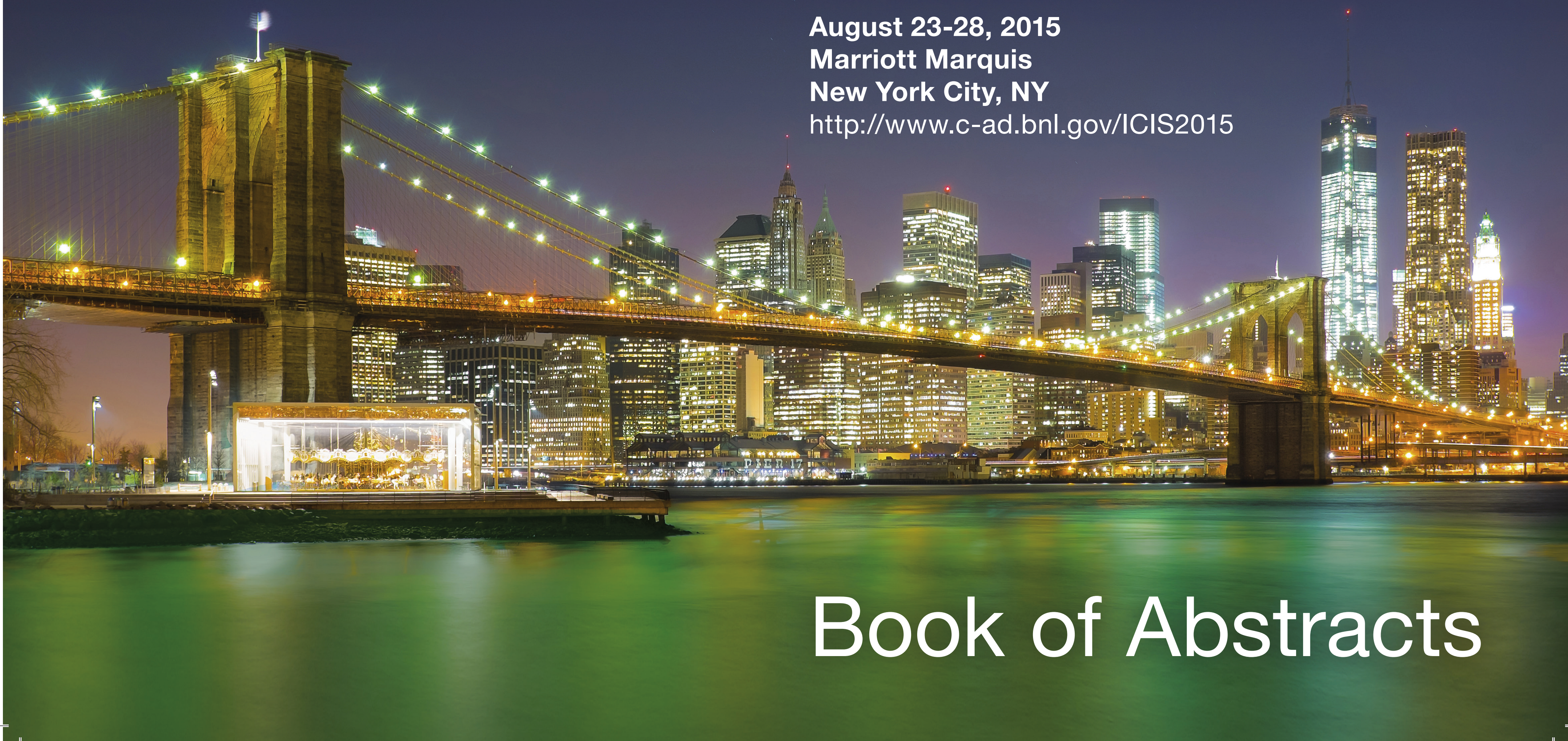
16th International Conference on Ion Sources

ICIS2015

August 23-28, 2015
Marriott Marquis
New York City, NY
http://www.c-ad.bnl.gov/ICIS2015



Book of Abstracts

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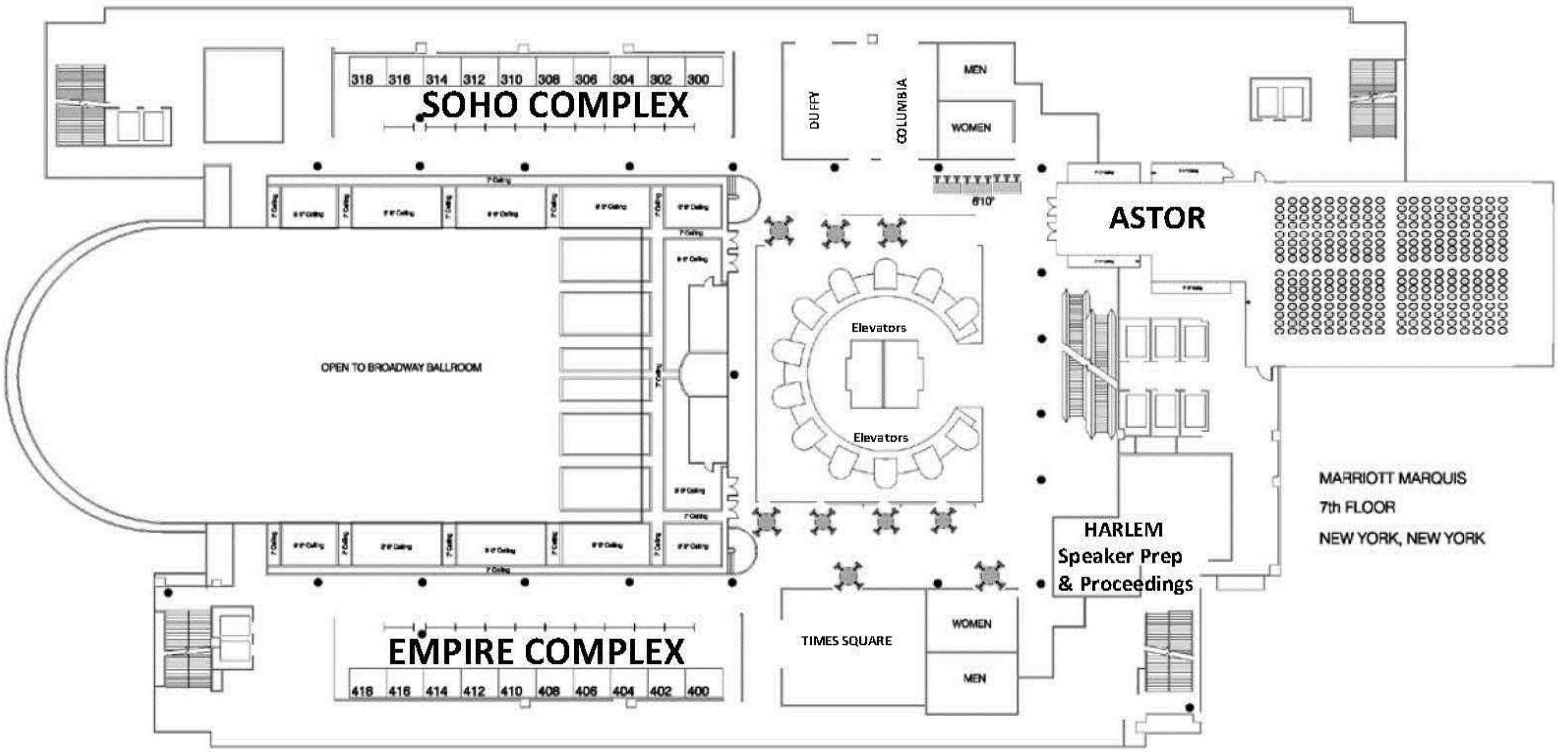
Brookhaven National Laboratory
International Conference on Ion Sources
August 23-28, 2015
New York, Marriott Marquis
7th Floor



Exhibitor Booth Designation

Soho Complex:

300	Trek, Inc
302	Friatec
304	SAES Group
306	Princeton Scientific Corp
308	Lanzhou Kejin Taiji Corp.

Empire Complex:

400	SigmaPhi Accelerator Technologies
402	PANTECHNIK
404	Phoenix Nuclear Labs
406	SAIREM Microwave & Radio Frequencies
408	Beam Imaging Solutions

Posters

Monday

Empire

C2 Beam extraction, transport and diagnostics
C5 Industrial and medical applications

Soho

C7 Electron Cyclotron Resonance Ion Sources
C8 Negative Ion Sources

Tuesday

Empire

C1 Fundamental processes
C8 Negative Ion Sources

Soho

C2 Beam extraction, transport and diagnostics
C6 Electron Beam Ion Sources / Traps, MEVVA and Laser Ion sources

Thursday

Empire

C3 Ion Sources for Nuclear Fusion
C4 Radioactive Ion Beams and Charge Breeders

Soho

C7 Electron Cyclotron Resonance Ion Sources
C10 Miscellaneous Ion Sources

ICIS2015 Exhibitors

Company Name & Booth #
Beam Imaging Solutions (408)
Friatec (302)
Lanzhou Kejin Taiji Corporation (308)
PANTECHNIK (402)
Phoenix Nuclear Labs (404)
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Trek, Inc. (300)

ICIS2015 Sponsors

Company Name
The DREEBIT GmbH
GMW Associates
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Monday Morning Oral Presentations

MonM01 (9:00)	Ion Source requirements for high energy accelerators (Invited)	Thomas	Roser
MonM02 (9:30)	Recent Developments of Ion Sources for Life Science Studies at the Heavy Ion Medical Accelerator in Chiba (Invited)	Atsushi	Kitagawa
MonM03 (10:00)	High density plasmas and new diagnostics: an overview (Invited)	Luigi	Celona
MonM04 (11:00)	Molecular ion sources for semiconductor ion implantation (Invited)	Ady	Hershcovitch
MonM05 (11:30)	Ambient Ionization, Ion Transport and Ion Mobility-based Detection for Sensing and Identification of Trace Materials	Samar	Guharay
MonM06 (11:50)	Ion beam sources for surface modification	André	Rosenkranz

Monday Afternoon Oral Presentations

MonA01 (16:00)	Towards 20 A Negative Hydrogen Ion Beams for Up to 1 hour Achievements of the ELISE Test Facility (Invited)	Ursel	Fantz
MonA02 (16:30)	First Experiments with the Negative Ion Source NIO1	Marco	Cavenago
MonA03 (16:50)	Final Design of the Beam Source for the MITICA Injector	Diego	Marcuzzi
MonA04 (17:10)	Improvement of Accelerator of N-NBI on LHD	Masashi	Kisaki

Monday Poster Session

Empire

C2 Beam extraction, transport and diagnostics
C5 Industrial and medical applications

Soho

C7 Electron Cyclotron Resonance Ion Sources
C8 Negative Ion Sources

Monday Afternoon Poster Session – Empire (14:00-16:00)

MonPE01	Simulation of beam profiles from extracted ion current distributions for mini-STRIKE	P.	Agostinetti
MonPE02	Multi-beamlet investigation of the deflection compensation methods of SPIDER beamlets	Carlo	Baltador
MonPE04	Modeling of the charge-state separation at ITEP Experimental facility for material science based on a Bernas ion source	Helen	Barminova
MonPE05	High intensity proton injector for facility of antiproton and ion research (FAIR)	Rustam	Berezov
MonPE06	A new solid state extractor pulser for the FNAL magnetron ion source	Daniel	Bollinger
MonPE07	Analysis of diagnostic calorimeter data by the transfer function technique	Rita S.	Delogu
MonPE08	Design and Fabrication of a Duoplasmatron Extraction Geometry and LEBT for the LANSCE H+ RFQ Project	Clifford M.	Fortgang
MonPE09	Scaning Effects of Applied Voltage to a Deceleration Electrode on the Ion Current Density Profile of Low-Energy and High-Current-Density Ion Beam Extracted through Concave Electrodes	Yutaka	Fujiwara
MonPE10	Effect of Coulomb Collision on the Negative Ion Extraction Mechanism in Negative Ion Sources	Ippei	Goto
MonPE11	Installation of Spectrally Selective Imaging System in RF Negative Ion Source	Katsunori	Ikeda
MonPE12	Study of Electron Current Extraction from a Radio Frequency Plasma Cathode Designed as a Neutralizer in Ion Source Applications	Sina	Jahanbakhsh
MonPE13	Prototyping of beam position monitor for medium energy beam transport (MEBT)section of RAON heavy ion accelerator	Hyojae	Jang
MonPE14	The Beam Injection Line Test of CYCIAE-100 Cyclotron	Xianlu	Jia
MonPE15	Beam dynamics simulations of post Low Energy Beam Transport	Hyunchang	Jin
MonPE16	Transportation of a radioactive ion beam for precise laser-trapping experiments	Hirokazu	Kawamura
MonPE17	Modification to the Accelerator of the NBI-1B Ion Source for improving the Injection Efficiency	T. S.	Kim
MonPE18	Development of ion beam analyzing system for KBSI heavy-ion accelerator	Byoung-Seob	Lee
MonPE20	Development of the Pepper-pot Emittance Meter for Diagnostics of Low-Energy Multi-Charged Heavy Ion Beams Extracted from an ECR Ion Source	Takashi	Nagatomo
MonPE21	Beam imaging in the injection line of the Superconducting Cyclotron of the INFN-LNS	Dario	Nicolosi

MonPE22	Castellated tiles as the beam-facing components for the diagnostic calorimeter of the negative ion source SPIDER	Simone	Peruzzo
MonPE23	Charge Neutralized Low Energy Beam Transport at Brookhaven 200 MeV Linac	Deepak	Raparia
MonPE24	Beam Simulation Studies of ECR Beam Extraction and Low Energy Beam Transport for FRIB	Haitao	Ren
MonPE25	Gas Flow and Density Profile in NIO1 Accelerator and Vessel	Emanuele	Sartori
MonPE26	Simulation of Space Charge Compensation in a multibeamlet negative ion beam	Emanuele	Sartori
MonPE27	Effects of a Dielectric Material in an Ion Source on the Ion Beam Current Dencity and Ion Beam Energy	Hajime	Sakakita
MonPE28	Numerical Simulations of the First Operational Conditions of the Negative Ion Test Facility SPIDER	Gianluigi	Serianni
MonPE29	Surface Modification of Ferritic Steels Using MEVVA and Duoplasmatron Ion Sources	Timur V.	Kulevoy
MonPE30	Development of a Long-Slot Microwave Plasma Source	Yusuke	Kuwata
MonPE31	Compact RF Ion Source for Industrial Electrostatic Ion Accelerator	Hyeok-Jung	Kwon
MonPE32	Enhancement of Ionization Efficiency of Hot-Cavity Ion Sources	Yuan	Liu
MonPE33	Development of a compact ECR ion source for various ion production	Masayuki	Muramatsu
MonPE34	Development of C6+ Laser Ion Source and RFQ for Carbon Ion Radiotherapy	Takayuki	Sako
MonPE35	Development of a Microwave Ion Source for Ion Implantations	Nobuaki	Takahashi
MonPE36	Low-energy Ion Beam-based Deposition of Gallium Nitride	Magdaleno R.	Vasquez

Monday Afternoon Poster Session – Soho (14:00-16:00)			
MonPS01	First Results of the 2.45 GHz Oshima Electron Cyclotron Resonance Ion Source	Toyohisa	Asaji
MonPS02	Electron Cyclotron Resonance Ion Sources with High Stability and Long Lifetime	Preston	Barrows
MonPS03	The characteristic of Evaporative Cooling Magnet for ECRIS	Xiong	Bin
MonPS04	Development of a compact high intensity ion source for light ions at CEA-Saclay	Oliver	Delferrière
MonPS05	Installation and first operation of the IFMIF LIPAC Injector	R.	Gobin
MonPS06	Microwave Mode Converter Optimized for Superconducting ECR Ion Source SECRAL	Junwei	Guo
MonPS07	Production of Multicharged Metal Ion Beams on the First Stage of Tandem-Type ECRIS	Shogo	Hagino
MonPS08	Development of superconducting magnet and LHe recondensing cryostats for RAON 28 GHz ECR Ion Source	Jeongil	Heo
MonPS09	Heavy ion injector based on ECR ion source for RISP linac	In-Seok	Hong
MonPS10	Compact Permanent Magnet H+ ECR Ion Source with Pulse Gas Valve	Yoshihisa	Iwashita
MonPS11	Microwave Emission Related to Cyclotron Instabilities in a Minimum-B Electron Cyclotron Resonance Ion Source Plasma	Ivan	Izotov
MonPS12	Cyclotron Instability in the Afterglow Mode of Minimum-B ECRIS	Ivan	Izotov
MonPS13	Suppression of Cyclotron Instability in ECR ion Sources by Two-frequency Heating	Vadim	Skalyga
MonPS14	First Experiments with Gasdynamic Ion Source in CW Mode	Vadim	Skalyga
MonPS15	First plasma and beam extraction of the RAON ECR ion source	Yonghwan	Kim
MonPS16	YFL Ion Source Research and Development: Studies of Different Plasma Processes and Towards the Higher Beam Intensities	Hannu	Koivisto
MonPS17	Negative Ion Surface Production in Low Pressure Cesium-free H2/D2 Plasmas	Kostiantyn	Achkasov
MonPS18	Determination of Energy and Angular Distribution Functions of the Surface-Produced Negative Ions in H2/D2 Plasmas by Mass Spectrometry	Kostiantyn	Achkasov
MonPS19	Development of a High Reliability, Long Lifetime H- Ion Source	Gabriel	Becerra
MonPS20	Effect of Plasma Grid Bias on Extracted Currents in the RF Driven Surface-Plasma Negative Ion Sources	Yuri	Belchenko
MonPS21	Efficient Cesiation in the RF Driven Surface-Plasma Negative Ion Sources	Yuri	Belchenko

MonPS22	Facilitation of High Voltage Conditioning and Improvement of High Voltage Holding in the large Surface-Plasma Negative Ion Sources with Cesium Deposition	Yuri	Belchenko
MonPS23	Determination of discharge parameters via OES at the Linac4 H– ion source	Stefan	Briefi
MonPS24	Different Approaches to Modeling the LANSCE H- Ion Source Filament Performance	Ilija	Draganic
MonPS25	Electron Stripping Rates of H- Ion Beam in the 80 kV High Voltage Extraction Column and Low Energy Beam Transport Line at LANSCE	Ilija	Draganic
MonPS26	Converter Electrode Erosion Processes in the H- Ion Source at LANSCE	Ilija	Draganic
MonPS27	Abnormal electron heating by magnetic filter field in a negative hydrogen ion source	June-Young	Kim
MonPS28	Optimization of plasma parameters with transverse magnetic field strength and pressure to maximize H- ion density in a negative hydrogen ion source	Won-Hwi	Cho
MonPS29	Saddle Antenna Radio Frequency Ion Sources	Vadim	Dudnikov
MonPS30	Compact surface plasma H- source with geometrical focusing	Vadim	Dudnikov
MonPS31	High Current DC Negative Ion Sources for Cyclotron	Haruhiko	Etoh
MonPS32	Charged Particle Flows in the Beam Extraction Region of a Negative Hydrogen Ion Source for NBI	Shaofei	Geng
MonPS33	Advanced Negative Ion Source	Alexey	Goncharov
MonPS34	Duty Factor Variation Investigation from 1% to 100% with One Microwave Driven Cs-Free Volume H- Source at PKU	Shixiang	Peng
MonPS35	Characterization of the 13.56-MHz CW Starter Plasma for the Pulsed, High Power 2-MHz Plasma of the SNS H- Ion Source	Baoxi	Han
MonPS36	A Collisional Radiative Model of Hydrogen Plasmas Developed for Diagnostic Purposes of Negative Ion Sources	Snejana	Iordanova
MonPS37	Efficiency Improvements With the Radiofrequency H— Ion Source RADIS	Taneli	Kalvas

Tuesday Morning Oral Presentations			
TueM01 (8:30)	Intense pulsed heavy ion beam production by EBIS and its future development (Invited)	Edward	Beebe
TueM02 (9:00)	New Development of Laser Ion Source for Highly Charged Ion Beam Production (Invited)	Huanyu	Zhao
TueM03 (9:30)	High Charge States Heavy Metal Ion Source Based on Vacuum Spark	Efim	Oks
TueM04 (9:50)	Design Steps Towards A High Brightness Electron Impact Ion Source	Oliver	De Castro
TueM05 (10:10)	Development and testing of a pulsed helium ion source for probing materials and warm dense matter studies	Qing	Ji
TueM06 (11:00)	Negative Ion Production and Beam Extraction Processes in a Large Ion Source (Invited)	Katsuyoshi	Tsumori
TueM07 (11:30)	Linac4 H– Ion Sources	Jacques	Lettry
TueM08 (11:50)	Recent Performance of and Plasma Outage Studies with the SNS H- Ion Source	Martin P.	Stockli
TueM09 (12:10)	Commissioning the Rutherford Appleton Laboratory (RAL) Scaled Penning Surface Plasma Source	Daniel	Faircloth

Tuesday Afternoon Oral Presentations			
TueA01 (16:00)	Inductively Driven Surface-Plasma Negative Ion Source for N-NBI use (Invited)	Yuri	Belchenko
TueA02 (16:30)	Particle model of full scale ITER-relevant negative ion source	Francesco	Taccogna
TueA03 (16:50)	Physics of Negative Ion Beam Formation and Extraction from the Plasma Electrode Surface in High Brightness Magnetized Plasma Sources	Gwenael	Fubiani
TueA04 (17:10)	Fine-Tuning to Minimize Emittances of J-PARC RF-Driven H^- Ion Source	Akira	Ueno

Tuesday Poster Session

Empire

C1 Fundamental processes
C8 Negative Ion Sources

Soho

C2 Beam extraction, transport and diagnostics
C6 Electron Beam Ion Sources / Traps, MEVVA and Laser Ion sources

Tuesday Afternoon Poster Session – Empire (14:00-16:00)

TuePE01	Probing vibrational levels of ground state hydrogen molecules by laser photodetachment	Spyridon	Aleiferis
TuePE02	A Multicusp Ion Source at MIT optimized for H2+	Spencer	Axani
TuePE03	Oscillatory instability development in extraction system of a negative ion source	Helen	Barminova
TuePE04	Mixed Pierce-two-stream instability development in extraction system of a negative ion source	Helen	Barminova
TuePE05	Experimental investigation of non-linear wave to plasma interaction in a quasi-flat magnetostatic field	Giuseppe	Castro
TuePE06	ICP source with immersed ferromagnetic inductor	Valery	Godyak
TuePE07	Novel Modification of Hall-Type Ion Source (Study and the First Results)	Alexey	Goncharov
TuePE08	Photoelectron Emission from Metal Surfaces Induced by Radiation Emitted by a 14 GHz Electron Cyclotron Resonance Ion Source	Janne	Laulainen
TuePE09	Modeling of Penning Trap	Anurag	Maan
TuePE10	Dust Particle Diffusion in Ion Beam TransportRegion	Naoki	Miyamoto
TuePE11	Recent progress of plasma modelling at INFN-LNS	Lorenzo	Neri
TuePE12	Integral Electrical Characteristics and Local Plasma Parameters of an RF Ion Thruster	Valentin	Riaby
TuePE13	Neutral Resonant Ionization in an H– Plasma Source: Potential of Doubly-Excited **H–	John S.	Vogel
TuePE14	Anion Formation in Sputter Ion Sources by Neutral Resonant Ionization	John S.	Vogel
TuePE15	Investigation on the electron flux to the wall in the VENUS ion source	Thomas	Thuillier
TuePE16	Cesium recycling in the large cesiated negative ion source toward JT-60SA and ITER	Masafumi	Yoshida
TuePE17	Negative hydrogen ion sources developed at IMP	Shuhao	Lin
TuePE18	Model and measurement of beam extraction of LNHIS1 and LNHIS2	Shuhao	Lin
TuePE19	Detailed Beam and Plasma Measurements on the VESPA Penning H– Ion Source C08 Oral 6_03_15	Scott R.	Lawrie
TuePE20	A Negative Ion Source Test Facility	S.	Melanson
TuePE21	Analysis of the Beam Halo in Negative ion Sources by Using 3D3V PIC Code	Kenji	Miyamoto
TuePE22	Cross-Checked Analysis of ONIX Simulation Results and Experimental Data for Negative Ion Extraction from the BATMAN testbed	Serhiy	Mochalskyy
TuePE23	Analysis of Electron Energy Distribution Function in the LINAC4 H- Source	Shintaro	Mochizuki
TuePE24	Status of the RF-Driven H- Ion Source for J-PARC Linac	Hidetomo	Oguri
TuePE25	Effect of High Energy Electrons on H- Production and Destruction in a High Current DC Negative Ion Source for Cyclotron	Moriaki	Onai
TuePE26	Beam deflection applied to Neutral Beam Injection for a Fusion Devices reactor	Nicola	Pilan
TuePE27	The Mechanical Design and Simulation of a Scaled H- Penning Ion Source	Theo	Rutter
TuePE28	Numerical study of plasma generation process and internal antenna heat loadings in J-PARC RF negative ion source	Takanori	Shibata
TuePE29	An Overview of the New Test Stand for H- Ion Sources at FNAL	Alejandro	Sosa
TuePE30	Characterization and Optimization of NIO1 Extraction Aperture by 3D PIC Model	Nicola	Ippolito
TuePE31	New source of MeV negative ion and neutral atom beams	Sargis	Ter-Avetisyan
TuePE32	Maintenance of J-PARC RF-Driven H^- Ion Source	Akira	Ueno
TuePE33	Alternative Modeling Methods for Plasma-Based Rf Ion Sources	Seth A.	Veitzer
TuePE35	Balmer-Alpha Spectrum Measurement of the LHD One-Third Ion Source	Motoi	Wada
TuePE36	The SNS External Antenna Ion Source and Spare RFQ Test Facility Readiness	Robert	Welton
TuePE37	The ISIS Pre-injector Reconfiguration	Trevor	Wood

Tuesday Afternoon Poster Session – Soho (14:00-16:00)			
TuePS01	Quasi-monoenergetic ions acceleration by nanosecond laser-irradiation of solid target	Carmen	Altana
TuePS02	Software tool for time evolution of EBIS/EBIT charge breeding in the radial (transverse) approximation	E. G.	Evstatiev
TuePS03	Influence of Plasma Properties on Extracted Beam in Laser Ion Source Controlled by Magnetic Field	Shunsuke	Ikeda
TuePS04	Effect of Solenoidal Magnetic Field on Moving Plasma Used in Laser Ion Source	Shunsuke	Ikeda
TuePS05	Laser Ion Source Optimization and Development at GANIL	Jose Luis	Henares
TuePS06	Eliminating unwanted electron in EBIS devices	Ady	Hershcovitch
TuePS07	Low Charge Heavy Ion Production with Sub-nanosecond Laser	Takeshi	Kanesue
TuePS08	Laser Ion Source for Isobaric Heavy Ion Collider Experiment	Takeshi	Kanesue
TuePS09	Contribution of Material's Surface Layer on Laser Ablation Plasma	Masafumi	Kumaki
TuePS10	Plasma Heating by Double Pulse Laser Irradiation	Masafumi	Kumaki
TuePS11	Iron Plasma Generation using Several Hundred Picoseconds of Nd_YAG Laser Pulse	Jun	Tamura
TuePS12	RF Synchronized Short Pulse Laser Ion Source	Yasuhiro	Fuwa
TuePS13	Proton Beam Production by Laser Ion Source with Hydride Target	Masahiro	Okamura
TuePS14	Ca and Li Ion Production for Laser Ion Source	Masahiro	Okamura
TuePS15	Singly/Negatively Charged Ion Production of a Laser Induced Plasma using a Capillary Graphite Target	Glynnis	Saquilayan
TuePS16	Lifetime of Hydrogenised Film Cathode in Vacuum Arc Discharge ion Source	Konstantin	Savkin
TuePS17	Liquid Metal Ion Source Assembly for External Ion Injection into Electron String Ion Source (ESIS) and Charge Breeding Efficiency Measurements	Matthew	Segal
TuePS18	Aluminum Multicharged Ion Generation Using Spark-Assisted Laser Ion Source	Haider	Shaim
TuePS19	Investigation on TNSA (Target Normal Sheath Acceleration) through the measure of Ions energy distribution	Salvatore	Tudisco
TuePS20	Energy Distributions and Angular Distributions of Pulsed Plasmas Based on Vacuum Surface Flashover	X.	Wan
TuePS21	Simulation of Ion Beam Injection and Extraction in an EBIS	Liangji	Zhao
TuePS22	Generation of Boron Ion Beam Based on Discharges with Composite LaB6 Cathode	Efim	Oks
TuePS24	Preliminary Design of Electrostatic Sensors for MITICA Beam Line Components	Silvia	Spagnolo
TuePS25	Upgrade of the Beam Extraction System of the GTS-LHC Electron Cyclotron Resonance Ion Source at CERN	Ville	Toivanen
TuePS26	Studies of the Beam Extraction System of the GTS-LHC Electron Cyclotron Resonance Ion Source at CERN	Ville	Toivanen
TuePS27	Design of a Microwave Frequency Sweep Interferometer for plasma density measurements in ECR Ion Sources	Giuseppe	Torrisi
TuePS28	Investigation of ion beam space charge compensation with a retarding potential analyzer at GSI accelerator facility	Cathrina	Ullmann
TuePS29	Development and brightness measurement of an electron impact gas ion source for proton beam writing applications	Jeroen Anton	van Kan
TuePS30	Extraction Characteristics of a Low-energy Ion Beam System with a Remote Plasma Chamber	Magdaleno R.	Vasquez
TuePS31	An RFQ Direct Injection Scheme for the IsoDAR High Intensity H2+ Cyclotron	Daniel	Winklehner
TuePS32	Progress of beam diagnosis system for EAST neutral beam injector	Yongjian	Xu
TuePS33	Particle Transport and Heat Loads in NIO1	Pierluigi	Veltri
TuePS34	Optics of the NIFS Negative ion source test stand by infrared calorimetry and numerical modeling	Pierluigi	Veltri
TuePS35	Status of permanent magnet Intense Proton Source for C-ADS Linac	Qi	Wu
TuePS36	Simulation Study of LEBT for Transversely Coupled Beam from an ECR Ion Source	Y.	Yang
TuePS37	Developments of Fast Emittance monitors for Ion Sources at RCNP	Tetsuhiko	Yorita
TuePS38	Simulation Study of Space Charge Compensation in Negative Hydrogen Ion Beam	Ailin	Zhang

Wednesday Morning Oral Presentations

WedM01 (8:30)	Advancement of Highly Charged Ion Beam Production by Superconducting ECR Ion Source SECRAL (Invited)	Liangting	Sun
WedM02 (9:00)	Status of ECR Ion Sources for the Facility for Rare Isotope Beams (Invited)	Guillaume	Machicoane
WedM03 (9:30)	Further improvement of RIKEN 28GHz SC-ECRIS for production of intense U beam	Takahide	Nakagawa
WedM04 (9:50)	Operation and commissioning of IFMIF (International Fusion Material Irradiation Facility) LIPAc Injector	Yoshikazu	Okumura
WedM05 (10:10)	Status of the SPIRAL2 injector commissioning	Thomas	Thuillier
WedM06 (11:00)	Limitation of the ECRIS Performance by Kinetic Plasma Instabilities (Invited)	Olli	Tarvainen
WedM07 (11:30)	Electron Density and Temperature measurements in Electron Cyclotron Resonance Ion Source plasma by means of X-ray spectroscopy and X-ray imaging	David	Mascali
WedM08 (11:50)	Ion Beam Emittance from an ECRIS	Peter	Spädtke
WedM09 (12:10)	Emittance measurement for RIKEN 28GHz SC-ECRIS	Yoshihide	Higurashi

Free Afternoon

Thursday Morning Oral Presentations

ThuM01 (8:30)	In gas-jet isomer selective laser ion source (Invited)	Nathalie	Lecesne
ThuM02 (9:00)	New Progress of High Current Gasdynamic Ion Source (Invited)	Vadim	Skalyga
ThuM03 (9:30)	Overview of Ion Source Characterization Diagnostics in Indian Test Facility (INTF)	Mainak	Badyopadhayay
ThuM04 (9:50)	Effects of advanced nanowire-based targets for nanosecond laser driven acceleration	Gaetano	Lanzalone
ThuM05 (10:10)	VUV-diagnostics of inelastic collision processes in low temperature hydrogen plasmas	Jani	Komppula
ThuM06 (11:00)	Innovation in EBIS/T Charge State Breeders for Stable and Radioactive Elements (Invited)	Stefan	Schwarz
ThuM07 (11:30)	Optimizing charge breeding techniques for ISOL facilities in Europe: conclusions from the EMILIE project	Pierre	Delahaye
ThuM08 (11:50)	Advanced Numerical Modelling of the PHOENIX-SPES charge breeder	Alessio	Galatà
ThuM09 (12:10)	Off-line Commissioning of EBIS and Plans for Its Integration into ATLAS and CARIBU	Peter	Ostroumov

Thursday Afternoon Oral Presentations

ThuA01 (16:00)	Optimum Plasma Grid Bias for a Negative Hydrogen Ion Source Operation with Cs	Marthe	Bacal
ThuA02 (16:20)	Investigation of the Boundary Layer during the Transition from Volume to Surface Dominated H− Production at the BATMAN Test Facility	Christian	Wimmer
(16:40)	Brightness Award Presentation and Talk		

Thursday Poster Session

Empire

C3 Ion Sources for Nuclear Fusion
C4 Radioactive Ion Beams and Charge Breeders

Soho

C7 Electron Cyclotron Resonance Ion Sources
C10 Miscellaneous Ion Sources

Thursday Poster Session – Empire (14:00-16:00)			
ThuPE01	First hydrogen operation of NIO1: characterization of the source plasma by means of an optical emission spectroscopy diagnostic	Marco	Barbisan
ThuPE02	Feasibility Study of a NBI Photoneutralizer Based on Nonlinear Gating Laser Recirculation	Alessandro	Fassina
ThuPE03	Off-normal and failure condition analysis of the MITICA negative-ion Accelerator	Giuseppe	Chitarin
ThuPE04	Multi-slit Triode Ion Optical System with Ballistic Beam Focusing	Vladimir	Davydenko
ThuPE05	Design optimization of RF lines in vacuum environment for the MITICA experiment	Michela	De Muri
ThuPE06	3D Self-consistent Modelling of a Matrix Source of Negative Hydrogen Ions	Anguel P.	Demerdjiev
ThuPE07	Development of the negative ion beams relevant to ITER and JT-60SA at Japan Atomic Energy Agency	Masaya	Hanada
ThuPE08	Mechanism of Grid Power Loading in Electro-Static Accelerator with Multiple Apertures and Acceleration Stages for ITER	Junichi	Hiratsuka
ThuPE09	Performance of positive ion based high power ion source of EAST neutral beam injector	Chundong	Hu
ThuPE10	Development of Design Technique for Vacuum Insulation in Large Size Multi-Aperture Multi-Grid Accelerator for Nuclear Fusion	Atsushi	Kojima
ThuPE11	Concepts of Magnetic Filter Fields in Powerful Negative Ion Sources for Fusion	Werner	Kraus
ThuPE12	Motivation of Concepts for the Negative Ion Extraction from a Single Element of the Matrix Source	Stiliyan St.	Lishev
ThuPE13	Development and tests of Molybdenum armed copper components for MITICA ion source	Mauro	Pavei
ThuPE14	Simulation of diatomic gas-wall interaction and accommodation coefficients for Negative Ion Sources and accelerators	Emanuele	Sartori
ThuPE15	Status of the Negative Ion Based Neutral Beam Injectors for ITER	Beatrix	Schunke
ThuPE16	Neutral beam injection system for the C-2 upgrade field reversed configuration experiment	Artem	Smirnov
ThuPE17	Physics-Electrical Hybrid Model for Real Time Impedance Matching and Remote Plasma Characterization in RF Plasma Sources	Dass	Sudhir
ThuPE18	Self-induced Steady-state Magnetic Field in the Negative Ion Sources with Localized RF Power Deposition	Dimitar T.	Todorov
ThuPE19	Ion Collector Design for an Energy Recovery Test Proposal with the Negative Ion Source NIO1	Vincenzo	Variale
ThuPE20	Transmission of electrons inside the cryogenic pumps of ITER Neutral Beam Injector	Pierluigi	Veltri
ThuPE21	Development and preliminary results of radio frequency ion source	Yahong	Xie
ThuPE22	Single Element of the Matrix Source of Negative Hydrogen Ions: Measurements of the Extracted Currents Combined with Diagnostics	Dimitar Y.	Yordanov
ThuPE23	Steady state thermal-hydraulic analysis of the MITICA experiment cooling circuits	Matteo	Zaupa
ThuPE24	Charge State Breeding Experiences and Plans at TRIUMF	Friedhelm	Ames
ThuPE25	Integration of RFQ Beam Coolers and Solenoidal Magnetic Field Traps	Marco	Cavenago
ThuPE26	The new ECR charge breeder for the selective production of exotic species project at INFN - Laboratori Nationali di Legnaro	Alessio	Galatà
ThuPE27	Electromagnetic Analysis of the Plasma Chamber of an ECR-based Charge Breeder	Alessio	Galatà
ThuPE28	The remote control system in the Target source of ISOL	QingHua	Huang
ThuPE29	Study on a singly charged ion source for radioactive 11C ion acceleration	Ken	Katagiri
ThuPE30	Electrical-thermal-structural coupled-field finite element modeling and experimental testing of high-temperature ion sources for the production of radioactive ion beams	Mattia	Manzolaro
ThuPE31	Charge breeder for the SPIRAL1 upgrade: preliminary results	L.	Maunoury
ThuPE32	Progress on the EBIS charge breeder system of RAON in Korea	Young-Ho	Park
ThuPE33	Background Reduction in the CARIBU ECR Charge Breeder	Richard	Vondrasek
ThuPE34	First results on Ge resonant laser photoionization in hollow cathode lamp	Daniele	Scarpa

Thursday Poster Session – Soho (14:00-16:00)			
ThuPS01	High Intensity High Charge State Ion Beam Production with an Evaporative Cooling Magnet ECRIS	Wang	Lu
ThuPS02	Investigation on the Pulsed Mode Operation of the Frequency Tuned CAPRICE ECRIS	Fabio	Maimone
ThuPS03	Producing Multicharged Fullerene Ion Beam Extracted from the Second Stage of Tandem Type ECRIS	Tomoki	Nagaya
ThuPS04	Effect of Axial Magnetic Field on a 2.45 GHz Permanent Magnet ECR Ion Source	Tsubasa	Nakamura
ThuPS05	Experimental Results of Launching Extraordinary Mode Microwaves on ECRIS Plasma	Takuya	Nishiokada
ThuPS06	Progress of High-Temperature Oven Development for 28 GHz ECR Ion Source	Jun-ichi	Ohnishi
ThuPS07	Improvements for Reliability and Lifetime Test of a High-Performance DC Microwave Proton Source	Shixiang	Peng
ThuPS08	Status of Development of the FRIB High Performance Superconducting ECR Ion Source	Eduard	Pozdeyev
ThuPS09	X-ray Pinhole Camera Setups used in the Atomki ECR Laboratory for Plasma Diagnostics	Richárd	Rácz
ThuPS10	Ion Beam Production with Sub-milligram Samples of Material from an ECR Source for AMS	Robert	Scott
ThuPS11	Design optimization and performances system of 28GHz ECRIS Heavy ion accelerator for multi charge ion implantation	Mi-Sook	Won
ThuPS12	Ka-band Microwave Power Transmission System for 28 GHz Electron Cyclotron Resonance Ion Source at KBSI	Mi-Sook	Won
ThuPS13	First Results of 28 GHz Superconducting Electron Cyclotron Resonance Ion Source for KBSI Accelerator	Mi-Sook	Won
ThuPS14	X-ray measurement on 28GHz KBSI ECRIS	Mi-Sook	Won
ThuPS15	First Operation and Effect of a New Tandem-Type Ion Source Based on Electron Cyclotron Resonance	Yushi	Kato
ThuPS16	Accessibility Condition on Waves Propagation and Multicharged Ion Production in Electron Cyclotron Resonance Ion Source Plasma	Yushi	Kato
ThuPS17	Beam Experiments with the Grenoble Test Electron Resonance Ion Source at iThemba Labs	Rainer	Thomae
ThuPS18	Measurement of Ion Species in High Current ECR H+/D+ Ion Source for IFMIF (International Fusion Materials Irradiation Facility)	Katsuhiro	Shinto
ThuPS19	Injection of auxiliary electrons for increasing plasma density in highly charged and high intensity ion sources	Fabrizio	Odorici
ThuPS21	Kinetic Instabilities in Pulsed Operation Mode of a 14 GHz Electron Cyclotron Resonance Ion Source	Olli	Tarvainen
ThuPS22	Two-Chamber Configuration of Bio-Nano ECRIS for Fullerene Modification	Takashi	Uchida
ThuPS23	Renewal of Control System for Efficient Operation in RIKEN 18 GHz Electron Resonance Ion Source	Akito	Uchiyama
ThuPS25	Development Status of a Next Generation ECRIS: MARS-D at LBNL	D. Z.	Xie
ThuPS26	A 45 GHz Superconducting ECR Ion Source FECRAL and Its Technical Challenges	Hongwei	Zhao
ThuPS27	Emittance study of an 28GHz ECR ion source for the RISP superconducting linac	Bum-Sik	Park
ThuPS28	Production of high current proton beams using complex H-rich molecules at GSI	Aleksey	Adonin
ThuPS29	Development of Wien Filter for Small Ion Gun of Analytical Equipment	Byoung-Seob	Lee
ThuPS30	The Study about Nozzle Type for Cluster Generation at Gas Cluster Ion Source	Byoung-Seob	Lee
ThuPS31	Design and preliminary tests of an external antenna driven cw ion source at IAP Frankfurt	Yuan	Xu
ThuPS32	Operation Modes of Hydrogen Ion Beam Source Based on Pulsed Penning Discharge with Hollow Cathode	Efim	Oks
ThuPS33	Ar/N2 Plasma Treatment of High Density Polyethylene via Atmospheric Microwave Plasma Pencil Ion Source Device	Matthew D.	Poral
ThuPS34	Study on the D-Ti ion ratio of metal deuteride cathode vacuum arc ion source	Tao	Wang

Friday Morning Oral Presentations			
FriM01 (8:30)	Recent Development of Plasma-Optical Systems (Invited)	Alexey	Goncharov
FriM02 (9:00)	Correlations between density distributions, optical spectra and ion species in a hydrogen plasma (Invited)	Daniel	Cortázar
FriM03 (9:30)	Industrial Applications of ECR-Based Neutron Generators	Scott	Christensen
FriM04 (9:50)	The RHIC Polarized Ion Source	Anatoli	Zelenski
FriM05 (10:40)	Intense beam transport and space charge compensation strategies (Invited)	Oliver	Meusel
FriM06 (11:10)	Hall Thruster for Space Applications: Advanced Concepts and Research Challenges (Invited)	Yevgeny	Raitses
(11:40)	Summary Talk	Atsushi	Kitagawa
(12:00)	Closing		

Monday
24 August 2015

MonM01

Ion Source Requirements for High Energy Accelerators

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The performance of accelerators and colliders used for particle and nuclear physics research is determined by the beam quality delivered by the ion source. The presentation will review the present status of and the future requirements for the beam intensity, brightness and polarization of ion sources used at high energy accelerator facilities.

