133476.

POSTER

Homogenous dense plasma fluxes formation from high frequency ECR discharge

Roman Shaposhnikov[1], Sergey Vladimirovich Golubev[1], Ivan Izotov[1], Roman L'vovich Lapin[1], Sergey Razin[1], Vadim Skalyga[2]

[1] IAP/RAS, Nizhny Novgorod
[2] IAP/RAS, Nizhny Novgorod; UNN, Nizhny Novgorod

Formation of ion beams with wide apertures and current at level of tens and hundreds Amperes is required in a wide range of studies. Usually plasmas of arc or high-frequency discharges are used for such applications. In this paper the possibility of using of an ECR discharge sustained by powerful millimetre wave gyrotron radiation for these purposes is considered. A high plasma density is required to solve the problem of obtaining high values of ion beam current density. The use of gyrotron as a source of millimetre wave radiation in the ECR discharge makes it possible to obtain plasma with high density and high ionization rate, close to 100%. Earlier at the IAP RAS the possibility of dense plasma fluxes production on the basis of ECR discharge in a magnetic field of one solenoid was demonstrated. In this paper, the characteristics of the outgoing plasma flux (density and homogeneity) were investigated. Estimations of the prospects for using such systems for high-current ion beams formation are presented.

The work was supported by Russian Science Foundation, Grant No. 16-19-10501.

Langmuir Probe diagnostics of two-electron temperature plasma generated in an axis-symmetric simple mirror plasma trap

Giuseppe Castro[1], Luigi Celona[1], Santo Gammino[1], David Mascali[1], Maria Mazzaglia[1], Giuseppe Torrisi[1], Eugenia Naselli[1-2], Rosalba Miracoli[3]

[1] INFN/LNS, Catania,
[2] Catania University, Catania, [3] ESS Bilbao, Zamudio

Langmuir Probes allow local plasma parameters characterization, especially electron density and temperature, and energy distribution function too, though they are invasive diagnostics tools and in some cases their application gives only qualitative results. An experimental campaign at INFN-LNS has been devoted to LP measurements of EEDF very close to ECR-heating layers in a Simple Mirror Trap. The goal was the detection of eventual Two Electron Temperature (TET) plasma layers, which are an indirect signature of Double Layer formation. The ion confinement process in linear traps, is generated by the superposition of three different mechanisms: i) the magnetic confinement in the rarefied plasma halo, ii) the diffusion confinement inside the high-density/high-temperature plasmoid, and iii) an electrostatic confinement due to the generation of a a double-layer at ECR layer. Two-electron temperature EEDF are deemed to be generated in the ECR layer by interaction of free electrons with the potential dip existing in the double-layer region. In this work, the two-electron temperature plasma is investigated as a function of the magnetic field gradient, neutral pressure and microwave power.

Study of the influence of magnetic field profile on plasma parameters in a simple mirror trap

Maria Mazzaglia[1], Giuseppe Castro[1], Luigi Celona[1], Santo Gammino[1], David Mascali[1], Giuseppe Torrisi[1], Rosalba Miracoli[2], Riccardo Reitano[1-3], Briefi Stefan[4], Fantz Ursel[4]

[1] INFN/LNS, Catania
[2] ESS Bilbao, Zamudio
[3] Universita Degli Studi Di Catania, Catania
[4] MPI/IPP, Garching

This work presents the multiple diagnostics characterization of the plasma in an axis-symmetric simple mirror trap as a function of magnetic field profile (mirror ratios and magnetic field gradient), neutral gas pressure and microwave power. The simultaneous use of Optical Emission Spectroscopy, Langmuir Probe and X-ray diagnostics allows the characterization of the whole electron energy distribution function (EEDF), from a few eV to hundreds of keV. Results show non-linear behaviours under small variations of even one source parameter and strong influence of EEDF on the Bmin/BECR ratio. Benefit and next developments will be highlighted.

A Particle-in-Cell/Monte-Carlo-Collision Code for the Simulation of Stepwise Ionization of Lithium in 2.45 GHz ECR Ion Source

Jingfeng Zhang[1], Jia-er Chen[1], Zhiyu Guo[1], Yaoxiang Jiang[1], Tenghao Ma[1], ShiXiang Peng[1], Haitao Ren[1], Jiang Sun[1], Jiamei Wen[1], Wenbin Wu[1], Tao Zhang[1]

[1] PKU, Beijing

A 2.45 GHz hybrid ion source for 7Li3+ production is designed at Peking University (PKU). In order to learn more on the physical processes inside the hybrid lithium ion source, a Particle-in-Cell/Monte-Carlo-Collision (PIC/MCC) code is written. This code can simulate the motion of particles in single spatial dimension and three velocity dimensions, abbreviated as 1D3V. In this model, the propagation of the 2.45 GHz microwave is processed using Finite-Difference Time-Domain (FDTD) method, and PIC and MCC method are used to handle the interaction of charged particles with electromagnetic field and collision process between particles, respectively. The validity of the PIC method has been confirmed by the simulation of two stream instability in this work. Moreover, the preliminary simulation results also show that the 2.45 GHz microwave energy can be absorbed effectively by electrons in the presence of an external magnetic field of 875 Gs. And the mirror magnetic field can increase the transverse velocities of electrons.