MonM02

Recent Developments of Ion Sources for Life Science Studies at the Heavy Ion Medical Accelerator in Chiba

Atsushi Kitagawa[1], Arne G. Drentje[1], Takashi Fujita[1], Masayuki Muramatsu[1], Keita Fukushima[2], Naohiro Shiraishi[2], Taku Suzuki[2], Katsuyuki Takahashi[2], Wataru Takasugi[2], Sándor Biri[3], Richárd Rácz[3], Yushi Kato[4], Takashi Uchida[5], and Yoshikazu Yoshida[5]

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Ion beam technology is a powerful tool for life science studies. With relativistic high-energy ion beams provided by the Heavy Ion Medical Accelerator in Chiba (HIMAC) many medical researches and various experiments on radiation effectiveness have been realized. Wide variety of ion species from H to Xe ions is required by users. Presently, three electron cyclotron resonance ion sources (ECRISs) and one Penning ion source are available to satisfy such requirements. The summary of recent requirements will be presented.

A similar capability is expected by some life science institutes and hospitals. However, downsizing to reduce construction and operation costs is also desired at such facilities. NIRS has developed a feasible solution with a hospital-specified accelerator complex in conjunction with improved ion sources of which the effectiveness has been tested at HIMAC. The performance of the 18 GHz ECRIS has been improved with various techniques like two frequency heating, biased electrodes, MIVOC, and so on. The results of developments will be summarized.

MonM03

High density plasmas and new diagnostics: an overview

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Since 2005 some unexpected issues have come to the attention of the ECRIS community, making questionable the dependence of the output currents and charge states only on macroscopic plasma parameters (density and temperature); plasma instabilities, local fluctuations and/or non uniform distribution of the plasma density, non linear response of the electron heating to the pumping wave frequency, or sensitivity to slight adjustments of the operating frequency and of the magnetic field, have been correlated with the intensity and emittance of the plasma-generated beams, showing that the parameters' space has not been fully explored, as well as the wave-to-plasma interaction in a closed resonant cavity (i.e. the ECRIS plasma chamber).

One of the most relevant limiting factors for the full understanding of ECRIS fundamental mechanisms consists in the few types of diagnostics tools so far designed and installed on such compact machines. Microwave-to-plasma coupling optimisation, including new methods of density overboost provided by plasma waves generation, as well as magnetostatic field tailoring for generating a proper electron energy distribution function, suitable for optimal ion beams formation, will require diagnostics tools spanning across the entire electromagnetic spectrum: from microwave interferometry to X-ray spectroscopy; these methods can be implemented in advanced forms including high resolution X-ray spectroscopy and spatially-resolved X-ray spectroscopy made by quasi-optical methods (pin-hole camearas). The ion confinement optimisation also requires a complete control of cold electrons displacement, which can be performed by optical emission spectroscopy (for X-ray and optical spectroscopy).

Several diagnostics tools have been recently developed at INFN-LNS, including "volume-integrated" X-ray spectroscopy in low energy domain (2-30 keV, by using SDD detectors) or highly energetic regimes (>30 keV, by using HpGe detectors). For the direct detection of the spatially-resolved spectral distribution of X-rays produced by the electronic motion, a "pin-hole camera" has been developed also taking profit from previous experiences in the ECRIS field.

The paper will give an overview of INFN-LNS strategy in terms of new microwave-to-plasma coupling schemes and advanced diagnostics supporting the design and construction of new ion sources and/or for optimizing the performances of the existing ones, with the goal of a microwave-absorption-optimization oriented design of future machines.

MonM04

Molecular ion sources for semiconductor ion implantation*

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As semiconductors become smaller shallow implantation is desired and ion energy needed for implantation decreases, resulting space charge (intra-ion repulsion) effects, which reduced beam currents and production rates. To increase production rates, molecular ions are used. Boron and phosphorous (or arsenic) ion implantation are needed for P-type and N-type semiconductors respectively. Carborane, which is the most stable molecular boron ion leaves unacceptable carbon residue on extraction grids. A self-cleaning carborane compound was synthesized: the m isomer of m-carborane-1,7-dicarboxylic acid ($C_4H_{12}B_{10}O_4$), when utilized in the ITEP Bernas ion source resulted in large carborane ion output, without carbon residue. Ion source acid operation at high temperatures still had carbon residue, which was remedied by a special O_2 elliptical cross section dissociator that injected miniscule amounts of O unto the grid prevented carbon deposition without loading up power supplies. Pure gaseous processes are desired for enable rapid switch among ion species. Molecular phosphorous was generated by introducing phosphine in dissociators via $4PH_3 = P_4 + 6H_2$ generated molecular phosphorous in a pure gaseous process (same applies for arsenic AsH_3). Molecular phosphorous was then injected into the HCEI Calutron-Bernas ion source, from which P_4^+ ion beams were extracted. For avoiding the use of ovens in deep implantation, high charge state phosphorous and arsenic can be generated by driving the HCEI Calutron-Bernas ion source harder and absorbing the hydrogen molecules in Pd after the dissociator. Results from devices and some additional concepts will be presented.

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MonM05

Ambient Ionization, Ion Transport and Ion Mobility-based Detection for Sensing and Identification of Trace Materials

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Generating intense ions and efficiently transporting these ions to a target form two basic requirements in many critical areas in science and technology including high energy accelerators, thermonuclear magnetic fusion, materials science, semiconductor device fabrication and inspection, and above all, medical applications [1, 2]. Many unique requirements from each of these disciplines engaged researchers over the past decades, and significant progress is noted both on basic problems related to collision processes, formation of ions, and ion dynamics as well as on related technology. Research activities continue to grow in the context of their role in many emerging applications [3]. In this pursuit, advancing the state-of-the art of ion mobility spectrometry (IMS) raises questions related to ionization and ion transport, especially from the standpoint of enhancing its intrinsic merit as an effective and efficient trace/residue sensing technology encompassing both physical and biological sciences. The key components and corresponding functionality of IMS [4,5] are: ionization sources generating ions of ambient (and/or injected) neutral molecules; pulsed injection (or gating) of these ions to a drift medium; transporting ions through a drift cell; and finally, measuring the response of these ions on a Faraday plate detector. Recent activities on modifying the ionization pathway through cluster ion formation shed light on selective ionization and enable manipulating molecular kinetics and enhancing functional attributes of IMS. Space-charge effects [6] constitute an important physics problem in the context of effectively transporting the ions and enhancing sensing capability, from the standpoint of providing high resolving power and sensitivity. This talk will address key questions on ionization problems, effective ion transport and detection. Illustrative examples will highlight different ionization schemes, effective transport approaches and utility of the device for detection and identification of different classes of complex molecules.

Acknowledgments: The author acknowledges support of the MITRE Innovation program. Thanks are due to Adrian Mariano and Wansheng Su of MITRE and to Herb Hill of Washington State University for collaboration. Valuable technical discussions and direct support on this topic from the Defense Threat Reduction Agency and Joint Project Manager for Nuclear Biological Chemical Contamination Avoidance are thankfully acknowledged. Distribution Statement A: Approved for Public Release; Distribution is Unlimited; Public Release Case ID:15-1196.

References

[1] Special issue on Ion Sources, Fundamentals and Applications, ed. M. Bacal, L. Grisham, S.K. Guharay, IEEE Trans. Plasma Sciences, vol. 36, no.4, 2008.
[2] “Ion Mobility Spectrometry: Ion Source Development and Applications in Physical and Biological Science”, Samar K. Guharay, P. Dwivedi, H.H. Hill, Jr., IEEE Trans. on Plasma Science, vol. 36, No. 4, 1458-1470, 2008
[3] “Negative Ions for Emerging Interdisciplinary Applications”, S. K. Guharay, Second International Symposium on Negative Ions, Beams and Sources, American Institute of Physics Conf. Proc. vol. 1390, 661-667, 2011
[4] “Modular Ion Mobility Spectrometer for Explosives Detection Using Corona Ionization”, K. Roscioli, E. Davis, W. Siems, A. Mariano, W. Su, S. K. Guharay, H. H. Hill, Analytical Chemistry, vol. 83, 5965-71, 2011
[5] “Ionization, Transport, Separation, and Detection of Ions in non-Electrolyte Containing Liquids”, Manuja R Lamabadusuriya, William F. Siems, Herbert H. Hill, Jr., Adrian Mariano, and Samar K Guharay, Analytical Chemistry, vol. 84, pp. 9295-9302, 2012
[6] “Effect of Space Charge on Resolving Power and Ion in Ion Mobility Spectrometry”, A. Mariano, W. Su, and S. K. Guharay, Analytical Chemistry, vol. 81, 3385-3391, 2009

MonM06

Ion beam sources for surface modification

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The focus of the presentation is the optimization and development of ion beam sources for processing equipment in the area of micro and nanometer surface treatment. Therefor RF or ECR coupled ion beam sources with a multiaperature grid system are used. The development focus is on the beam intensity, the beam shape, the stability and reliability of the parameters. A distinction is made between focused grid systems for localized scanning etching technologies and homogenous broad beam sources. Referring to the presented sources the presentation includes one or two applications with their respective requirements for ion beam sources in such an industrial field. One industrial application is the IonScan series as a production ready tool for ion beam trimming with a collimated beam. The main application is tuning of the resonant frequency of SAW and BAW filters, where inhomogeneities over the wafer during the whole production line would lead to high spread of frequencies and sequentially to a high failure rate. The issue during the development is the stability of the parameters during a twentyfour-seven process in an industrial field and the reproducibility of the parameters of wearing parts e.g. grid systems. Another application is the IonSys series, based on broad beam sources, for sensitive and well controllable deposition and etching processes. These etching processes are used for e.g. magnetoresistance nanopillars, facets etching and ion beam smoothing. The deposition processes are used for multilayer coatings, X-ray filters, optical elements, anti-reflective coating, highly reflective mirrors, sensors or gradient layers. Especially characteristic with the IonSys is the good etch rate and deposition uniformity that meets the standards of reproducibility and stability.

MonA01

Towards 20 A Negative Hydrogen Ion Beams for Up to 1 hour: Achievements of the ELISE Test Facility

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The RF ion source test facility ELISE (Extraction from a Large Ion Source Experiment) is part of the R&D roadmap of the European ITER domestic agency F4E for the ITER neutral beam injection systems. ELISE is dedicated to demonstrate the ITER requirements in terms of accelerated negative hydrogen densities (230 A/m^2 H^-, 200 A/m^2 D^-) at an electron-to-ion ratio of less than one for a source of the same width but only half the height of the ITER source (0.9 x 1 m^2). According to an extraction area of 0.1 m^2, consisting out of 640 beamlets with a diameter of 14 cm each, and including the calculated stripping loss for negative ions in the extraction system of 30% a current of 33 A for H^- and 28.5 A for D^- has to be extracted at a source pressure of 0.3 Pa. Another challenging requirement concerns the beam duration und beam homogeneity: beams up to 3600 s have to be achieved and deviations in the uniformity of the large beam of less than 10% are allowed only. The negative ions are created via the surface conversion process, i.e. the conversion of mainly atoms and positive ions at surfaces with a low work function, for which caesium is evaporated into the source.

The ELISE test facility went into operation in November 2012 with a first maintenance phase after two years of operation. For hydrogen a stable 1 hour plasma discharge with repetitive 10 s beam pulses was demonstrated with 9.3 A extracted current and an electron-to-ion ratio of 0.4 using a 20 kW RF power for each of the four drivers only, which is less than a quarter of the available RF power. At 45 kW RF power per driver and thus half of the available RF power a stable 400 s plasma discharge with extracted beam pulses of 18.3 A (same duty cycle) at an electron-to-ion ratio of 0.7 could be achieved. Challenges in the long pulse operation are the caesium dynamic in the source and the stability of the co-extracted electron current, the latter being the limiting parameter for the power load on the extraction grids and thus for the source performance. The paper focusses on the presentation of the results achieved and the challenges with special focus on long pulse operation. Furthermore, the latest results from the new campaign in which, for the first time, deuterium will be used for source conditioning of a Cs-cleaned source will be reported.

MonA02

First Experiments with the Negative Ion Source NIO1

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Power efficiency of neutral beam injectors for DEMO reactor and other fusion applications critically depends on components, including a multiaperture negative ion source. Its optimization promotes the research of a rich variety of physical issues, for which reduced-size model sources may be of help. The ion source NIO1 (Negative Ion Optimization 1) built by Consorzio RFX and INFN aims to provide such model, and a versatile test bench for innovations and for simulation code validations. The modular design of source and accelerator column allows for replacement of improved parts and electrodes, and many ports are provided for beam diagnostics and pumping. Electrode design and power supplies are rated for a nominal beam current of 130 mA at -60 kV, divided into 9 beamlets with multiaperture extraction electrodes; a 2 MHz (tunable by +/-10 %) radiofrequency generator can provide up to 2.5 kW power in continuous regime, with a cooling system recently improved. Both hydrogen and air were used as feeding gas; the former loads significantly more the pumping system. The general status of the project is reported; conditions for transition to inductive plasma coupling roughly agree with results from a smaller plasma generator and their scaling is discussed. Information on specific physical issues (beam transport, cesium feeding, pumping, and spectrometry) is here summarized.

MonA03

Final Design of the Beam Source for the MITICA Injector

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The MITICA experiment (Megavolt ITER Injector & Concept Advancement) is the prototype and the test bed of the Heating and Current Drive Neutral Beam Injectors (HNB), which will be necessary for the full-performance exploitation of ITER. MITICA injector experiments shall demonstrate the reliable and accurate emission of a 17 MW beam of neutral particles of deuterium or hydrogen for duration up to 1 hour, fulfilling ITER specific requirements. MITICA test bed is in the final design phase and will be procured and installed in PRIMA facility (Padova Research on Injector Megavolt Accelerated) in Padova, Italy. The beam source is the key component of the system, as its goal is the generation of the 1 MeV accelerated beam of deuterium or hydrogen negative ions. The beam source is a complex system, having overall dimensions in the order of 4x4x3 m^3 and a weight of around 20 tons.

A major effort has been put in place in the recent months for the design closure, in collaboration with ITER Organization, F4E and European and Japanese laboratories (IPP, CEA, JAEA), solving the remaining outstanding issues, namely the optimization of the thermo-mechanical behavior of the accelerator grid segments subjected to a substantial heat power deposition, the finalization of the mechanical structure of the accelerator coherently identifying a reliable assembly and alignment procedure, the completion of the design of all involved interfaces with surrounding components and maintenance tools, and the conclusion of last R&D campaign on large ceramic insulators.

Comprehensive analyses have also been carried out to finally verify the structural and electrostatic design of the overall structure with regard to normal operation, main fault conditions and seismic events.

This paper presents the highlights of the latest developments for the finalization of the MITICA beam source design, together with a description of the most recent analyses and R&D activities carried out in support of the design.

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

MonA04

Improvement of Accelerator of N-NBI on LHD

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Three negative-ion-based NBIs (N-NBI), which are called NBI #1, #2, and #3, have been operated on the Large Helical Device (LHD) for plasma heating. Among them, NBI #1 has a different accelerator design with the multi-slotted grounded grid (MSGG) and injects the neutral beam of more than 6 MW with higher stability [1]. The others use the multi-aperture grounded grid (MAGG) and the injection power is limited to around 5 MW. One of the main advantages of the ion source of NBI #1 is a higher voltage holding capability. After the ion-source conditioning, the achieving acceleration voltage is in almost the same for three N-NBIs, but in NBI #2 and #3 the electrical breakdown takes place more frequently. We have suspected that the lower voltage holding capability of NBI #2 and #3 relates to the surrounding structures of the GG support and/or the GG structure itself.

To improve the voltage holding capability on NBI #2 and #3 we modified the surrounding structures of the GG support of NBI #3 and also applied the MSGG instead of the MAGG. In the experiment, we found the improvement in the voltage holding capability. In addition, the heat loading on GG reduced by 40% and the arc efficiency, which is defined as the ratio of the acceleration current to the arc power, increased without any modification of the plasma source. In the presentation, the beam optics with the MSGG will be discussed in detail together with above topics.

References

[1] K. Tsumori, M. Osakabe, O. Kaneko, Y. Takeiri, K. Nagaoka *et al*., Rev. Sci. Instrum. 79, 02C107 (2008).

MonPE01

Simulation of beam profiles from extracted ion current distributions for mini-STRIKE

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In order to develop ITER heating and current drive neutral beam injectors, two experiments are planned to operate in the next future in the PRIMA testbed facility at Consorzio RFX (Padova, Italy). The experiments are a full-size negative ion source, SPIDER, and a prototype of the whole ITER injector, MITICA.

The STRIKE diagnostic calorimeter will be used in SPIDER to investigate the beam properties. A small-scale version of STRIKE, called mini-STRIKE, has been developed and built to check the performance of this type of diagnostic system in existing experiments. It is made of two CFC tiles directly exposed to the beam, whose temperature profile is measured by a thermal camera providing a fine spatial resolution. The tiles are produced with a special technique that permits to obtain a much higher value of thermal conductivity along the thickness (or beam) direction, with respect to the other two directions (perpendicular to the beam). This results in a well-defined footprint of the beam also on the downstream side of the tiles, where it is acquired by the thermo-camera.

BATMAN is a negative ion beam test facility equipped with a radiofrequency source, operating at IPP (Garching bei München, Germany). Its main aim is to investigate the physics underlying generation and extraction of negative ions in the framework of the activities leading to the construction of SPIDER and MITICA. The mini-STRIKE diagnostic calorimeter has been mounted in BATMAN and used for the investigation of the beam properties.

This contribution describes the adaptation to the negative ion beam of BATMAN of the codes, which are currently used to model the SPIDER and MITICA experiments. In particular, the SLACCAD and EAMCC codes have been used to simulate the beam optics, the NBImag code for the magnetic fields and a dedicated model developed in COMSOL for the temperature distribution on the tile. The latter one is a non-linear, transient, finite element model that calculates the temperature across the downstream surface of the tile during and after the beam pulse, by applying as boundary condition on the upstream side the heat load calculated by the EAMCC code, and taking into account the anisotropy of the thermal conductivity in the CFC.

The current density across the extraction area is influenced by several factors like the source geometry, the magnetic field and the particle drifts inside the source, and the cesium distribution. The main outcome of the present contribution is the development of a minimisation method to estimate the extracted current distribution using the footprint of the beam recorded with the mini-STRIKE diagnostic. First results of the application of the method to the BATMAN beam are given.

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

MonPE02

Multi-beamlet investigation of the deflection compensation methods of SPIDER beamlets

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The ITER experiment will be the first step towards energy from fusion. Nuclear reaction will occur in a hot (Te < 40keV) plasma requiring external heating systems like the injection of energetic beams of particles. In order to gain a better understanding of the physics of neutral beam injectors (NBI) and to optimize the prototype of ITER injectors, a dedicated test facility is under construction at Consorzio RFX, Padova (Italy). It will feature two major experiments: MITICA (Megavolt ITER Injector and Concept Advancement), a complete prototype of the ITER NBIs, and a full-scale ion source, named SPIDER (Source for Production of Ions of Deuterium Extracted from an Rf plasma). SPIDER is designed to extract and accelerate a 355 A/m^2 current of H^- (or 293 A/m^2 of D^-) up to 100 kV and its construction is entering the final phase, with most of the components already procured and the first beam expected by the end of 2016.

SPIDER accelerating stage is composed of three electrodes (plasma grid PG, extraction EG and grounded grid GG), each featuring 16 groups of 5x16 apertures tracing beamlet path. Two effects perturb the beamlet path during the acceleration stage: space charge repulsion and the deflection induced by the permanent magnets (CESM) embedded in the extraction grid, needed to suppress co-extracted electrons. These two effects have respectively electrostatic and magnetic origin and can be reduced by electrostatic or magnetic means. A unique feature of SPIDER experiment is the presence of different methods of compensation for the deflection induced by CESM: a magnetic one which make use of a second group of permanent magnets, embedded in the GG; and an electrostatic one which consists in offsetting the apertures of the GG, thus steering the beamlet in order to counteract the deflection.

The purpose of this work is to evaluate and compare benefits, collateral effects and limitations of electrical and magnetic compensation methods for beamlet deflection. The study of these methods has been carried out extensively by means of numerical modelling tools: multi beamlet simulations have been performed. This is a further step with respect to the earlier analyses on this ion source [1].

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

[1]P.Agostinetti et Al., Physics and engineering design of the accelerator and electron dump for SPIDER, 28 april 2011, Nucl. Fusion 51 (2011) 063004 (16pp).

MonPE04

Modeling of the charge-state separation at ITEP Experimental facility for material science based on a Bernas ion source

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Experimental facility for material science at ITEP based on a multi-charged ion source (ECRIS and Bernas ion source) is developed. The ion charge-state separation is provided by means of the bending magnet. The experiment automation requires the preliminary modeling of the beam particle behavior after the particle extraction from the source, including the particle pre-acceleration and the turn in the dipole magnetic field. The program CAMFT [1] is supposed to be involved into the program of the experiment automation for material research and material processing. CAMFT is developed to simulate the intense charged particle bunch motion in the external magnetic fields with arbitrary geometry by means of the accurate solution of the particle motion equation. Program allows the consideration of the bunch intensity up to 10^{10} ppb. Preliminary calculations are performed at ITEP supercomputer. The results of the simulation of the sheet beam acceleration and following turn are presented for different initial conditions.

[1] H. Y. Barminova, M. S. Saratovskyh. In Proc. 4th ICMSQUARE, Mykonos, Greece, 2015.

MonPE05

High intensity proton injector for facility of antiproton and ion research (FAIR)

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The high current ion source with the low energy beam transport (LEBT) would serve as injector into the proton LINAC to provide primary proton beam for the production of antiprotons. The pulsed ion source developed and made in CEA/Saclay, operates with a microwave frequency equal to 2.45 GHz based on ECR plasma production with two coils each with 87.5 mT magnetic field. The compact LEBT consists of two solenoids with a maximum magnetic field of 260 mT with two integrated magnetic steerers for adjusting the horizontal and vertical beam position. The total length of the compact LEBT is 2.3 m. The length reduced to minimize expected emittance growth along the beam line. For measuring ion be am intensity behind the pentode extraction system, between solenoids and at the end of the beam line a beam transformer and a Faraday cup will be installed. To get information about the beam quality and position the diagnostic chamber with different equipment will be installed between two solenoids. The proton injector has to deliver 100 mA proton beam with the energy 95 keV at the entrance of the RFQ with the emittance lower than 0.3π mm mrad (normalized, rms). This paper presents the status of the proton injector and proton LINAC for FAIR anti-proton research.

MonPE06

A New Solid State Extractor Pulser for the FNAL Magnetron Ion Source

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A new solid state extractor pulser has been installed on the Fermi National Accelerator Laboratory (FNAL) magnetron ion source, replacing a vacuum tube style pulser that was used for over 40 years. The required ion source extraction voltage is 35 kV for injection into the RFQ. At this voltage the old pulser had a rise time of over 150 microseconds due to the di/dt limit of the vacuum tube. This along with the lifetime of the tubes, on the order of 3 months, the long lead time when ordering tubes, and the fact that there was only one manufacturer of them, led us to investigate solid state switches. The solid state switches in the new pulser are capable of 50 kV and 30 A pulses and are the same switches that we have installed in our Einzel lens chopper. When installed in the operating system they have a rise time of 9 microseconds and so far have been able to withstand frequent extractor sparks. This paper will discuss the pulser design and operational experience to date.

MonPE07

Analysis of diagnostic calorimeter data by the transfer function technique

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The ITER project requires additional heating provided by two injectors of neutral beams resulting from the neutralization of accelerated negative ions. To study and optimise negative ion production, the SPIDER test facility (particle energy 100keV; beam current 50A) is under construction in Padova, with the aim of testing beam characteristics and to verify the source proper operation. The SPIDER beam will be characterized by the instrumented calorimeter STRIKE, whose main components are unidirectional carbon composite tiles. Some prototype tiles have been employed as a small-scale version of STRIKE (mini-STRIKE) to test the effectiveness of the beam diagnostic.

This contribution describes the analysis procedure applied to the thermal measurements on the rear side of the tiles with the purpose of reconstructing the energy flux due to the negative ion beam colliding on the front side. The method is based on the transfer function technique and allows a fast analysis by means of the FFT algorithm.

The efficacy of the method has been tested both on simulated and measured mini-STRIKE temperature profiles: in all cases the energy flux features are well reproduced and beamlets are well resolved; limits and restrictions of the method are also discussed, providing strategies to handle issues related to signal noise and digital processing.

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

MonPE08

Design and Fabrication of a Duoplasmatron Extraction Geometry and LEBT for the LANSCE H^+ RFQ Project

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The 750-keV H^+ Cockcroft-Walton at LANSCE will be replaced with a recently fabricated 4-rod RFQ with injection energy of 35 keV. The existing duoplasmatron source extraction optics need to be modified to produce up to 35 mA of H^+ current with an emittance <0.02 pi-cm-mrad (rms,norm) for injection into the RFQ. Parts for the new source have been fabricated and assembly is in process. We will use the existing duoplasmatron source with a newly designed extraction system and LEBT for beam injection into the RFQ. In addition to source modifications we need a new LEBT for transport and matching into the RFQ. The LEBT uses two magnetic solenoids with enough drift space between them to accommodate diagnostics and a beam deflector. The LEBT is designed to work over a range of space-charge neutralized currents and emittances. The LEBT is optimized in the sense that it minimizes the beam size in both solenoids for a point design of a given neutralized current and emittance. Special attention has been given to estimating emittance growth due to source extraction optics and solenoid aberrations. Examples of source-to-RFQ matching and emittance growth (due to both non-linear space charge and solenoid aberrations) are presented over a range of currents and emittances about the design point. A mechanical layout drawing will be presented along with the status of the source and LEBT, design and fabrication.

MonPE09

Scaning Effects of Applied Voltage to a Deceleration Electrode on the Ion Current Density Profile of Low-Energy and High-Current-Density Ion Beam Extracted through Concave Electrodes

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A high current density (~3.0 mA/cm^2) and low energy (60 - 170 eV) ion beam is extracted through three sets of electrodes (acceleration, deceleration and grounded electrodes) with concave shape (nominal focal length of ~350mm)[1-3]. The highly focused low energy ion beam is obtained with the ion charge compensation by the secondary electrons emitted from the grounded electrode on which an additional electron beam is irradiated[2-4]. To explore an optimum condition for acheiveing higher ion current density, the applied voltage to the deceleration electrode was scanned from -300 V to -2,500 V. The results indicate that ion beam current density has two mamimum peaks at around -500 V and -2,200 V, respectively. We will present the results of the applied voltage scanning with and without electron beam irradiation to the grounded electrode and discusse the possible mechanism of the beam profile modification.

References

[1] H. Sakakita, et al., Rev. Sci. Instrum. **83**-02B708 (2012) 1-3.
[2] Y. Hirano, et al., Jpn. J. Appl. Phys. **52** (2013) 066001, 1-6.
[3] Y. Hirano, et al., Rev. Sci. Instrum. **85**, 02A728 (2014) 1-3.
[4] Y. Fujiwara, et al., Rev. Sci. Instrum. **85**, 02A726 (2014) 1-3

MonPE10

Effect of Coulomb Collision on the Negative Ion Extraction Mechanism in Negative Ion Sources

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Negative hydrogen ion (H^-) beam has a wide range of applications, such as fusion plasma heating, accelerators for medical use and high energy particle physics. However, the extraction mechanism of negative ions from the ion sources has not been fully understood yet. To clarify the extraction mechanism of H^- ions is an important subject for optimizing the negative ion beam extraction. In our previous study, numerical simulations using the 2D3V-PIC (two dimension in real space and three dimension in velocity space)·(Particle In Cell), and 3D3V-PIC model have been carried out to understand the H^- extraction mechanisms[1-3].

In this study, for two purposes described below, Coulomb collisions such as electron-H^-, H^--H^+ have been taken into account to our 2D3V-PIC. The first aim is to estimate the detailed effect of electron transport across the filter magnetic field. Electron diffusion across the filter magnetic field is introduced by a simple model derived from diffusion equation with some approximations in the previous PIC model of the extraction region[4]. One of the main causes of the electron diffusion across the filter field is Coulomb collision. The detailed effect of Coulomb collisions on the diffusion process will be discussed in this paper. The second aim is to clarify the energy relaxation process of surface produced H^- ions. The energy of H^- ions produced on the PG surface is estimated to be ~ 1 eV from the theoretical formula[5]. However, the energy of H^- ions in the extraction region is estimated to be ~ 0.1 eV from the beam emittance calculated by using the PIC simulation[6]. This result indicates that the energy of surface produced H^- ions could be reduced by some physical mechanisms such as Coulomb collisions with lower energy particles.

References

[1] K. Miyamoto, S. Okuda, and A. Hatayama, Appl. Phys. Lett., **100**, 233507(2012).
[2] K. Miyamoto, S. Okuda, S. Nishioka, and A. Hatayama, J. Appl. Phys., **114**, 103302/1-7(2013).
[3] S. Nishoka, K. Miyamoto, S. Okuda, I.Goto, A. Hatayama and A. Fukano, Rev. Sci. Instrum. **85**, 02A737/1- 3(2014).
[4] I. Goto, K. Miyamoto, S. Nishioka and A. Hatayama, AIP Conf. Proc. **1655**, 020011(2015).
[5] R. McAdams, A. J. T. Holmes, D. B. King, and E. Surrey, Plasma Sources Sci. Technol. **20**, 035023-1 (2011).
[6] K. Miyamoto (private communication).

MonPE11

Installation of Spectrally Selective Imaging System in RF Negative Ion Source

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Understanding of negative hydrogen ion behavior near the production surface is an important issue to maintain high negative beam current in a hydrogen negative ion source for NBI. We install a spectrally selective imaging system based on a GigE vision camera with Gigabit Ethernet connection, in the RF negative ion source in ELISE. A distribution of H_α emission near the plasma grid has been clearly observed, and the time trace of its intensity is consistent with the signal intensity of H_α emission observed by optical emission spectroscopy located at the opposite side viewing port. Signal reductions of H_α emission during beam extraction are the same characteristics in both. Reduction area is widely distributed in the extraction region in the long discharge operation, which behavior is similar to the reduction distribution measured in arc discharge source.

MonPE12

Study of Electron Current Extraction from a Radio Frequency Plasma Cathode Designed as a Neutralizer in Ion Source Applications

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Plasma cathodes have been introduced in recent years as an alternative for the hollow cathodes in electric propulsion applications. These types of electron sources use a bulk plasma generated inside the device chamber to extract electrons. Because of its compact geometry, high efficiency, and easy generation, the RF plasma has been considered as a preferable source to be employed in plasma cathode devices. A radio frequency plasma cathode is designed and manufactured at the Bogazici University Space Technologies Laboratory (BUSTLab) to be used as a neutralizer and an electron source for the various ion thrusters (ion sources) developed at BUSTLab. RF plasma cathode is capable of being switched on instantaneously, compared to the hollow cathode that takes considerable time to be operational. It also does not include an insert material which causes serious lifetime problems in the operation of hollow cathode.

In this study, the successful design and manufacturing process of an RF cathode are presented. The effect of the various design parameters, such as chamber geometry and orifice dimensions, as well as the operational parameters, such as applied RF power and gas flow rate, on the plasma generation inside the device and the electron beam extraction from it are broadly studied. With the use of a home-built double Langmuir probe, RF plasma parameters (electron density and electron temperature) inside the RF plasma cathode are measured at various operational conditions of the device. In addition, the extracted electron current measurements are presented, and the most efficient design parameters and operational conditions are determined.

MonPE13

Prototyping of beam position monitor for medium energy beam transport (MEBT) section of RAON heavy ion accelerator

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A heavy ion accelerator, RAON is going to be built by Rare Isotope Science Project (RISP) in Korea. Its target is to accelerate various stable ions such as uranium, proton, xenon from electron cyclotron resonance ion source (ECR-IS) and some rare isotopes from isotope separation on-line (ISOL). The beam shaping, charge selection and modulation should be applied to the ions from these ion sources because RAON adopts a superconducting linear accelerator structure for beam acceleration. For such treatment, low energy beam transport (LEBT), radio frequency quadrupole (RFQ) and medium energy transport (MEBT) will be installed in injector part of RAON accelerator. Recently development of a prototype of stripline beam position monitor(BPM)to measure the position of ion beams in MEBT section is under way. In this presentation, design of stripline, electromagnetic simulation results and RF measurement test results performed on the prototyped BPM will be described.

MonPE14

The Beam Injection Line Test of CYCIAE-100 Cyclotron

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

MonPE15

Beam dynamics simulations of post Low Energy Beam Transport section in RAON heavy ion accelerator

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RAON heavy ion accelerator of the Rare Isotope Science Project (RISP) in Daejeon, Korea, has been designed to accelerate multiple-charge-state beams for various science programs. In the RAON accelerator, the rare isotope beams which are generated by an Isotope Separation On-Line (ISOL) system with a wide range of nuclei and charges will be transported through the post Low Energy Beam Transport (LEBT) section to the Radio Frequency Quadrupole (RFQ). To transport many kinds of rare isotope beams stably to the RFQ, the post LEBT should be designed to keep the small twiss parameters and to satisfy the requirement of RFQ at the end of post LEBT. We will present the recent lattice design of the post LEBT in RAON accelerator and the result of the beam dynamics simulations. In addition, the error analysis and correction in the post LEBT will be also described.

MonPE16

Transportation of a radioactive ion beam for precise laser-trapping experiments

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A radioactive francium (Fr) atom is known to enhance the effect of an atomic parity violation and an electric dipole moment, which means the violation of the time-reversal symmetry, due to its large nucleus. We are aiming at a discovery of the violation of fundamental symmetries by precision measurements of such observables using laser-trapped neutral Fr atoms.

Fr is produced through the nuclear fusion reaction between an oxygen beam and a gold target. The produced Fr is ionized at the surface of the gold target and is transported by electrostatic fields corresponding to a few keV. A problem was revealed that the purity of the produced ion beam was quite low because of impurities contained within the materials. The low-purity beam degrades the efficiency of the laser trapping. Therefore, a Wien filter was installed to purify the beam by mass separation. Accordingly, the purity was improved approximately 1000 times and it will lead to an improvement of the trapping efficiency. We report results obtained from the Wien filter experiment.

An imperceptible beam transportation has also been studied using stable rubidium isotopes to simulate a procedure from the production to the laser trapping of the radioactive element. Additionally, a newly-designed Fr ion source is developed to increase a production yield.

MonPE17

Modification to the Accelerator of the NBI-1B Ion Source for improving the Injection Efficiency

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Neutral beam injection (NBI) heating experiments in Korea Superconducting Tokamak Advanced Research (KSTAR) have demonstrated that the injection energetic neutral beam is one of the most effective and powerful methods for heating a tokamak plasma since 2010 KSTAR campaign. As a request for the additional neutral beam power of 2.0 MW so as to support advanced plasma experiments of KSTAR, a NBI-1B ion source was developed and installed at NBI-1 System of KSTAR in 2012. Maximum 100 keV/50A deuterium ion beam by NBI-1B ion source was successfully extracted, beam power transmission efficiency, however, was discovered to be poor (below than 70 %) during 2012 and 2013 experimental campaign of KSTAR. Minimizing power loss of a neutral beam through KSTAR NBI-1 beamline is required to keep high injection efficiency to the tokamak plasma. The long beamline with limited area of the beam duct diminishes the effectiveness of neutral beam injection to the tokamak plasma, and imposes modification of the accelerator of the ion source for further improvement of the beam optics. A technique to steer ion beamlets by aperture displacement appear to be the most powerful and practical method to focus the beam and to improve the injection efficiency considering the cost efficiency. In this paper the injection efficiencies and the heat loads on the beamline components by steering of ion beamlets are investigated numerically to find optimum modification of the accelerator design of the NBI-1B ion source and the experimental results with the modified accelerator of NBI-1B ion source are described.

MonPE18

Development of ion beam analyzing system for KBSI heavy-ion accelerator

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The Korea Basic Science Institute (KBSI) has been developing a heavy ion accelerator system to produce high current, multi-charge state ions employing a 28 GHz superconducting electron cyclotron ion source. An analyzing system as a part of the LEBT apparatus was developed to separate the ion beams. The desired species of ion beam, which was generated and extracted from the ECR ion source including various particles, could be selected by 90 degree dipole electromagnet. Two dimensional electromagnetic design of the dipole magnet was firstly performed for searching basic parameters to meet the requirement of LEBT design. Due to the non-symmetric structure in the coil as well as non-linear permeability of yoke material coil, three dimensional analysis was carried out to confirm the design parameters. Power supply for analyzing magnet was also developed to satisfy the high precision control (~10 ppm), which is enable to separate various species ion beam. After the fabrication and installation, we observed the performance of analyzing system through the 3-axis field measurement. In this paper, we present the operational results of analyzing system for KBSI accelerator. The effectiveness of beam selection is confirmed during the test of analyzing system by injecting ion beam from ECR ion source.

MonPE20

Development of the Pepper-pot Emittance Meter for Diagnostics of Low-Energy Multi-Charged Heavy Ion Beams Extracted from an ECR Ion Source

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To improve the beam transport in LEBT, it is important to understand the dynamics of ion beams extracted from an ECR ion source. Transverse emittances are crucial parameters for beam quality, and the beam intensity can be optimized by means of emittance matching with the LEBT's acceptance. Moreover, the importance of decoupling any inter-plane correlation in the transverse 4D emittance is discussed as it can lead to increasing the beam brightness [1]. Within this scope, we have developed an emittance meter based on the pepper-pot method that can measure the 4D phase-space distribution. For simplicity, the ion beam passing through the pepper-pot pin-holes directly impinges on a transparent scintillator and the light is collected from the backside by means of a CMOS camera. The scintillator is a critical part of the device and investigations on scintillators with several MeV/u ion beams were performed [2]. However, because of lower energy and higher intensity of the beam extracted from the ECR source, degradation of the scintillator induced by irradiation is a concern. At first, scintillators including CsI, KBr, CaF_2 and quartz have been investigated with proton beam (~100 eμA, 6.52 keV). Quartz was found to be the most resilient to damage featuring also linear light emission proportional to beam intensity, but light output was lower than the others. On the other hand, light emissions from CsI, KBr and CaF_2 was initially higher but degraded quickly. A commercial CMOS camera has been customized for water-cooled operation that results in significant thermal noise reduction under high gain/long exposure time operation. Software based on Labview takes care of the data acquisition and real time emittance calculation. Typical processing time from image capture to 4D phase space plots is around 1 s.

References

[1] C. Xiao et.al., Phys. Rev. STAB, **16**, 044201 (2013), L. Groening, Phys. Rev. STAB, **14**, 064201 (2011).
[2] Eiko Gütlich et.al, IEEE Trans. Nucl. Sci., **57**, 1414 (2010).

MonPE21

Beam imaging in the injection line of the Superconducting Cyclotron of the INFN-LNS

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A cheap and efficient diagnostic system for beam monitoring has been recently developed at INFN-LNS in Catania. It consists of a high sensitivity CCD camera detecting the light produced by an ion beam hitting the surface of a scintillating screen and a frame grabber for image acquisition. A scintillating screen, developed at INFN-LNS and consisting of a 2 µm BaF_2 layer evaporated on an Al 2 mm thick plate, has been tested by using a ^{20}Ne beam of different charge states in the keV energy range. The CAESAR ECR ion source has been used for investigating the influence of the frequency and magnetic field tuning effects, the impact of the microwave injected power and of the focusing solenoids along the LEBT on the beam shape and current. These tests will allow to better understand the interplay between the plasma and beam dynamics and, moreover, to improve the transport efficiency along the low energy beam line and the matching with the superconducting cyclotron, particularly relevant in view of the expected upgrade of the machine. A new diagnostic tool for mAs current beams, based on a Microchannel Plate for detecting Secondary Electron Emission by an Al foil, is now under investigation and will complete a wide gamma of beam monitoring setups soon available at the INFN-LNS.

MonPE22

Castellated tiles as the beam-facing components for the diagnostic calorimeter of the negative ion source SPIDER

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Operation of the thermonuclear fusion experiment ITER requires additional heating via injection of neutral beams from accelerated negative ions. In the SPIDER test facility, under construction in Padova, the production of negative ions will be studied and optimised. The STRIKE diagnostic (Short-Time Retractable Instrumented Kalorimeter Experiment) will be used to characterise the SPIDER beam during short pulse operation (several seconds) to verify the degree of attainment of ITER requirements about the maximum allowed beam non-uniformity (below ±10%). The major components of STRIKE are 16 tiles, corresponding to the SPIDER beam arrangement, which are observed on the rear side by a thermal camera. The main requirements of the tiles are: to preserve the thermal pattern throughout the heat conduction from the front to the rear side; to tolerate very high and localised heat loads and the consequent thermo-mechanical stresses.

This contribution describes a solution for tiles made of an essentially homogeneous and isotropic material like graphite, machined in such a way that heat is forced to propagate mostly in one direction (castellated tiles). In order to assess the reliability and the diagnostic capabilities of the tiles under high power irradiation, suitable finite element thermo-mechanical analyses were undertaken in the conditions expected of the SPIDER beam; moreover experimental tests on a prototype exposed to a high power beam were performed in the GLADIS facility at IPP (Max-Plank-Institut für Plasmaphysik) Garching. The results of these studies are described as well as the numerical simulations of the data measured when the size of the thermal camera pixels is comparable to the typical dimension of the elements of the castellated tiles for SPIDER.

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

MonPE23

Charge Neutralized Low Energy Beam Transport at Brookhaven 200 MeV Linac

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Space charge effects are most severe at low energy. The H- magnetron source proved about 100 mA H- beam to be match into the radio-frequency quadrupole accelerator. During the 450 microsecond long pulses, capturing the positive ion from residual gas ionization beam gets neutralizes. The neutralization time for the critical density depends upon the background gas and its pressure. Critical density for Xenon gas at 35 keV is about 43 times smaller than of Hydrogen and stripping cross section is only 5 times than of Hydrogen gas. We are using Xenon gases to reduce neutralization time and to improve transmission through the 200 MeV Linac. We have tried few other gases and We are also using pulse nitrogen gas to improve transmission and stability of polarized H- beam from OPPIS.

MonPE24

Beam Simulation Studies of ECR Beam Extraction and Low Energy Beam Transport for FRIB*

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To meet the beam power requirements of 400 kW at the fragmentation target for FRIB, simultaneous acceleration of two-charge states should be used for heavier ions. These intense multi-charged ion beams will be produced by a 28 GHz electron cyclotron resonance (ECR) ion source at a high voltage of 35 kV. After extraction, the ion beam will be pre-accelerated to 12 keV/u with a 50 kV platform, transported down to an achromatic charge state selection (CSS) system followed by a vertical transport line, and then injected into a radio frequency quadrupole (RFQ) accelerator. The TRACK code developed at ANL is used to perform the simulations of the ECR beam extraction and low energy beam transport (LEBT) for FRIB. In this study, we include the magnetic field of ECR ion source into simulations. Different initial beam conditions as well as different space charge neutralization levels are tested for the ECR beamline. The beam loss in CSS system and the corresponding protective measures are discussed. The detailed results about the beam dynamic simulation and beam loss in CSS system will be presented in this paper.

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MonPE25

Gas Flow and Density Profile in NIO1 Accelerator and Vessel

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NIO1 (Negative Ion Optimization 1) is a versatile ion source constructed to study the physics of production and acceleration of H- beams up to 60 keV [1]. In ion sources, the gas is steadily injected in the plasma source to sustain the discharge, while high vacuum is maintained by a dedicated pumping system located in the vessel. In order to study the processes occurring during the acceleration phase in between the electrodes and also downstream, with respect to the accelerator, knowledge of the density of the background gas is required: in electrostatic accelerators of negative ions, extracted beam ions are lost by collision processes with the background gas, attenuating the beam current, affecting the beam space charge, and causing heat deposition onto the electrodes by stray particles and onto the source backplate by back-streaming positive ions.
In this paper, the three dimensional gas flow in NIO1 is studied in the molecular flow regime by the Avocado code [2]. The analysis of the gas density profile along the accelerator considers the influence of effective gas temperature in the source, of the gas temperature accommodation by collisions at walls, and of the gas particle mass. The calculated source and vessel pressures are compared with experimental measurements in NIO1 during steady gas injection.

This projects has received funding from the European Union's Horizon 2020 research and innovation program.

References

[1] M. Cavenago et al., Design of a versatile multiaperture negative ion source, Rev. Sci. Instrum. 81, 02A713 (2010)
[2] E. Sartori, P. Veltri, AVOCADO: A numerical code to calculate gas pressure distribution, Vacuum 90 (2013)

MonPE26

Simulation of Space Charge Compensation in a multibeamlet negative ion beam

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Space charge compensation (SCC) is a typical phenomenon of ion beam physics [1]: the beam space charge is compensated for by accumulating, in the beam potential well, charges having opposite polarity, usually generated by collisional processes.

In this paper we investigate the case of the drift of a H- ion beam, in a bi-dimensional approximation of the NIO1 negative ion source [2]. H- beam ion transport and plasma formation are studied via particle-in-cell simulations. Differential cross sections are sampled to determine the velocity distribution of secondary particles generated by ionization of the residual gas (electrons and slow H2+ ions) or by stripping of the beam ions (electrons, H, H+). The simulation includes three beamlets of a horizontal section, so that multibeamlet space charge and secondary particle diffusion between the three separate generation regions are considered.

Simulations show that the beam space charge is effectively screened by the secondary plasma, with a characteristic time for potential compensation around 3μs in agreement with theoretical expectations. As expected in the case of negative ions, a slight overcompensation of the electric potential is verified. Effects on the beamlet emittance are discussed.

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References:

[1] P. Spädtke, The role of space charge compensation for ion beam extraction and ion beam transport, Rev. Sci. Instrum. 85, 02A744 (2014)
[2] M. Cavenago et al., Design of a versatile multiaperture negative ion source, Rev. Sci. Instrum. 81, 02A713 (2010)

MonPE27

Effects of a Dielectric Material in an Ion Source on the Ion Beam Current Dencity and Ion Beam Energy

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A strong self-focusing phenomena has been observed at a high current density and low energy ion beam extracted through three electrodes with a concave shape (nominal focal length of 350 mm) [1-4]. To understand this phenomenon, an electron temperature, an electron density and a space potential in the ion source before and after the transition to a self-focusing state are measured by using an electrostatic probe whivh is covered by a dielectric material. The experimental results show that a significant change does not appear. However, we found new interesting effects characterized by the position of the electrostatic probe in the ion source chanber. The effects of dielectric material show that ion beam current density and ion beam energy are obviously increased to put the electrostatic probe at the close position to an accerelation electrode. We will present the results of ion beam current density profile and ion beam energy distribution at each different positions of the electrostatic probe, and will discusse about the possible mechanism of new effects.

References

[1] H. Sakakita, et al., Rev. Sci. Instrum. **83**-02B708 (2012) 1-3.
[2] Y. Hirano, et al., Rev. Sci. Instrum. **85**, 02A728 (2014) 1-3.
[3] Y. Hirano, et al., Jpn. J. Appl. Phys. **52** (2013) 066001, 1-6.
[4] Y. Fujiwara, et al., Rev. Sci. Instrum. **85**, 02A726 (2014) 1-3.

MonPE28

Numerical Simulations of the First Operational Conditions of the Negative Ion Test Facility SPIDER

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The ITER project requires additional heating provided by two injectors of neutral beams resulting from the neutralisation of accelerated negative ions. To study and optimise negative ion production, the SPIDER (Source for Production of Ions of Deuterium Extracted from an Rf plasma) test facility is under construction in Padova, with the aim of testing beam characteristics and to verify the source proper operation.

The SPIDER beam parameters are a particle energy of 100keV and a beam current of 50A; the beam source will be of the radiofrequency type; negative ions will be mostly generated on the source surfaces covered by a thin layer of evaporated caesium. SPIDER experiments will start in 2016.

The present contribution will briefly describe the specific features of the SPIDER accelerator and the expected preliminary phases of the SPIDER operations, dedicated to source and accelerator commissioning: with the goal of improving SPIDER performances, voltage holding conditioning of the accelerator, caesium conditioning of the source, beam extraction will be carried out.

The expected beam features will also be described by means of numerical simulations, considering the detailed magnetic and electrostatic configuration of the accelerator, the various operational phases, the corresponding expected source and beam parameters. These results will be most useful to prepare for the earliest experimental campaigns.

MonPE29

Surface Modification of Ferritic Steels Using MEVVA and Duoplasmatron Ion Sources

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Metal Vapor Vacuum Arc (MEVVA) ion source is a unique tools for production of high intensity metal ion beam that can be used for material surface modification. From other hand the duoplasmatron ion source provides the high intensity gas ion beams. The MEVVA and Duoplasmatron ion sources developed in Institute for Theoretical and Experimental Physics (ITEP were used for the reactor steel surface modification experiments. Response of ferritic-martensitic steel specimens on titanium and nitrogen ions implantation and consequent vacuum annealing is investigated. Increase in microhardness of near surface region of irradiated specimens is observed. Local chemical analysis shows atom mixing and redistribution in the implanted layer followed wit formation of ultrafine precipitates after annealing.

MonPE30

Development of a Long-Slot Microwave Plasma Source

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A rectangular-shape microwave source capable of producing uniform plasma has been being developed for charge neutralization and ion beams extraction. A long rectangular plasma source has been already developed [1], but this type of plasma source utilizes a complicated geometry to achieve coupling of microwave power into the produced plasma. A plasma source with the simple structure shown in Figure 1 has been proposed to extend maintenance interval for use in semi-conductor production environment. It has two antennas movable in the direction to change the spacing between the chamber wall and the antennas. Electron temperature and density distributions of the produced plasmas are investigated for different antenna positions and permanent magnet arrangements.

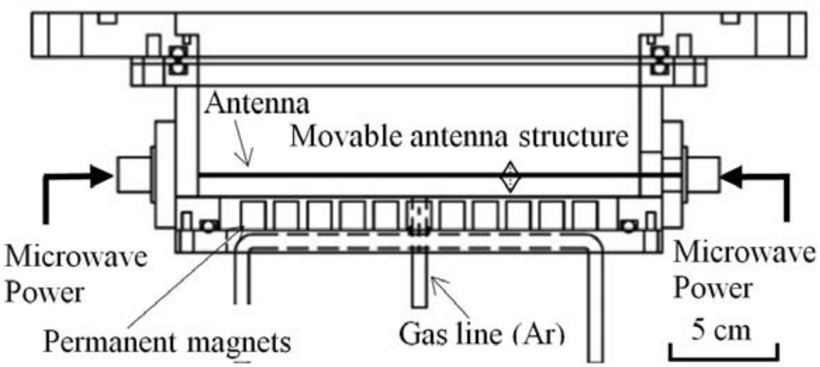

Fig.1. Cross section of the rectangular plasma source.

Reference

[1] T. Yasui, K. Nakase, H. Tahara and T. Yoshikawa: J. Appl. Phys. Vol. **35** (1996) 5495.

MonPE31

Compact RF Ion Source for Industrial Electrostatic Ion Accelerator

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KOMAC (KOrea Multi-purpose Accelerator Complex) is developing a single-ended electrostatic ion accelerator to irradiate gaseous ions, such as hydrogen, nitrogen, etc., on materials for industrial applications. The maximum accelerating voltage is 1 MV, and the maximum beam current is 10 mA. For the high-voltage power supply that should be robust and capable for high-current operation, ELV (electron accelerator from Budker Institute of Nuclear Physics, Novosibirsk, Russia) type has been selected. An ion source is installed in the high-voltage terminal in high-pressure tank of sulphur hexafluoride insulating gas. Because of the limited space and the limited electrical power (<500 W) in the high-voltage terminal, the ion source should be compact and electrically efficient. The 200-MHz RF ion source has been developed for this purpose. In this conference the result of the development will be presented.

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MonPE32

Enhancement of Ionization Efficiency of Hot-Cavity Ion Sources*

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Hot-cavity surface ionization sources are evaluated for applications of detecting uranium and thorium impurity levels in the high purity copper materials to be used for the experiment to search for neutrinoless double-beta-decay [1]. The performance of the ion sources is characterized using uranyl nitrate and thorium nitrate sample materials with sample sizes between 20 – 40 □g of 238U or 232Th. The ionization efficiencies obtained are about 1% and 3% for U with Ta and W cavities, respectively, and 2.5% for Th with a W cavity. It has been reported that increasing the neutral density in the cavity, by feeding in a non-ionizing gas such as Xe, could increase the ionization efficiency substantially [2]. We have investigated this enhancement effect for a Ta-cavity source with Xe, Kr and Ne noble gases. It is observed that the overall ionization efficiency for U can be increased by a factor of 5 with a noble gas added and the largest enhancement is obtained with Kr. The enhancement is ascribed to the reduction of the mean free path and thus the probability of wall recombination of the ions. The characteristics of the gas effect will be reported.

References

1. N. Abgrall, et al., Advances in High Energy Physics, Vol. 2014, Article ID 365432.
2. R. Kirchner, Nucl. Instr. and Meth. A 292 (1990) 203.

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MonPE33

Development of a compact ECR ion source for various ion production

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There is a desire that a carbon-ion radiotherapy facility will produce various ion species for fundamental research. Although the present Kei2-type ion sources are dedicated for the carbon-ion production, a future ion source is expected: 1) carbon-ion production for medical use, 2) various ions with a charge-to-mass ratio of 1/3 for the existed linac injector, and 3) low cost for modification. A prototype compact electron cyclotron resonance (ECR) ion source, named Kei3, based on Kei series has been developed to correspond to produce these various ions at National Institute of Radiological Sciences (NIRS). The Kei3 has an outer diameter of 280 mm and a length of 1120 mm. The magnetic field is formed by the same permanent magnet as Kei2. The movable extraction electrode has been installed in order to optimize the beam extraction with various current densities. The gas-injection side of vacuum chamber has enough space for an oven system. We measured dependence of microwave frequency, extraction voltage, and puller position. Charge state distributions of helium, carbon, nitrogen, oxygen, and neon were also measured.

MonPE34

Development of C6+ Laser Ion Source and RFQ for Carbon Ion Radiotherapy

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A prototype C6+ injector using a laser ion source has been developed for the compact synchrotron dedicated to the carbon ion radiotherapy. The injector consists of a laser ion source and a 4-vane RFQ. Ion beams are extracted from the plasma and directly injected into the RFQ [1]. The drift space is covered by a solenoid to guide the low-energy beams. The RFQ is designed to accelerate high intensity pulsed beam. The vanes and the cavities are designed with integral structure to reduce power consumption. Design concept and experimental are presented.

References

[1] M. Okamura, T. Katayama, R. A. Jameson, T. Takeuchi, and T. Hattori, Rev. Sci. Instrum. 73, 761 (2002).

MonPE35

Development of a Microwave Ion Source for Ion Implantations

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A microwave ion source is expected to be a long-life ion source, because of fewer consumable. Thus, we have been developing a microwave ion source for ion implantations. In this paper, we report on a newly developed plasma chamber and the extracted P^+ beam currents. The volume of the plasma chamber is optimized by changing the length of a BN cylinder which is installed in the plasma chamber. The extracted P^+ beam current is more than 30mA, 25kV using PH_3 gas.

MonPE36

Low-energy Ion Beam-based Deposition of Gallium Nitride

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A dual chamber sputter-type plasma system was used to extract low-energy ion beams for thin film growth of gallium nitride (GaN). The first chamber is made of a quartz cylinder with a 6 mm diameter copper antenna wrapped around the cylinder. Inductively coupled gas discharge was realized in the first chamber using a 13.56 MHz radio frequency power with autotuning matching circuit connected to the antenna. The discharge was then guided by electromagnetic fields into another chamber where a liquid gallium (Ga) target was poured onto a tungsten reservoir. At the back of the target are water-cooled cylindrical and annular SmCo magnets used to confine the electrons near the target surface. In addition, target was also biased negatively with respect to the chamber to control the sputtering yield of Ga. Opposite the target is a dual-electrode extraction system that forms a low-energy ion beam of gas ions as well as post-ionized sputtered Ga atoms.

A degreased silicon (Si) (100) target was placed opposite the extraction electrodes in the downstream region and exposed to low-energy ion beams of Ga, argon (Ar), and nitrogen (N). The rf power was set at 50 W while the extraction potential was varied from 50 to 70 V. Target bias was set at -300 V and deposition time at 5 hours. Partial pressure ratio of N_2 to Ar was set below 0.10 while the total system pressure was set at 0.088 Pa. X-ray diffraction analysis of the substrate revealed two peaks at $2\theta = 33.01°$ and $2\theta = 69.14°$ which can be attributed to GaN film and Si substrate, respectively. The result indicates the growth of highly oriented films. X-ray reflectivity measurements also revealed the film thickness with the estimated growth rate ranging from 10 to 16 nm/h.

References

[1] M. R. Vasquez Jr., S. Imakita, T. Kasuya, S. Maeno and M. Wada, Rev Sci. Instrum. **81** (2010) 02B717.
[2] M. R. Vasquez Jr., S. Tokumura, T. Kasuya, S. Maeno, and M. Wada, Rev. Sci. Instrum. **83** (2012) 023301.
[3] M. R. Vasquez Jr., S. Tokumura, T. Kasuya, and M. Wada, Rev. Sci. Instrum. **85** (2014) 02A717.

MonPS01

First Results of the 2.45 GHz Oshima Electron Cyclotron Resonance Ion Source

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A new electron cyclotron resonance ion source has been built at Oshima College (Oshima-ECRIS). The design was described in the previous paper [1]. A 2.45 GHz magnetron microwave source and permanent magnets were adopted as basic components. Since we focus on industrial applications using middle charged ions, it is necessary to develop high-efficiency techniques of the ion production with a low-cost and low-power ion source. In addition, a solid-state amplifier at 2.5-6.0 GHz was installed to study two-frequency plasma heating. Three solenoid coils were set up for adjusting axial magnetic fields. We have conducted argon plasma generation and the ion beam production for the first year. Ion saturation current densities in the ECR plasma were measured with a biased disk. For 2.45 GHz and 4.65 GHz two-frequency plasma heating, the ion density was 1.4 times higher than 2.45 GHz single-frequency heating. The difference of plasma emission regions due to ECR zones is clear from those plasma photos. After that, we have extracted Ar ion beams and the mass spectra of those have been analyzed with a sector magnet. The details will be reported.

[1] T. Asaji, et al., Rev. Sci. Instrum. 85, 02A940 (2014).

MonPS02

Electron Cyclotron Resonance Ion Sources with High Stability and Long Lifetime

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Phoenix Nuclear Labs (PNL) has developed high current microwave ion sources (MWS) for a number of scientific and industrial applications with an emphasis on injectors for high yield neutron generators. Solenoid electromagnets surrounding a microwave resonant cavity produce a magnetic field tuned to match the electron cyclotron resonance (ECR) of 2.45 GHz microwaves. Input microwave power efficiently produces ions which are extracted into a high current, low emittance beam with a set of electrostatic lenses.

The PNL neutron generator couples the extracted beam to a DC electrostatic accelerator that transports the deuterium beam into either a solid or gas target to produce neutrons through the deuterium-deuterium fusion reaction. Additionally, a wide range of other gasses have been used in these ion sources including hydrogen, nitrogen, oxygen, and argon.

Applications being served by the PNL technology include thermal and fast neutron radiography, medical isotope production, externally driven sub-critical assemblies, explosives detection, nuclear instrumentation testing and calibration, semiconductor processing, and high energy physics research. For these applications, long lifetime, stability, high beam current, excellent beam performance, and high reliability are of critical importance.

As PNL's MWS design does not depend on filaments, electrodes, or other consumable components, exceptional reliability and long lifetimes are achievable. Continuous uptime of >99% and thousands of hours of operation have been demonstrated on multiple systems. The total beam current extracted from the ECR ion source is typically 50-75 mA at 50 kV for deuterium with an average current density of 125 mA/cm^2. Extracted deuterium beam currents as high as 90 mA have been measured with current density of 225 mA/cm^2. In addition, the high gas efficiency of the ion source allows a relatively low input gas flow rate of 1-5 SCCM, which reduces vacuum pumping requirements for the rest of the system.

For PNL's gas target neutron generators, excellent performance beam is required. A deuterium ion beam exceeding 50 mA must be focused to a diameter of only a few mm at a location several meters downstream from the
ion source in order to achieve the approximately 1 million-fold pressure differential between the target and accelerator regions. In order to meet the strict emittance requirements, a custom, direct inject extraction system has been developed at PNL.

An overview of the PNL ion source will be given and operational data will be reported.

MonPS03

The characteristic of Evaporative Cooling Magnet for ECRIS

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Compared with traditional de-ionized pressurized-water cooled magnet of ECRIS, evaporative cooling magnet has some special characteristics about cooling efficiency and operation. The analysis is carried out according to the design and running of LECR4 (Lanzhou Electron Cyclotron Resonance ion source No. 4, since Jul, 2013), whose magnet is cooled by evaporative cooling technology. The insulation coolant replaces the de-ionized pressurized-water to absorb the heat of coils, and the properties of coolant keep stable for a long time under no treatment. The coils of magnet are immersed in the liquid coolant and the cooling is more efficient, so the current density of coils can be improved further. The heat transfer executes under atmospheric pressure, and the temperature of coils is lower than 70℃ when the current density of coils is 12A/mm^2. On the other hand, the heat transfer temperature of coolant is about 50℃, and the heat can be transferred to fresh air which can save cost of water cooling system. The running of LECR4 about two years shows that evaporative cooling technology can be used into magnet of ECRIS, and the application advantages are very obvious.

MonPS04

Development of a compact high intensity ion source for light ions at CEA-Saclay

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During the past 5 years, a R&D program has been launched to improve the beam quality of ECR 2.45 GHz high intensity light ion sources for high power accelerators like IPHI, IFMIF, or SPIRAL2. The main goal was to minimize the divergence and emittance growth of intense beams due to the space charge as early as possible on the dual solenoid low energy transfer for a better injection in the RFQ, the second stage of acceleration. This has been achieved by reducing the length of the extraction system, and also the length of the LEBT, to be able to put the first solenoid as closely as possible to the extraction aperture. This was performed with the ALISES[1] concept (Advanced Light Ion Source Extraction System). Encouraging results have been obtained in 2012[2] but limitations due to Penning discharges in the accelerating column have been observed and also successfully simulated with 3D electromagnetic TOSCA[3] code. Taking advantages of ALISES source geometry, intensive studies and simulations have been undertaken to find a solution to eliminate the discharge phenomena. Innovative and compact source geometry has been found and all the components of the source have been fabricated. The source has been assembled at the beginning of this year and first tested without plasma, to make high voltage tests with optimal magnetic field. After successful results, the source has been installed on the BETSI test bench to produce the first plasma and extract the first proton beam. A proton beam of 43 mA has been easily produced at 50 kV, with an extraction aperture of 6mm diameter in CW mode.

This new prototype and its performances will be described, as well as magnetic field configuration studies and its influence on the extracted beam.

References

[1]O. Delferrière et al., Rev. Sci. Instrum. 83, 02A307 (2012).
[2]S. Nyckees et al., Rev. Sci. Instrum. 83, 02A349 (2012)
[3]Opera-3D, Cobham, Kidlington, Oxford OX5 1JE, UK

MonPS05

Installation and first operation of the IFMIF LIPAC Injector on the Rokkasho site in Japan

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Abstract: The IFMIF LIPAC Injector, dedicated to high intensity deuteron beam production has been designed, built and tested at CEA/Saclay between 2008 and 2012. After the completion of the acceptance tests at Saclay, the Injector has been fully disassembled and prepared for the 2 long months shipment between Europe and Japan. Beginning of 2014, the 35 large packages have been opened and the Injector re-installation has been performed between March and May 2014. Then after the check-out phase, the production of the first hydrogen plasma and first proton beam occurred in October and November 2014. Hydrogen and deuteron beam commissioning is now in progress after having proceeded with the final tests on the entire Injector equipment including high power diagnostics. After a brief summary of the achieved results obtained at Saclay, this article reports the different phases of the injector installation pointing out the safety and security needs, as well as the first beam production results in Japan. Detailed operation and commissioning results are reported in a second article[1].

[1] Y. Okumura et al., "Operation and commissioning of the LIPAC Injector" (to be adapted with the effective title of the second article)

MonPS06

24 GHz Microwave Mode Converter Optimized for Superconducting ECR Ion Source SECRAL

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Over-sized round waveguide with a diameter about Ø33.0 mm excited in the TE_{01} mode has been widely adopted for microwave transmission and coupling to the ECR (Electron Cyclotron Resonance) plasma with the superconducting ECR ion sources operate at 24 or 28 GHz, such as SECRAL and VENUS. In order to study the impact of different microwave modes on ECRH efficiency and especially the production of highly charged ions, a set of compact and efficient TE_{01}-HE_{11} mode conversion and coupling system applicable to 24 GHz SECRAL whose overall length is 330 mm has been designed, fabricated and tested. In this paper, a TE_{01}-HE_{11} mode conversion system is analyzed, which includes a TE_{01} round waveguide taper, a TE_{01}-TE_{11} mode converter and a TE_{11}-HE_{11} mode converter. Numerical simulation on the basis of the mode coupling theory for the purpose of structure design optimization is done by relevant MATLAB code-written and all the calculations are verified by the commercial CST Microwave Studio software. Good agreements between offline tests and calculation results have been achieved, which indicates the TE_{01}-HE_{11} converter meets the application design. The detailed results of the optimized coupling system will be presented in the paper.

MonPS07

Production of Multicharged Metal Ion Beams on the First Stage of Tandem-Type ECRIS

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Multicharged metal ion beams are expected to be applied in wide range of fields. We have constructed tandem-type ECRIS which consists of two individual ion sources.[1] We aim at synthesizing endohedral metallofullerenes by transporting metal ion beam from the first stage into the fullerene plasma in the second stage. Since dissociated fragments and impurities disturb synthesis of new material in gas-phase, high purity metal vapor source is required. We have already developed induction heating (IH) evaporator for solid state metal.[2,3] The structure is complicated, and then vapor flux is rather than small. Therefore, we developed new radiation heating evaporator and directly ohmic heating evaporator which can generate large vapor flux. This radiation heating evaporator is heated by thermal radiation of a tungsten wire. Tungsten wire is surrounded by molybdenum plate, and heating metal is attached to the molybdenum plate.

The aim of this paper is to investigate properties of new two evaporators and produce metal ion beam on the first stage of tandem-type ECRIS. In the experiment, we used solid state iron. As a result, it is successful to extract Fe^+ ion beam from the first stage and introduce Fe^+ ion beam to the second stage. In near future, we are planning synthesis experiment of Fe and C_{60}.

References

1. Y. Kato, et al, RSI, **85**, 02A950 (2014)

2. Y. Kato, et al, RSI, **77**, 03A335 (2006)

3. O. Kutsumi, et al, RSI, **81**, 02A322 (2010)

MonPS08

Development of superconducting magnet and LHe recondensing cryostats for RAON 28 GHz ECR Ion Source

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RAON, 28GHz electron cyclotron resonance ion source (ECR IS) was designed and tested as a Rare Isotope Science Project (RISP). It is expected that RAON would provide not only rare isotope beams, but also stable heavy ions, ranging from protons to uranium. In order to have the required steady heavy ion beam for ECR IS, we have to use 28 GHz microwave source, as well as the requirement of a high magnetic field. The superconducting magnet using NbTi wire was designed and manufactured for producing ECR IS, and test was conducted. In this paper, the ECR IS design and fabrication process are presented of the superconducting magnet and LHe recondensing cryostats. Experimental results show the quench current is increased whenever quench occurs, but not yet reached the designed current. The experiment is going to find the best requirement to reach designed current and the heat capacity of LHe recondensing cryostats is analyzed according to RF power and current.

MonPS09

Heavy ion injector based on ECR ion source for RISP linac

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The injector for the main driver linac of the Rare Isotope Science Project (RISP) in Korea has been developed to supply heavy ions up to uranium which will be used to inflight fragmentation (IF) system. The injector has critical components, composed of superconducting electron cyclotron resonance (ECR) ion sources, a radio frequency quadrupole (RFQ), and matching systems for low and medium energy beam. Physical and engineering design of these critical components was performed. We have built superconducting magnets for ECR ion source and a prototype of one segment of the RFQ structure for the following purposes to develop a fabrication technology to satisfy the specifications, to demonstrate stable operation in wide dynamic range, and to compare the experiment with simulation results for the design.

MonPS10

Compact Permanent Magnet H+ ECR Ion Source with Pulse Gas Valve

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

MonPS11

Microwave Emission Related to Cyclotron Instabilities in a Minimum-B Electron Cyclotron Resonance Ion Source Plasma

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Electron cyclotron resonance ion sources (ECRIS) have been essential in the research and applications of nuclear physics over the past 40 years. They are extensively used in a wide range of large-scale accelerator facilities for the production of highly charged heavy ion beams of stable and radioactive elements. ECRISs are susceptible to kinetic instabilities due to resonance heating mechanism leading to anisotropic electron velocity distribution function. Instabilities of cyclotron type are a proven cause of frequently observed periodic bursts of “hot” electrons and bremsstrahlung, accompanied with emission of microwave radiation and followed by considerable drop of multiply charged ions current. Detailed studies of the microwave radiation associated with the instabilities have been performed with a minimum-B 14 GHz ECRIS operating on helium, oxygen and argon plasmas. It is demonstrated that during the development of cyclotron instability “hot” electrons emit microwaves in sub-microsecond scale bursts at temporally descending frequencies in the 8-15 GHz range with two dominant frequencies of 11.09 and 12.59 GHz regardless of ECRIS settings i.e. magnetic field strength, neutral gas pressure or species and microwave power. The possible energy range of the electron population amplifying plasma waves is estimated and arguments on possible excited plasma wave modes are given.

MonPS12

Cyclotron Instability in the Afterglow Mode of Minimum-B ECRIS

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It was shown recently that cyclotron instability in non-equilibrium plasma of a minimum-B electron cyclotron resonance ion source (ECRIS) causes perturbation of the extracted ion current and generation of strong bursts of bremsstrahlung emission, which limit the performance of the ion source. The present work is devoted to the dynamic regimes of such plasma instability in ECRIS operated in pulsed mode. Instability develops in decaying plasma shortly (1 - 10 ms) after heating microwaves are switched off, and manifests itself in the form of powerful pulses of electromagnetic emission associated with precipitation of high energy electrons along the magnetic field lines. Time-resolved measurements of microwave emission bursts related to cyclotron instability in the decaying plasma are presented. The temporal resolution was high enough to study the fine structure of dynamic spectra of electromagnetic emission at different operating regimes of the ion source. It was found that even in various gases (helium, oxygen and argon were studied) and at different values of magnetic field and heating power the dynamic spectra demonstrate common features: decreasing frequency within a single burst as well as from one burst to another. The analysis have shown that instability is driven by the resonant interaction of hot electrons distributed between the ECR surface and the trap center with slow extraordinary wave propagating quasi-parallel to the magnetic field.

MonPS13

Suppression of Cyclotron Instability in ECR ion Sources by Two-frequency Heating

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Multiple frequency heating is one of the most effective techniques to improve the performances of ECR ion sources. The method increases the beam current and average charge state of the extracted ions and enhances the temporal stability of the ion beams. It has been recently demonstrated that the appearance of the periodic ion beam current oscillations in ECRIS at high heating power and low magnetic field gradient is associated with kinetic plasma instabilities. The present study demonstrates that the stabilizing effect of two-frequency heating is connected with the suppression of electron cyclotron instability in ECRIS plasmas. Experimental data show that the interaction between the secondary microwave radiation and the hot electron component of ECR ion source plasmas plays a crucial role in mitigation of the instabilities.

MonPS14

First Experiments with Gasdynamic Ion Source in CW Mode

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A new type of ECR ion sources – a gasdynamic ECR ion source was invented recently at the Institute of Applied Physics (IAP RAS, Nizhniy Novgorod, Russia). The main advantages of such devices are extremely high ion beam current with a current density up to 600 – 700 mA/cm^2 in combination with low emittance i.e. normalized RMS emittance below 0.1 π·mm·mrad. Previous investigations were carried out in pulsed operation mode under conditions of plasma heating with 37.5 or 75 GHz gyrotron radiation with power up to 100 kW at SMIS 37 experimental facility.

The present work demonstrates the first experience of operating the gasdynamic ECR ion source in CW mode. A test bench of SMIS 24 facility has been developed at IAP RAS. 24 GHz radiation of CW gyrotron was used for plasma heating in magnetic trap with simple mirror configuration. Initial studies of plasma parameters were performed. Ion beams with pulsed and CW high voltage were successfully extracted from the CW discharge. Obtained experimental results demonstrate that all gasdynamic source advantages could be realized in CW operation.

MonPS15

First plasma and beam extraction of the RAON ECR ion source

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Raon[(1)] ECR ion source has been built in test site in Korea. First plasma was ignited with a 28GHz MW power, and the beam was extracted. Oxygen was selected as the first beam species because 1)it could be handled easily in a gaseous form and 2)it can enhance the alumina layer on the plasma chamber surface which can increase the beam current[(2)]. As the start-up state, the magnetic field was charged up as the 60% of the designed target value at which ECR zone can be formed in the discharge region. We measured O5+ beam of 100uA at the first beam extraction experiment. It is thought that beam loss occurred in our beam transport line. Further experiments are being done to increase the beam current of a highly charge state such as O6+ through the optimization of the plasma discharge parameters and focusing lattice operating conditions.

[1] D. Jeon, in Proceedings of IPAC2013, Shanghai, China, 2013, THPWO062.

[2] Z. Xie et al, Review of Scientific Instruments **67**, 886, (1996).

MonPS16

JYFL Ion Source Research and Development: Studies of Different Plasma Processes and Towards the Higher Beam Intensities

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Several research and development projects are in progress at the Department of Physics, University of Jyväskylä (JYFL). The work can be divided in the plasma studies and in development of ion sources, their diagnostics and different methods. The experimental plasma research covers the highly charged plasma instabilities [1], VUV emission of light ion sources [2] and photon induced electron emission [3]. The development work focuses on the diagnostics needed for the visible light emission of ECR plasma. The object of the work is to receive information from the reactions between the neutrals and highly charged ions. The ion source development covers also the work performed for RADIS [4] and beam line upgrade of the JYFL 14 GHz ECRIS. The status of the new 18 GHz ECRIS, HIISI, will be given as well. According to the schedule the first ion beam from HIISI will be extracted by summer 2016.

[1] O. Tarvainen et al., elsewhere in these proceedings and references therein.
[2] J. Komppula et al., elsewhere in these proceedings and references therein.
[3] J. Laulainen et al., elsewhere in these proceedings.
[4] T. Kalvas, et al., elsewhere in these proceedings.

MonPS19

Development of a High Reliability, Long Lifetime H$^-$ Ion Source

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Phoenix Nuclear Labs (PNL) has designed a high current, long lifetime, negative hydrogen (H$^-$) ion source [1] and begun construction and testing. This system is being developed in partnership with the Fermi National Accelerator Laboratory as part of an ion beam injector servicing future Intensity Frontier particle accelerators under development at Fermilab and other Department of Energy laboratories. The beam specifications for Fermilab's Low Energy Beam Transport (LEBT) section are 5-10 mA of continuous H- ion current at 30 keV with <0.2 π-mm-mrad emittance.

In this application, continuous output with high reliability, long lifetime, and high efficiency are critical. Existing ion sources used by Fermilab rely on plasma-facing electrodes which erode over time and are inherently limited to lifetimes of a few hundred hours, while also requiring relatively high gas loads on downstream components. PNL's H$^-$ ion source design features an electrodeless Electron Cyclotron Resonance (ECR) microwave plasma generator which has been extensively developed in our positive ion source systems, which have demonstrated 1000+ hours of operation and >99% continuous uptime at PNL.

The device is driven by a plasma chamber that produces energetic electrons, positive hydrogen ions, and neutral hydrogen atoms. Positive ions and hyperthermal neutrals drift toward a caesiated molybdenum surface, where a fraction is converted into H$^-$ hydrogen ions, which are subsequently extracted into a low-energy beam using electrostatic lenses. A transverse magnetic dipole filter field preferentially removes high-energy electrons emitted by the source plasma, in order to decrease the rate of negative-ion destruction via electron-impact detachment.

The design of the H$^-$ ion source subsystems and preliminary diagnostic results will be presented and discussed.

References

[1] Sherman, J. et al. *High Reliability, Long Lifetime, Negative Ion Source*. International patent application PCT/US2014/044382 (2014).

MonPS20

Effect of Plasma Grid Bias on Extracted Currents in the RF Driven Surface-Plasma Negative Ion Sources

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Extraction of negative ions from the large inductively driven surface-plasma negative ion source was studied. The dependencies of the extracted negative ion current and of the Plasma Grid (PG) current vs PG bias potential were recorded for two modifications of radio-frequency driver with and without Faraday screen and for the different level of PG cesium coverage conditioning. The maximal PG current was not depended on driver modification and cesium conditioning (at the fixed level of discharge power). The maximal negative ion current was ~2 higher for the activated cesium coverage of PG, and it was not depended on the driver modification as well. The acceptable minimal value of PG bias potential, at which the extracted negative ion current is maximal, was lower for the driver without Faraday screen and for the case of activated cesium. The obtained dependencies display that the extracted negative ion current depends on the potential difference between the near-PG plasma and the PG bias potentials, while the absolute value of plasma potential in the driver and in the PG area are less important for the negative ion production. The last conclusion confirms the main mechanism of negative ion production through the surface conversion of fast atoms.

MonPS21

Efficient Cesiation in the RF Driven Surface-Plasma Negative Ion Source

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The decrease of plasma grid surface work function and the proper procedure of cesium seed to the large negative ion source are crucial for the neutral beam injectors of fusion devices. An external system of directed cesium delivery was tested in the large radio-frequency (RF) negative ion source, developed at BINP [1]. The system uses an external oven for cesium evaporation from the industrial pellets with cesium chromate and titanium, and the long distribution tubes to direct cesium onto the plasma grid. The plasma grid heating to temperature 120 – 250 oC facilitates the redistribution of deposited cesium over the plasma grid surface.
An efficient long-term cesiation of the plasma grid surface was obtained. The single cesium seed to the source has provided an enhanced level of H- production during two month experimental cycle in spite of the night, weekend and accident stops. An additional boost of negative ion yield and the gradual source conditioning by RF discharge was recorded. The procedure of cesium seed, of cesium conditioning, and the data on long-time persistent operation with no additional cesium seed are discussed.

References

[1] Yu. Belchenko, A. Gorbovsky, A. Ivanov et al. "Negative ion production in the RF multiaperture surface-plasma source Multiaperture Negative Ion Source". AIP Conf. Proc. 1655, 040002 (2015).

MonPS22

Facilitation of High Voltage Conditioning and Improvement of High Voltage Holding in the large Surface-Plasma Negative Ion Sources with Cesium Deposition

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The large long-pulsed surface-plasma sources of negative ions with the multi-aperture multi-electrode Ion Optical System (IOS) are under development at Budker Institute of Nuclear Physics. The directed deposition of cesium to the plasma grid surface is applied in the sources to enhance the negative ion production and to decrease the co-extracted electron flux. The essential feature of the large BINP sources is an active temperature control of the IOS electrodes by circulation of hot thermal fluid through the channels, drilled in the electrode bodies [1]. This heating prevents accumulation of cesium on the IOS electrodes and improves the source high voltage conditioning and holding capacity. The effect of IOS high voltage conditioning and high voltage holding capacity improvement due to IOS heating was studied for the various regimes of operation including the full-scale beam production and acceleration. The procedure of IOS conditioning and the data obtained with the source having the temperature controlled IOS electrodes are discussed.

References

[1] Yu. Belchenko, A. Gorbovsky, A. Ivanov *et al* "Negative ion production in the RF multiaperture surface-plasma source Multiaperture Negative Ion Source". AIP Conf. Proc. **1655**, 040002 (2015).

MonPS23

Determination of discharge parameters via OES at the Linac4 H^- ion source

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At the accelerator complex of CERN an upgrade of the LHC injector chain is being implemented. One part of this upgrade is the realization of a negative hydrogen linear accelerator, the Linac4. The ion source for this accelerator is RF driven with an external coil (RF frequency 2 MHz, power up to 100 kW). It can be operated in two modes: the first one where H^- ions are generated in the plasma volume via vibrationally excited hydrogen molecules and the second one where the H^- ions are produced from hydrogen ions and atoms impinging on a low work function surface which is created by evaporating cesium into the source. In order to optimize the H^- yield in both operation modes, a detailed knowledge of the plasma parameters and the processes taking place in the discharge is mandatory.

To gain insight in the plasma parameters optical emission spectroscopy measurements have been carried out with a high resolution spectrometer at the Linac4 test stand at CERN without adding cesium to the ion source. The performed evaluations cover the analysis of the atomic Balmer radiation and the molecular Fulcher emission (d $^3\Pi_u \rightarrow$ a $^3\Sigma_g^+$ transition, located between 590 and 650 nm) via the collisional radiative models Yacora H and Yacora H_2. The obtained discharge parameters like the electron density and temperature as well as the vibrational and rotational temperature of the hydrogen molecules are presented for a variation of the gas pressure and RF power.

MonPS24

Different Approaches to Modeling the LANSCE H⁻ Ion Source Filament Performance

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An overview of different approaches to modeling of hot tungsten filament performance in the LANSCE H^- surface converter ion source is presented. The most critical components in this negative ion source are two specially shaped wire filaments heated up to the working temperature range of 2600 °K to 2700 °K during normal beam production. In order to prevent catastrophic filament failures (creation of hot spots, wire breaking, excessive filament deflection towards source body etc.) and to improve understanding of the material erosion processes, we have simulated the filament performance using three different models:

The first semi-empirical model is based on the wire temperature calculation using monitored DC heating currents and initial wire diameters [1]. Results of temperature calculations, relative ohmic resistance changes, thermal evaporation mass rates, and reduction of wire diameters are averaged along the length of wire in this model [2].

The second model is based on a finite element analysis taking into account geometric features of the ion source, filament shapes and positions. The Solidworks Simulation FEA code was used to calculate the steady-state temperature profile along the filament including additional ohmic heating due to the pulsed arc discharge current. This model addresses an asymmetric heating process which indicated the filament peak temperature would move in the direction corresponding to the load asymmetry [2].

The third filament model is an extended analytical approach based on previous filament simulation efforts at LANL [3]. New analytical model and numerical simulations offer a very precise time evaluation of filament characteristics (temperature and wire diameter profiles, tungsten mass evaporation rate, thermionic electron emission, etc.) during ion source operations for beam production cycles of four weeks (28 days). New simulations extrapolate source performance under different operational conditions, giving a better understanding of the measured observables and providing directions for future experiments.