Numerical simulations of magnetically confined plasmas

Alessio Galatà[1], Carmelo Sebastiano Gallo[1], David Mascali[2], Giuseppe Torrisi[2]

[1] INFN/LNL, Legnaro (PD)
[2] INFN/LNS, Catania

A 2.45 GHz hybrid ion source for $7Li3^{+}$ production is designed at Peking University (PKU). In order to learn more on the physical processes inside the hybrid lithium ion source, a Particle-in-Cell/Monte-Carlo-Collision (PIC/MCC) code is written. This code can simulate the motion of particles in single spatial dimension and three velocity dimensions, abbreviated as 1D3V. In this model, the propagation of the 2.45 GHz microwave is processed using Finite-Difference Time-Domain (FDTD) method, and PIC and MCC method are used to handle the interaction of charged particles with electromagnetic field and collision process between particles, respectively. The validity of the PIC method has been confirmed by the simulation of two stream instability in this work. Moreover, the preliminary simulation results also show that the 2.45 GHz microwave energy can be absorbed effectively by electrons in the presence of an external magnetic field of 875 Gs. And the mirror magnetic field can increase the transverse velocities of electrons.

Addressing Contamination in ECR Charge Breeders

Richard Vondrasek[1]

[1] ANL, Argonne, Illinois

The Electron Cyclotron Resonance (ECR) ion source was first utilized for charge breeding in 1995 [1]. Since that time the charge breeding technique has been refined. Single charge state efficiency has improved by a factor of ten, the efficiency discrepancy between solid and gaseous species has narrowed, and low-mass species efficiency has improved. But the limiting characteristic of the ECR charge breeder continues to be a high level of contamination which often obscures the beam of interest [2]. Multiple techniques have been employed to reduce this contamination with varying levels of success, and attempts are currently underway to improve upon the successes achieved to date. This paper will review those past techniques, current attempts, and possible future paths for reducing the contamination level in ECR charge breeders.

[1] R. Geller, C. Tamburella, and J. L. Belmont, Review of Scientific Instruments 67, 1281 (1996)

[2] R. Vondrasek, J. Clark, A. Levand, T. Palchan, R. Pardo, G. Savard, and R. Scott, Review of Scientific Instruments 85, 02B903 (2014)

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OES and other diagnostics for the ESS Proton Source

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The high intensity proton source for the European Spallation Source, designed and commissioned at INFN-LNS, is able to produce a stable total current between 40 and 125 mA through an 8 mm extraction aperture, with a proton fraction of up to 87%. The best source condition for the PS-ESS requirements has been investigated by means of the Optical Emission Spectroscopy (OES). OES permitted to evaluate simultaneously the H/H2 relative abundances together with plasma and electron temperature. Results from OES will be discussed and compared together with results from Faraday-cup and Doppler shift measurements. Benefit of the diagnostics and further improvements foreseen in next future will be highlighted.

Cryogen free gyrotron magnet

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A review of a custom-built cryogen-free magnet system intended for use as part of the European development program of the 1MW continuous wave, cylindrical cavity gyrotron at 170 GHz for the ITER electron cyclotron system.

The magnet system houses a 1 MW gyrotron whilst providing a physical and mechanical structure which is compatible with further development towards a generation of 2MW coaxial cavity gyrotrons.

The magnet comprises four niobium-titanium windings producing a peak field of 7.1T at the gyrotron cavity within a 240 mm UHV room temperature bore. Two of the four windings are negatively wound to rapidly diminish the field at the cathode 364 mm below the field centre. The opposing interactive forces between the windings at full field are >114 Tonnes.

It was essential to undergo a thorough analysis of field perturbation generated by mechanical strain in the windings at high field to ensure the magnetic field profile was within 1% of a theoretical optimised profile for electron transport.

A tilt alignment between the gyrotron mechanical axis and the magnetic axis of <0.02° is maintained even following intentional quenching of the magnet at full field.

POSTER

First results of the FAIR proton-Linac injector commissioning at CEA-Saclay designed for the future FAIR installation at GSI

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The construction of the source and Low Energy Beam Transport of the future Proton-Linac for the FAIR facility in Darmstadt, Germany (Facility for Antiproton and Ion Research) is going forward at CEA-Saclay in France. The latest results of normalized emittance and of species proportions are shown at different position, directly at the source exit, between the 2 solenoids of the LEBT, and also around the theoretical focal point at RFQ entrance position. A new software for emittance treatment allows separating the different species after emittance measurement and is used to process the data. This paper presents the status of the FAIR injector commissioning at Saclay in summer 2018.

Status of the carbon ion source commissioning at MedAustron

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MedAustron is a synchrotron-based Ion therapy center situated in lower Austria. Accelerated proton beams with energies of 62-252 MeV/u are used to treat patients with cancer since 2016. Carbon ion beam is currently under commissioning and will provide treatment in 2019 with energies of 120-400 MeV/u. The Injector features three identical ECRIS from Pantechnik, two of which are used to generate proton and carbon beams with energies of 8 keV/u. The generated beam is sent to a 400keV/u RFQ and a 7MeV/u H-mode Linac, following injection into a 77m synchrotron via a middle energy transfer line, where the energies for patient treatment are reached. The beam is sent to four irradiation rooms via a high energy transfer line, two of which are currently used for medical treatment. The medical environment of the accelerator puts strict requirements on the source performances in terms of long term stability and uptime. The extracted carbon intensity needs to be on the order of 150 eμA with maximum current fluctuations of ±2.5% on continuous run. In this work we discuss the status of carbon commissioning with particular emphasis on the experimental results obtained during the ion source tuning.