Results of all models were compared with recorded EPICS data taken during the LANSCE beam production cycles. The models were used to support the recent successful transition from the beam pulse repetition rate of 60Hz to 120 Hz or during the increase of linac duty factor from 5 % to 10 %.

References

1) H. A. Jones and I. Langmuir, "The Characteristics of Tungsten Filaments as Function of Temperature" *General Electric Review,* **30**, part I p310, part II p354, part III p408, (1927).
2) I. N. Draganic, J. F. O'Hara and L. J. Rybarcyk "Lifetime Study of Tungsten Filaments in an H-Surface Converter Ion Source" NA-PAC 2013, THPAC23.
3) E. Chacon-Golcher, "Erosion and Failure of Tungsten Filament", LANL report LA-UR-08-5251 (2008).

MonPS25

Electron Stripping Rates of H⁻ Ion Beam in the 80 kV High Voltage Extraction Column and Low Energy Beam Transport Line at LANSCE

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Detailed vacuum calculations were performed for various operating conditions of the LANSCE H^- Cockcroft-Walton (CW) injector and the LANSCE Ion Source Test Stand (ISTS). The ISTS is used to simulate and study of the operational CW injector. The vacuum pressure was estimated for both the CW and ISTS at five different points: inside the H^- ion source, in front of the Pierce electrode, at the extraction electrode, at the column electrode and at the ground electrode. A static vacuum analysis of residual gases and working hydrogen gas was completed for the normal ion source working regime. Gas density and partial pressure of hydrogen gas were estimated for different gas injection mass flows. Negligible differences of vacuum pressures and gas densities at the CW H^- dome and at the ISTS were documented.

Using the concept of the total cross section from atomic collisional physics, the attenuation of H^- beam current and generation of electron current in the high-voltage acceleration columns and low energy beam transport lines of the CW and ISTS were calculated. The interaction of H^- ions (as a projectile in the energy range from 250 eV to 80 keV) on molecular hydrogen H_2 (as a target at room temperature) is discussed as a dominant collision process in describing electron stripping rates [1]. These results are used to estimate the observed increase in the ratio of electrons to H- ion beam in the low energy beam transport line at ISTS.

References

1) T. Tabata and T. Shirai, "Analytical Cross Sections for Collisions of H^+, H_2^+, H_3^+, H, H_2, and H^- with Hydrogen Molecules" *Atomic Data and Nuclear Data Tables,* **76**, p 1-25, (2000).

MonPS26

Converter Electrode Erosion Processes in the H^- Ion Source at LANSCE

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During the 2014/2015 LANSCE beam production period an unexpected degradation of the converter surface in the H^- ion source was observed. Small dimples were created in the center of the molybdenum electrode on the smooth, curved electrode surface during normal beam production cycles (see Figure 1).

In ordered to understand the observed degradation of the ion source, a simple model of the electrode surface degradation was developed. In the model were included several dominant atomic collision processes in H^- ion source and high voltage electrostatic extraction column (U= 80 kV). The model includes the following collision processes: the electron impact ionization on molecular hydrogen [1], the electron impact ionization on atomic cesium [2], ion-beam sputtering of hydrogen ions (H^+ and H_2^+) on a molybdenum surface [3], ion-beam sputtering of cesium atoms (Cs^+) on a molybdenum surface [3], and arc discharge plasma sputtering.

Model results indicate that the observed dimples seen on the converter electrode surface was caused by an increase of extracted electron current and unbalanced cesium oven temperature. The model explains that hydrogen ions have no significant influence on the converter electrode dimpling. The dominant electrode mass loss mechanism is found to be the beam sputtering caused by high energy single charged positive Cs ions.

Based on the measured sputtered Mo mass during regular beam operation of the ion source, the partial Cs vapor pressure was estimated, showing elevated Cs injection inside the source and the high-voltage extraction column.

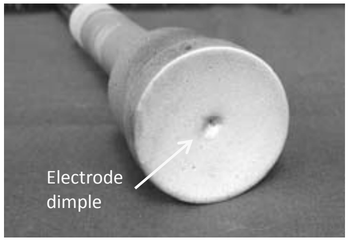

Figure 1. A dimple of 2 mm deep and 5 mm wide created in the center of the molybdenum converter electrode is shown.

References

1) H. Tawara, Y. Itikawa, H. Nishimura, and M. Yoshino, " Cross Sections and Related Data for Electron Collisions with Hydrogen Molecules and Molecular Ions" *J. Phys. Chem. Ref. Data*, **19**, p 617 - 636, (1990); J. S. Yoon, et al. "Cross Section for Electron Collisions with Hydrogen Molecules" *J. Phys. Chem. Ref. Data*, **37**, p 913-931, (2008).

2) M. Lukomski, et al., "Electron-Impact Ionization Cross Sections out of the Ground State 6 ^{2}P Excited States of Cesium", Phys. Rev. A, **74**, 032708 (2006).

3) Y. Yamamura and H. Tawara, "Energy Dependence of Ion –Induced Sputtering Yields from Monoatomic Solids at Normal Incidence" *Atomic Data and Nuclear Data Tables,* **62**, p 149-253, (1996).

MonPS27

Abnormal electron heating by magnetic filter field in a negative hydrogen ion source

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Abnormal heating of the electrons near RF antenna (driver region) is observed with magnetic filter near the extraction region in the planar type inductively coupled H^- ion source. Axial profile of plasma parameters are measured with an RF compensated Langmuir probe from the driver region to the extraction region. Axial variations of the electron density and the temperature near the extraction region at low pressure show great agreement with previous results [1]. However, the electron temperature significantly changes near the driver region at low pressure discharge in the presence of filter field. The abrupt variation of the electron temperature is analyzed with the consideration of two components of magnetic filter fields (parallel and perpendicular to axial direction in the cylindrical source chamber). It is believed that the electron cyclotron resonance (ECR) heating near 4.8 G (axial magnetic field) may occur as electron heating near the driver region at low pressure of 3 mTorr. At relatively higher pressure of 20 mTorr, the ECR effect disappears due to the increased electron-neutral collision frequency, and the experimental results well follows the previous result [1]. Although electron cooling effect via filtering of high energy electrons has been considered as a main effect of the magnetic filter in the negative hydrogen ion source, appropriate level of the axial component of the magnetic filter field at low pressure may contribute to increase electron temperature significantly in the driving region. As a desire to develop high performance negative ion source, the increased electron temperature through the ECR effect with optimized filter field configuration may give another path to enhance the efficiency of the negative ion source.

[1] A. Aanesland, J. Bredin, P. Chabert, and V. A. Godyak, Appl. Phys. Lett. 100, 044102 (2012)

MonPS28

Optimization of plasma parameters with transverse magnetic field strength and pressure to maximize H^- ion density in a negative hydrogen ion source

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Transverse magnetic filter field as well as operating pressure is considered to be an important control knob to enhance negative hydrogen production via plasma parameter optimization in the transformer coupled plasma (TCP) H^- ion source. As expected from the particle transport with the transverse filter field electron temperature in the extraction region is well controlled by increasing the field strength, but electron density near the extraction region was unexpectedly observed to be increased rather than decreased with higher field strength.[1] To clarify the unexpected electron density profile with the transvers field, axially movable Langmuir probe is installed for the profile of plasma parameters obtained from the electron energy distribution function. Increase of electron density is measured toward the maximum magnetic field position in the extraction region, which may be explained by reduced axial diffusion of low energy electrons as the magnetic field strength is increased. Noting that parallel and perpendicular electron diffusion coefficients change significantly with the magnetic field, measured electron temperatures and densities are analyzed by considering that more low energy electrons are transported across the field and accumulated near the extraction region with the increased magnetic field strength. In addition, effect of operating pressure on plasma parameters is understood from the diffusion coefficient changed with a momentum transfer frequency. Operating pressure affects the transport of each energy electron oppositely due to a different trend with pressure between parallel and perpendicular diffusion. Much higher pressure lessens the effect of magnetic filter with regard to a low energy electron accumulation. Furthermore, reduced electron temperature with an increased pressure in the heating region cause a decrease of ro-vibrationally excited hydrogen molecule density, which affects H- ion production with the lessened magnetic filter effect. Thus, values of magnetic field strength and operating pressure are optimized to maximize volume production of H^- ions by obtaining appropriate plasma parameters, and confirmed by measuring H^- ion population. To apply the magnetic filter effect on low energy electron accumulation effectively, magnetic filter position as well as strength must be considered seriously.

[1] O.Fukumasa, H.Naitou and, S.Sakiyama, Jpn. Appl. Phys. Vol.30, No.6A, June, 1991, pp. L1063-L1065

MonPS29

Saddle Antenna Radio Frequency Ion Sources

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In this paper we present an overview of the positive and negative ions production in saddle antenna (helicon discharge) radio frequency (SA RF) ion sources. An efficiency of H^- ion production in recently developed RF surface plasma sources (SPS) with solenoidal antennas was improved to 1-1.5 mA/kW. The efficiency of positive ion generation in these RF ion sources was up to 2 mA/kW. About 60 kW of RF power is typically needed for 50 mA beam current production from a 7 mm emission aperture. This efficiency is relative low because in the RF discharge with solenoidal antenna, the plasma is generated near the coil and diffuses to the axis creating a nearly uniform plasma density distribution in all cross sections of the discharge chamber, when the plasma flow is necessary only near an emission aperture. The efficiency of the extracted ion generation was improved significantly with using of the saddle antenna. In the RF discharge with the saddle antenna the plasma is generated near the axis and the magnetic field suppress the plasma diffusion from the axis, creating a peaked plasma density distribution on the emission aperture. With the SA the efficiency of positive ion generation in the plasma has been improved up to 200 mA/cm^2 per kW of RF power at 13.56 MHz. After cesiation, the current of negative ions to the collector was increased from 1 mA to 10 mA with RF power 1.5 kW in the plasma (6 mm diameter emission aperture) and up to 30 mA with 4 kW RF power in the plasma and 250 Gauss longitudinal magnetic field. In the tested version of the SA RF SPS the specific efficiency of H^- production was increased a factor of 7, up to 20 mA/cm^2-kW. Continuous wave (CW) operation of the SA SPS has been tested on the small test stand. The general design of the CW SA SPS is based on the pulsed version. Some modifications were made to improve the cooling and cesiation stability. CW operation with negative ion extraction was tested with RF power up to 1.8 kW from the generator (~1.2 kW in the plasma) with production up to Ic=7 mA. Stable generation of H^- beam without intensity degradation was demonstrated in the AlN discharge chamber for a long time (~40 days) with high RF power in the RF SPS with external antenna. Features of SA RF discharges and ions generation will be discussed.

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MONPS30

COOMPACT SURFACE PLASMA H- ION SOURCE WITH GEOMETRICAL FOCUSING

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Factors limiting operating lifetime of a Compact Surface Plasma Sources (CSPS) are analyzed and possible treatments for lifetime enhancement are considered. Noiseless discharges with lower gas and cesium densities are produced in experiments with modified discharge cell. With this discharge cells it is possible to increase emission aperture and extract a necessary beam from the discharge with lower current with corresponding increase source lifetime. A design of an advanced CSPS with geometrical focusing of H- flux is presented.

MonPS31

High Current DC Negative Ion Sources for Cyclotron

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Filament driven multi-cusp negative ion sources have been developed for proton cyclotrons in medical applications. In Cs-free operation, H^- beam of 10 mA and D^- beam of 3.3 mA were obtained stably at an arc power of 3 kW and 2.4 kW respectively. The maximum H^- current reached 15 mA at an arc power of 6.6 kW by increasing the magnetic filter field without Cs. In Cs-seeded operation, H^- beam of 16 mA was obtained at a lower arc power of 2.8 kW with less electron current accompanied [1]. Further enhancement of the beam current is demanded for many applications of cyclotron, such as cancer therapy and medical radioisotope production. In order to increase H^- beam current up to 20 mA, some improvements of the source are in progress. The relationship between H^- production and the magnetic filter field has been investigated by beam measurements, plasma diagnostics, and numerical analysis with KEIO-MARC code [2] for different magnetic filter field strengths. The Cs-seeded operation has been tested with a plasma electrode made of molybdenum to optimize the plasma electrode temperature for H^- production. The shape and the diameter of tungsten filaments have been optimized to extend their lifetime. In this paper, the results of these improvements are presented.

References

[1] H. Etoh *et al*., Rev. Sci. Instrum **85**, 02B107 (2014)

[2] T. Shibata, M. Kashiwagi, T. Inoue, A. Hatayama and M. Hanada, J. Appl. Phys. **114**, 143301 (2013)

MonPS32

Charged Particle Flows in the Beam Extraction Region of a Negative Hydrogen Ion Source for NBI

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In order to investigate the extraction mechanism of the H^- ions in a negative hydrogen ion source for NBI, experiments by a directional Langmuir probe combined with photodetachment are carried out in the beam extraction region of the ion source. Using Langmuir-probe and photodetachement modes, flows of electron, positive and negative ions are separated. The angle electron flow becomes orienting to normal to surface plane of the plasma grid with approaching the grid. The positive ions have the same flow direction as electrons. The direction is insensitive to the structure of magnetic field, and the result suggests diffusion and drift motions could be dominant to the flows. On the other hand, H^- ion flow direction normal the plasma grid is opposite to those of electrons and positive ions. By comparing the recovery times of the photodetachment currents at four symmetric probe tips, H^- ion temperature is estimated to be 0.10 eV ~ 0.15 eV.

MonPS33

Advanced Negative Ion Source

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We describe new low maintenance and low noise plasma source for production cylindrical axial symmetric negative ion beams with moderate energy. The results of emission efficiency investigation of advanced negative particles (H^-) source with combined discharge of hollow cathode type, as well as one in crossed electric and magnetic fields, are presented. Cylindrical beam of negative hydrogen ions is extracted by applied potential of 10 kV with current density of about 5 A/cm^2 at the source emission aperture. The total beam current was up to 200 mA for negative hydrogen ions and up to 1,5 A for electrons. The beams have high divergence after the source. The ion beam downstream at 50 cm distance provided the current of 20 mA onto 10 cm diameter collector. Current density measurements were performed by means of two types sectioned collectors. It is shown that the extracted current value is comparable with that inherent for known cold cathode type negative ion sources. Calculated H^- ion current density exceeds a couple of amperes. This can be explained by the effect of surface-plasma mechanism of ion formation due to cesium presence in the source. The elaborated ion source has simple and compact design, and provides stable gas discharge with low noise level. The source tests have demonstrated high efficiency of intense hydrogen negative ion production under low enough gas pressure in drift chamber. The presented source can be also attractive for creation of compact efficient plasma electron source.

References

P. Moehs et al. Negative Hydrogen Ion Sources for Accelerators// IEEE Trans. On Pl. Sci. December 2005, v. 33, № 6, p. 1786-1798.

V.P. Goretskii, A.M. Dobrovolskiy. Peculiarities of Hydrogen Negative Ion Beams Extraction Axially Symmetric Source with Crossed Fields// Problems of Atomic Science and Technology, 2015, № 1. Series: Plasma Physics (21), p. 73-76. ISSN 1562-6016. BAHT. 2015. №1(95)

MonPS34

Duty Factor Variation Investigation from 1% to 100% with One Microwave Driven Cs-Free Volume H- Source at PKU

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A microwave driven Cs - free volume H^- source, that has the ability to deliver tens mA H^- at 35 keV, was developed at Peking University (PKU)[1]. Recently special efforts were paid on the investigation of duty factor variation possibility from 1% to 100% with one of this kind source. Experiments were carried out with a fixed pulsed length of 1 ms and different intervals of 99 ms, 49 ms, 39 ms, 29 ms, 19 ms, 9 ms, 4 ms, 2 ms, 1 ms, 0.5 ms and 0 ms, respectively. Experimental results prove that this source can deliver tens mA H^- beam at different duty factor. The RF power efficiency increases from 6 mA/kW to 20 mA/kW when the duty factor growths from 1% to CW at a fixed RF power. Under a given duty factor, RF power efficiency keeps constant and the H^- current increases with RF power linearly. Detail will be presented in the paper.

[1] Yuan Xu, Shixiang Peng, Haitao Ren, Tao Zhang, Ailin Zhang, Jingfeng Zhang, Jie Zhao, Zhiyu Guo and Jia'er Chen, Gas flow influence on negative hydrogen ion generation within the microwave-driven negative ion source. **WEPWA027**, *Proceeding of IPAC 2105*, 3rd-9th May, 2015, Richmond, Virginia, USA.

MonPS35

Characterization of the 13.56-MHz CW Starter Plasma for the Pulsed, High Power 2-MHz Plasma of the SNS H^- Ion Source

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The H^- ion source of the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory is driven by up to 80-kW of 2-MHz RF in 1-ms long pulses at 60 Hz. The high power plasma is generated from a starter plasma that is maintained by continuous ~300-W 13.56-MHz RF, which is initially ignited with a H_2 pressure burst. The RFQ transmission improves with RF power, but requires low H_2 flows for thermal stability. To minimize the risk of plasma outages at low H_2 flows, the 13.56-MHz RF matching network was characterized over a broad range of its two tuning capacitors. The intensity of the plasma's emitted H-α line between the 60 Hz pulses of the 2-MHz RF as well as the reflected power of the 13.56-MHz RF were mapped against the capacitor settings. Optimal tunes for the maximum H-α intensity and for the minimum reflected power appear consistent. Low limits of the H_2 flow not causing plasma outages were explored within the range of the map. The tolerance of the 13.56-MHz RF matching against the influence of the high power 2-MHz RF during and after the pulse was studied for different power levels and matching tunes of the 13.56-MHz RF and for different H_2 gas flows.

MonPS36

A Collisional Radiative Model of Hydrogen Plasmas Developed for Diagnostic Purposes of Negative Ion Sources

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A collisional radiative model of low-pressure hydrogen plasmas is elaborated and applied in optical emission spectroscopy diagnostics of a single element of the matrix source of negative hydrogen ions [1]. The planar-coil inductive discharge studied is sustained at a frequency of 27 MHz by rf power varied in the range *P* = (90 – 160) W. The collisional radiative model accounts for the main processes determining both the population densities of the first ten states of the hydrogen atom and the densities of the positive hydrogen ions H^+, H_2^+ and H_3^+. In the calculations the electron density and electron temperature are varied whereas the gas temperature is included as an external parameter experimentally obtained [2]. The ratio of the H_α to H_β line intensities is calculated from the numerical results for the excited state population densities, obtained as a solution of the set of the steady-state rate balance equations. The comparison of measured and theoretically obtained ratios of line intensities yields the values of the electron density and temperature as well as of the degree of dissociation, i.e. of the parameters which have a crucial role for the negative ion production.

References

[1] St. Lishev, Ts. Paunska, A. Shivarova, and Kh. Tarnev, *Rev. Sci. Instrum.* **83**, 02A702 (2012).
[2] S. Iordanova, and A. Pashov, *AIP Conf. Proc.* **1655** 040012 (2015).

MonPS37

Efficiency Improvements With the Radiofrequency H— Ion Source RADIS

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A CW 13.56 MHz radiofrequency-driven H— ion source RADIS is under development at the University of Jyväskylä for replacing an existing filament-driven ion source at the MCC30/15 cyclotron. Previously, production of 1 mA H— beam, which is the target intensity of the ion source, has been reported at 3 kW of RF power [1]. The original ion source front plate with an adjustable electromagnet based filter field, has been replaced with a new front plate with permanent magnet filter field. The new structure is more open and enables a higher flux of ro vibrationally exited molecules towards the plasma electrode and provides a better control of the potential near the extraction due to a stronger separation of the main plasma from the plasma electrode. While the original system provided better control over the e—/H— ratio, the new configuration has led to a higher production efficiency of 1 mA H— at 1.75 kW RF power. The latest results and upgrade plans are presented.

[1] T. Kalvas, *et. al.*, AIP Conf Proc **1655**, 030015 (2015).

Tuesday

25 August 2015

TueM01

Intense Pulsed Heavy Ion Beam Production by EBIS and its Future Development *

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An Electron Beam Ion Source for the Relativistic Heavy Ion Collider (RHIC EBIS) was commissioned at Brookhaven in September 2010 and since then it routinely supplies ions for RHIC and NASA Space Radiation Laboratory (NSRL) as the main source of highly charged ions from Helium to Uranium. Using three external primary ion sources for 1+ injection into the EBIS and an electrostatic injection beam line, ion species at the EBIS exit can be switched in 0.2 s. Therefore, one species is often provided for NSRL and a second species at the same time provided to RHIC. Also, for asymmetric collisions in RHIC, EBIS has provided, with fast switching, Au^{32+}+Cu^{11+}, Au^{32+}+$3He^{2+}$, and Au^{32+}+Al^{5+}. A total of 20 different ion species have been produced to date. Increased use of the relatively newly installed Laser Ion Source (LION) for 1+ ion injection into EBIS has simplified EBIS species changes and has been advantageous for operation in the fast injection mode. Reliability and stability have been very good, with the EBIS running 24/7 for months at a time, and often unattended.

For future *polarized* $3He^{2+}$ production we are looking into a concept that utilizes an additional superconducting solenoid where gas would be polarized in a high field, followed by injection and ionization at a relatively high pressure (~10^{-7} mB) region by the EBIS electron beam. Ions would then be transferred to the lower pressure (~10^{-9} mB) main trap, similar to the electron manipulation of ions formed from neutrals in a cryogenic EBIS. This would allow us to produce a good ratio of He^{2+} to He^{1+} ions and maintain a high level of polarization. This concept could also allow us to increase EBIS output intensity for ions that can be introduced as light or isotopically pure gases. Options to increase future performance also include addition of isotope separation in the external source injection line for accumulation of ions of low isotopic abundance in the EBIS during slow injection. A substantial increase of EBIS high charge output intensity could be obtained with increased electron beam current and source trap length. The length and the capacity of the ion trap has been previously increased by 20% by extending the trap by two more drift tubes, compared with the original design, and we believe that approximately linear gains in output can be obtained by further increasing the EBIS solenoid and trap length, with no impact to the present electron beam launching and collection schemes. The benefits of two parallel EBIS's working together, each comprised from serial superconducting solenoids / trap section modules similar to the Tandem EBIS concept will also be presented.

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TueM02

New Development of Laser Ion Source for Highly Charged Ion Beam Production

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Due to its capability of producing intensive short pulsed highly charged ion beams, laser ion sources had been considered as the most promising ion sources to realize the single turn injection mode for the filling of synchrotrons. In addition, the combination of a laser ion source and RFQ linac based on direction plasma injection scheme (DPIS) may shrink both the dimension and cost of the cancer therapy synchrotron to a large extent. To demonstrate the feasibility of the above mentioned application, our researches have been being focused on the production of C^{6+} ion beams by a laser ion source based on commercial Nd:YAG lasers. It turned out that a laser ion source based on a commercial Nd:YAG laser can meet the requirements of the cancer therapy synchrotrons in terms of the yields of C^{6+} and repeatability. Besides, the production of ions from a variety of elements heavier than carbon were also investigated, the experimental results of which will be presented.

TueM03

High Charge States Heavy Metal Ion Source Based on Vacuum Spark

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Elevation of ion charge states in vacuum discharge plasma is interesting for ion beams physics, because for practical using it leads to proportional increasing of ion beam energy with the same accelerating voltage. The ion charge state elevation of metal ion beam could be provided in vacuum arc ion source by using vacuum spark, which is initial stage of vacuum arc. Since the voltage between anode and cathode remains high compare with the vacuum arc higher charge states of metal ions in discharge plasma were generated and than extracted in ion beam. The using a spark of pulse duration less 10 microseconds and with amplitude current up to 10 kA provides generation of ion beams with current of several amperes with pulse repetition rate up to 5 pps. The higher ion charge states for heavy ions (bismuth) were up to 15+ and mean ion charge state was more than 10+. Physics and techniques of vacuum arc spark ion source are discussed.

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TueM04

Design Steps Towards A High Brightness Electron Impact Ion Source

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The capabilities of focused ion beam (FIB) applications are strongly dependent on the ion source performance. High brightness beams are mendatory in ion-milling to create small features with good erosion rates, aswell as in ion-imaging for high lateral resolution with sufficiently high recording signals. In addition the ion species are of importance for many applications, e.g. reactive ions are needed for high secondary ion yields in Secondary Ion Mass Spectrometry (SIMS).

As the ion source we are targeting should be flexible with respect to the choice of ion species, electron impact is the most suitable ionisation technique as it allows to create various ion species by only changing the gas feed to the ion source. In addition to high brightness, a low energy spread of the extracted ion beam is of importance.

Charged particle optics simulation studies have been realised in order to get an estimation of the achievable ion source performance. In a first design concept, a small electron column with thermionic emission from a hairpin filament has been investigated. The electron beam is focused into the ionisation region of the ion source, which consists of two parallel electrodes spaced by 1 mm. The combination of a cylindrical ionisation volume with dimensions in the submillimeter range and an electrode potential difference of only 10 V creates a small potential drop across the ionisation volume and generates a low energy spread ion beam. By setting the ionisation region to a pressure of 0.1 mbar and injecting an electron beam at 1 keV and 50 µA, a 30 nA Ar^+ ion beam of a 5-25 µm source size can be extracted through an aperture of 100 µm. With a half opening beam angle between 5-20 mrad at 6 keV of ion beam energy the reduced brightness B_r is determined to be around 50-55 A m^{-2} sr^{-1} V^{-1}. The mentioned range for source size and beam angle is due to a variation of potentials within the ion extraction column. A decrease in source size is accompanied by an increase in beam angle which explains the range of B_r values corresponding to different potential settings. The energy spread of the ion beam defined as full width half maximum value is about 1 eV, which is favourable to limit the influence of chromatic aberrations on the achievable spot size in FIB applications.

Switching to a LaB_6 electron emitter would reduce the ionisation volume by a factor of 10 while keeping a comparable electron current. The benefit for B_r is about a factor of 3 leading to 150 A m^{-2} sr^{-1} V^{-1}. However, the required operating pressure is below 10^{-7} mbar which is a hundred times lower than that of the hairpin filament. Gas conductance calculations and measurements have been performed in order to determine how the required vacuum level could be reached in the electron column part of the design.

Comparing the results stated above to conventional electron impact ion sources for which B_r is about 1 A m^{-2} sr^{-1} V^{-1}, the here presented design study represents a clear improvement of performance. Current design modifications are expected to lead to further increase the extracted ion current while keeping the same result in terms of ion beam source size and half opening beam angle, resulting in a further enhancement of the brightness of the source.

TueM05

Development and testing of a pulsed helium ion source for probing materials and warm dense matter studies*

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Pulsed ion beams can be used to for isochoric heating of target materials for high energy density physics experiments and warm dense matter (WDM) studies. The Neutralized Drift Compression Experiment (NDCX-II) was designed and commissioned as a pulsed, linear induction accelerator to drive thin foils to WDM states with peak temperatures of ~ 1 eV using intense, short pulses (~ 1ns) of 1.2 MeV lithium ions[1]. At that kinetic energy, heating a thin target foil near the Bragg peak energy using He^+ ions is a better match than Li^+ ions [2]. We also expect a higher current density of helium ions form a plasma source compared to the Li^+ ions from a hot plate type ion source [3].

The He^+ ion source developed for NDCX-II is a filament-driven multi-aperture plasma ion source [4] with an overall beam diameter of 7 cm. This diameter allows for favorable beam optics in the existing 150 kV injector column, while relaxing the current density requirements that would otherwise be demanded from a smaller ion beam diameter. At 1700W of arc power, the measured He^+ ion current density on axis reached as high as 80 mA/cm^2. Both filament and arc power supplies are pulsed to reduce the heat load and we are exploring pulsing the helium gas supply to reduce the base pressure within the system. The repetition rate of the linear induction accelerator is 0.03 Hz. A plasma extension chamber surrounded by 28 permanent magnets was attached the ion source to contain helium plasma within a larger chamber, resulting in an increased uniform region from 3.5 cm to approximately 6-7 cm in diameter. A grid assembly of hundreds of 1-mm-diameter apertures with more than 50% transparency was used to extract helium ions. The measured pulsed He^+ ion beam reached more than the objective 160 mA at peak current within a 4 µs pulse width. With such a He^+ ion source, we anticipate achieving ~50 to 80 nC of charge in a 1 ns pulse on target after neutralized drift compression and focusing to ~1 mm^2 diameter beam spots. The equivalent peak currents are ~5 to 8 kA/cm^2. Results from pulsed helium ion beam experiments will be reported at the conference.

References

[1] W. L. Waldron et al, NIM A 733, 226 (2014).
[2] W. M. Sharp et al, NIM A 733, 147 (2014).
[3] P. K. Roy et al, NIM A 733, 112 (2014).
[4] K. W. Ehlers et al, Rev. Sci. Instrum. 50, 1353(1979).

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TueM06

Negative Ion Production and Beam Extraction Processes in a Large Ion Source

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Recent research results of a large (700 mm long, 350 mm wide and 230 mm deep) negative ion source at the National Institute of Fusion Science are described. An electrostatic probe with four-independent electrodes measures flow of charged particles in plasma. One of the probe electrodes is utilized as a single Langmuir probe for photodetachment negative ion density measurement. Line integrated negative ion density obtained by cavity-ring down photodetachment measurement provides data to calibrate the local density of negative hydrogen (H-) ions measured by means of photodetachment method. This method is available to obtain negative-ion density even in the plasmas including quite low electron densities. The probe *I-V* characteristics have shown flat plasma potentials profile as the source is operated without Cs, while the profile shows a slope when Cs is introduced into the discharge. Higher electron density shields penetration of bias potential into the plasma with smaller distance. Electrons and negative ions respond against the change in extraction electric field in different manner in the magnetized region produced by the filter field and electron extraction suppression field. Temperatures of negative ions are measured with saturation cavity ring-down method, and that of hydrogen atoms are observed with high-resolution spectroscopy and Hα absorption spectroscopy. Data obtained from a laser Cs absorption spectroscopy, Cs flux monitor and a local work function measurement system characterize Cs recycling in the source and its correlation to the extracted H- ion current density from the source.

TueM07

Linac4 H^- Ion Sources

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CERN's 160 MeV H^- linear accelerator (Linac4) is a key constituent of the injector chain upgrade of the Large Hadron Collider (LHC) that is being installed and commissioned. A cesiated surface ion source prototype is being tested and has delivered a beam intensity of 45 mA within an emittance of 0.3 π·mm·mrad. The optimum ratio of the co-extracted electron-to ion-current is below 1 and the best production efficiency, defined as the ratio of the beam current to the 2 MHz RF-power transmitted to the plasma, reached 1.1 mA/kW. The H^- source prototype and the first tests of the new ion source optics, electron-dump and front end developed to minimize the beam emittance are presented. A temperature regulated magnetron H^- source developed by the Brookhaven National Laboratory (BNL) was built at CERN and a two stage extraction is being produced. The first tests of the magnetron operated at 0.8 Hz repetition rate are described.

TueM08

Recent Performance of and Plasma Outage Studies with the SNS H- Ion Source

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Early in 2014, after several years of producing neutrons with ~1 MW proton beams, SNS started to ramp to higher power levels that can be sustained with high availability. Powers of up to 1.4 MW may be possible despite a compromised RFQ, which requires higher RF power than design levels to approach the nominal beam transmission. Unfortunately at higher power the RFQ often loses its thermal stability, a problem apparently enhanced by beam losses and high influxes of hydrogen. This led to the semi-retirement of the high-performing source #3. The apparently lower beam losses of the other two sources shifted the goal to delivering as much H- beam as possible with the least amount of hydrogen in the source, which led to plasma outages. Ongoing plasma outage studies show that the 13 MHz supply struggles with the ~90% power reflected by the 1-ms long 2-MHz plasma pulses. Possible mitigations are being tested, starting with a 4-ms RC filter for the reflected power signal.

Lowering the H2 pressure initially increases the H- beam current due to reduced losses, and since mid-2014 ~50 mA are routinely injected into the RFQ. Subsequent LEBT retuning improves the RFQ transmission by better matching the reduced-divergence beams. Accordingly ~35 mA H- beams exiting the RFQ have become routine.

To further support higher powers, under-performing sources are replaced after two weeks while well- performing sources are used for up to 8 weeks, frequently exceeding 3 A□h of H- without showing signs of aging.

These new approaches increased the average RFQ output peak current at the end of the pulse by ~2 mA while the standard deviation was reduced from 1.9 to 1.3 mA compared to the prior year, which included the high performing source #3.

TueM09

Commissioning the Rutherford Appleton Laboratory (RAL) Scaled Penning Surface Plasma Source

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

The new source described in the paper should deliver the full duty cycle requirements for FETS, produce higher beam currents and yield longer lifetimes for ISIS operations when run at lower discharge currents. Electrode heaters will allow lower duty factor operation and pre-operation heating. Thus reducing reliance on the use of destructive DC discharges to achieve operational temperatures. This is especially important for FETS commissioning because daily source shutdowns are planned.

This paper gives a status update of the FETS project, details the new source design and provides initial results.

References

[1] D.C. Faircloth et al., "The front end test stand high performance H– ion source at Rutherford Appleton Laboratory", Review of Scientific Instruments, Volume 81, Issue 2, (2010).

[2] D. C. Faircloth et al., "Optimizing the front end test stand high performance H– ion source at RAL", Rev Sci Instrum 82 (2, Part 2) 02A701 (2012).

TueA01

Inductively Driven Surface-Plasma Negative Ion Source for N-NBI use

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A stable H- beam with a current ~1A, energy 90 kV, and pulse duration up to 7 s was routinely extracted and accelerated from the long-pulse surface-plasma source prototype, developed at BINP for N-NBI use. The H- ions are produced on the hot surface of a plasma grid, covered by cesium and illuminated by fast plasma particles from the inductively driven radio-frequency discharge. A multiaperture, five-electrode ion optical system is used for beam formation. The essential BINP source features are: 1) an active temperature control of the ion-optical system electrodes by circulation of hot thermal fluid through the channels, drilled in the electrode bodies, and 2) the directed cesium deposition to the plasma grid electrode using a long tube, connected to the plasma grid periphery [1]. The long term effect of cesium was obtained just with the single cesium deposition. The high voltage strength of ion-optical system electrodes was considerably improved with actively heated electrodes. The 90 keV H- beam is transported to the entrance of the high-voltage post-accelerator with the help of the low energy beam transport section.

References

[1] Yu. Belchenko, A. Gorbovsky, A. Ivanov, et al. "Negative ion production in the RF multiaperture surface-plasma source Multiaperture Negative Ion Source". AIP Conf. Proc. **1655**, 040002 (2015).

TueA02

Particle model of full scale ITER-relevant negative ion source

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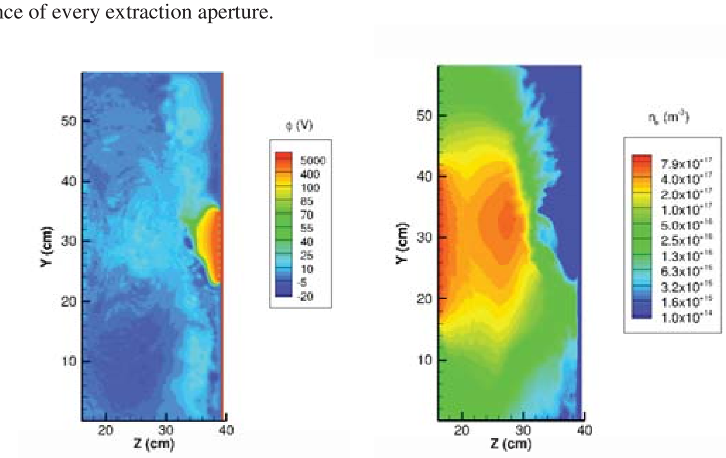
One of the most important problems in the simulation of negative ion extraction is related to the injection conditions at the source plane (the extracted current strongly depends on the source condition) and to the fact that up to now only a single aperture has been resolved [1-3]. At the same time, full scale source simulations have shown the importance of plasma dis-homogeneity along the extraction grid (y-direction) due to the presence of the magnetic filter but without the possibility of solving the transport and extraction of negative ions through the single aperture (low grid resolution) [4] For this reason, a 2.5D PIC-MCC model of the full scale ITER-relevant negative ion source has been developed keeping the single grid cell small enough to resolve in detail the extraction dynamics till the EG grid. Results (see Figs. 1 where the plasma potential and electron density structures in the expansion and extraction regions have been reported) have shown the complex electron dynamics through the magnetic filter and the strong coupling between expansion and extraction regions determining different boundary conditions at the entrance of every extraction aperture.



(a) (b)

Fig. 1 – (a) Map of (a) electric potential φ(V) and (b) electron density *n*e(m-3) in the {y,z} plane in the expansion and extraction regions. The driver region is on the left, not simulated.

References

[1] F. Taccogna, P. Minelli, S. Longo, *Plasma Sources Sci. Technol.* **22**, 045019, 2013.
[2] S. Mochalskyy, et al., *Plasma Phys. Control. Fusion* **56**, 105001, 2014.
[3] A. Hatayama, et al., *Rev. Sci. Instrum.* **85**, 02A510, 2014.
[4] G. Fubiani, J.-P. Boeuf, *Phys. Plasmas* **21**, 073512, 2014.

TueA03

Physics of Negative Ion Beam Formation and Extraction from the Plasma Electrode Surface in High Brightness Magnetized Plasma Sources

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The origin and extent of the aberrations found in high brightness negative ion beams generated by positive ion and neutral atom impacts on the cesiated surface of the plasma electrode (which separates the ion source plasma from the particle accelerator) in negative ion sources is not well understood. High brightness negative ion beams are typically employed in a wide range of applications such as in tandem type electrostatic accelerators, cyclotrons, storage rings in synchrotrons, as a precursor to produce neutrons in the Spallation Neutron Source (SNS) or to generate high power neutral beams in magnetic fusion devices. Aberrations, which have been observed experimentally, may have critical consequences for the accelerator parts and induce both a significant loss of transmitted beam power and an increase of the beam divergence. It is consequently crucial to characterize in details the origin of the aberrations in negative ion sources. Negative ion transport properties in the vicinity of the extraction aperture are difficult to assess experimentally (most of the relevant physics occurs within a few Debye length which is sub-millimetric in typical high power ion sources) and numerical modelling is used instead to calculate the plasma characteristics in the extraction region. The vast majority of self consistent numerical models for negative ion beam extraction are based on the Particle-In-Cell (PIC) method with Monte-Carlo Collisions (MCC). The simulation domain is a zoom around a single plasma electrode aperture and one of the main difficulties is to reproduce numerically accurate plasma profiles in that area. Negative ions typically have a kinetic energy of orders of a few electron-volts and are consequently very sensitive to small variations of the plasma potential; this can easily lead to erroneous estimates for the extracted negative ion beam characteristics. Current PIC models fail to reproduce some fundamental experimental observations, which is the extraction of a negative ion beam from a plasma electrode with a flat surface around the aperture. We believe this is due to a lack of knowledge on the particle distribution functions in the extraction region. These numerical models use as input parameters the particle densities and temperatures obtained from experimental measurements alone. Doing so, the calculated depth of the virtual cathode in front of the plasma electrode greatly exceeds the negative ion kinetic energy and hence most ions are reflected back onto the electrode surface reducing consequently significantly the extracted negative ion beam current (far below measured values).

In this work, we propose a different numerical approach: the plasma parameters in the extraction region are obtained from a 3D PIC-MCC calculation of the whole ion source volume [1,2]. We model the typical working conditions of an ITER prototype Radio-Frequency (RF) tandem-type high brightness negative ion source, which corresponds to a plasma electrode positively biased with respect to the other walls of the device such that the electrode is floating (i.e., the total current collected on the latter is void). We demonstrate that for flat potential profiles in the vicinity of the plasma electrode and virtual cathodes depths of order $\Delta\phi \sim -1$V, a negative ion beam current density $j_{H^-} \sim 25$ mA/cm^2 with a ~15% halo may be extracted from a hydrogen plasma with a flat electrode surface. These values are comparable to experimental measurements.

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission. Support from CEA and from the French Fédération de Recherche sur la Fusion Magnétique is acknowledged. This work was granted access to the HPC resources of CALMIP supercomputing centre under the allocation 2013-P1125.

[1] G. Fubiani et al., Physics of Plasmas **20**, 113511 (2013)
[2] G. Fubiani et al., Physics of Plasmas **21**, 073512 (2014)

TueA04

Fine-Tuning to Minimize Emittances of J-PARC RF-Driven H$^-$ Ion Source

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The Japan Proton Accelerator Research Complex (J-PARC) cesiated rf-driven H$^-$ ion source (IS) [1-3], whose requirements are a peak beam intensity of 60mA within normalized emittances of 1.5πmm•mrad both horizontally and vertically, a flat top beam duty factor of 1.25% (500μs×25Hz) and a life-time of longer than 1month, has been successfully operated for about one year. The results of the fine-tuning to minimize the emittances of the J-PARC-IS with plasma chamber #3, which had the largest emittances with initial settings among four plasma chambers, will be presented in this paper. The rod-filter-filed will be finely tuned by selecting magnets with slightly different field strengths and/or changing gap-lengths. The dependence of the beam-hole-diameter on the emittances will be also presented. The tuning procedure to improve the emittances is one of the most important technology for the IS of the high-energy and high-intensity accelerator.

References

1. A. Ueno et. al., AIP Conference Proceedings 1655, 030008 (2015).
2. A. Ueno et. al., AIP Conference Proceedings 1655, 030009 (2015).
3. A. Ueno et. al., AIP Conference Proceedings 1655, 030010 (2015).

TuePE01

Probing vibrational levels of ground state hydrogen molecules by laser photodetachment

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In this work, a study of the vibrationally excited hydrogen molecules formed via recombinative desorption of hydrogen atoms on surfaces of selected materials is performed. Assuming that dissociative attachment of low energy electrons is the main generation channel of hydrogen negative ions [1], highly excited states of molecules ($H_2(X^1\Sigma_g^+, v'' \geq 5)$) can be correlated with thenegative ion density [2].

In order to focus on the recombinative desorption of atoms, a two stage/chamber configuration is employed. In the first stage, a filament maintained at moderate temperature (~1500 K) dissociates hydrogen molecules and provides an abundant density of atomic hydrogen, which then recombine on the walls of the chamber [3,4]. The material of the chamber can be conveniently changed and its temperature is controlled.

The highly excited molecular hydrogen generated inside the first chamber escapes through a nozzle into the second chamber. Here, four dipolar sources [5] are used as a source electrons [6] of controlled temperature. From the combination of cold electrons and highly excited molecules, negative ions are generated and measured by the photodetachment technique [7].

[1] M. Bacal, Nucl. Fusion **46**, S250 (2006).
[2] J. M. Wadehra, Phys. Rev. A **29**, 106 (1984).
[3] B. Jackson and D. Lemoine, J. Chem. Phys. **114**, 474 (2001).
[4] X. Sha, B. Jackson, and D. Lemoine, J. Chem. Phys. **116**, 7158 (2002).
[5] A. Lacoste, T. Lagarde, S. Béchu, Y. Arnal, and J. Pelletier, Plasma Sources Sci. Technol. **11**, 407 (2002).
[6] S. Béchu, A. Soum-Glaude, A. Bès, A. Lacoste, P. Svarnas, S. Aleiferis, A. A. Ivanov, and M. Bacal, Phys. Plasmas **20**, 101601 (2013).
[7] M. Bacal, Rev. Sci. Instrum. **71**, 3981 (2000).

TuePE02

A Multicusp Ion Source at MIT optimized for H_2^+

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The IsoDAR experimental program aims to decisively test the sterile neutrino hypothesis. In essence, it is a novel cyclotron-based neutrino factory that expands the frontiers in both high intensity cyclotrons and electron flavor anti-neutrino sources. By accelerating H_2^+ ions rather than protons, we can reduce space-charge effects, and deliver twice the number of protons per nucleus on target. The requirement for IsoDAR is an H_2^+ current of 5 mA injected into the cyclotron and captured by the RF. For this purpose, we are currently developing a dedicated H_2^+ multicusp ion source and low energy beam transport system with bunching for the IsoDAR cyclotron. In this contribution we are presenting the final technical design of the ion source, simulations of the beam extraction, and report on the status of assembly at MIT.

TuePE03

Oscillatory instability development in extraction system of a negative ion source

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Ion source based on a volume ion production as a rule is characterized by the presence of the working gas in the extraction system leaking from the gas-discharge chamber. Depending on the residual gas pressure the quasineutral or plasma regimes of the beam propagation are realized. In both regimes the development of the different plasma-beam instabilities may occur. In the paper presented the development of the oscillatory instability is discussed which takes place under some conditions in the three-component plasma system. This instability is caused by the secondary (plasma) electrons inside the beam volume. The quantity of the electrons may be rather small – about 0.01 percents of the density of the beam. Analytically the range of the stable beam propagation is determined. The case of one-dimensional system is considered that corresponds to the diode with the large aspect ratio. The instability increment is shown to be rather small. Maximum increment of the oscillations corresponds to the thermal particle velocities, and one can say about resonance character of the instability. The group velocity of the oscillations is near the beam particle velocity so the oscillations are the “drift” oscillations. The instability is studied numerically too with the help of COMSOL Multiphysics.

TuePE04

Mixed Pierce-two-stream instability development in extraction system of a negative ion source

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Negative ion source based on a volume ion production is characterized by essential working gas leakage into the extraction system. The working gas presence in the area of the beam propagation leads to both positive and negative effects, one of the positive effects being the compensation of the beam own space charge. One of the negative effects is the possible development of the plasma instabilities that may result in the beam current oscillation or breakdown, so it is of importance to work in the range of the gun parameters far from the instability threshold. In the paper presented the conditions of the development of the mixed Pierce-two-stream instability are discussed. Analytically the range of the stable beam propagation is determined. The instability threshold is shown to be increased compared with the pure Pierce instability caused by the finite mobility of the background ions. The conditions of the growth of the inclined perturbations are investigated in the case of the beam real geometry, when the transverse dimension of the beam is quite comparable or less than the specific inter-electrode distance. The instability simulation in COMSOL Multiphysics is performed too.

TuePE05

Experimental investigation of non-linear wave to plasma interaction in a quasi-flat magnetostatic field

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A detailed characterization of wave-to-plasma interaction in a quasi-flat magnetostatic field at 3.75 GHz has been carried out by using a small-wire movable RF antenna. The plasma-affected RF spectral emission during Electron Bernstein Waves (EBW) heating has been measured by means of a 1kHz-50 GHz spectrum analyzer. EBW are generated by extraordinary waves at the Upper Hybrid Resonance by means of non-linear mechanisms. The coupling between the EM waves and the electrostatic waves lead to a characteristic spectral emission in the low frequency range (ion waves) and around the pumping wave frequency. The EM spectra have been characterized for different values of the microwave power, frequency and pressure in different spatial regions of the plasma. The more relevant results consist in the broadening of the pumping wave spectrum above critical RF power thresholds, and the generation of sidebands at given Δf with respect to the pumping frequency, with corresponding components in the low frequency domain (ion waves around 10-100 kHz). These non-linearities are accompanied by the formation of an overdense plasma and by the emission of intense fluxes of X-rays in the 100 eV-10 keV domain. The results will be discussed and interpreted along the paper.

TuePE06

ICP Source with Immersed Ferromagnetic Inductor

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Application of ferromagnetic enhanced inductors in inductively coupled plasma (ICP) sources results in many attractive features comparing to traditional ICPs without ferromagnetic cores[1]. Ferromagnetic enhanced ICPs, (FMICPs) have extremely high power transfer efficiency reaching 99%, that corresponds to 1% power loss in the inductor, which is an order of magnitude less than that in best helicon plasma sources. The ability to operate at low frequency (1-2 order of magnitude lower than that in traditional ICPs), with high power factor allows for elimination of matching networks, and practically absence of capacitive coupling make FMICP a superior plasma source for many applications.

A special class of FMICP having immersed inductor with ferrite core is reviewed in this presentation. Electrical and plasma characteristics measured for wide range of RF power (25-600 W) and gas pressure (1 mTorr-1 Torr) in Ar and Xe gas for few FMICP sources with immersed ferrite inductors are discussed. Particularly, the power transfer efficiency, inductor RF voltage and current, power factor, and extracted ion and electron currents are given as functions of RF power and gas pressure. A simple in construction compact plasma cathode (for thruster ion neutralization and for e-beam/plasma study) has been developed and its superior performance (comparing to known plasma cathodes) has been demonstrated. Similar advantage should be expected for ion sources build on the same scheme.

Reference

V. Godyak, Ferromagnetic enhanced inductive plasma sources J. Phys. D: Appl. Phys. **46** (2013) 283001 (23pp)

TuePE07

Novel Modification of Hall-Type Ion Source (Study and the First Results)

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We describe the original approach to use the plasma accelerators with closed electron drift (Hall-type ion sources), which, unlike traditional accelerators with metal and dielectric walls, have open (gas) walls and can be applied for creation cost effective low maintenance plasma devices based on plasma lens configuration for production converging towards axis accelerated ion beams. Based on the idea of the continuity of current transferring at the system in the frame of one-dimensional model, exact analytical solutions describing electric potential and electron density distribution along acceleration gap are found. It was shown that potential distribution is parabolic for different operation modes in low-current mode, as well as in high current quasi neutral plasma mode, and does not depend on electron temperature. It is found that, under conditions for which all electrons originated within the gap by impact ionization only, and go out towards anode due to classical mobility in transverse magnetic field, the condition of full electric potential drop in the accelerating gap corresponds to the gap length equality to the anode layer thickness.

Experimental model of cylindrical Hall-type plasma ion source that produced ion plasma flow converging towards the axis system was created. The current-voltage characteristics of the accelerator in different operating modes were defined. In high-current quasi neutral plasma mode of accelerator operation, plasma jet is observed. It is shown that along the jet axis potential drop arise which can be used for ion beam accelerating. It is noted the power ion plasma flow increases with discharge current density growth. Note also, the ion current density at the jet axis can reach up to 2-3% of total discharge current. The obtained experimental results are in qualitative agreement with theoretical consideration.

Note also, the described plasma ion source can be attractive for many different high-tech applications, e.g., for creation effective plasma lens with positive space charge cloud for focusing negative intense charged particle beams (electrons and negative ions) and for potential devises of low cost and compact thrusters.

References

Alexey Goncharov Invited Review Article: The Electrostatic Plasma Lens, Rev. Sci. Instrum. 84, 021101 (2013).

V. Gushenets, A. Goncharov, A. Dobrovolskiy, S. Dunets, I. Litovko, E. Oks., A. Bugaev, Electrostatic plasma lens focusing of an intense electron beam in an electron source with a vacuum arc plasma cathode// IEEE Trans. Plasma Sci., v. 41, № 4, Part 3 (2013), pp. 2171-2174.

TuePE08

Photoelectron Emission from Metal Surfaces Induced by Radiation Emitted by a 14 GHz Electron Cyclotron Resonance Ion Source

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Previous measurements with a filament-driven multi-cusp arc discharge volume production H□ ion source [1] suggest that photoelectron emission could contribute to properties of hydrogen ion source plasmas. In this study photoelectron emission measurements have been performed using a room-temperature 14 GHz ECR ion source. It is shown that the photoelectron emission from Al, Cu, and stainless steel (SAE 304) surfaces, which are common plasma chamber materials, is predominantly caused by plasma VUV-emission. Characteristic X-ray emission from the plasma has an insignificant contribution to photoelectron emission. In the measurement setup the radial line-of-sight plasma volume is between the poles of the sextupole magnetic field, i.e. photoelectron emission induced by direct wall bremsstrahlung is not observed. Photoelectron currents are measured as a function of microwave power with different magnetic field strengths, neutral gas pressures and plasma elements. The total photoelectron flux from the plasma chamber wall is estimated from the measured photoelectron currents by taking into account the measurement geometry. The total photoelectron flux is compared to estimated electron losses from the plasma in order to deduce the significance of the effect on ECR ion source plasma properties.

References

[1] J. Laulainen, T. Kalvas, H. Koivisto, J. Komppula, and O. Tarvainen, AIP Conf. Proc. 1655, 020007 (2015).

TuePE09

PIC Modeling of Penning Trap

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The Penning Ion Gauge or the Penning Trap that uses a combination of electric and magnetic fields to trap ions has applications in accelerator physics. Such Ion Sources are used to inject ions into accelerators which are extracted after acceleration for various purposes. The Particle in Cell Algorithm has been a popular tool for plasma simulations for the past few decades and has been gaining popularity as computational abilities of today's machines increase. An attempt was made to simulate a simplified 1 dimensional voltage mirror of a penning trap by ignoring the magnetic field using the 1-D Electrostatic Particle in Cell Algorithm and include certain boundary conditions which can be later improved upon to model behavior like sputtering and ionization events. Simulation results in phase space indicate the oscillation of ions around an equilibrium saddle point. This paper discusses further attempts at modeling the Penning Ion Gauge behavior.

References

[1] Electrostatic PIC simulation of plasmas in one dimension, Martin D, School of Physics and Astronomy, The University of Manchester, Fourth Year M.Phys Project Report, January 2007.
[2] Gueye, S.B., Talla, K. and Mbow, C. (2014) Solution of 1D Poisson Equation with Neumann-Dirichlet and Dirichlet-Neumann Boundary Conditions, Using the Finite Difference Method. Journal of Electromagnetic Analysis and Application, 6, 309-318. http://dx.doi.org/10.4236/jemaa.2014.610031.
[3] Introduction to Plasma Physics and Controlled Fusion, FF Chen.
[4] The Physics and Technology of Ion Sources, I. Brown
[5] Plasma Physics via Computer Simulations, CK Birdsall, AB Langdon
[6] Industrial Accelerators and Their Applications. World Scientific; Hamm, Robert W.; Hamm, Marianne E. (2012).

TuePE10

Dust Particle Diffusion in Ion Beam Transport Region

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Ion beam equipment produces dust particles of μm order sizes in an ion beam transport region. The particles originate in ion source plasma, and traverse the extractor to reach the region of low density ion beam produced plasma. The transport of dust particles is determined by local electric fields formed at the boundary of the ion beam produced plasma. An experimental setup is assembled to measure the distribution of dust particles in the ion beam transport region. The setup consists of a test chamber, a monoplasmatron source, an extractor and a solid state laser. A monoplasmatron plasma generator has a hollow cathode electrode, an anode electrode and a floating electrode that constricts plasma flow from the cathode to the anode. A 100 mm outer diameter 70 mm height Pyrex glass tube houses the monoplasmatron electrodes. Three electrodes with their 2 mm diameter apertures at the center served as the extractor to form the ion beam. All monoplasmatron electrodes are made of graphite and the produced carbon dusts by plasma sputtering are extracted to the ion beam transport region in the test chamber having 310 mm inner diameter and 120 mm height cylindrical shape. A graphite laser dump which has a triangular prism shape is held in the test chamber to eliminate a reflection laser light. Laser scattering light from an incident laser light at 532 nm wavelength shows where and when a μm order particles passes through the ion beam transport region. As the result, dusts with the size more than 10 μm were found distributed in the center of the ion beam, while less than 10 μm size dusts distributed along the edge of the ion beam. This observation coincides with the charge up model of the dust in the plasma boundary region.

TuePE11

Recent progress of plasma modelling at INFN-LNS

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The ion sources R&D team of the INFN-LNS has been working on the modelling of microwave generated plasmas for many years, dealing with the demands coming from different projects like ESS, AISHA, ECR-based charge breeders, VESPRI, Daeδalus. At first a stationary version of the PIC code was developed following a path that now is going to become a standard for particle tracking code also in commercial products. Electromagnetic properties of the plasma and full-waves simulations are now affordable for non-homogenous and magnetized (i.e. non-isotropic) plasma via "cold" approximation. The diffusion and thermalization of plasma particles by elastic Coulomb collisions via the Fokker-Planck equation are now included instead of the Spitzer collisions. High level of performance was reached with optimization of the code for parallel environment. A wide database of different cross sections related to reactions occurring in an hydrogen plasma was collected and implemented. The next step consists of merging such a variety of approaches for retrieving an "as-a-whole" picture of plasma dynamics in MDIS sources for intense proton beams production. The preliminary results will be summarized in the paper, that shows as the realization of a predictive software including the complete processes involved in plasma formation is still rather far, but a better comprehension of the source behaviour is possible and so the simulations may support the optimization phase.

TuePE12

Integral Electrical Characteristics and Local Plasma Parameters of an RF Ion Thruster

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Comprehensive diagnostics has been carried out for an RF ion thruster (RIT) based on inductively coupled plasma (ICP) with an external flat antenna coil enhanced with ferrite core. The ICP was confined within a cylindrical chamber with low aspect ratio to minimize plasma loss to the chamber wall. Integral diagnostics of the ICP electrical parameters (RF power and coil current) allowed for evaluation of the antenna coil, matching network, and eddy currents loss and the true RF power deposited to plasma. Spatially resolved electron energy distribution function (EEDF), plasma density, electron temperature, and plasma potentials were measured with movable single Langmuir probes.

TuePE13

Neutral Resonant Ionization in an H^- Plasma Source: Potential of Doubly-Excited $^{**}H^-$

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All excited states of the H anion are doubly excited, with both electrons above the 1s orbital, and sets of $^{**}H^-$ resonances occur at and below the energies of the *n*=2, 3 and 4 states of H. These states are unbound, with lifetimes of 100 femtoseconds or less, that only appear as enhancements in electron and photon reactive cross sections with H and H^-. One state, $^{**}H^-$ ($2p^2\ {}^3P^e$), is calculated to be bound at 9.7 meV with a several nanosecond lifetime, and was originally proposed as a metastable state of $^{**}H^-$ to explain broadening of Lyman-α radiation in space plasmas. This state is thought to be unobtainable in terrestrial experimentation because its photonic production from H^- violates parity conservation, and the resonance does not show up in energy scans of electron-hydrogen collisions. Hydrogen plasmas are optically dense to Lyman-α radiation, creating an over-population of *H(n=2) neutral atoms. Energy of 10.2 eV is stored in such *H(2s) and is available to interactions throughout the source plasma volume during its 200 msec lifetime. The collision of two *H(n=2) atoms is energetically open to the production of a doubly excited anion through neutral resonant ionization in which the n=2 electron of one atom transfers to one of the three open n=2 orbitals of the other atom.

A study of the collision dynamics of two *H(2) atoms in the potential-energy versus separation (E vs r) plane shows that an ionic pair involving an $^{**}H^-$ resolves at least three long-standing collision experiments. These required unphysical assumptions if only vertical transitions in (E vs r) are allowed. This same analysis shows the energetic pathway from the collision of two *H(2) atoms to a doubly-excited anion/proton pair to a doubly excited hydrogen molecule which then has several paths to the unexcited ion pair. The experimental signal of this process in a plasma ion source is difficult to quantify because the $^{**}H^-(2p^2\ {}^3P^e)$ is never isolated and no specific optical emission is expected. However, the resulting H^+, H^- should both have an energy of 3.77 eV.

TuePE14

Anion Formation in Sputter Ion Sources by Neutral Resonant Ionization

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A widespread theory of surface ionization explains negative secondary ionization mass spectrometry (SIMS) and is extended to Cs sputter ion sources (CSIS), but SIMS and CSIS differ greatly in analytical practice. Primary ion beams sputter analyzed surfaces in SIMS at controlled erosion rates while CSIS uses a primary ion beam with 10^3 to 10^5 higher power densities to rapidly erode a material. Highly focused Cs^+ beams in CSIS sources create mm-diameter sputter craters that support small blue plasma balls on which negative ion currents and ionization efficiencies are notably dependent. Sputtering produces overwhelmingly neutral products that the plasma has long been thought to ionize as in a charge-change vapor, but taking place at 1000-fold lower energies. Neutral atoms at keV energy were shown to capture electrons from neutral Cs in the 1960's and calculations showed in the 1970's that cross sections rose dramatically at lower energies with Cs atoms in excited states. Resonant behavior was demonstrated in the 1980's with neutral resonant ionization (NRI) occurring at high rates for eV energy collisions.

A collision-radiation model of a Cs plasma in a recess was developed that followed electronic excitation and optical resonance up to the Cs(7d) state to understand control of the excited states. NRI cross sections are essentially unknown, but the Landau-Zener-Stückelberg formalism predicts that the maxima rise as the inverse square of the energy deficit: the difference between the ionization potential of the Cs state and the electron affinity of the sputtered neutral atom. The model shows production of Cs excited states under conditions that maximize measured CSIS ion current, explaining much "lore" of sputter sorcery. The model has been directly tested. The predicted reduction of $^{36}S^-$ ions by addition of Ir or Pt to AgCl samples for ^{36}Cl AMS is seen from suppression of Cs(5d). The high level of Cs(7d) in a 0.5 mm recess explains the 83 μA/mm² C^- current density compared to the 20 μA/mm² from a 1 mm recess that is a strong refutation of the surface ionization hypothesis of CSIS operation.

TuePE15

Investigation on the electron flux to the wall in the VENUS ion source

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The long-term operation of high charge state electron cyclotron resonance ion sources fed with high microwave power has caused damage to the plasma chamber wall in several laboratories. Porosity, or a small hole, can be progressively created in the wall on a year time scale, which can cause a water leak from the cooling system into the plasma chamber vacuum. A burnout of the VENUS chamber is investigated. Information on the hole formation and on the necessary local hot electron power density is presented. Next, the hot electron flux to the wall is studied by means of simulations. First, the results of a simple model assuming that electrons are fully magnetized and strictly following magnetic field lines are presented. The model qualitatively reproduces the traces left by the plasma on the wall and shows characteristic sub-patterns, which are seen experimentally. However, it is too crude to reproduce localized power densities of the electrons at the wall necessary to make a hole in the chamber wall. Second, the results of a Monte-Carlo simulation following a population of hot electrons into the ion source is presented. The simulation includes electron scattering. This time, a localized, high power density deposition to the wall results. A comparison between simulation and experiment is discussed in the case of the VENUS source. Finally, options to avoid hole formation in ECR ion sources chamber walls are explored.

TuePE16

Cesium recycling in the large cesiated negative ion source toward JT-60SA and ITER

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As the negative ion source for neutral beam injection in JT-60SA and ITER, a large cesiated negative ion sources have been designed to produce the high current beams of > 20 A from an ion extraction area of > 45 cm x 110 cm. In order to maintain the high current beam production, cesium (Cs) is continuously injected to enhance the surface production of negative ions on the plasma grid (PG). In this case, Cs recycling such as high Cs consumption and long conditioning phase is one of the critical issues. Therefore, it is important to clarify physics of the Cs recycling in the negative ion source. As the first step, time evolution of spatial profile of negative ion production during an initial conditioning phase has been experimentally investigated in the JT-60 negative ion source, where a Cs nozzle is installed in the center of the negative ion source and negative ions are extracted from the PG (45 cm x 110 cm). Up to 0.4 g Cs injection, there is no enhancement of the negative ion production and no observation of the Cs emission signal in the source, suggesting the injected Cs is mainly deposited on the water-cooled wall near the nozzle. After 0.4 g Cs injection, enhancement of the negative ion production appeared only at the central segment of the PG. The calculation of the Cs neutral/ion trajectories implied that a part of Cs was ionized near the nozzle and was transported to this area. The expansion of the area of the surface production was saturated after ~2 g Cs injection corresponding to ~6 x 10^3 s discharge time. From the results, it is found that Cs ionization and its transport plays an important role for the negative ion production.

TuePE17

Negative hydrogen ion sources developed at IMP

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A test stand and two negative hydrogen ion sources with hot cathode arc discharge were developed at IMP. The first one, Lanzhou negative hydrogen ion source 1 (LNHIS1), adopted Halbach hexapole magnet as plasma confinement, performs 1 mA DC H^- beam with 900 W arc power. The second one, Lanzhou negative hydrogen ion source 2 (LNHIS2), used ten poles Multi-Cusp magnet as plasma confinement, performs 4.5 mA DC H^- beam with 2200 W arc power. This paper presents our progress and compares the two sources.

TuePE18

Model and measurement of beam extraction of LNHIS1 and LNHIS2

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A set of online electrical movable three-electrode extraction system was designed and fabricated for a negative hydrogen ion sources test stand. Two negative hydrogen ion sources, Lanzhou Negative Hydrogen Ion Sources 1 and 2 (LNHIS1 and LNHIS2), were test at this stand with this extraction system. Beam intensity and emmittance were measured respectively with a Faraday cup and an Alison scanner. Model of beam extraction used PBGUNS code was given and compared with the test results.

TuePE19

Detailed Beam and Plasma Measurements on the VESPA Penning H^- Ion Source

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The Vessel for Extraction and Source Plasma Analyses (VESPA) [1] has been operational at the Rutherford Appleton Laboratory (RAL) for one year. This project supports and guides the overall ion source R&D effort for the ISIS pulsed spallation neutron and muon facility at RAL. The overall aims for the project are: to investigate exactly what properties and H^- production mechanisms the ion source plasma has, through optical emission spectroscopy techniques; to completely redesign the extraction system for loss-less injection into a magnetic low energy beam transport (LEBT); to quantify the effect of removing caesium trapping; to investigate whether the source lifetime can be increased through overall efficiency improvements, and to support R&D occurring in parallel, such as a scaled ion source [2].

Having commissioned the VESPA and successfully extracted beam [3], the initial problems, such as high operating temperatures, poor vacuum pressure and lower than expected beam current, have been solved. The VESPA produces 100 mA of pulsed H^- beam, proving that collimation on the analyzing dipole magnet is the reason only 50 mA is measured on the ISIS operational source for the same set-points. Perveance scans indicate that the source is production-limited (i.e. saturates away from the Child-Langmuir curve) at extraction voltages above 14 kV unless the discharge current in increased from the standard 55 A to 70 A.

A high resolution optical monochromator is used to measure plasma properties using argon as a diagnostic gas. The hydrogen gas temperature increases by the square root of arc current, up to 2.8 eV for 50 A; whereas the electron temperature has a slight linear decrease toward 2.1 eV. Gas and electron densities are in the same order of magnitude at around 1×10^{19} m^{-3}, with electron density increasing and gas density decreasing with arc current. SRIM calculations prove that operating the ion source under argon in high current pulsed mode is extremely difficult because the cathode-coated caesium is heavily sputtered by argon.

References

[1] S. R. Lawrie *et al*, "Development of the Front End Test Stand (FETS) and Vessel for Extraction and Source Plasma Analyses (VESPA) Negative Hydrogen Ion Sources at the Rutherford Appleton Laboratory (RAL), Rev. Sci. Instrum 85, 02B127 (2014).

[2] D. C. Faircloth et al, "Operational and Theoretical Temperature Considerations in a Penning Surface Plasma Source", AIP Conf. Proc. 1655, 030013 (2015).

[3] S. R. Lawrie *et al*, "First Beam Measurements on the Vessel for Extraction and Source Plasma Analyses (VESPA) at the Rutherford Appleton Laboratory (RAL), AIP Conf. Proc. 1655, 030011 (2015).

TuePE20

A Negative Ion Source Test Facility

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Progress is being made in the development of an Ion Source Test Facility (ISTF) by D-Pace Inc. in collaboration with Buckley Systems Ltd in Auckland NZ. The project is planned in two phases, with the first phase schedule to be completed by October 2015. The ISTF will have multiple purposes. It will primarily be used for the development and commercialization of ion sources. D-Pace Inc. licensed from the University of Jyvaskyla a CW 13.56MHz RF H^- 30 keV Volume-Cusp ion source with the goal to increase the current from 1 mA to 5 mA DC. We expect to test the first model by early 2016. We also plan to further improve D-Pace's TRIUMF licensed filament powered H^- DC Volume-Cusp 15 mA, 30 keV ion source to 20-25 mA. Thirdly, D-Pace Inc. plans to investigate the production of exotic negative ion beams such as C^-. The ISTF will also be used to characterize and further develop various D-Pace Inc. products under development. This includes TRIUMF licensed devices such as an emittance/phase space scanner, wire scanner, sliding slit Faraday Cups, slits, collimators; and D-Pace devices such as AC raster scanning magnets, scintillator based beam profile monitors and low energy transport (LEBT) systems. The ISTF will also be used to factory acceptance test ion sources and beam diagnostics devices before shipment to customers. Finally, an analyzer permits energy spectrum measurements to be made or mass spectrometer measurements. Collaborative R&D or independent 3rd party experiments would be possible. The first phase of the ISTF, schedule to be commissioned in August 2015, will incorporate a single faraday cage and ion source bay for the developing the RF and filament powered volume cusp sources. Analysis equipment will include a single vacuum box with ports for emittance/phase space scanner, wire scanner and faraday cup. The second phase, schedule to be commissioned August 2016, will see a 1:1000 Analyzer/Spectrometer System added to the ISTF.

TuePE21

Analysis of the Beam Halo in Negative ion Sources by Using 3D3V PIC Code

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Negative ion based neutral beam injection system is one of the promising candidates for plasma heating and current drive of magnetic fusion reactors. The negative ion source which can produce negative ion beams with high power and long pulse is the key component for this system. One of the key issues for the design and development of such negative ion sources is to clarify negative ion trajectories. Especially, to understand the physical mechanism of the beam halo formation in the negative ion sources is inevitable for the suppression of the heat loads in the accelerator.

In this study, the negative ion trajectories from the plasma meniscus to the accelerator are investigated to clarify the halo formation and analyze the beam halo in the accelerator quantitatively. The negative ion trajectories from the plasma meniscus to the extractor are calculated by using the 3D PIC code in which the plasma meniscus is calculated self-consistently without any assumptions. On the other hand, the negative ion trajectories in the accelerator are calculated by using the commercial software (Omnitrak, Advanced Science Laboratory, Inc.) with the boundary condition that the potential at the location of 20 mm away from the exit of the extractor is given to be 52.4 kV.

The physical mechanism of the halo formation reported in ref. [1] with the 2D PIC code is verified: The beam halo consists of the negative ions extracted from the periphery of the meniscus, while the beam core consists of the negative ions extracted from the center of the meniscus. The curvature of the meniscus becomes larger near the periphery. Therefore, the difference of negative ion extraction location results in a geometrical aberration, and then the beam halo.

References

[1] K. Miyamoto, S. Okuda, A. Hatayama, M. Hanada, and A. Kojima, Appl. Phys. Lett., 102, 023512-1 (2013).

TuePE22

Cross-Checked Analysis of ONIX Simulation Results and Experimental Data for Negative Ion Extraction from the BATMAN testbed

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The development of a large area RF driven negative hydrogen ion source is one of the key issues in the construction of the Neutral Beam Injection system (NBI) of the international experimental fusion reactor ITER. The source should supply 66 A (j=33.0 mAcm-2) extracted current in hydrogen and 57 A (j=28.5 mAcm-2) in deuterium operation under a pressure of 0.3 Pa. Obtaining these parameters is a scientifically and technically very challenging goal.

To improve the understanding of the negative ion (NI) extraction process and to determine conditions at which the extracted NI current reaches its maximum with simultaneously co-extracting a relatively low electron current (Ie /INI <1 for ITER) the 3D PIC MCC electrostatic code ONIX is exploited. Simulations were performed for plasma parameters (particle densities, temperatures, …) experimentally obtained on the source testbed BATMAN. The results of these simulations enable performing a cross-checked analysis with experimental results. Additionally, they can play a crucial role for the model validation.

After the code has been benchmarked and validated by various tests, predictive modeling of the extraction of NI has been performed. The results show that the extracted hydrogen NI current density could reach about ~30 mAcm-2, as measured in the experiments under the same plasma and source conditions. The dependency of the negative ion density in the bulk plasma region on the extracted NI current from both the modeling and the experiment was investigated by the code: the extracted current from NI produced at the Cs covered plasma grid (PG) surface, initially moving towards the bulk plasma and then being bend towards the extraction surfaces is lower compared to the extracted NI current from directly extracted surface produced ions. The separate distributions of the negative ion extracted current from the bulk plasma region and the PG surface will be shown here for different NI plasma volume densities and NI emission rates from the plasma grid wall respectively.

TuePE23

Analysis of Electron Energy Distribution Function in the LINAC4 H- Source

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A numerical simulation code based on the Electromagnetic Particle in Cell (EM-PIC) Model with Monte Carlo method for Collision processes (MCC) has been developed to understand the Radio Frequency Inductively Coupled Plasmas (RF-ICP) [1]. It is possible for the code to obtain the Electron Energy Distribution Function (EEDF) and Ion Energy Distribution Function (IEDF) in RF-ICP. This is the most distinct feature of the code compared with the conventional fluid model.

The code has been improved step-by-step by including various effects, such as i) capacitive component of the electric field[2], ii) Coulomb collision[3] and iii) coupling to the Collisional Radiative (CR) model[4,5] for the calculation of Balmer emission lines from the source plasmas. The code has already been applied to the simulation of the Linac4 H- source plasma. Most of these studies, however, were focused on the macroscopic property of RF plasmas and detailed discussion of the EEDF in RF plasmas has not been given so far.

In this paper, with the RF-code described above, we mainly discuss the characteristic features of the EEDF in RF plasmas. The relationship between the EEDF and plasma source parameters (magnitude of RF field, RF-coil current, etc.) will be investigated. Also, the numerical results of the EEDF in RF plasmas have been compared with those by simple theoretical approach [6] based on the Boltzmann equation.

References

[1] S. Yoshinari, T. Hayami, R. Terasaki, A. Hatayama and A. Fukano, Rev. Sci. Instrum. 81, 02A728 (2010)
[2] S. Mattei, M. Ohta, M. Yasumoto, A. Hatayama, J. Lettry and A. Grudiev, Rev. Sci. Instrum. 85, 02B115 (2014)
[3] S. Mochizuki, S. Mattei, T. Shibata, K. Nishida, A. Hatayama and J. Lettry, AIP Conf. Proc. 1655, 020016 (2015)
[4] T. Yamamoto, T. Shibata, M. Ohta, M. Yasumoto, K. Nishida, A. Hatayama, S. Mattei, J. Lettry, K. Sawada and U. Fantz, Rev. Sci. Instrum, 85, 02B118 (2014)
[5] T. Shibata, S. Mattei, K. Nishida, A. Hatayama and J. Lettry, AIP Conf. Proc. 1655, 020008 (2015)
[6] V. E. Golant, A. Zhilinskii, S. A. Sakhavov, Fundamentals of Plasma Physics, (Wiley, New York, 1977)

TuePE24

Status of the RF-Driven H^- Ion Source for J-PARC Linac

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For the upgrade of the Japan Proton Accelerator Research Complex (J-PARC) linac beam current, a cesiated RF-driven negative hydrogen ion source [1-3] was installed in 2014 summer shutdown period, and started to operate on September 29, 2014. The ion source has been successfully operated with a beam current and a duty factor of 33 mA and 1.25 % (500 µs and 25 Hz), respectively. The result of recent beam operation showed that the ion source is capable of continuous operation for approximately 1,100 h. The spark rate at the beam extractor was observed to be less than once a day, which is acceptable level for the user operation. Although the antenna failure occurred during the user operation on October 26, 2014, there were no further serious troubles since then. In this paper, we will present the some operation parameters and the beam stability of the RF-driven ion source through the long-term user operation.

References

1. A. Ueno et. al., AIP Conference Proceedings 1655, 030008 (2015).
2. A. Ueno et. al., AIP Conference Proceedings 1655, 030009 (2015).
3. A. Ueno et. al., AIP Conference Proceedings 1655, 030010 (2015).

TuePE25

Effect of High Energy Electrons on H^- Production and Destruction in a High Current DC Negative Ion Source for Cyclotron

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In cyclotron used for medical application, negative hydrogen ions (H^-) are commonly injected and accelerated to obtain higher extraction efficiently [1]. In such application of H^- ions, it is highly required to enhance the H^- production in ion sources and for obtaining high H^- beam current. In this study, we focus on the multi-cusp DC arc-discharge source [2]. A systematic study of the EEDF (Electron Energy Distribution Function) in the arc-discharge plasma has been conducted. Especially, the effect of the EEDF on the efficient H^- production has been studied by the KEIO-MARC code (Kinetic modeling of Electrons in the IOn source plasmas by the Multi-cusp ARC-discharge) [3] .

By using the results of the EEDF from the code, H^- production rate/destruction rate is calculated by a system of zero-dimensional (0D) rate equations. Effects of 1) filter magnetic configuration, and 2) arc-discharge power, on the EEDF and on the resultant H^- production/destruction have been studied systematically. In addition, their optimizations are being carried out. Furthermore, some improvements of the KEIO-MARC code regarding neutral reactions and transport are being conducted. The results of those improvements will also be reported.

References

[1] M. E. Phelps, “Electronic Generators,” in *PET: Molecular Imaging and Its Biological Applications*, (Springer, New York, 2004), pp. 227–229.
[2] H. Etoh *et al*., *Rev. Sci. Instrum.* **85**, 02B107 (2014).
[3] T. Shibata *et al.*, J. Appl. Phys. **114**, 143301 (2013).

TuePE26

Beam deflection applied to Neutral Beam Injection for a Fusion Devices reactor

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An innovative scheme of a neutral beam injector (NBI), based on the electrostatic acceleration and magneto-static deflection of negative ions, suitable for DEMO-like fusion reactor, is proposed and analyzed in term of feasibility and performance. The scheme is based on the deflection of a high energy 2 MV and high current (some tens of Amperes) negative ion beam by a large magnetic deflector placed between Beam Source (BS) and neutralizer. This scheme has the potential of solving two key issues concerning the operation of neutral beam injectors for a fusion reactor: the maximum acceleration voltage and the direct exposure of the Beam Source (BS) to the neutron flux from the fusion reactor. A beam deflection of 45 degrees has been applied as it is sufficient to screen the BS from the neutron flux therefore allowing the electrostatic accelerator to be insulated from the grounded vessel by compressed SF6. The latter is essential to obtain a stable injector performance at higher accelerating voltages. The scheme has been analyzed from the point of view of the beam optics in order to ensure the divergence is within acceptable values and it has been found that the scheme is quite effective as the deflector is able to guarantee, not only the steering effect, but also the necessary beam aiming.

TuePE27

The Mechanical Design and Simulation of a Scaled H$^-$ Penning Ion Source

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The ISIS cesiated Penning compact surface plasma source (CSPS) used at Rutherford Appleton Laboratory, whilst a reliable and well proven design, is unable to produce the beam parameter requirements for the upcoming Front End Test Stand (FETS) experiment. To this end a larger, scaled ion source is being developed which crucially features a plasma volume eight times larger than the ISIS source.

This new source should deliver a substantially higher beam current at the same 50Hz repetition rate, whilst at the same time providing a longer lifetime due to the use of optimised electrode cooling and pre-operational heating, designed to reduce reliance on the use of destructive DC discharge to achieve operational temperatures.

This paper describes the mechanical design changes required to accommodate the 8 fold increase in plasma volume whilst maintaining similar overall external dimensions to the ISIS source. Both the optimized cooling systems and the cathode pre-heating design are shown, including the linked fluid dynamic and steady-state thermal analyses.

TuePE28

Numerical study of plasma generation process and internal antenna heat loadings in J-PARC RF negative ion source

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Plasma generation process and thermal heat loadings from plasma to internal antenna in J-PARC RF ion source are investigated by EM-PIC MC (Electro-Magnetic Particle-In-Cell Monte-Carlo) code coupled with SOR (Successive-Over-Relaxation). From the experimental study, it has been clarified that the life-time has strong relation with defects or inclusions produced in manufacture process [1].

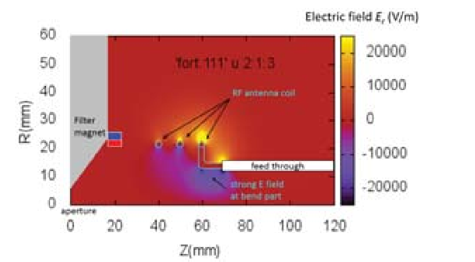

Fig.1 SOR calculation result of capacitive electric field due to potential given on RF antenna; 240V on the first turn (Z=60mm) of antenna coil and bend part, 160 and 80V on the second and third turn of coil (Z=50, 40mm), respectively.

On the other hand, thermal heat loadings from plasma to antenna surface is another candidate for cause of the failure. Optimization of the plasma (e-, H^+, H_2^+ and Cs^+) acceleration to antenna surface may lead to relax the criteria of antenna manufacture for preventing the failure of RF antenna. The numerical model solves (i) plasma transport with collisions, (ii) induced EM field and (iii) capacitive electric field by antenna surface potential as shown in Fig.1, which shows strong capacitive electric field produced at the bend part and near feed through. Spatial distributions of heat loadings onto the antenna for different plasma particle species are calculated and reported in the paper.

Reference

[1] R. F. Welton, V. G. Dudnikov, B.X. Han, et al., AIP Conf. Proc. **1515**, 341 (2013).

TuePE29

An Overview of the New Test Stand for H^- Ion Sources at FNAL

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A new test stand at FNAL is being constructed to carry out experiments to develop and upgrade the present magnetron-type sources of H^- ions of up to 80 mA at 35 keV in the context of the Proton Improvement Plan (PIP). The aim of this plan is to provide high-power proton beams for the experiments at FNAL. The technical details of the construction and layout of this test stand are presented, along with a prospective set of diagnostics to monitor the sources.

TuePE30

Characterization and Optimization of NIO1 Extraction Aperture by 3D PIC Model

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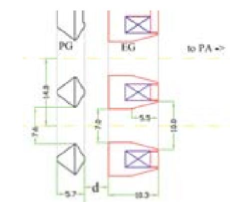
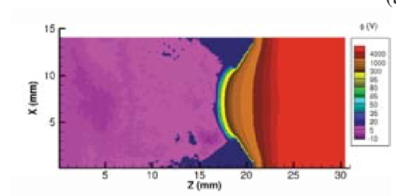
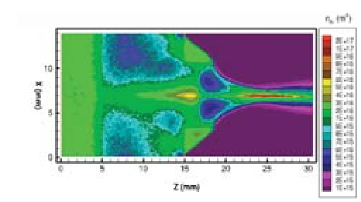
The geometry of a single aperture in the extraction grid plays a relevant role for the optimization of negative ion transport and extraction probability in a hybrid negative ion source [1]. For this reason, a 3D PIC-MCC model of the extraction region around the single aperture including part of the source and part of the acceleration (EG grid) regions has been developed for the new aperture design prepared for NIO1 source [2] (see Fig. 1.a).

Results have shown as the dimension of the flat and chamfered parts and the slope of the latter in front of the source region maximize the negative ion extraction probability (allowing the best EG field penetration and therefore minimizing the potential well). In Figs. 1.b and 1.c, plasma potential and negative ion density in the plane {x,z} has been reported, respectively (the PG is biased at φPG=15 V, while φEG=9 kV).



(a)





(b) (c)

Fig. 1 – (a) Schematic cross-cut ({x,z} plane) of the NIO1 aperture in the extraction region. (b) Map of (b) plasma potential φ(V) and (c) H- ion density *n*H-(m-3) in the same plane as result of the present numerical model.

References

[1] F. Taccogna, P. Minelli, S. Longo, *Plasma Sources Sci. Technol.* **22**, 045019, 2013.
[2] M. Cavenago, P. Veltri, *Plasma Sources Sci. Technol.* **23**, 065024, 2014.

TuePE31

New source of MeV negative ion and neutral atom beams

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Negative ions play a major role in a number of areas of physics and chemistry, for high current tandem accelerators, ion beam microscopy and lithography. Nowadays the neutral atoms are considered essential in the fusion experiments for additional heating of the plasma. The way to generate neutral atom beams is to produce a positive and negative ions, to accelerate them and then to neutralise. However, the efficiency is very low.

Additionally, there is a *strong fundamental interest* in negative ions: here in screening of nucleus the inter–electronic interactions become relatively more important than the electron–nuclear interactions. In the interplay of these attractive and repulsive interactions the electron correlation plays an important role.

After reviewing the relevant theoretical and experimental background on negative ion acceleration mechanisms this presentation will discuss the results of recent experiments where energetic (~MeV energies) negative ion and neutral atom beams have been generated at the passage of energetic positive ions through a liquid spray. We are demonstrating the efficient production of negative ions and neutral atom beams from MeV positive ions in the electron capture and loss processes, where the energy and momentum of the projectile is preserved. The process is rather general and different negative ions and neutral atom beams can be generated.

We will discuss the physical aspects of the phenomena and open problems. At the moment we do not have clear explanation, but it is suggestive that the processes are more complex than the considered single electron capture and loss, or the shell effects in the electronic structure of the projectile ion and/or target atoms may influence the probabilities.

Substantial work would be required for sophisticated model analyses in order to better understand the dynamics involved in the electron transfer processes.

TuePE32

Maintenance of J-PARC RF-Driven H^- Ion Source

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The Japan Proton Accelerator Research Complex (J-PARC) cesiated rf-driven H^- ion source (IS) [1-3], whose requirements are a peak beam intensity of 60mA within normalized emittances of 1.5πmm•mrad both horizontally and vertically, a flat top beam duty factor of 1.25% (500μs×25Hz) and a life-time of longer than 1month, has been successfully operated for about one year. The maintenances of four plasma chambers with internal-rf-antennas, which were developed at the Spallation Neutron Source (SNS) [4], will be presented in this paper. The J-PARC-IS was successfully operated with the antennas, which were classified by pre-conditionings [1]. The proper pre-conditioning procedure to avoid unnecessary antenna failures and the beam performance of each plasma chamber will be also presented.

References

1. A. Ueno et. al., AIP Conference Proceedings 1655, 030008 (2015).
2. A. Ueno et. al., AIP Conference Proceedings 1655, 030009 (2015).
3. A. Ueno et. al., AIP Conference Proceedings 1655, 030010 (2015).
4. M. P. Stockli, et. al., Review of Scientific Instruments 81, 02A729 (2010).

TuePE33

Alternative Modeling Methods for Plasma-Based Rf Ion Sources

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Rf-driven ion sources for accelerators and many industrial applications benefit from detailed numerical modeling and simulation of plasma characteristics. For instance, modeling of the SNS internal antenna H- source has indicated that a large plasma velocity is induced near bends in the antenna where structural failures are often observed. This could lead to improved designs and ion source performance based on simulation and modeling. However, there are significant separations of time and spatial scales inherent to Rf-driven plasma ion sources, which makes it difficult to model ion sources with explicit, kinetic Particle-In-Cell (PIC) simulation codes. In particular, if both electron and ion motions are to be explicitly modeled, then the simulation time step must be very small, and total simulation times must be large enough to capture the evolution of the plasma ions, as well as extending over many Rf periods. Additional physics processes, such as plasma chemistry and surface effects such as secondary electron emission increase the computational requirements in such a way that even fully parallel explicit PIC models can not be used.

One alternative method is to develop uid-based codes coupled with electromagnetics in order to model ion sources. Time-domain uid models can simulate plasma evolution, plasma chemistry, and surface physics models with reasonable computational resources by not explicitly resolving electron motions, which thereby leads to an increase in the time step. This is achieved by solving fluid motions coupled with electromagnetic using reduced-physics models, such as single-temperature magnetohydrodynamics (MHD), extended, gas dynamic, and Hall MHD, and two-fluid MHD models. We show recent results on modeling the internal antenna H- ion source for the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL) using the fluid plasma modeling code USim. We present simulation results demonstrating plasma evolution over many Rf periods for different plasma equation systems. We perform the calculations in parallel, on unstructured meshes, using finite-volume solvers in order to obtain 2nd-order accuracy.

TuePE35

Balmer-α Spectrum Measurement of the LHD One-Third Ion Source

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Doppler shift of Balmer-α line spectrum emission from hydrogen atoms in extraction region of a negative hydrogen (H^-) ion source can give information on how hydrogen plasma in the region interact with the plasma grid surface of the ion source. A spectrometer of 1 m focal length (Acton Research Corporation Model AM-510) with a CCD detector capable of resolving 2 pm records optical emission spectra around Balmer-α line from the plasma in the extraction region of the LHD one-third ion source. The observed line spectra exhibit broadening due to fine structure, together with additional broadening arising from some change in discharge operation parameters like pressure and arc power. An optical fiber coupled to a collimator lens collects photons along the line of sight intersecting the plasma grid surface with an angle smaller than 7.5 degree. The measured spectra have shown a blue shift with the broadening, when the plasma grid was biased more negatively than the voltage corresponding to the plasma potential of the extraction region. The blue shift component increased as the plasma grid was biased more negatively. Fundamental processes determining the final velocity distribution of hydrogen atoms are investigated including evaluation of the contribution from surface collision at the plasma grid surface based on ACAT (Atomic Collisions in Amorphous Target) code calculation.

TuePE36

The SNS External Antenna Ion Source and Spare RFQ Test Facility Readiness

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The Oak Ridge National Laboratory operates two world-class neutron scattering facilities, the High Flux Isotope Reactor and the Spallation Neutron Source (SNS). The SNS produces neutrons by first forming an H^- beam from an RF-driven, Cs-enhanced ion source, accelerating it to ~1GeV in a linac and accumulating the doubly-stripped beam in a storage ring. The <1µs-long, ~35-A beam pulses are then extracted from the ring at 60 Hz, and directed onto a liquid Hg target, whereby neutrons are produced through spallation and guided through beam lines into 20 world class instruments. Currently the facility operates routinely with ~1.2 MW of beam power on target. In the near-term, the goal is to operate routinely at 1.4 MW, and then later near 2.8 MW when the facility is upgraded with a second target station. This paper describes the status of two accelerator components expected to play key roles in achieving these goals: a newly constructed RFQ accelerator and the External Antenna ion source. Currently, the RFQ is being conditioned in a newly constructed test facility and the external antenna source is also being tested on a separate test stand. This paper will summarize the results of experiments and the testing of these systems in order to assess their operational readiness.

TuePE37

The ISIS Pre-injector Reconfiguration

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The ISIS pre-injector consists of: a high current negative Penning ion source; a 35 KV post extraction acceleration gap; a 3 solenoid Low Energy Beam Transport (LEBT); a mechanical beam stop and beam diluter for machine setup and a 655KeV 4-rod 202.5 MHz Radio Frequency Quadrupole (RFQ).
The present pre-injector configuration has successfully delivered beam for ISIS operations for over 10 years since the RFQ replaced the old Cockcroft-Walton 665KV high voltage platform. At the time it was felt necessary to maintain the ability to revert to the old Cockcroft-Walton setup in order to keep the risk to ISIS operations as low as possible. In order to do this the entire new pre-injector installation had to be squeezed into the space previously occupied by the old Medium Energy Beam Transport (MEBT). Space was so limited that the RFQ had to be installed directly up against the first tank of the Drift Tube Linac (DTL). This results in significant beam loss due to mismatching of the beam parameters.
With the reliability of the RFQ more than proven and the desire to reinstate a MEBT, this paper details the reconfiguration work done to expand the area and prepare for the installation of a new MEBT. The civil, electrical and mechanical work undertaken are outlined and the new layout of ancillary equipment detailed. The new ancillary equipment installed is also stated. The motivation for building a new MEBT is discussed and a new design briefly mentioned.

TuePS01

Quasi-monoenergetic ions acceleration by nanosecond laser-irradiation of solid target

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An experimental campaign aiming to investigate the laser driven light-ion acceleration in nanosecond domain has been carried out at the LENS (Laser Energy for Nuclear Science) laboratory of INFN-LNS in Catania. A Q-switched Nd:YAG laser with 1012 W/cm2 laser intensity, 1064 nm fundamental wavelengths, 6 ns pulse duration, operating in single shot mode, was employed to ablate a 2 mm thick aluminum target. Advanced diagnostics tools were used for characterizing the plasma plume and ion production, including ion collectors (IC) for time-of-flight measurements, an X-ray sensitive CCD camera for the X-ray imaging and flux measurements, an intensified CCD camera for the time resolved optical imaging, a Thomson Parabola (TP) for the identification of different ion species and measurements of cut-off energy.
The wide gamma of diagnostics tools now available at the LENS laboratory of INFN-LNS is allowing a deep investigation of the ion acceleration mechanism and of the interplays with the plasma parameters. The occurrence of proton acceleration with the production of a quasi-monoenergetic beam is a relevant result that will be discussed in details along the paper, including the fundamental implications in laser-target interaction and following plasma plume expansion.

TuePS02

Software tool for time evolution of EBIS/EBIT charge breeding in the radial (transverse) approximation*

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We present a software tool that is capable of following the radial (transverse) time evolution of charge breeding in EBIS/EBIT devices. The underlying assumption is that the longitudinal (parallel) dynamics is largely decoupled from the transverse dynamics, an assumption which is valid after a short initial "equilibration" transition. The extra information that such simulation provides includes radial (transverse) distributions of charge, field, and velocity, transverse temperature; and includes space charge effects, fractional overlap between ions and electron beam, particle losses to the radial wall, and other diagnostic information.

What makes such (1D) simulations more practical is the utilization of a newly developed, general energy-conserving particle algorithm [1]. It allows to relax the stringent condition that relates the numerical grid size to the simulation time step in the traditional particle-in-cell (PIC) method and to also use a minimal number of computational particles. These properties provide the critical computational advantage for the energy-conserving method and make long time (tens of miliseconds) charge breeding numerical simulations possible on a single multi-core desktop station.

[1] E. G. Evstatiev and B. A. Shadwick. "Variational formulation of particle algorithms for kinetic plasma simulations." JCP **245**, 376-398 (2013).

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TuePS03

Influence of Plasma Properties on Extracted Beam in Laser Ion Source Controlled by Magnetic Field

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At Brookhaven National Laboratory (BNL), laser ion source produces various heavy ion beams provided to Relativistic Heavy Ion Collider (RHIC) and NASA Space Radiation Laboratory (NSRL)[1]. The ion species and beam current are required to be changed to meet the user's requirements. A solenoid magnet is placed to control the beam current which can control the diverging angle of the plasma. Since the property of plasma is different with target condition, the effect of the magnetic field is expected to vary. To operate the ion source reliably, we investigated the magnetic effect on different ion beams.

References

[1] T. Kanesue et al., Proceedings of IPAC2014, Dresden, Germany, pp. 1890-1892, 2014

TuePS04

Effect of Solenoidal Magnetic Field on Moving Plasma Used in Laser Ion Source

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In typical configuration of laser ion source, there is a drift section where plasma moves from a laser target to an extraction electrode with extending its volume. The density of the plasma decreases to the extent that ion beam can be extracted. At the section, solenoidal magnetic field is useful to guide the plasma and inject more particles into the electrode than without external field. To guide the plasma efficiently, we investigate the effect of the magnetic field on the plasma and vice versa. We measure the change of the plasma flux and magnetic field in the solenoid and discuss the interaction of them from the point of plasma guiding.

TuePS05

Laser Ion Source Optimization and Development at GANIL

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Resonant Ionisation Laser Ion Source (RILIS) has emerged as an important technique in many facilities for its reliability and quality to generate selective and efficient Radioactive Ion Beams (RIBs). GISELE (GANIL Ion Source using Electron Laser Excitation) is an off-line test bench RILIS developed to study a fully operational laser ion source at GANIL. The aim of this project is to find the best technical solution which combines high selectivity and ionization efficiency with small ion beam emittance and stable long term operation. The ion source body has been designed as a modular system to investigate different experimental approaches by varying the geometry and the tube design parameters to compare and to develop the future on-line laser ion source. Different ion source geometries were tested in order to improve the efficiency and reduce the emittance. Latest results concerning the contaminant reduction inside the ion source either by, electric field potential or low work function materials, will be presented. In addition, a method to measure the energy distribution of the ion beam as a function of the time of flight will be discussed. GISELE has been funded by the French Research National Agency (ANR) and is under development at GANIL in collaboration with IPN Orsay (France), Univ. of Mainz (Germany), TRIUMF (Canada) and CERN (Switzerland). This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 289191.

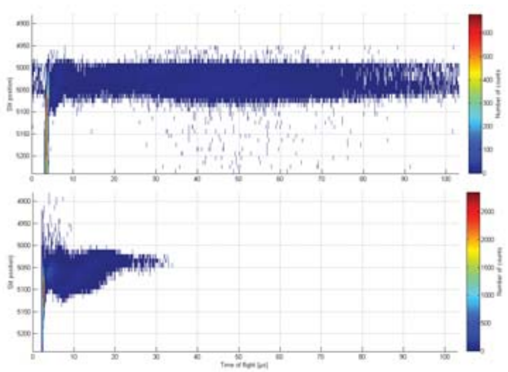

Figure. Time profile structures of ^{124}Sn measured by the slit-grid method, applying positive and negative voltage in the ionizer (respectively).

TuePS06

Eliminating unwanted electron in EBIS devices*

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In principle, an electron beam ion source (EBIS) device has a very simple mode of operation: an electron beam propagating through a gated ion trap step-wise ionizing trapped ions to high charge states. The electron beam, which is confined by an extremely large magnetic field, is injected from an electron gun through the trap into an electron collector. The ions are confined by the electron beam space charge radially and by high voltage electrodes (gates) axially. Unlike earlier EBIS devices, where the Debye length was larger than the radial dimension of trap plasma, the RHIC EBIS Debye length meets requirements needed for plasma theories to be valid in its analysis. Any instability requires a free source of energy to grow. Electrons stripped from ions can form a layer that slips past other particles in an EBIS trap, or accumulate in the gates. In either case, these electrons can be a source of free energy for diocotron instability by providing a slipping stream or a variety of microinstabilities due to axial positive slope gradients in configuration and velocity space. Possible solution to the problem is to remove these electrons from the trap. One option is to install an additional drift tube between the gate and the collector biased to higher Voltage than the other tubes, and bleed these electrons to ground in an additional split drift tube inserted upstream from the highest Voltage tube. Analysis of this idea will be presented.

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TuePS07

Low Charge Heavy Ion Production with Sub-nanosecond Laser

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We have investigated laser ablation plasma of various species using a nanosecond and a sub-nanosecond laser for both high and low charge state ion production. We found that with sub-nanosecond laser, the generated plasma has long tail which is low charge state ions determined by an electrostatic ion analyzer even when the laser irradiation condition for highly charged ion production. This can be caused by insufficient laser absorption in plasma plume. This property might be suitable for low charge state ion production. We used a nanosecond laser and a sub-nanosecond laser for low charge state ion production. The results of comparison will be shown in this paper.

TuePS08

Laser Ion Source for Isobaric Heavy Ion Collider Experiment

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Heavy-ion collider experiment in isobaric system is under investigation at Relativistic Heavy Ion Collider (RHIC). The laser ion source for RHIC-EBIS (LION) is required to provide charge state 1+ ions. Since a natural abundance of particular isotope is low, an isotope enriched material is needed as a target. To investigate the minimum target consumption condition and injector performance, pre-experimental study is being performed using neutrally found materials.

TuePS09

Contribution of Material's Surface Layer on Laser Ablation Plasma

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A laser ion source (LIS) utilizes ablation plasma induced by laser irradiation. The plasma comprises multi charged ions which will be extracted and delivered to following accelerators. The highly focused laser irradiation always makes a crater on the material. However the evaporated material is not fully converted to the ions in the plasma. For example our past result[1] showed that a contribution of a 250 nm depth surface carbon layer of an aluminum target was very small on the laser ablation plasma. To clarify the effect of the surface layer of the target material, we are analyzing ion species and charge state distributions in the plasmas produced from carbon coated metal targets with various coating thickness.

References

[1] M. Kumaki et al., Rev. Sci. Instrum., 02B925, 85(2) 2014

TuePS10

Plasma Heating by Double Pulse Laser Irradiation

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We have attempted to generate highly charged ions by using a laser ion source. We found that laser energy induced by sub-nanosecond pulse is not efficiently absorbed by the plasma. This might be caused by a short pulse duration of the laser. To promote the energy absorption, we are investigating sequential laser irradiation scheme. At the first irradiation, low temperature plasma is created then expanded. The second laser energy may be absorbed in the region of expanded plasma by first laser shot. The experimental result using Ekspla SL334 will be reported and discussed.

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TuePS11

Iron Plasma Generation using Several Hundred Picoseconds of Nd:YAG Laser Pulse

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Laser ion sources have been developed for the purpose of generating high intensity heavy ion beams. We have produced high intensity laser plasma by using Nd:YAG laser with several nanoseconds of the laser pulse and successfully generated high intensity heavy ion beams by applying the direct plasma injection scheme. The capability of the source to generate high intensity and high charge state beams strongly depends on the power density of the laser irradiation. Therefore we focused on using higher power laser to generate higher charge state heavy ions. We irradiated an iron target with several hundred picoseconds of Nd:YAG laser pulse and produced Fe20+ ions. In case of the nanosecond laser with similar laser power, the highest charge state was Fe18+. In this presentation, the charge state distribution of the laser-produced iron plasma under a variety of irradiation condition is summarized.

TuePS12

RF Synchronized Short Pulse Laser Ion Source

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A laser ion source that produces bunched ions is proposed. In this ion source, plasma is produced by irradiation of a short pulse laser in RF accelerating field synchronized with the laser pulse. The ions in the plasma are accelerated before its expansion, and a bunched ion beam can be extracted, while electrons go to the other direction. We have been carrying out experiments using single shots of short pulse lasers to investigate the fundamental process. In this presentation, some results of ion extraction experiments will be reported.

TuePS13

Proton Beam Production by Laser Ion Source with Hydride Target

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We have studied proton beam production from laser ion source using hydrogen rich target materials [1]. In general, gas based species are not suitable for laser ion source since formation of dense laser target is difficult. Plastic based material could be used as a target; however most of the plastics are almost transparent for conventional long wavelength laser light. In order to achieve reliable operation, we are testing some hydride targets using a sub nanosecond Q-switched YAG lasers which may suppress ions from the substrate material. The latest experimental results will be presented.

References

[1] M. Sekine, K. Kondo, M. Okamura, N. Hayashizaki, REVIEW OF SCIENTIFIC INSTRUMENTS 83, 02B318 (2012)

TuePS14

Ca and Li Ion Production for Laser Ion Source

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Some metals are soft and chemically active at atmospheric condition. To investigate the feasibilities of making a target for laser ion source, we are examining target fabrication procedures and plasma productions. At the conference, we will report Ca and Li ion beam properties using high and low laser power densities and discuss possible issues for operations.

ddddd

TuePS15

Singly/Negatively Charged Ion Production of a Laser Induced Plasma using a Capillary Graphite Target

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A new type of laser ion source is currently being developed for the production of singly/negatively charged ions using a capillary graphite target. The basic target design utilizes the small dimension of the narrow conduit to constrict the plume expansion of the laser induced plasma. Focusing a Q-switched Nd:YAG laser at 20 W maximum average power and 10 Hz repetition rate, the beam is directed along the axis of the graphite tube producing a dense plasma inside of the capillary through laser ablation. The injection of neutral gas to the plasma region inside the graphite target increases the collision rate within the structure to further cool down the expanding plasma plume. Operating with the streaming neutral gas injection scheme allows the injected gas to interact with the plasma and a reduction in the bulk electron temperature can be achieved which is favorable for negative ion production. The spatial and temporal propagation of the laser induced plasma plume in a background gas flow is studied using a high speed camera. The plasma composition and ion energy distribution will be determined by employing a time-of-flight/magnetic deflection energy spectral analyzer coupled to a Faraday cup detection system. The laser parameters and suitable conditions of the streaming neutral gas injection will be investigated for the effects to singly/negatively charged ion production.

References

1. A. Mendenilla, H. Takahashi, T. Kasuya, and M. Wada, Rev. Sci. Instrum. **77**, 03A518 (2006).
2. S.I. Anisimov, B.S. Luk'yanchuk, and A. Luches, Appl. Surf. Sci. **96-98**, 24 (1996).
3. X. Wang, S. Zhang, X. Cheng, E. Zhu, W. Hang, and B. Huang, Spectrochim. Acta B **99**, 101 (2014).

TuePS16

Lifetime of Hydrogenised Film Cathode in Vacuum Arc Discharge ion Source

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The paper describes the results of investigation of the mass-to-charge state of the plasma ions produced in a vacuum arc discharge with a composite cathode. The cathode is a bottom end of copper disk covered by hydrogen-saturated zirconium film of thickness 10, 15 and 35 µm. With the such cathode the vacuum arc ion source provides generation of multicomponent gas and metal ion beams with a hydrogen ion fraction from several percent to several tens of percents. During the arc current pulse the fraction of hydrogen in the plasma decreases, while the copper and zirconium ions fractions increase. It was also investigated evolution of hydrogen ions fraction in the process of the film erosion. For this purpose lifetime tests were performed. The lifetime of the film cathode as the source of hydrogen ions depends of film thickness and the pulse repetition rate. At the end of the tests the zirconium ions of the beam disappeared almost completely.

Work is supported by the Russian Science Foundation under grant # 14-19-00083.

TuePS17

Liquid Metal Ion Source Assembly for External Ion Injection into Electron String Ion Source (ESIS) and Charge Breeding Efficiency Measurements

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The Electron String Ion Source (ESIS) is basically a modified Electron Beam Ion Source (EBIS) and they both were first proposed, developed and used in JINR for efficient production of intense beams of highly charged ions[1,2]. ESIS-type ion sources have various attractive advantages which are proven with the injection of neutral gases and neutral atoms of some metals into the ESIS. However, for charge breeding and study of rare ion beams or short-lived isotopes that are produced in nuclear reactions, external injection of corresponding 1+ ion beams into ESIS is required.

An assembly for a commercial Ga^+ liquid metal ion source (LMIS) in combination with an ion transportation and focusing system, a pulse high-voltage quadrupole deflector and a beam diagnostics system has been constructed in the framework of the iThemba Labs (Cape Town, South Africa) – JINR (Dubna, Russia) collaboration. First results on Ga^+ ion beam commissioning will be presented. Outlook of further experiments for measurements of charge breeding efficiency in the ESIS with the use of external injection of Ga^+ and Au^+ ion beams will be reported as well.

References:

[1]E.D. Donets, et al., Rev. Sci. Instrum., Vol. 75, 1543-1545 (2004)

[2]E.D. Donets, et al., Rev. Sci. Instrum., Vol. 83, No 2, Part 2, 02A512 (2012)

TuePS18

Aluminum Multicharged Ion Generation Using Spark-Assisted Laser Ion Source

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Multicharged ions (MCI) sources are of interest for their utilization in surface modification, e.g., etching and deposition, for ion implantation, and for fundamental studies of ion-surface interactions. In laser MCI sources, the MCIs are generated by focusing a laser pulse on a solid target causing its ablation and ionization. The laser-matter interaction produces dense plasma consisting of ions, electrons, clusters, and neutral particles. We report on the development of a spark-assisted laser multicharged ion (SALMCI) source to enhance the plasma ionization by depositing spark energy into the laser ablated plume. The SALMCI source is composed of a laser MCI source and a separate spark stage to deposit energy into the laser ablated plasma. A Q-switched 7.4 ns pulse width Nd:YAG laser (λ = 1.06 µm) is used to ablate a solid target. For an aluminum target, the spark discharge results in significant enhancement of the MCIs generated along with higher charge states than observed with the laser source alone. With amplification stage (spark discharge energy of 1.25 J) and laser pulse energy (72 mJ/pulse), the total charge measured increases by a factor of ~9 and charge state up to Al^{6+} was observed compared to Al^{+3} generated with only the laser pulse. Using a laser pulse energy of 45 mJ, charge amplification by a factor of ~13 was observed for spark discharge energy of 1.00 J. This approach also minimizes target damage by the laser pulse since the laser is mainly used to introduce the vapor into the spark while the energy delivered by the spark is used to heat the plasma increasing MCI production.

TuePS19

Investigation on TNSA (Target Normal Sheath Acceleration) through the measure of Ions energy distribution

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An experimental campaign aiming to investigate the ion acceleration mechanisms through laser-matter interaction in femtosecond domain has been carried out at the ILIL facility with a laser intensity of 2E19 W/cm2. We will show the energy spectra of light-ions depending on structural characteristics of the target and role of surface and target bulk in the acceleration process. In order to obtain these information a Thomson Parabola Spectrometer and CR-39 have been used.

TuePS20

Energy Distributions and Angular Distributions of Pulsed Plasmas Based on Vacuum Surface Flashover

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The discharge may take place while insulators are placed between high voltage electrodes in vacuum. It can produce copious quantities of plasma has been used in ion sources. The expansion of plasma can influnce ion extractor and is important to improved understanding of discharge process. In the paper characteristics of short pulsed plasmas generated by surface flashover discharge in vacuum has been studied by the Electrostatic Quadrupole Plasma analysers (EQP). The ion energy distributions of different charge states of different metal ions are measured. Charge exchange collisions between ions and neutrals created in vacuum discharge can affect the ion charge state distributions and ion energy distributions. Average energy and beam intensity of titanium ions with different charges reduce, while the angular increases deviating from the axis of plasma jet.

Reference

[1] J. R. Harris. Measurements of an expanding surface flashover plasma. *J. Appl. Phys.*, 2014, 114: 193302.
[2] A. G. Nikolaev, G. Yu. Yushkov, K. P. Savkin, and E. M. Oks. Angular distribution of plasma in the vacuum arc ion source. *Rev. Sci. Instrum.*, 2012, 83: 02A503.
[3] A. O. Eriksson, I. Zhirkov, M. Dahlqvist, J. Jensen, L. Hultman, and J. Rosen. Characterization of plasma chemistry and ion energy in cathodic arc plasma from Ti-Si cathodes of different compositions. *J. Appl. Phys.*, 2013, 113: 163304.

TuePS21

Simulation of Ion Beam Injection and Extraction in an EBIS*

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To simulate Electron-Beam Based Ion Sources (EBIS), FAR-TECH has developed an integrated toolset [1] consisting of: PBGUNS, which calculates steady-state electron beam from cathode to electron collector and ion beam injection and extraction in complicate beam line structures; and EBIS-2D, which is a time-dependent, self-consistent particle-in-cell code that tracks both the injected primary ions and the ions from the background neutral gas in the trap region of an EBIS.

We will present an example simulation of Au+ charge breeding experiment at BNL RHIC EBIS [2]. In the experiment, the injected Au+ ion beam current was 1mA. In the simulations, the trajectories of injected ions from the injection deflector to the collector entrance are calculated with PBGUNS self-consistently by including the space charges from both ions and electrons. From the collector entrance to the ion trap, the ion beam, starting with initial conditions within the 100% acceptance of the electron beam, is tracked by EBIS-2D until 200 microseconds after the trap barrier is closed. In the trap, the evolution of the ion charge state distribution (CSD) is estimated by CHASER (0D charge state estimator). The extraction of charge bred ions is simulated with PBGUNS. The simulations of the ion injections with different ion beam currents show significant ion space charge effects on beam capture efficiency and the ionization efficiency. The simulated CSD is in good agreement with experimental measurements when the electron beam neutralization effects are included in the 0D model.

[1] J. S. Kim, L. Zhao, J. A. Spencer and E. G. Evstatiev, "Electron-beam-ion-source (EBIS) modeling progress at FAR-TECH, Inc. ", AIP Conf. Proc. **1640**, 44 (2015)
[2] E. Beebe, J. Alessi, S. Binello, T. Kanesue, D. McCafferty, J. Morris, M. Okamura, A. Pikin, J. Ritter and R. Schoepfer, "Reliable operation of the Brookhaven EBIS for highly charged ion production for RHIC and NSRL", AIP Conf. Proc. **1640**, 5 (2015)

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TuePS22

Generation of Boron Ion Beam Based on Discharges with Composite LaB_6 Cathode

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Boron ion beam is widely used for implantation in semiconductors. Another attractive application for such ions is metal surface modification to improve operating parameters and to increase lifetime of machine parts and tools. For this purpose requirement for high purity boron ion beams is not so demanding like for semiconductor technology. That is why a composite cathode of lanthanum hexaboride (LaB_6) was chosen to produce boron ions. Two discharge units were used in experiments: vacuum arc and planar magnetron in self-sputtering mode of operation. The discharges operate in pulsed mode with pulse length of 100 µs, pulse repetition rate up to 10 pps and discharge current of about 100 A. For arc discharge, the boron plasma is generated in cathode spots, where as for magnetron discharge the main process is sputtering of the cathode material. The paper presents results of comparative test experiments for both discharges aimed to find optimal discharge parameters that provide maximum yield of boron ions. As a result of optimizations, for both discharges the extracted ion beam current reaches hundreds of milliamps and the fraction of boron ions in the total extracted ion beam was as high as 80%.

Work is supported by the Russian Science Foundation under grant # 14-19-00083.

TuePS24

Preliminary Design of Electrostatic Sensors for MITICA Beam Line Components

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In MITICA, the full-scale prototype of ITER Neutral Beam Injector (NBI), deuterium negative ions will be extracted from the ion source, accelerated and neutralized; the emerging beam, after removal of residual ions, will be finally dumped onto a calorimeter. Monitoring the formation of plasma and its parameters is crucial, for different reasons, in each component of the beam-line. To this aim, various types of electrostatic probes are planned to be installed along the MITICA beam-line.

In particular, the Neutralizer and the Electric Residual Ion Dump (ERID) will be equipped with two sets of double probes. In the case of the neutralizer, where plasma is generated by the collisions between the beam ions and the neutral gas particles, the probes will allow to gain information about the beam collisional processes in view of a neutral fraction optimization. In the ERID component, a transverse electric field is applied to remove ions emerging from the neutralizer: the objective of the probes is to verify that plasma is not formed, which otherwise might shield the electric field and invalidate the deflection properties of the device. In both components, pairs of probes will be placed on the panels at different vertical and axial positions, and configured as Langmuir probes, so to provide local ion density and electron temperature measurements.

Moreover, biased electrodes are being considered for MITICA calorimeter to collect secondary emission electrons produced by collisions with the calorimeter surfaces. While calorimetric measurements provide a vertical profile of the neutral beam at the calorimeter, the electrodes, together with a neutron imaging diagnostic, will provide a horizontal profile of the beam, to study horizontal steering, divergence and uniformity of the beam.

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

TuePS25

Upgrade of the Beam Extraction System of the GTS-LHC Electron Cyclotron Resonance Ion Source at CERN

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Linac3 is the first accelerator in the heavy ion injector chain of the Large Hadron Collider (LHC), providing multiply charged heavy ion beams for the CERN experimental program. The ion beams are produced with GTS-LHC, a 14.5 GHz Electron Cyclotron Resonance Ion Source (ECRIS), operated in afterglow mode. Improvement of the GTS-LHC beam formation and beam transport along Linac3 is part of the upgrade program of the injector chain in preparation for the future High Luminosity LHC (HL-LHC).

A mismatch between the ion beam properties in the ion source extraction region and the acceptance of the following Low Energy Beam Transport (LEBT) section has been identified as one of the factors limiting the Linac3 performance. The installation of a new focusing element, an einzel lens, into the GTS-LHC extraction region is foreseen as a part of the Linac3 upgrade, as well as a redesign of the first section of the LEBT. Details of the upgrade and results of a beam dynamics study of the extraction region and LEBT modifications will be presented.

TuePS26

Studies of the Beam Extraction System of the GTS-LHC Electron Cyclotron Resonance Ion Source at CERN

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The 14.5 GHz GTS-LHC Electron Cyclotron Resonance Ion Source (ECRIS) provides multiply charged heavy ion beams for the CERN experimental program. The GTS-LHC beam formation has been studied extensively with lead, argon and xenon beams with varied beam extraction conditions using the ion optical code IBSimu. The simulation model predicts self-consistently the formation of triangular and hollow beam structures which are often associated with ECRIS ion beams, as well as beam loss patterns which match the observed beam induced markings in the extraction region. These studies provide a better understanding of the properties of the extracted beams and a way to diagnose the extraction system performance and limitations, which is otherwise challenging due to the lack of direct diagnostics in this region and the limited availability of the ion source for development work.

TuePS27

Design of a Microwave Frequency Sweep Interferometer for plasma density measurements in ECR Ion Sources

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The Electron Cyclotron Resonance Ion Sources (ECRIS) development is strictly related to the availability of new diagnostic tools, nowadays consisting of only few types of devices designed for such compact machines. Microwave Interferometry is a non-invasive method for plasma diagnostics and represents the best candidate for plasma density measurement. Interferometry in ECR Ion Sources is a challenging task mainly due to their compact size. The typical density of ECR plasmas is in the range $10^{11}\div10^{12}$ cm^{-3} and it needs a probing beam wavelength of the order of few centimetres, comparable to the chamber radius. The paper describes the design of a new microwave interferometer developed at the LNS-INFN laboratories based on the so-called “frequency sweep” method to prevent the generation of "multipaths", due to the modal behaviour of the microwaves and their reflections inside the cavity. In this work the measurement technique and the preliminary results obtained during the experimental tests will be presented.

TuePS28

Investigation of ion beam space charge compensation with a retarding potential analyzer at GSI accelerator facility

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During ongoing experiments at the GSI ion source test benches the space charge compensation of heavy ion beams was investigated. A retarding potential analyzer (RPA) was used to estimate the uncompensated beam potential. Measurements were done at a high current test bench with a multi cusp ion source (MUCIS) directly behind a triode extraction system to verify the functionality of the RPA system. With a variation of the grid mesh size within the device other experiments at the high current test injector HOSTI were performed. The measurements were done after a post acceleration system with ion energies up to 120 keV. Results from single aperture as well as multi aperture extraction systems are shown along the calculation of the space charge compensation and beam potential.

At HOSTI a Cold or HOt Reflex Discharge Ion Source (CHORDIS) was used to change the conditions for the measurements. All measurements were performed with Helium, Argon and Xenon and are exemplary presented.

TuePS29

Development and brightness measurement of an electron impact gas ion source for proton beam writing applications

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In the recent past we have demonstrated the potential of proton beam writing (PBW) as a leading candidate for next generation lithographic technique 1. We are now progressing towards sub-10 nm lithography in nuclear microprobe experiments, but the beam resolution and writing time are limited by the low brightness radio frequency (RF) ion source currently used. We are developing a high brightness electron impact gas ion source, with expected brightness of about 4 to 5 orders of magnitude higher than RF ion source 3.

The idea of this electron impact gas ion source is to create ion beams, with small virtual source size of about 100 nm diameter, from a miniature chamber, by ionizing the gas molecules with electrons 3. The experiments are performed inside an environmental scanning electron microscope (ESEM). The extracted total ion beam current and ion source brightness were studied as function of gas inlet pressure (helium or argon gas), electron beam energy (500 to 2000 eV) and ion extraction voltage. With an electron beam current of 7 nA, this ion source produces 300-500 pA of Ar ions. The ion source reduced brightness is measured to be more than 100 A/m^{2}SrV, being one tenth of the electron beam brightness (measured as 10^3 A/m^{2}SrV) for 700 eV electrons. The results are limited by the poor brightness of the existing ESEM, but if used with a standard SEM our ion source brightness is expected to be 10^5 A/m^{2}SrV.

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References:

1 J.A. van Kan, A. A. Bettiol and F. Watt, Nano Lett. **6** (2006) 579.
2 F. Watt, M.B.H. Breese, A.A. Bettiol and J.A. van Kan, Mater. Today **10** (2007) 20.
3 D. Jun and P. Kruit, J. Vac. Sci. Technol. B, **29** (2011) 6.
4 N. Liu, P.S. Raman, X. Xu, H. Tan, A Khursheed and J.A. van Kan, Nucl. Instr. Meth. Phys. Res. **B348** (2015) 23.

TuePS30

Extraction Characteristics of a Low-energy Ion Beam System with a Remote Plasma Chamber

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Low-energy beams of ions were extracted from a dual-chamber plasma ion source system. The first chamber is a cylindrical quartz chamber terminated by stainless steel flanges with one flange having a gas inlet port. A 6 mm diameter copper tube is wound around the side of the chamber to realize an antenna configuration. Inductively coupled discharge is excited via 13.56 MHz radio-frequency (rf) power with autotuning matching system through the antenna. The plasma is driven into another chamber using a "launch" and "steer" electromagnetic coils. In the second chamber, a sputtering target, backed by water-cooled SmCo magnets, is placed which can be independently biased by a dc potential to control the sputtering yield. The surface of the target is parallel to flow of the discharge from the first chamber. Opposite the target is a dual-electrode ion extraction configuration capable of extracting low-energy ion beams.

In the present scheme, argon (Ar) plasma is excited in the first chamber and driven into the second chamber where a liquid gallium (Ga) is poured onto a tungsten holder. An optical emission spectrometer connected to a fiber optic cable. The other end of the cable was placed near the viewport. The line of sight of the fiber optic cable is positioned just above the surface of the target. The emission spectra revealed species of Ar as well as Ga. The intensities of the Ga emission line increases with increasing target bias. Ion beam transport characteristics were monitored using a lab-fabricated ion energy distribution analyzer as well as *ExB* mass analyzer. Results indicated the extraction of ions at different extraction potentials with well-defined beams from 70 to 100 V at different rf powers and gas pressures. Mass spectral analyses from the *ExB* probe showed the extraction of Ar and Ga ions at different target bias, extraction potentials and rf powers. Upon the addition of minute amounts of nitrogen, formation of gallium nitride films on a silicon substrate was realized.

References

[1] M. R. Vasquez Jr., S. Imakita, T. Kasuya, S. Maeno and M. Wada, Rev Sci. Instrum. **81** (2010) 02B717.
[2] M. R. Vasquez Jr., S. Tokumura, T. Kasuya, S. Maeno, and M. Wada, Rev. Sci. Instrum. **83** (2012) 023301.
[3] M. R. Vasquez Jr., S. Tokumura, T. Kasuya, and M. Wada, Rev. Sci. Instrum. **85** (2014) 02A717.

TuePS31

An RFQ Direct Injection Scheme for the IsoDAR High Intensity H_2^+ Cyclotron

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IsoDAR is a novel experiment designed to measure neutrino oscillations through electron-antineutrino disappearance, thus providing a definitive search for sterile neutrinos. In order to generate the necessary anti-neutrino flux, a high intensity primary proton beam is needed. In IsoDAR, H_2^+ is accelerated, and is stripped into protons just before the target, to overcome space charge issues at injection. As part of the design, we have refined an old proposal to use an RFQ to axially inject bunched H_2^+ ions into the driver cyclotron. This method has several advantages over a classical low energy beam transport (LEBT) design: (1) The bunching efficiency is higher than for the previously considered two-gap buncher and thus the overall injection efficiency is higher. This relaxes the constraints on the H_2^+ current required from the ion source. (2) The overall length of the LEBT can be reduced. (3) The RFQ can also accelerate the ions. This enables the ion source platform high voltage to be reduced from 70 kV to 15 kV, making underground installation easier. In this contribution, we will discuss advantages and disadvantages of this scheme, present a compact extraction system including a segmented Einzel lens and the RFQ design parameters, and will show first beam dynamics simulations from the ion source extraction to the mid-plane of the cyclotron.

TuePS32

Progress of beam diagnosis system for EAST neutral beam injector

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As the first full superconducting non-circular cross section Tokomak in the world, Experimental Advanced Superconducting Tokamak (EAST) is used to explore the forefront physics and engineering issues on the construction of Tokomak fusion reactor. Neutral beam injection has been recognized as one of the most effective means for plasma heating. According to the research plan of the EAST physics experiment, two sets of neutral beam injector (4～8MW，10～100s) were built and operational in 2014.

The paper presents the development of beam diagnosis system for EAST neutral beam injector (NBI) and the latest experiment results obtained on the test-stand and EAST-NBI-1 (the first heating neutral beam of EAST). Those results show that EAST NBI operates properly and all targets reach or almost reach the design targets. All these lay a solid foundation for the achievement of high quality plasma heating and current driving for EAST.

TuePS33

Particle Transport and Heat Loads in NIO1

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NIO1 is a compact radio frequency (RF) ion source based on inductively coupled plasma (ICP), jointly developed by Consorzio RFX and INFN-LNL [1], installed at RFX and currently in its initial operation phase. It is designed to generate a 60 kV-135 mA hydrogen negative ion beam, composed of 3 x 3 beamlets over an area of about 40 x 40 mm2. There are three acceleration grids named plasma grid (PG) at -60 kV, extraction grid (EG) at -52 kV and post acceleration grid (PA) at the ground voltage, followed by a repeller electrode (REP) for a better control of the space charge compensation of the extracted beam [1].
A major difference with other H- ICP sources is that NIO1 aims at continuous operation (in conditions similar to those foreseen for the larger ion sources of the Neutral Beam Injectors for ITER, exploiting its flexibility to address the several still open important issues related to beam extraction, optics, and performance optimization) which implies a detailed thermo-mechanical analysis of the beam-facing components, in particular the accelerator grids.
Together with the first operation of NIO1, the construction of a new ion extraction system was started for optimizing the beam optics and exploring alternative electrostatic and magnetic configurations [2]. In particular, the accelerator will be modified by completely replacing the extraction grid: the new electrode will feature larger apertures with an increased chamfer at the hole exit and the realization of other slots in between apertures, to place additional magnets, useful to optimize the electron filtering and residual ion deflection [3].
A fully 3D analysis of the entire NIO1 beam considering the new extraction grid has been performed for the first time by a fully 3D version of EAMCC [4,5], a relativistic particle tracking code based on the Monte-Carlo method for describing the transport of particles under prescribed electric and magnetic fields and the main secondary particle formation processes responsible of non-negligible heat loads on the accelerator grids. The H- beam, the beam halo fraction and the co-extracted electrons have been simulated for determining the heat loads on grids and the power transmitted out of the accelerator. The main results are presented in this paper, after a brief description of the device, the proposed upgrade and the reference conditions for the simulations.

Acknowledgement

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References

[1] M. Cavenago et al., *Design of a versatile multiaperture negative ion source*, Rev. Sci. Instrum. 81, 02A713 (2010).
[2] P. Veltri et al., *Design of the new extraction grid for the NIO1 negative ion source*, AIP Conf. Proc. 1655, 050009 (2015).
[3] M Cavenago et al., *Deflection compensation for multiaperture negative ion beam extraction: analytical and numerical investigations*, Plasma Sources Sci. Technol. 23, 065024 (2014).
[4] G. Fubiani at al., *Modeling of secondary emission processes in the negative ion based electrostatic accelerator of the International Thermonuclear Experimental Reactor*, Phys. Rev. ST Accel. Beams 11, 014202 (2008).
[5] N. Fonnesu et al., *A multi-beamlet analysis of the MITICA accelerator*, AIP Conf. Proc. 1655, 050008 (2015).

TuePS34

Optics of the NIFS Negative ion source test stand by infrared calorimetry and numerical modeling

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At the National Institute for Fusion Science (NIFS, Japan), neutral beams with the energy up to 15 MW are routinely injected to the hydrogen plasma confined in the Large Helical Device (LHD) using three negative ion beam-lines[1]. Together with the heating beam-lines, a test stand beamline is also operated at NIFS, to gain a better understanding of the physics regulating the formation, extraction and acceleration of negative ions, and their conversion to neutrals. The test stand is based on a 1/3-scaled negative ion source of the same arc-driven source adopted for the LHD beamline, and its acceleration system is a standard triode. The electrode grids are divided into 2 segments having slightly different geometries of the intermediate steering grid (SG) and a common multi slotted grounded grid. In this paper the beamlet optics of both systems was studied by means of an instrumented calorimeter [2] made of carbon fibre composite (CFC) tiles; the tiles were constructed making the propagation of thermal energy along the beam direction largely dominant with respect to the other directions, so that the thermal pattern on the rear plane of the tile has a strong correlation with the power profile deposited by the beamlets on the beam-facing plane of the tile. Infrared image of this thermal pattern is analysed to study the beamlet characteristics obtained in different source conditions [3]. The experimental measurements are then compared with 3D numerical simulations, in order to validate the codes, and to assess their degree of reliability. The simulations show a satisfactory agreement with the experimental results; some minor discrepancies are highlighted and their possible causes are addressed in the manuscript.

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References

[1] Y. Takeiri et al., AIP Conf. Proc., Vol. 1515 Issue 1, p139 (2013)
[2] G. Serianni et al., AIP Conf. Proc., Vol. 1515 Issue 1, p579 (2013)
[3] V. Antoni et al., AIP Conf. Proc. Vol. 1655, 060005 (2015)

TuePS35

Status of permanent magnet Intense Proton Source for C-ADS Linac

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Two compact and intense 2.45GHz permanent proton sources and their corresponding low energy beam transport systems (LEBT) were developed successfully for China Accelerator Driven Sub-Critical system (C-ADS) in 2014, one of which were built at IMP, Lanzhou and the other at IHEP, Beijing. Both proton sources can deliver stable 10mA/35keV proton beams at CW mode to the entrances of the downstream RFQs. The beams extracted by a 3-electrode extraction system are transported by the low energy beam transport system (LEBT), which is composed of 2 identical solenoids, and into the 3.2MeV or 2.1MeV radio-frequency quadrupole (RFQ). In order to ensure superconducting cavities commissioning and protection, an electrostatic-chopper has been designed and installed in the LEBT line that can chop the cw beam into a pulsed one. The achieved fall/rise time of the chopper is less than 20 ns. The performance of the proton source and the LEBT, such as beam reliability, beam profile, emittance and RFQ injector matching will be presented.

TuePS36

Simulation Study of LEBT for Transversely Coupled Beam from an ECR Ion Source

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A Low-Energy intense-highly-charged ion Accelerator Facility (LEAF) program has been launched at IMP. This accelerator facility consists of a superconducting Electron Cyclotron Resonance (ECR) ion source, a Low Energy Beam Transport (LEBT) system and a Radio Frequency Quadrupole (RFQ). It is especially of interest for the extracted ion beam from the ECR ion source, which is transversely coupled, and this property will significantly affect the beam transmission in the LEBT line and the matching with the downstream RFQ. In the beam transport design of LEAF, beam decoupling in the LEBT is considered to lower down the projection emittances and the feasibility of the design has been verified by beam simulation with a transversely coupled beam from the ECR ion source.

References

1. YANG Y, SUN L T, ZHANG X Z et al. Proceedings of IPAC14. Dresden, Germany, TUPRO054, 2014.
2. YANG Y, YUAN Y J, SUN L T et al. Rev. Sci. Instrum, 2014, **85** : 113305.
3. ZHAO H W, SUN L T, ZHANG X Z et al.,Rev. Sci. Instrum, 2006, **77**: 03A333.
4. Thomas P. Wangler, Principles of RF Linear Accelerators. New York: Wiley & Sons, 1998: 259-290.

TuePS37

Developments of Fast Emittance monitors for Ion Sources at RCNP

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Recently several developments of Low Energy Beam Transport (LEBT) line and its beam diagnostic systems have been done in order to improve the injection efficiency of ion beam to AVF Cyclotron at Research Center for Nuclear Physics (RCNP) Osaka University. One of those is the development of Fast Emittance monitors. A fast monitor which consists of XY slits and profile monitor with rotating wire and can measure emittance within 75 seconds is already exists. For more efficient development of beam, a new emittance monitor which can measure within several seconds is needed and a Pepper Pod Emittance Monitor (PPEM) has been developed. The PPEM consists of copper pepper pod mask, multichannel plate (MCP), fluorescent screen, mirror, and CCD camera. The CCD image is taken via IEEE1394b to PC and analyzed immediately and frequently. The details of the PPEM and beam development with this PPEM will be presented.

Wednesday
26 August 2015

WedM01

Advancement of Highly Charged Ion Beam Production by Superconducting ECR Ion Source SECRAL

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At Institute of Modern Physics, CAS, the superconducting ECR ion source SECRAL has been put into operation for about 10 years now. It has been the main working horse to deliver intense highly charged heavy ion beams for the accelerators. Since its first plasma at 18 GHz, R&D work towards more intense highly charged ion beam production as well as the beam quality investigation has never been stopped. When SECRAL was upgraded to its typical operation frequency 24 GHz, it had already showed its promising capacity of very intense highly charged ion beam production. And it has also provided the strong experimental supply for the so called scaling laws of microwave frequency effect. However, compared to the microwave power heating efficiency at 18 GHz, 24 GHz microwave heating doesn't show the ω^2 scale at the same power level, which indicates that microwave power coupling at gyrotron frequency needs better understanding. In this paper, after a review of the operation status of SECRAL with regard to the beam availability and stability, the recent study of the extracted ion beam transverse coupling issues will be discussed, and the test results of the both TE_{01} and HE_{11} modes will be presented. A general comparison of the performance working with the two injection modes will be given, and a preliminary analysis will be introduced. The latest results of the production of very intense highly charged ion beams, such as 1.42 emA Ar^{12+}, 0.9 emA Xe^{27+} and so on, will be presented.

WedM02

Status of ECR Ion Sources for the Facility for Rare Isotope Beams

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The Facility for Rare Isotope Beams (FRIB) is currently under construction at Michigan State University. Once operational the superconducting heavy ion linac will accelerate all the stable isotopes above 200 MeV/u with a beam power of up to 400 kW. The ion beam will be generated with one of two Electron Cyclotron Resonance (ECR) ion sources that are planned for the facility. Ahead of the commissioning schedule, the first ECR ion source and associated equipment are planned to be moved in the coming months to the front end area of FRIB and to be ready to deliver beam by the end of 2016. Operating at 14 GHz, this first ECR will be used for the commissioning and initial operation of the facility but will not be sufficient to reach the final beam power on the fragmentation target. A high performance ECR ion source is in development to reach high intensity of high charge state heavy ion beam such as uranium. A superconducting magnet structure compatible with operation at 28 GHz for this ion source has been designed at Lawrence Berkeley National Laboratory by the Superconducting magnet group and preparations for the construction are underway. Although the magnetic performances and most of the magnet components are very similar to the ones used with the VENUS magnet, the support structure of the FRIB ion source uses an innovative design that incorporates adjustable keys allowing for a precise adjustment of the sextupole preload minimizing the risk of failure and will provide significant operational margin. This ion source however will be first operated at 24 GHz with a 10 kW gyrotron recently tested successfully with NSCL SuSI ion source. The paper reviews the overall work in progress and development done with ECR ion sources for FRIB.

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WedM03

Further improvement of RIKEN 28GHz SC-ECRIS for production of intense U beam

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This spring, we successfully produced more than 200euA of U^{35+} even though we used the lower injected RF power (28+18GHz) and the magnetic field strength lower than the ordinary High-B mode operation for 28GHz. Although the sputtering method gives lower beam intensity and higher consumption rate, we could dramatically reduce the consumption rate of metal U from ~8.6 to ~2.8mg/h with sputtering method to produce intense beam of U^{35+} (~150euA), which is almost same or even lower than the oven method. Based on these results, we successfully produced stable intense beam of U^{35+} ion in RIBF experiment for long term (more than one month) with low material consumption this year. To obtain these results, we systematically studied the effect of main parameters (magnetic field, gas pressure etc) on the beam intensity for various heavy ions (Ar~U) with 18 and 28GHz. In these studies, we observed that the beam intensity is strongly dependent on the main parameters. For examples, we observed that the beam intensity was saturated at B_{inj}>1.5B_{ext} and B_r>1.1B_{ext} for U^{35+} ions in a wide range of B_{ext}. Optimum value of B_{min} for maximizing the beam intensity was dependent on the microwave frequency and the gas pressure. We found that the optimum value of B_r to maximize the beam intensity is strongly dependent on B_{min} in a certain condition. We also observed the limitation of sputtering method at higher RF power.

In this contribution, we present how to optimize the ion source performance, how to minimize the consumption rate and the analysis of the long-term production of intense U ion beams. We present the effect of the magnetic field distribution on the beam intensity for various heavy ions and its mechanism in detail. We also discuss the optimum structure for higher frequency based on these results.

WedM04

Operation and commissioning of IFMIF (International Fusion Material Irradiation Facility) LIPAc Injector

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Under the framework of ITER Broader Approach (BA) agreement between Japan and EU, IFMIF-EVEDA (Engineering Validation and Engineering Design Activities) project has been launched in 2007 in Japan to validate the key technologies to realize IFMIF. IFMIF is an accelerator based neutron facility having two set of linear accelerators each producing 125mA/CW deuterium ion beams (250mA in total) at 40MeV. The LIPAc (Linear IFMIF Prototype Accelerator) being developed in the IFMIF-EVEDA project consists of an injector, a RFQ accelerator, and a part of superconducting Linac, whose target is to demonstrate 125mA/CW deuterium ion beam acceleration up to 9MeV. The injector has been developed in CEA Saclay and already demonstrated 140mA/100keV deuterium beam [1]. The injector was disassembled and delivered to the International Fusion Energy Research Center (IFERC) in Rokkasho, Japan, and the commissioning has started after its reassembly 2014; the first beam production has been achieved in November 2014 [2]. Up to now, 100keV/120mA/CW hydrogen ion beam has been produced with a low beam emittance of 0.2 π.mm.mrad (rms, normalized). Full performance of the injector will be presented with the characteristics of the ECR ion source and the Low Energy Beam Transport consisting of two solenoid coils.

[1] R. Gobin, et al., Rev. Sci. Instrum. **85**, 02A918 (2014)

[2] R. Gobin, et al., "Installation and first operation of the IFMIF LIPAc Injector at BA Rokkasho site in Japan.", to be presented in this conference.

WedM05

Status of the SPIRAL2 injector commissioning

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At the "Grand Accélérateur d'Ions Lourds" (GANIL - Caen, France), the SPIRAL2 project, dedicated to stable and radioactive ion beam production, is based on a 40 MeV continuous working linear accelerator (LINAC). The accelerator is currently under installation in its tunnel. The LINAC injector is composed of two low energy beam lines transport (LEBT): one is dedicated to the light ion beam production, the other to the heavy ions. The light ion source is a permanent magnet 2.45 GHz electron cyclotron resonance (ECR) source developed at CEA Saclay to produce and inject the requested 5 mA deuteron beam into the radio frequency quadrupole (RFQ) preceding the LINAC. This source is based on the SILHI design which has demonstrated a great reliability. The first light ion beam has been successfully produced in December 2014. This important result is presented. The heavy ion source installed on the other LEBT is PHOENIX V2, an 18 GHz room temperature ECR source delivered by the LPSC. The RFQ chosen for the project can accommodate incoming ions with a charge over mass ratio higher or equal to 1/3 and a β~2.10-4. A status of the SPIRAL2 injector commissioning is given. PHOENIX V2 has been tested during 2 years at LPSC and the first beam of the heavy ion source, under preparation, is expected during the summer 2015. An upgrade of the PHOENIX V2 source, named PHOENIX V3, has been designed during the "Cluster of Research Infrastructures for Synergies in Physics" European project [1]. This new source is aimed to replace the PHOENIX V2 after the commissioning of the accelerator, in order to increase the beam intensities of ions up to the mass 50 approximately. The design of the PHOENIX V3 source is shown. The source is under assembly at LPSC and its first beam, expected during the summer 2015, should also be reported.

References

[1] EU Grant Agreement 283745

WedM06

Limitation of the ECRIS Performance by Kinetic Plasma Instabilities

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Electron cyclotron resonance ion source plasmas are prone to kinetic instabilities due to the anisotropy of their electron energy distribution. The instabilities are associated with strong microwave emission and periodic bursts of energetic electrons escaping the magnetic confinement. The experimental setup used for detecting the instabilities is described. It is shown that the repetition rate of the periodic instabilities increases with increasing magnetic field strength and microwave power and decreases with increasing neutral gas pressure, the magnetic field strength being the most critical parameter. The effect of the ion source parameters on the growth and damping rates of the instabilities are discussed qualitatively. The instabilities explain the periodic ms-scale oscillation of the extracted beam current observed with several high performance ECRISs and restrict the parameter space available for the optimization of extracted beam currents of highly charged ions. Experiments with the JYFL 14 GHz ECRIS have demonstrated that due to the instabilities the optimum B_{min}-field is less than $0.8B_{ECR}$, which is the value suggested by the semiempirical scaling laws guiding the design of modern ECRISs. Finally, the effect of the instabilities on the energy spread of the extracted ion beams is described and possible methods to mitigate their effect on ECRIS performance are discussed.

WedM07

Electron Density and Temperature measurements in Electron Cyclotron Resonance Ion Source plasma by means of X-ray spectroscopy and X-ray imaging

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An experimental campaign aiming to investigate ECR plasma X-ray emission has been recently carried out at the ECRIS laboratory of ATOMKI based on a collaboration between the Debrecen and Catania ECR teams. In a first series, the X-ray spectroscopy was performed through SDD and HpGe detectors, characterizing the volumetric plasma emission. The on-purpose developed collimation system was suitable for direct plasma density evaluation, performed "on-line" during beam extraction and CSD characterization. A campaign for correlating the plasma density and temperature with the output charge states and the beam intensity for different pumping wave frequencies, different magnetic field profiles and single-gas/gas-mixing configurations was carried out. The ion source in most cases was tuned to maximize the Ar^{4+} production. The microwave frequency was swept in the 12.8-13.5 GHz range with steps of 40 MHz and the forwarded power was 30 W at each step. The results reveal a surprisingly very good agreement between warm-electrons density fluctuations, output beam currents and the calculated electromagnetic modal density of the plasma chamber. In a second series, a new setup based on a CCD camera coupled to a small pin-hole allowing X-ray imaging was installed and numerous X-ray photos were taken in order to study the peculiarities of the ECRIS plasma structure (overall shape, density distribution, response to tuning parameters like frequency and magnetic field). Preliminary results of the 2D X-ray-imaging will be presented.

WedM08

Ion Beam Emittance from an ECRIS

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Simulation of ion beam extraction from an Electron Cyclotron Resonance Ion Source (ECRIS) is a fully 3 dimensional problem, even if the extraction geometry has cylindrical symmetry. To improve the magnetic confinement of such sources a multi-pole is added to the mirror field. Experimentally quadrupoles, hexapoles, and octupoles have been tried, however, in most cases a hexapole is used. This makes the extraction of a low emittance ion beam even more complicated because of coupling between the different planes of the six dimensional phase space by the magnetic field. Because of the strong magnetic flux density not only the electrons are strongly magnetized, but also the Larmor radius of ions is much smaller than the geometrical dimension ofthe plasma chamber. This has a strong influence on the behavior of charged particles within the plasma: the moveability of both, electrons and ions, is high in the direction of the magnetic field, but restricted in the perpendicular direction. This will influence several physical properties such as shielding, collision, and similar. If we assume that the influence of collisions is small on the path of particles, we can do particle tracking through the plasma if the initial coordinates of particles are known. We generated starting coordinates of ions by simulation of the electrons, accelerated by the 14.5 GHz rf-power fed to the plasma. For the simulation of the plasma electrons the TrapCAD code has been used, whereas for the ion tracking and diagnosis the KOBRA3 code was chosen. With that we were able to investigate the influence of different electron energies on the extracted ion beam. Using these assumptions we can reproduce the experimental results obtained 10 years ago, where we monitored the beam profile with the help of viewing targets. Especially the effect that different parts of the ion beam will be focused differently by a magnetic solenoid can be explained. Due to the coupling between different planes, simple projections of the six dimensional phase space into a 2D plane seems to be not very useful. The integration which is performed by doing a projection has to be replaced by a more differential presentation, namely to choose a slice of the full phase space. Methods have been developed to investigate arbitrary 2D cuts of the 6D phase space. The visualization of the simulation results is an important task. To this date we are able to discuss full 4D information. Currently, we extend our analysis tools towards 5D and 6D, respectively.

WedM09

Emittance measurement for RIKEN 28GHz SC-ECRIS

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In 2012, the intense beam of highly charged uranium ions was extracted from RIKEN 28GHz SC-ECRIS. Following this success, an intense beam of U^{35+} ions was used for the radio isotope beam factory (RIBF) experiment for a long period. It is obvious that production of high quality beams is crucial issue for the RIKEN RIBF project. For this reason, since 2014, we systematically measured the emittance and beam intensity of highly charged uranium ions under various conditions. Furthermore, in 2015, we measured the full four-dimensional transverse phase-space distribution of highly charged U ion beam including correlations between the horizontal and vertical planes for the beam axis.

In these experiments, we observed that the emittance of the highly charged U ions are strongly affected by the aberration of the analyzing magnet in a certain condition. The effect of the aberration was reduced by decreasing the beam size in the analyzing magnet, which can be controlled by the focusing element (solenoid coil) placed between ion source and analyzing magnet.

It is well-known that the simple model calculation indicates that the emittance size increases with increasing the magnetic field. However, we observed that the emittance size of U^{35+} ions for lower B_{ext} and very asymmetric magnetic field distribution (B_{ext}~1.45T, B_{inj}~3T) was larger than that for higher B_{ext} and relatively symmetric magnetic field distribution (B_{ext}~1.8T, B_{inj}~3 T), even when the effect of the aberration was removed.

In this contribution, we present the experimental results and procedure of data analysis in detail. We also discuss about the mechanism of emittance growth described above.

Thursday
27 August 2015

ThuM01

In Gas-Jet Isomer Selective Laser Ion Source

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Rare Elements in-Gas Laser Ion Source and Spectroscopy at S^3 (REGLIS^3) is the new set-up currently under construction at the SPIRAL2/GANIL facility for the production of high-intensity radioactive ion beams, preselected by the Super Separator Spectrometer (S^3). REGLIS^3 will be a source for the production of low-energy, high-quality radioactive ion beams and at the same time a tool for high-precision laser and mass spectroscopic measurements [1], amongst others. It is based on the 'In-Gas Laser Ionization and Spectroscopy' (IGLIS) technique, which is currently being developed at KU Leuven in Belgium. In this technique, a radioactive ion beam is thermalized and neutralized in a gas cell. A continuous flow of gas leads the atoms to the gas cell exit, where a de Laval nozzle produces a quasi-parallel supersonic gas jet in which the laser based resonant ionization takes place. The selectively-ionized atoms of interest are then captured in a segmented Radio-Frequency Quadrupole (RFQ) ion guide system, accelerated and mass separated. The low temperature, small velocity spread and low pressure in the jet, enable the different spectroscopic broadening mechanisms to be reduced significantly in comparison to previous in-gas laser ionization spectroscopy results, where the ionization region was placed within the gas cell, rather than in the gas jet [2]. In recent experiments the in-gas-jet technique was tested in on-line conditions at the Leuven Isotope Separator On-Line (LISOL) facility, where traces of the hyperfine splitting (HFS) of $^{214,215}Ac$ were obtained with a spectral resolution of $5x10^{-7}$, improving 25-fold the relative uncertainties of previous results obtained by in-gas-cell experiments. Moreover, the results show that the total ionization efficiency in the gas jet is comparable to that in the gas cell (~0.5 %) and can potentially be improved up to one order of magnitude. With these new results, the selective production of isomer ions can be investigated. In this talk, the new results of in-gas-jet laser spectroscopy technique will be presented and compared to previous results obtained at LISOL by in-gas-cell laser spectroscopy.

References

[1] R. Ferrer et al., Nuclear Instruments and Methods B317 (2013) 570-581.
[2] Y. Kudryavtsev et al., Nuclear Instruments and Methods B297 (2013) 7-22.

ThuM02

New Progress of High Current Gasdynamic Ion Source

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The experimental and theoretical research carried out at the Institute of Applied Physics (IAP RAS, Nizhniy Novgorod, Russia) resulted in development of a new type of ECR sources – gasdynamic ECR ion sources. The ideas underlying development of such sources were borrowed from the field of conventional ECR sources of multicharged ions, as well as from investigations of problems of fusion in mirror traps (FMT). The gasdynamic ECR ion sources differ from the Geller sources by the mechanism of plasma confinement in a magnetic trap. It is the quasi-gasdynamic mechanism similar to that is used in FMT.

Experimental studies of gasdynamic ECR ion sources were performed at SMIS 37 facility. In these experiments plasma was created by 37.5 GHz gyrotron radiation with power up to 100 kW. Such high frequency of microwaves allowed to create and sustain plasma with significantly higher density (up to $2{\cdot}10^{13}$ cm^{-3}) and at the same time to maintain the main advantages of conventional ECRIS such as high ionization degree and low ion energy. Reaching such high plasma density relies on the fact that the critical density for the microwave radiation grows with the frequency squared. Using high microwave power allowed to keep the average electron energy on a high enough level (50-300 eV) for efficient ionization even in the case of so-called quasi gasdynamic regime of plasma confinement at neutral gas pressure range of $1{\cdot}10^{-4}$ - $1{\cdot}10^{-3}$.

Gasdynamic ECR ion source demonstrated a good performance for production of high current (100-300 mA) multicharged ion beams with moderate average charge (4-5 for Argon). Especially effective gasdynamic ion sources appeared to be for formation of hydrogen or deuterium beams. In recent experiments a possibility of beam extraction with proton current up to 500 mA and current density 600 – 700 mA/cm^2 was demonstrated. One of the main advantages of such systems is extremely low emittance of extracted beams. It was shown that normalized RMS emittance of 500 mA proton beam is below 0.07 $\pi{\cdot}$mm$\cdot$mrad.

ThuM03

Overview of Ion Source Characterization Diagnostics in Indian Test Facility (INTF)

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Indian Test facility (INTF) is envisaged to characterize ITER Diagnostic Neutral Beam (DNB) system and establish the functionality of its eight inductively coupled RF plasma driver based negative hydrogen ion source and its beam line components. A number of diagnostics are planned in INTF to characterize the ion source performance. Negative ion source, where the negative hydrogen ion production is enhanced by Cesium evaporation, will be monitored by optical emission spectroscopy (OES) and cavity ring down spectroscopy (CRDS). Plasma near the extraction region in the ion source will be studied using standard electrostatic probes. The beam divergence and negative ion stripping losses are planned to be measured using Doppler Shift Spectroscopy. During initial phase of ion beam characterization, similar parameters will also be characterized with Carbon Fiber Composite (CFC) based infrared (IR) imaging diagnostics. Safe operation of the beam will be ensured by using standard thermocouples and standard electrical voltage-current measurement sensors. A novel concept based on plasma density dependent plasma impedance to characterize the RF driver plasma using RF electrical impedance matching parameters will be tested in INTF. The results from this novel method will be validated with OES data.

The paper will discuss about the overview of the complete INTF diagnostics including its present status of procurement, experimentation, interface with mechanical systems in INTF and integration with INTF data acquisition & control systems.

ThuM04

Effects of advanced nanowire-based targets for nanosecond laser driven acceleration

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An experimental campaign aiming to investigate the effects of innovative nanostructured targets based on Ag and Ni nanowires on laser energy absorption in the ns time domain has been carried out at the LENS (Laser Energy for Nuclear Science) laboratory of INFN-LNS, Catania. Nanowires structures are deemed to increase the light absorption in the visible and infrared range due to plasmonic excitation driven by the incoming photons. The tested targets were realized at INFN-Bologna by anodizing aluminum sheets in order to obtain layers of porous Al2O3 of different thickness, on which nanowires of various metals (Ag and Ni) are grown by electrodeposition with different heights. Targets were then irradiated by Nd:YAG 2J, 6 ns infrared laser (λ=1064 nm) at different pumping energies. Advanced diagnostics tools were used for characterizing the plasma plume and ion production: two IC (ion collectors) for time-of-flight measurements, an X-ray sensitive CCD camera for X-ray imaging and X-ray flux measurements and an ICCD-camera for time resolved optical imaging. A detailed study of irradiated surfaces has been carried out through optical and electron scanning microscopy (SEM).

As compared with targets of pure Al or Al2O3, a huge enhancement (of almost two order of magnitude) of the X-ray flux emitted by the plasma has been observed when using the nanostructured targets, with a corresponding decrease of the "optical range" signal, pointing out the energetic content of the laser produced plasma was remarkably increased. This analysis was furthermore confirmed by TOF spectra.

ThuM05

VUV-diagnostics of inelastic collision processes in low temperature hydrogen plasmas

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Inelastic collision processes of hot electrons (Ee>9 eV), such as ionization and electronic excitation, have a crucial role on the performance of negative (H^-) and positive (H^+, H_2^+) hydrogen ion sources. Direct diagnostic of those processes is extremely challenging due to their sensitivity to the high energy tail of the electron energy distribution function (EEDF). Vacuum ultraviolet (VUV) emission of molecular hydrogen plasmas can be utilized as a robust diagnostics for molecule ionization, dissociation and production rates of high vibrational levels (n>5) and metastable states. The method is based on comparison of the rate coefficients of the given processes to the excitation rate coefficients of the lowest excited states. Because of similar threshold energies and functional shapes of cross sections the method is only slightly sensitive to the variation of the EEDF and other plasma parameters. The principle of the diagnostics and with a robust method to measure absolute VUV-emission are presented. Practical ways to apply these methods to (mechanical) development of hydrogen ion sources are discussed, as well as the possibility to use the obtained reaction rates support the development and benchmarking of plasma simulation codes.

ThuM06

Innovation in EBIS/T Charge State Breeders for Stable and Radioactive Elements

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The most attractive features of EBIS/T based charge breeders are short breeding times, narrow charge distributions, low background, high efficiency and the flexible time structure of the ejected low-emittance ion pulses. Notably driven by the need for high-performance charge breeders at radioactive ion beam (RIB) facilities, significant progress has been made to further improve these characteristics: Increasing the electron-beam current density to reduce charge breeding times is conceptually simple, but has turned out rather difficult in reality. Several groups have made progress in moving away from immersed-cathode electron-gun designs with current densities of hundreds of A/cm2 towards 103 to 104 A/cm2. These current densities will become necessary to deliver high charge states of heavy nuclei in a short time and/or provide sufficient space-charge capacity to handle high-current ion beams in next-generation RIB facilities. As an alternative to pulsed injection, efficient capture of DC beams has become possible with the development of high-density electron beams of >1A.

Requests for the time structure of the charge bred ion pulse range from ultra-short pulses, e.g. for injection into isolated RF 'buckets' in accelerators, to quasi-continuous beams. Progress is being made on both ends of this spectrum, by either dividing the extracted charge in many time-focused pulse-lets, adjusting the extraction potential for a near-uniform long pulse (>ms) or adding dedicated devices to spread the ion bunches delivered from the EBIS/T in time.

Recent advances in EBIS/T charge state breeding will be presented, along with progress in simulations and device models that have been vital to pushing performance limits.

ThuM07

Optimizing charge breeding techniques for ISOL facilities in Europe: conclusions from the EMILIE project

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Since the pioneering work of Tamburella et al. for the PIAFE project[1], the charge breeding technique in ECRIS and EBIS sources has nicely evolved. The development of the PHOENIX ECR charge breeder at LPSC, and REX-EBIS at ISOLDE by the REX-ISOLDE collaboration, paved the way for many facilities which are now using or developing one or the other technique[2]. On the roadmap to EURISOL, SPES and GANIL/SPIRAL 1 plan to use a PHOENIX ECR charge breeder, while ISOLDE has upgrade plans for REX-EBIS. The EMILIE project[3] gathers 8 European laboratories to tackle present issues of both charge breeding techniques for future facilities, for example:

- The low duty cycle of the EBIS beam, by the development of an EBIS beam debuncher
- The beam purity limitations of ECR charge breeders by using appropriate materials, vacuum and separation techniques
- The relatively low capture of light ions in ECR charge breeders, by optimizing the 1+ ion beam optics

During the EMILIE project, a number of experimental results have been obtained. These concern for example the study of the 1+ beam capture under different conditions using the Phoenix ECR charge breeder at LPSC[4,5,6], the capture of light ions using the ANL ECR charge breeder[7,8], and the charge breeding of carbon beams at LPSC[9]. A prototype of hot 1+ ECR source was also developed[5]. The SPIRAL 1 charge breeder has been upgraded to make use of UHV and pure Al components, optimized gas injection and improved 1+ beam ion optics[8], and is now being tested at LPSC[10]. The ECR charge breeder for SPES, recently tested at LPSC, has shown very good performances for charge breeding of Rb and Cs ions[11] . The EBIS beam debuncher is being commissioned at LPC Caen and is about to produce first results. As a first milestone, the first trapping tests show that the Paul trap, on which the debuncher is based, can confine ions over periods longer than 100 ms.

This contribution intends to summarize the experimental results obtained in the frame of EMILIE, drawing conclusions on the studies undertaken so far, and discussing a possible optimized charge breeding scheme for future large scale radioactive ion beam facilities like EURISOL.

References

[1]: C. Tamburella et al., Rev. Sci. Instrum. 68(1997)2319
[2]: see for example P. Delahaye, NIM B 317(2013)389; R. Vondrasek, proceedings of the EMIS 2015 conference, in preparation
[3]: "Enhanced Multi-Ionisation of short-Lived Isotopes for Eurisol", P. Delahaye et al, Rev. Sci. Instrum. 83(2012)02A906
[4] : H. Koivisto et al, Rev. Sci. Instrum. 85(2014)02B917
[5]: T. Lamy et al, ECRIS 2014 conference proceedings, JACoW
[6]: O. Tarvainen et al, Plasma Sources Science Tech., in print
[7]: R. Vondrasek et al, Rev. Sci. Instrum. 83(2012)113303
[8]: P. Delahaye et al, Nucl. Instrum. Meth. A 693(2012)693
[9]: L. Maunoury et al, Rev. Sci. Instrum. 85(2014)02A504
[10]: L. Maunoury et al, contribution to this conference
[11]: A. Galatà et al, contribution to this conference

ThuM08

Advanced Numerical Modelling of the PHOENIX-SPES charge breeder

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A Charge Breeder is a crucial device of an ISOL facility, allowing post-acceleration of radioactive ions: it accepts an incoming 1+ beam, then multiplying its charge with a highly charged q+ beam as an output. The overall performances of the facility (intensity and attainable final energy) critically depend on the Charge Breeder optimization. Experimental results collected along the years confirm that the breeding process is still not fully understood and room for improvements still exists: a new numerical approach has been therefore developed, and applied to the description of a $^{85}Rb^{1+}$ beam capture by the plasma of the 14.5 GHz PHOENIX ECR-based Charge Breeder (ECR-CB), installed at LPSC and adopted for the Selective Production of Exotic Species (SPES) project under construction at INFN-LNL. The results of the numerical simulations will be described along the paper. The ion capture process of the incoming beams at different input energies has been studied for different plasma parameters, in order to finally get a physically meaningful picture of the charge breeding process. The results, obtained by implementing plasma models of increasing accuracy, very well agree with the theoretical predictions, showing the key role played by the plasma ion temperature. In addition, the model is now able to reproduce with high accuracy the experimental results obtained at LPSC within the EMILIE project, when including in the code plasma densities in agreement with density estimations published elsewhere.

ThuM09

Off-line Commissioning of EBIS and Plans for Its Integration into ATLAS and CARIBU

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An Electron Beam Ion Source Charge Breeder (EBIS-CB) has been developed at Argonne to breed radioactive beams from the CAlifornium Rare Isotope Breeder Upgrade (CARIBU) facility at ATLAS. The EBIS-CB will replace the existing ECR charge breeder to increase the intensity and significantly improve the purity of reaccelerated radioactive ion beams. The CARIBU EBIS-CB has been successfully commissioned offline with an external singly-charged cesium ion source. The performance of the EBIS fully meets specifications to breed rare isotope beams delivered from CARIBU. The EBIS can provide charge-to-mass ratios ≥1/7 for all CARIBU beams with low breeding times in the range from 6 ms to 28 ms. The breeding efficiency into a single charge state of cesium has been demonstrated up to 20%. The overall transmission of cesium beam through the EBIS is 70% routinely and can be increased to 80% with significant effort. A 1.6 Ampere electron beam at a 10 Hz repetition rate and up to a 40% duty cycle has been used for charge breeding experiments. Also, 90% duty cycle at a 30 Hz repetition rate has been demonstrated for a 1.0 Ampere electron beam. Operation at higher repetition rates is required to maintain a high bunching efficiency by avoiding space charge limitation in an RFQ cooler-buncher (CB) which will precede the EBIS-CB. Recently, it was decided to include a multi-reflection time-of-flight (MR-TOF) mass-spectrometer between the RFQ-CB and EBIS-CB. The MR-TOF can provide isobar purification with a mass resolution down to 1/50,000.

The EBIS is ready to be relocated and integrated into ATLAS and CARIBU. A long electrostatic beam transport system including two 180° bends in the horizontal and vertical planes has been designed. Currently, the beam transport system components are being procured and fabricated to be installed and commissioned by the end of this year. This paper will present the results of the EBIS off-line commissioning and discuss the design of the new beamline and the overall integration of the EBIS-CB into ATLAS.

ThuA01

Optimum Plasma Grid Bias for a Negative Hydrogen Ion Source Operation with Cs

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The functions of a biased plasma grid of a negative hydrogen (H^-) ion source for both pure volume and Cs seeded operations are examined. Proper control of the plasma grid bias in pure volume sources yields: optimization of the extracted negative ion current: reduction of the co-extracted electron current: flattening of the spatial distribution of plasma potential across the filter magnetic field: change in recycling from hydrogen atomic/molecular ions to atomic/molecular neutrals and enhanced concentration of H^- ions near the plasma grid. These functions are maintained in the sources seeded with an alkali metal. However an additional function appears in the Cs seeded sources, namely direct emission of negative ions under positive ion and neutral hydrogen bombardment. The thickness of the Cs deposition on the plasma grid changes the local H^- ion density and electron density near the plasma grid, and thus the performance of the ion source. Factors affecting the source performance with and without Cs introduction are discussed.

ThuA02

Investigation of the Boundary Layer during the Transition from Volume to Surface Dominated H^- Production at the BATMAN Test Facility

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The BATMAN test facility is equipped with a ⅛ scale H^- source for the ITER NNBI. BATMAN is dedicated to physical investigations including the understanding of the processes involved in the surface negative ion generation and extraction. As most of the extracted negative ions are generated on the caesiated plasma grid (1st grid of the accelerator system), understanding the physics occurring in the vicinity of the plasma grid, called the boundary layer, is of particular importance. Several diagnostics are available to study this several cm thick layer: Langmuir probes and OES are used to determine basic plasma parameters, Cavity-Ring-Down Spectroscopy allows for the measurement of the H^- density. Moreover, Tunable Diode Laser Absorption Spectroscopy is dedicated to measure the caesium density.

A transition from volume to surface dominated H^- production can be observed during the Cs conditioning phase, however only if the source had been carefully cleaned from remaining caesium and its compounds. This phase was followed by the mentioned diagnostics in the boundary layer while operating the source at ITER relevant parameters (in particular at a pressure of 0.3 Pa). The transition from an electron-ion plasma towards an ion-ion plasma, in which negative hydrogen ions become the dominant negatively charged particle species, will be presented. The influence on the plasma composition, distribution and potential as well as on the source performance (extracted H^- current density as well as co-extracted electron current density) will be shown.

ThuPE01

First hydrogen operation of NIO1: characterization of the source plasma by means of an optical emission spectroscopy diagnostic

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NIO1 is a compact and flexible radiofrequency H^- ion source, developed by Consorzio RFX and INFN-LNL. Aim of the experimentation on NIO1 is the optimization of both the production of negative ions and their extraction and beam optics. The source will be also a test bed for the instrumentation to be installed on the ITER neutral beam test facility. In the initial phase of its commissioning, NIO1 was operated with nitrogen [1], but now the source is regularly operated also with hydrogen. Filling pressure and RF power scans have been done to characterize the source with both gases. To evaluate the source performances an optical emission spectroscopy diagnostic was installed. The system includes a low resolution spectrometer in the spectral range of 300-800 nm and a high resolution (50 pm) one, to study respectively the atomic and the molecular emissions in the visible range. The plasma is observed along lines of sight longitudinal with respect to the source or parallel and close to the plasma grid. The spectroscopic data have been interpreted also by means of a collisional-radiative model developed at IPP Garching [2]. Besides the diagnostic hardware and the data analysis methods, the paper presents the measures of the source plasma parameters as a function of the radiofrequency power and of the internal gas pressure. In particular, the correlation between the E-H transition, the operative conditions and the plasma properties are investigated.

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References

[1] B. Zaniol, M. Barbisan, M. Cavenago, M. De Muri, A. Mimo, R. Pasqualotto and G. Serianni, *NIO1 diagnostics*, AIP Conf. Proc. 1655, 060010 (2015).

[2] D.Wünderlich, S. Dietrich, U. Fantz, *Application of a collisional radiative model to atomic hydrogen for diagnostic purposes*, J. Quant. Spectrosc. Radiat. Transfer, Vol. 110, Issues 1–2, Jan. 2009, Pages 62-71

ThuPE02

Feasibility Study of a NBI Photoneutralizer Based on Nonlinear Gating Laser Recirculation

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Low efficiency of gas neutralizers is regarded as a major limit in negative ion NBI for fusion reactor plants, hence the importance in the development of alternative neutralization concepts. Electron photodetachment by means of intense radiation fields is the most promising solution in terms of efficiency (which in principle can reach saturation) and pumping requirements [1]. The standard approach for this type of neutralizer is based on a Fabry-Perot cavity [2]; in this work a different design is analyzed, trying to overcome Fabry-Perot concept criticalities. The present study is based on the RING concept [2], which exploits a lower gain, non resonating cavity for laser beam recirculation. Laser source is positioned outside the cavity, while a non linear medium acts as an optical switch to trap the laser second harmonic within the neutralizer region: with multiple mirrors configuration and with proper cavity geometry it is possible to reach 90% of neutralization rate. Thermal load issues on the second harmonic generator are critical and will be analyzed in detail; requirements on laser sources will be discussed and some proposals will be presented.

References

[1] Kovari M. & Crowley B. *Laser photodetachment neutraliser for negative ion beams*. Fusion Eng. Des. 85, 745–751 (2010)

[2] W. Chaibi, C. Blondel, L. Cabaret, C. Delsart, C. Drag and A. Simonin; *Photo-neutralization of negative ion beam for future fusion reactor; Negative Ions Beams and Sources*, NIBS conference proceeding; Aix en Provence, France, September 2008

[3] M. Y. Shverdin et al., *High-power picosecond laser pulse recirculation*, Optics Letters Vol. 35, No. 13, July 1, 2010.

ThuPE03

Off-normal and failure condition analysis of the MITICA negative-ion Accelerator

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MITICA is the prototype of the Heating Neutral Beam Injectors (HNB) for ITER and is constituted by a negativeion source, a multi-grid electrostatic accelerator, a neutralizer and a residual ion dump. The injector is designed to produce a 17 MW beam of neutral particles (deuterium or hydrogen) up to 1 MeV. Two HNBs are planned to be installed in ITER at Cadarache, France. MITICA is under construction in the PRIMA facility in Padova, Italy. The design of MITICA/HNB [1] has required extensive optimizations in order to guarantee that the thermomechanical stresses in the materials do not exceed the tolerable limits for the required fatigue life. This result has been achieved by: (a) reducing and uniforming the heat loads on the accelerator grid and beam line components, and (b) improving the heat removal capability of the active cooling system of the grids. This involved an extensive optimization of the electric and magnetic field configuration and of the geometry of the accelerator grids,
suppressing the electrons before they are accelerated at higher energy, and improving the optics of the ion beamlets.

However, deviation from the expected magnetic and electrostatic configuration can be caused by "off-normal" or "failure" operating conditions of the accelerator, such as undesired mechanical displacement of the grids, nonuniform extracted ion current, demagnetization of magnets, partial failure of the accelerator grid power-supplies and also operation with different ion species.

Purpose of the present work is to analyse and identify the "off-normal" operating conditions which could possibly become critical in terms of thermomechanical stresses or of degradation of the optical performances of the beam, and to give indications on protective actions to be taken.

References

[1] V. Antoni et al.: "Physics design of the injector source for ITER neutral beam injector " Rev. Sci. Instrum. 85, 02B128 (2014), DOI: 10.1063/1.4857235

Disclaimer

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ThuPE04

Multi-slit Triode Ion Optical System with Ballistic Beam Focusing

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High power focused neutral beams with small divergence are necessary for heating of localized regions inside plasma. Particularly they are useful in the devices with narrow access ports through which only small size, high power density beams can be transported. In the neutral beams developed in the Budker Institute, the ballistic beam focusing is provided by spherically shaped multi-aperture electrodes of ion optical system. Use of slit apertures in the ion optical system additionally reduces a width of the focused beam in the direction along the slits due to smaller divergence in this direction, which is determined only by the ion temperature of plasma emitter. For application in powerful heating neutral beam injectors focusing triode ion optical systems with slit apertures are developed. Formation of high perveance beam in slit geometry of the grid was optimized by making use of three dimensional KOBRA-INP code. Results of the simulations are in agreement with experimental data on ion beam formation from single slit aperture.

At present, two versions of focusing multi-slit triode ion optical system are developed. The first ion optical system forms the proton beam with 15 keV energy, 140 A current, and 30 ms duration. The second ion optical system is intended for heating neutral beam injector of TCV tokamak. The injector produces focused deuterium neutral beam with 35 keV energy, 1 MW power, and 2 s duration. In the later case the angular beam divergence of the neutral beam is 20-22 mrad in the direction across the slits of the ion optical system and 9 mrad in the direction along the slits.

ThuPE05

Design optimization of RF lines in vacuum environment for the MITICA experiment

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Operation of the thermonuclear fusion experiment ITER requires additional heating via injection of neutral beams from accelerated negative ions; two injectors will deliver a total power of 33 MW. The MITICA experiment (Megavolt ITER Injector & Concept Advancement) is the prototype and the test bed of the ITER Heating and Current Drive Neutral Beam Injectors (HNB). MITICA injector experiments shall demonstrate the reliable and accurate emission of a 17 MW beam of neutral particles of deuterium or hydrogen for duration up to 1 hour, fulfilling ITER specific requirements. MITICA test bed is in the final design phase and will be procured and installed in PRIMA facility (Padova Research on Injector Megavolt Accelerated) in Padova, Italy.

This contribution regards the transmission line of MITICA experiment. The design of MITICA RF coaxial lines considered lines of 1" 5/8, but thermal simulations carried out on MITICA RF lines model showed that the temperature of the lines was too high with respect to the maximum operational limit indicated by the supplier. This operation condition can deteriorate the correct functionality of the coaxial lines, due to the risk of losing the good electrical contact on the sliding connections between the parts of the line at higher temperature. The effects of emissivity enhancement and of the increasing in the diameter of the conductors, aimed to lowering the maximum temperature of the lines after 1 hour pulse, are presented: the calculations show the thermal results of MITICA RF lines and of other components involved in the interface between HV Bushing and the MITICA Beam Source, as a function of the emissivity value and of other geometrical parameters. Moreover, five coating products were tested: the outgassing behavior of the selected products and their emissivity assessment are also presented, together with the definition of the application procedures.

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

ThuPE06

3D Self-consistent Modelling of a Matrix Source of Negative Hydrogen Ions

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The study is in the scope of the research on the matrix source [1] of negative hydrogen ions: a matrix of small radius discharges inductively driven by a planar coil. A single-coil driving of the whole matrix is constructively the most proper decision, provided that the same discharge behaviour in the separate discharges of the matrix can be ensured. Recent results [2] obtained for different shapes of zigzag coils driving the matrix have shown that a zigzag coil with an omega-shaped conductor on the bottom of each discharge tube, having similarities with a single coil driving of each discharge, shows up with the highest rf efficiency displayed by high values of the induced current and high rf power deposition into the plasma. This is a result obtained from a 3D model which provides the spatial distribution of the rf field and of the current induced into the plasma, i.e. an electrodynamical description, for given values of the plasma parameters. Since the final decision for the rf driving of the matrix should be based on conclusions for the same spatial distribution of the plasma parameters in the separate discharge tubes, the 3D model from Ref. 2 is extended here to a self-consistent one, with a gas-discharge part within the ambipolar diffusion approximation.

References

1. St. Lishev, Ts. Paunska, A. Shivarova, and Kh. Tarnev, *Rev. Sci. Instrum*. **83**, 02A702 (2012).
2. A. Demerdzhiev, St. Lishev, Kh. Tarnev, and A. Shivarova, *AIP Conf. Proc*. **1655**, 040011 (2015).

ThuPE07

Development of the negative ion beams relevant to ITER and JT-60SA at Japan Atomic Energy Agency

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In International Thermo-nuclear Experimental Reactor (ITER) and JT-60 Super Advanced (JT-60 SA), the D- ion beams of 1 MeV, 40 A and 0.5 MeV, 22 A are required to produce 3600 s and 100 s for the neutral beam injection, respectively. In order to realize such as powerful D- ion beams for long duration time, Japan Atomic Energy Agency (JAEA) has energetically developed cesium (Cs)-seeded negative ion sources (CsNIS) and electro-static multi-aperture and multi-stage accelerators (MAMuG accelerator) which are chosen as the reference design of ITER and JT-60 SA. In the development of the CsNIS, a 100s production of the H- ion beam has been demonstrated with a beam current of 15 A by modifying the JT-60 negative ion source [1]. At the higher current, the long pulse production of the negative ions has been tried by the mitigation of the arcing in the plasma inside the ion source. As for the long pulse acceleration of the negative ions in the MAMuG accelerator, the beam steering angle has been controlled to reduce the power loading of the acceleration grids A pulse duration time has been significantly extended from 0.4 s to 60 s at reasonable beam power for ITER requirement [2]. The achieved pulse duration time is limited by the capacity of the power supplies in the test stand. In the range of < 60s, there are no degradations of beam optics and voltage holding capability in the accelerator. It leads to the further extension of the pulse duration time at higher power density.

This paper reports the latest results of development onthe negative ion source and accelerator at JAEA.

References

[1] M. Yoshida, M. Hanada, et al., Rev. Sci Instrum. 85, 02B314 (2014).

[2] N.Umeda et. al., AIP conference proceedings 1655, 05001 (2015)

ThuPE08

Mechanism of Grid Power Loading in Electro-Static Accelerator with Multiple Apertures and Acceleration Stages for ITER

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In order to design the ITER negative ion accelerator, where the D^- ion beams of 40A are accelerated up to 1 MeV for 3600 s, power loading and localized power density on the acceleration grids are serious problems for long pulse accelerations. The past calculation results suggested that the power loading of the acceleration grids was caused by the over-focus of the negative ions in the extraction grid [1]. Tail of the negative ion is over-focused by strong converged electric field at the edge of aperture of the extraction grid and intercepted with the acceleration grids located in downstream. In order to reduce the over-focused ions, the trajectory of the negative ions was optimized by enlarging apertures of the extraction grid. This solution has been experimentally confirmed, where the power loading of the acceleration grid was reduced from 13% to 10% of the beam power. Moreover, the power density profile was estimated by a detailed calculation with a 3D simulation code. The results showed that the peak power density around the apertures of ground grid was reduced from $18MW/m^2$ to $7MW/m^2$ for 1MeV beam acceleration, suggesting that suppression of the converged electric field at the edge of aperture of the extraction grid also contribute to the reduction of the peak power density.

References

[1] J. Hiratsuka, M. Hanada *et. al.*, Plasma Fusion Res. **10**, 3405045 (2015).

ThuPE09

Performance of positive ion based high power ion source of EAST neutral beam injector

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A positive ion based source was developed for a high power neutral beam injector (NBI) on the Experimental Advanced Superconducting Tokamak (EAST)[1-5]. The ion source contains a bucket hot cathode arc chamber with 650 mm long, 260 mm width and 300 mm depth. There are 32 hairpin filaments with diamond of 1.5 mm and 160 mm long to supply primary electrons. A tetrode type accelerator with slit type used to extract the ions from the plasma and accelerated to the desired energy. The beam extraction area is 120 mm ×480 mm with beam transmittance of 60 %. The designed beam species is deuterium with beam power of 2-4 MW and beam energy of 50-80 keV and beam pulse length of 10-100 s.

There are 5 ion sources was developed so far. They most have the same structure. The ion sources need to be conditioned and performance tested on the test bead before installed on the EAST-NBI. The hydrogen was used for the test and each ion source needs to deliver 4 MW beam power with beam energy of 80 keV. The optimum beam perveance is 2.8 μp with beam energy of 50 keV. Long pulse beam extraction also tested to achieve 100 s on the test bed. Consider the high power deposited on the calorimeter, the beam was modulated with suitable frequency and duty ratio. When the conditioning finished, the ion sources were moved to the EAST-NBI. The deuterium beam was extracted and injected into the EAST plasma. Details of the performance of positive ion source on the test bad and EAST-NBI will be presented.

References

1. C. D. Hu, Y. H. Xie, S. Liu, Y. L. Xie, C. C. Jiang, S. H. Song, J. Li and Z. M. Liu Rev. Sci. Instrum. **82,** (2011).
2. C. D. Hu, Y. H. Xie and N. Team Plasma Science & Technology **14,** (2012).
3. Y. H. Xie, C. D. Hu, S. Liu, J. Li and C. C. Jiang Nucleat Instruments and Methods in Physics Research A **676,** (2012).
4. C. D. Hu and N. Team Plasma Science & Technology **15,** (2013).
5. Y. H. Xie, C. D. Hu, S. Liu, C. C. Jiang, L. Z. Liang, J. Li, Y. L. Xie and Z. M. Liu Plasma Science & Technology **16,** (2014).

ThuPE10

Development of Design Technique for Vacuum Insulation in Large Size Multi-Aperture Multi-Grid Accelerator for Nuclear Fusion

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Optimization techniques of the vacuum insulation design have been developed in order to realize a reliable voltage holding capability of multi-aperture multi-grid (MAMuG) accelerators for giant negative ion sources for nuclear fusion. In this method, the nested multilayer configuration of each acceleration stage in the MAMuG accelerator can be uniquely designed to satisfy the target voltage within given boundary conditions. The evaluation of the voltage holding capabilities of each acceleration stages were based on the past experimental results of the area effect and the multi-aperture effect on the voltage holding capability [1]. Moreover, total voltage holding capability of multi-stage was estimated by taking the multi-stage effect into account, which was experimentally obtained in this time. In this experiment, the multi-stage effect appeared as the superposition of breakdown probabilities in each acceleration stage, which suggested that multi-stage effect can be considered as the voltage holding capability of the single acceleration gap having the total area and aperture. The analysis on the MAMuG accelerator for JT-60SA agreed with the past gap-scan experiments with an accuracy of less than 10% variation.

References

A. Kojima, M. Hanada, A. Hilmi et. al., Rev. Sci. Instrum. 83, 02B117 (2012).

ThuPE11

Concepts of Magnetic Filter Fields in Powerful Negative Ion Sources for Fusion

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In large negative ion sources for fusion a magnetic field in front of the first grid of the extraction system is essential to reduce the current of co-extracted electron below a required limit. In case of the ITER source the electron current has to be smaller than the ion current. At Max-Planck-Institut für Plasmaphysik (IPP) two RF sources of different size are currently being tested, the small 0.3 x 0.6 m^2 prototype source and the 0.9 x 1.0 m^2 source at the ELISE testbed, which has the same width, but only half the height of the ITER source.

Due to the small width of the prototype source it is possible to span the magnetic field between two rows of permanent magnets placed close to the lateral walls. In the large source the field has to be generated by a current of several kA flowing through the plasma facing grid and returning thorough three rods on the top side of the source. These two concepts have substantial different field profiles perpendicular and parallel to the plasma grid. The field strength of the permanent magnets is higher close to the grid and the field lines converge to the sides like in a magnetic bottle. An advantage of the field produced by the current is the possibility to adjust the field strength according to the experimental situation.

Filter field variations have great impact on the currents of negative ions and electrons as well as on the plasma density, the plasma drift in the source and the beam homogeneity. Magnetic fields in the volume, where the plasma is produced, have influence on the plasma sustainment at low pressure.

Many experiments carried out with the small source and the large ELISE source now allow comparing between the source performances achieved by the two concepts of magnetic filter fields. The result of this comparison and possible improvements of the ELISE filter field configuration will be reported.

ThuPE12

Motivation of Concepts for the Negative Ion Extraction from a Single Element of the Matrix Source

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The 2D model of a single element of the matrix source [1] presented in the study is in the trends of recent experiments [2] on the negative ion extraction from the source. The matrix source of volume-produced negative ions, studied regarding fusion applications, is with the design of a matrix of small radius discharges, with planar coil inductive driving and single aperture extraction from each discharge. The efficiency of the source is based on strong accumulation of negative ions in the discharge region with high dc potential, due to the flux of the ions in the dc electric field in the discharge when the discharge radius is small. Since the spatial distribution of the negative ions obeys that of the dc potential in the discharge, the two concepts studied for the ion extraction involve control on its behaviour in the vicinity of the first electrode of the extraction device. The first concept is for extraction of ions non-locally accumulated in the discharge region with high dc potential. Since in the planar coil inductive discharges the maximum of the dc potential is close to the coil, the concept is for ion extraction from a short length discharge, with a high bias applied to the first electrode of the extraction device. The latter ensures straightening in the axial profile of the dc potential needed for avoiding the capture of the ions inside the discharge. The second concept – ion extraction from a long length discharge with and without a magnetic filter – is for extraction of ions locally produced close to the extraction device. The high potential applied to the first electrode of the extraction device is needed for formation of a deep potential well in front of it and, respectively, of a strong electric field for the ion acceleration towards the electrode. The results for the spatial distribution of the plasma parameters in the discharge obtained from the presented 2D model and the outlined conclusions appear as a motivation of these two concepts.

References

1. St. Lishev, Ts. Paunska, A. Shivarova, and Kh. Tarnev, *Rev. Sci. Instrum.* **83**, 02A702 (2012).
2. St. Lishev, D. Yordanov, and A. Shivarova, *AIP Conf. Proc.* **1655**, 040013 (2015).

ThuPE13

Development and tests of Molybdenum armed copper components for MITICA ion source

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The operation of the thermonuclear fusion experiment ITER requires additional plasma heating via injection of high energy neutral beams from accelerated negative ions; two injectors will deliver a total heating power of 33 MW.

The MITICA experiment (Megavolt ITER Injector & Concept Advancement) is the prototype and the test bed of the ITER Heating and Current Drive Neutral Beam Injectors (HNB); it is in the final design phase and will be procured and installed in PRIMA facility (Padova Research on Injector Megavolt Accelerated) in Padova, Italy.

The presence of back-streaming positive ions (BSI+), generated by secondary particle reactions in the MITICA 1 MV accelerator and scattered back at high energy towards the RF source, causes serious problems to the impinged components. In fact, the high power density deposition and the material erosion by sputtering can seriously damage the parts. Such an eroded material pollutes the plasma and it is then detrimental for the ion source operation.

A proper technical solution, based on explosion bonding technique, has been identified for the production of a 1 mm thick Mo armor layer (having molybdenum a much lower sputtering yield, compared with copper) on copper substrate, compatible with ITER requirements, but such an innovative solution needed to be validated. After having preliminarily tested the solution with thermal shock tests on small samples, larger prototypes have been recently manufactured and tested in the high heat flux test facility GLADIS to check the strength of the molybdenum-copper interface. This paper presents the experimental results as well as the results of the numerical fluid-dynamic analyses of the prototypes simulating the high heat flux test conditions in GLADIS. Moreover, the issues encountered during the production and testing of the prototypes, together with the results obtained are presented, being significant for the future manufacturing and operation of the MITICA RF source parts.

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

ThuPE14

Simulation of diatomic gas-wall interaction and accommodation coefficients for Negative Ion Sources and accelerators

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Particle-wall interactions determine in different ways the operating conditions of plasma sources, ion accelerators and beams operating in vacuum. A strong contribution to gas heating in plasma source is given by ion neutralization at walls; beam losses and stray particle production – particularly detrimental for high current negative ion systems such as beam sources for fusion – are caused by collisional processes with residual gas. The gas density profile is determined by the scattering of neutral particles at the walls. The modeling of realistic gas flows in vacuum involves some assumption on the gas-surface interaction, concerning the features of inelastic scattering, momentum and energy exchange, and the angular distribution of scattered particles. The influence of the accommodation coefficient on efficiency losses in the case of accelerators for fusion was shown in the past [1]. The study of such gas-wall interactions, scattering and accommodation parameters, can be performed by use of Molecular Dynamics (MD) techniques.

This paper shows that MD studies at the nano-scale can provide Momentum Accommodation Coefficient (MAC) and Energy Accommodation Coefficient (EAC), which in non-isothermal flows (such as the neutral gas in the accelerator, coming from the plasma source) affect the gas density gradients. For ideal surfaces the computation also provides the angular distribution of scattered particles. Classical MD method has been applied to the case of diatomic molecules. Single collision events, against a frozen wall or a fully thermal lattice, have been simulated using probe molecules. The two wall modeling approximations and data from literature are compared to verify the numerical results.

ThuPE15

Status of the Negative Ion Based Neutral Beam Injectors for ITER

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The R&D effort for the large surface area negative ion source for the neutral beam injectors of the International Tokamak Experimental Reactor (ITER) is well underway and results and achievements are reported in many contributions to this conference as well as the technical details of the multi aperture multi grid RF ions source chosen as the ITER ion source. This contribution highlights the status of the integration of the Heating Neutral Beam (HNB) and the Diagnostic Neutral Beam (DNB) systems into the ITER plant.

The current ITER baseline foresees 2 HNB's operating at 1 MeV 40 A D^0, each capable of delivering 16.5 MW of deuterium ions to the plasma, with a 3rd HNB injector foreseen as an upgrade option that would bring up the total neutral beam power to 50MW [1]. In addition a dedicated DNB will be injecting 100 keV 60 A of H^0 for charge exchange recombination spectroscopy (CXRS) [2]. Installation and maintenance logistics as well as the nuclear environment have strongly influenced the injector design. The beam line configurations have been optimised considering vacuum and gas feed requirements with special attention paid to the controlled transmission over long lengths (~22m) and through narrow ducts. The manufacturing technologies and the materials chosen have to be compatible with the ITER safety constraints.

The ITER operating scenarios will be briefly discussed and the required performance parameters emphasised, such as the HNB operation at 870keV H^0 hydrogen ions in the planned low current hydrogen phase which will allow commissioning of the auxiliary systems used on ITER.

References

[1] R. Hemsworth, et. al., Nuclear Fusion, 49 (2009) 045006
[2] A. Chakraborty., et. al., IEEE Transactions on Plasma Science, 38 (2010) 248

ThuPE16

Neutral Beam Injection System For the C-2-Upgrade Field Reversed Configuration Experiment

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Tri Alpha Energy, Inc. is a privately funded company pursuing research of Field Reversed Configuration (FRC) plasmas for fusion reactor applications. Over the past decade, TAE has brought together world-class technical specialists in such fields as FRC plasma science, magnets, neutral and neutralized beams, pulsed power, diagnostics, controls, electronics and fabrication, and has well over 500 years of combined fusion research experience. This group of scientists, engineers and technologists is working at TAE's state-of-the-art plasma research facility in Orange County, California.

The core of the facility is the world's largest FRC plasma device named C-2,[1] in which neutral beams (20 - 40 keV hydrogen, ~ 4 MW total)[2] were injected tangentially to produce a significant fast-ion population. In the C-2 experiment, neutral beam injection (NBI), coupled with electrically-biased plasma guns at the plasma ends, magnetic end plugs, and advanced surface conditioning, led to dramatic reductions in turbulence-driven losses and greatly improved plasma stability.[3] Under such conditions, highly reproducible, macroscopically stable, hot FRCs with total plasma temperature of ~ 1 keV and record lifetimes were achieved.[4]

The C-2 device has been recently upgraded with a new NBI system, which was designed and built in collaboration with the Budker Institute of Nuclear Physics (Novosibirsk, Russia). The C-2-Upgrade NBI system consists of six highly reliable and robust injectors based on positive ion technology. The system can deliver up to a total of 10 MW of hydrogen beam power (15 keV, 8 ms pulse), by far the largest ever used in compact toroid plasma experiments. The injectors feature flexible, modular design based on a triode ion optical system with slitted multi-aperture inertially cooled grids and geometrical beam focusing. The cold-cathode arc discharge plasma sources[5] generate up to 180 Amps of extracted ion current.

The NB injectors were commissioned in the on-site test facility that allows a complete characterization of the injector performance, including measurements of the beam divergence and focal length, and determination of the beam composition. In my talk, I will briefly describe the C-2U device and main aspects of the TAE experimental effort. The primary focus of the talk will be on the TAE NBI program, specifically: 1) the development of the NB injectors in a collaborative effort with Budker Institute, 2) test facility, diagnostics, and associated components and infrastructure, 3) integration with the C-2U machine, 4) results of acceptance tests and operating experience.

References

[1] M.W. Binderbauer *et. al*, Phys. Rev. Lett **105**, 045003 (2010).
[2] A. Sorokin *et. al*, Rev. Sci. Instrum. **81**, 02B108 (2010).
[3] M. Tuszewski *et. al*, Phys. Rev. Lett **108**, 255008 (2012).
[4] M.W. Binderbauer *et. al*, accepted to Phys. Plasmas in 2015.
[5] A.A. Ivanov *et. al*, Rev. Sci. Instrum. **79**, 02C103 (2008).

ThuPE17

Physics-Electrical Hybrid Model for Real Time Impedance Matching and Remote Plasma Characterization in RF Plasma Sources

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For RF plasma sources, impedance matching & plasma characterization is very important for efficient plasma operation. In long pulse operation, particularly with high power (~ 100kW or more) where plasma load may vary due to different reasons (e.g. pressure, power, etc.), online tuning of impedance matching circuit is useful. In many cases, manual tuning is not feasible in real time. In some cases matching quality is found out indirectly by phase value cos (ϕ), between RF output voltage and corresponding current. It has been found and verified by experiment that cos (ϕ) may not be a true representative of RF impedance matching for efficient RF power coupling with plasma load in an inductively coupled plasma (ICP) source. In ICP plasma load depends on plasma density. Plasma density characterization is an integral activity for source operation. In some cases due to remote interfaces, radio activation and maintenance issues high power probes are not allowed to incorporate in the ion source design for plasma characterization. Therefore, for characterization, more remote schemes are envisaged. Using electrical parameter one scheme is described [1] to estimate plasma density. Heat load dissipated in the RF antenna can be estimated from the cooling circuit associated with the antenna. Which can be a representative of impedance mismatch with plasma load. Measuring mismatch in the plasma load impedance by using calorimetric data using air-core transformer model for matching [2] can be another alternative procedure. Both the schemes are based on air core transformer model and some limitations are present in the model, which are also discussed in those references. To overcome some of the issues, one physics based code *HELIC* [3] is linked with the model to study the influence of the RF field interaction with the plasma to its impedance.

In this work we shall present the physics-electrical coupled model based on wave-antenna spectrum coupling in the perspective of both automatic remote RF tuning & plasma characterization. This model can be useful for both type of RF sources i.e. ICP & Helicon sources.

References

1. M. Bandyopadhyay, Dass Sudhir and A. Chakraborty, "Plasma density estimation of a fusion grade ICP source through electrical parameters of the RF generator circuit" Nuclear Fusion **03**, 033017, (2015); DOI: 10.1088/0029-5515/55/3/033017.
2. Dass Sudhir, M. Bandhyopadhyay, W. Kraus, A. Ghalaut, G. Bansal and A. Chakraborty, "Online Tuning of Impedance Matching Circuit for Long Pulse Inductively Coupled Plasma Source Operation-An Alternate Approach" Review of Scientific Instruments, **85**, 013510, (2014).
3. D. Arnush, "Role of Trivelpiece-Gould Waves in Antenna Helicon Wave Coupling", Phys. Plasmas 7, 3042 (2000).

ThuPE18

Self-induced Steady-state Magnetic Field in the Negative Ion Sources with Localized RF Power Deposition

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The study is an extension of a recent activity [1,2] on modelling of the SPIDER source [3] which is under development regarding the neutral beam injection system of ITER. The source is with eight drivers (inductive discharges with cylindrical coils) and a large-area chamber common for all the drivers. In the 2D modelling ([1,2] as well as here) the modelling domain is half of a single driver with the volume from the large-area chamber belonging to it. The previous results [1,2] show that due to a shift in the positions of the maxima of the electron density and temperature, associated with the localization of the rf power deposition outside the region of high electron density, the regime of the discharge is non-ambipolar, with a vortex dc current flowing in a rf discharge. The conclusion drawn is for strong non-locality in the discharge behaviour and, respectively, for strong impact of the fluxes not only of the charged particles but also of the neutral species, including also the energy fluxes. The study of the discharge structure is extended here with accounting for the dc magnetic field self-induced by the dc current. The results are for the modifications, caused the magnetic field, in the discharge behaviour.

References

1. D. Todorov, A. Shivarova, Ts. Paunska, and Kh. Tarnev, *Phys. Plasmas* **22**, 033504 (2015).
2. D. Todorov, Ts. Paunska, Kh. Tarnev, and A. Shivarova, *AIP Conf. Proc*. **1655**, 050007 (2015).
3. P. Sonato et al., *Fusion Eng. Des*. **84**, 269 (2009).

ThuPE19

Ion Collector Design for an Energy Recovery Test Proposal with the Negative Ion Source NIO1

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Commercial viability of fusion power plants depends also on minimizing the recirculation power used to operate the reactor. In thermonuclear fusion research, the neutral beam heating is one of the most important ways to ensure the plasma heating. For the future fusion power plant project DEMO, a neutral beam wall plug efficiency at least of 0.4 ÷ 0.55 is required[1]. The neutral beam wall plug efficiency foreseen for the present fusion reaction project (ITER) instead is only about 20% [1]. Neutral beams are realized by using a negative ion source whose D^- beam can be neutralized by a gas cell. In that process the production efficiency of the neutral beam is lower than 55% but an increase up to75% could be obtained when an ion beam energy recovery system is applied[2].

Recently the test negative ion source NIO1 (60 keV, 9 beamlets with 15 mA H^- each) has been designed and built at RFX (Padua) to study how negative ion production efficiency and the beam quality could be improved in fusion application [3].

In this paper a proposal to use the NIO1 source also for a beam Energy recovery test experiment is done and a preliminary design of a negative ion beam collector with simulations of beam energy recovery is also presented and discussed.

References

[1] R. Mc Adams, ‘Beyond ITER:Neutral beams for DEMO’, invited paper on Proceedings ICIS 2013, Chiba, Japan.

[2] H. J. Hopman, ‘Energy Recovery for Negative Ion Based Neutral Beam Lines’, Nuclear Fusion, vol.29, n. 4, (1989)

[3] M. Cavenago et al.,’NIO1 a Versatile Negative Ion Source’, on Proceedings IPAC 2010, Kioto, Japan.

ThuPE20

Transmission of electrons inside the cryogenic pumps of ITER Neutral Beam Injector

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The conversion of fast ions to neutrals and their injection in magnetically confined plasmas is fundamental to increase the particle energy and enhance the fusion process. In advanced fusion devices the use of negative ions is necessary, due to their high neutralization yield in collisions with a gas target even at particle energy around 1MeV. This feature is exploited by interposing along the negative ion beam path a neutralizer, i.e. a component where a flux of neutral gas is steadily injected. On the open sides of the neutralizer the gas leaks out, determining beam losses (by stripping inside the accelerator or re-ionization of neutrals after the neutralizer) that should be limited as much as possible.

The opposite requirements of high gas density in the neutralizer and low density elsewhere in the accelerator and the beamline determines huge requirements for the pumping system; cryogenic pumps are a standard choice in nowadays neutral beam injector. In such pumps particles are trapped on the active surfaces of the pump, kept at liquid helium temperature and combined with the use of highly sorbing materials such as activated charcoal.

In the ITER NBI beamline, 8x2.5 m2 cryogenic pumps are installed on either side of the beamline vessel, for a total pumping speed of 5000 m3/s in hydrogen and an expected background pressure down to 10-3 Pa in the vessel [1] during the beam-on phase. The charcoal active surfaces are shielded from any source of direct heat (radiation from other components or high energy secondary particles); nonetheless, stray electrons may overcome those barriers by multiple bounces and compromise the pump operation. Their contribution to the overall efficiency of the cooling plant was never verified but it is necessary to assure the proper operation of the pumping system, especially during long beam pulses.

In this paper we present a simulation of the electron propagation of the electrons inside the pump. A general electron transmission probability has been calculated by simulating a uniform distribution of electron, and following their trajectories in one of the 16 periodic modules of the pump, taking into account their geometry and the local magnetic field. The resulting transmission probability, depending on the initial position, angle, and energy of the particles has been applied to project the starting distribution of electrons entering the pumps (calculated a priori with beam transport models described elsewhere [2,3]) on the critical panels, to obtain the power load on the active surfaces of the pumping system of ITER NBI and its test facility MITICA.

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References

[1] M. Dremel et al., Fusion Engineering and Design 84, 689–693, (2009) .
[2] E.Sartori, P.Veltri, et al., IEEE Transaction on Plasma Science, vol. 42, n.3, (2014)
[3] P. Veltri, P. Agostinetti, M. D. Palma, E. Sartori, and G. Serianni, Fusion Eng. Des., vol. 88, nos. 6-–8, pp. 1011–1014, (2013).

ThuPE21

Development and preliminary results of radio frequency ion source

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The neutral beam injector (NBI) on the Experimental Advanced Superconducting Tokamak (EAST) is designed with high power of 2-4 MW and long pulse of 10-100 s. The hot cathode bucket ion source is employed on the EAST-NBI system. Consider the lifetime of hot cathode during long pulse operation and the future requirement of high power ion source of NBI for the next generation of fusion device, the radio frequency (RF) ion source was designed and development.

A RF driver has a cylinder structure with diameter of 210 mm and height of 160 mm. The thickness is 8 mm. A copper faraday shield with thickness of 3 mm is installed in the RF driver. A 6 turns RF coil with outer diameter of 6.5 mm and inner diameter of 4mm is installed out the driver to couple the RF power to plasma. A manual marching box is also designed with RF frequency of 1 MHz frequency. The RF driver was tested on the RF driver test bed. The puffer gas can be changed between with hydrogen and argon. The RF power can achieve 10 kW with stable plasma. The plasma parameters were measured with double probe system.

In the future, the auto marching box will be developed and the RF plasma will be tested with RF power large than 10 kW. Besides, a RF source with two drivers will be development and tested too.

ThuPE22

Single Element of the Matrix Source of Negative Hydrogen Ions: Measurements of the Extracted Currents Combined with Diagnostics

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Combining experiments on the negative ion extraction with discharge diagnostics (probe and laser photodetachment diagnostics),the study is an extension of recent experiments [1-3] in a single discharge of the matrix source [4]. The single element of the source is a small (2.25 cm) radius hydrogen discharge ending at the first electrode of the extraction device (a three electrode system completed by a plasma electrode, an extraction/electron suppression electrode, with permanent magnets embedded in it, and a Faraday cup for measuring the extracted negative-ion current). The discharge is inductively driven by a planar coil positioned on its front wall. The axially movable Langmuir probe used in the probe diagnostics provides results for the axial variation of the electron density and temperature and of the plasma potential. In the laser photodetachment measurements a radially oriented laser beam (from a Surelite III-10 Nd:YAG laser operating at its second harmonics) combined with the probe provides results for the electronegativity and the negative ion density in the vicinity of the extraction device. In the measurements on the extraction, the extracted currents of negative ions and electrons are measured for different voltages applied to the electrodes of the extraction device. The conclusions are for the correlation between the plasma parameters and the extracted current densities.

References

1. St. Lishev, D. Iordanov, Kh. Tarnev, and A. Shivarova, 31st Int. Conf. on Phenomena in Ionized Gases (ICPIG-2013, July 14-19, 2013, Granada, Spain), topic no. 8.
2. St. Lishev, D. Yordanov, and A. Shivarova, *Rev. Sci. Instrum.***85**, 02B101 (2014).
3. St. Lishev, D. Yordanov, and A. Shivarova, *AIP Conf. Proc*. **1655**, 040013 (2015).
4. St. Lishev, Ts. Paunska, A. Shivarova, and Kh. Tarnev, *Rev. Sci. Instrum*. **83**, 02A702 (2012).

ThuPE23

Steady state thermal-hydraulic analysis of the MITICA experiment cooling circuits

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The MITICA (Megavolt ITER Injector Concept Advancement) experiment [1] is the full scale prototype of the Heating and Current Drive Neutral Beam Injectors for ITER, to be built at Consorzio RFX (Padova). The injector is designed to deliver about 17 MW neutral beam of deuterium particles, obtained from a precursor beam of negative ions accelerated to 1 MeV. The MITICA components will be subjected to heat loads between 2 and 19 MW and heat fluxes up to 20 MW/m^2, during one hour beam pulses, thus setting demanding requirements for a reliable active cooling.

The high heat fluxes on the accelerating grids due to stray particles, the temperature control required for optimal cesium deposition on plasma grid and plasma source walls, the highly concentrated load on the back plate due to back streaming ions, and the delicate RF drivers, make the MITICA beam source [2] a very challenging system in which the correct prediction of the flow rate partitioning and coolant temperatures are mandatory. The beam line components [3] also deal with severe heat loads, high coolant temperature and pressure, and like the beam source, are subjected to regulatory limits.

Several analyses have been carried for optimizing the cooling circuits. The thermo-hydraulic behavior of each cooling circuit under steady state condition has been investigated by using one-dimensional models. Complex geometries whose hydraulic behaviors are not available in literature have been studied by detailed three dimensional CFD models and then their characteristic curves (pressure drop vs. mass flow rate) have been included in the one-dimensional models as concentrated pressure drop elements to fully characterize the circuits. The models have been used as versatile tools in order to improve and modify the cooling circuits' layout during the design. The final results, obtained considering a number of optimizations for the cooling circuits, show that all the requirements in terms of flow rate, temperature and pressure drop are properly fulfilled.

References

[1] V. Toigo, et al., Progress in the realization of the PRIMA neutral beam test facility, Nuclear Fusion **55** 083025

[2] D. Marcuzzi, et al., "Final Design of the Beam Source for the MITICA Injector", to be presented at this conference

[3] M. Dalla Palma, et al., "Design and R&D for manufacturing the beamline components of MITICA and ITER HNBs", in press, doi:10.1016/j.fusengdes.2015.06.092

ThuPE24

Charge State Breeding Experiences and Plans at TRIUMF

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At the ISAC facility at TRIUMF radioactive isotopes are produced by bombarding solid targets with high energy (480MeV) protons. The products diffuse out of the target into an ion source. Ions are extracted at several tens keV and selected in a mass separator. After separation they are either sent directly to experiments or post-accelerated. Due to the proximity of the target at high temperature and in high radiation fields, the ion sources have to be robust and with low maintenance requirements. As a result, mainly singly charged ions can be extracted. For post-acceleration, charge state breeding with an electron cyclotron resonance ion source (ECRIS) has been chosen. Shortly after the installation and first tests of this source it became clear, that the background from stable contaminants in the source plasma can be orders of magnitude higher than the intensity of the rare radioactive ions. Several measures, including changing materials for the plasma chamber and the surrounding components, have been implemented to reduce this background. Further reduction has been achieved by using the post-accelerator chain as a mass filter. This made a first physics experiment on accelerated Sr isotopes possible in 2013. Several more experiments have since followed.

With the planned expansion of the isotope production capabilities at TRIUMF within the ARIEL project, two new target stations, one using photo-fission induced by a high-power electron beam at 50 MeV and the other one using 480 MeV protons as at ISAC, will be put into operation within the next 5 years. Additionally, a new electron beam ion source (EBIS) based charge state breeding system will be installed. Background from such a source is expected to be much lower as no plasma wall interaction is involved. The drawback is that for the efficient operation of such a system pulsed beam operation is required. Bunching of the incoming beam after mass separation will be done with a gas-filled radio frequency quadrupole cooler/buncher. In order to minimize decay losses from short-lived isotopes the repetition frequency will be at 100 Hz.

Results from the existing system and design parameters for the planned facility will be presented.

ThuPE25

Integration of RFQ Beam Coolers and Solenoidal Magnetic Field Traps

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Electromagnetic traps are a flexible and powerful method of controlling particle beams, possibly of exotic nuclei, with cooling (of energy spread and transverse oscillations) provided by collisions with light gases as in the Radio Frequency Quadrupole Cooler (RFQC) or with charged particles (as in electron coolers or charge breeder trapping). In particular in the context of the Coolbeam project, a prototype of an RFQC is being built, and two test beamlines are being considered. Both beamlines are based on a alkali metals surface ionization source, followed by a low energy transport at about 5 keV, deceleration into RFQC to energy E_b , and reacceleration towards an emittance meter. One beamline is planned to be placed with a suitable adapter inside the existing Eltrap solenoid, capable of providing a magnetic flux density component B_z up to 0.2 T, where z is the solenoid axis. Confinement in the transverse plane is provided both by B_z and the rf voltage V_{rf} (up to 1 kV at few MHz). Transport is provided by a static electric field E_z (order of 100 V/m), while gas collisions (say He at 1 Pa, to be maintained by differential pumping) provide cooling or heating depending from V_{rf}. So the major parameters E_b, E_z, V_{rf} (and possibly B_z) must be optimized for maximizing beam transmission (at a cooling rate adequate for SPES project needs), both by experiments and by numerical simulations, as it is summarized. A status of installation progress is here reported, including commissioning of the emittance meter and of several insulators and feedthroughs needed.

ThuPE26

The new ECR charge breeder for the selective production of exotic species project at INFN - Laboratori Nationali di Legnaro

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The Selective Production of Exotic Species (SPES) project is an ISOL facility under construction at Istituto Nazionale di Fisica Nucleare - Laboratori Nationali di Legnaro (INFN-LNL). 1+ radioactive ions, produced and extracted from the Target-Ion-Source system, will be charge bred to high charge states by an ECR charge breeder (SPES-CB): the project will adopt an upgraded version of the PHOENIX charge breeder, developed since about twenty years by the Laboratoire de Physique et de Cosmologie (LPSC). The collaboration between LNL and LPSC started in 2010 with charge breeding experiments performed on the LPSC test bench and led, in June 2014, to the signature of a Research Collaboration Agreement for the delivery of a complete charge breeder and ancillaries, satisfying the SPES requirements. Important technological aspects were tackled during the construction phase, as for example beam purity issues, electrodes alignment and vacuum sealing. This phase was completed in spring 2015, after which the qualification tests were carried out at LPSC on the 1+/n+ test stand. This paper describes the characteristics of the SPES-CB, with particular emphasis on the results obtained during the qualification tests: charge breeding of Ar, Xe, Rb and Cs satisfied the SPES requirements for different intensities of the injected 1+ beam, showing very good performances, some of which are "best ever" for this device. The SPES beam lines have been modified since the original design, details about these modifications will also be reported.

ThuPE27

Electromagnetic Analysis of the Plasma Chamber of an ECR-based Charge Breeder

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The optimization of the efficiency of an ECR-based charge breeder is a twofold task: efforts must be paid to maximize the capture of the injected 1+ ions by the confined plasma and to produce high charge states to allow post-acceleration at high energies. Both tasks must be faced by studying in details the electrons heating dynamics, influenced by the microwave-to-plasma coupling mechanism. Numerical simulations are a powerful tools for obtaining quantitative information about the wave-to-plasma interaction process, the first step being the determination the electromagnetic field allowed inside the plasma chamber.

This paper presents a numerical study of the microwaves propagation and absorption inside the plasma chamber of the PHOENIX charge breeder, which the Selective Production of Exotic Species (SPES) project, under construction at Legnaro National Laboratories (LNL), will adopt as charge breeder. Calculations were carried out with a commercial 3D FEM solver: first, all the resonant frequencies were determined by considering a simplified plasma chamber as an empty cavity. Then, the realistic geometry was taken into account, together with a plasma with a simplified structure, to study the wave-plasma interaction for the three closest frequencies to the operating one (14.521 GHz). The results give important information about the power absorption and losses, and will allow the calculation of electron motion using a single particle approach: the last will be a valuable output allowing to obtain a plasma model to be used in a refined step of calculation reproducing the breeding process itself.

ThuPE28

The remote control system in the Target source of ISOL

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BRISOL(Beijing Radioactive Isotope Separate On-Line) , as a subproject of BRIF(Beijing Radioactive Ion-beam Facilities) ,a remote control system is developed in it's target source for the purpose of maintenance under the condition of high radioactivity level due to Neutron activation. In this design scheme, the target source is separated into 3 modules individually. The connections between modules and main system, include cooling water, power supply etc, are integrated into quick connect coupling module. A crane with high position precision is equipped for conveying the modules form it's vacuum container to hot-cell or replace it to right position.

ThuPE29

Study on a singly charged ion source for radioactive ^{11}C ion acceleration

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A new singly charged ion source has been developed to realize an ISOL (Isotope Separation On-Line) system for a PET imaging simultaneously with the heavy-ion cancer therapy using radioactive ^{11}C ion beams. In the ISOL scheme, ^{11}C molecules are firstly produced by irradiating boron compound target with proton beams provided by a small cyclotron. Then, 1+ ions are firstly produced from the ^{11}C molecules with the singly charged ion source. Finally, after the isotope separation with an analyzing magnet, the $^{11}C^{+}$ ions are further ionized by employing an EBIS/ESIS as a charge breeding ion source to obtain required charge state for the HIMAC injector.

The singly charged ion source employs a barium impregnated tungsten cathode and ionizes the ^{11}C molecules by electron bombardment. Because the singly charged ion source is required to have high ionization efficiency, effective flight paths of the electrons emitted from the cathode have to be extended. For that reason, magnetic field is applied in the ionization region of the ion source and its direction is set parallel to that of the ion extraction. To decide the geometric parameters of the ion source, ionization efficiency was estimated considering balance among inflow of molecules and outflow of molecules/ions from the ionization region. Based on those considerations, the electron bombardment ion source was designed and fabricated. Details of the design and experimental results showing its fundamental performances are to be presented.

ThuPE30

Electrical-thermal-structural coupled-field finite element modeling and experimental testing of high-temperature ion sources for the production of radioactive ion beams

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In the specific field of isotope separation on line (ISOL) facilities, two of the most widely used ion source types are the hot-cavity ion source[1] (used for both surface and laser ionization) and the forced electron beam induced arc discharge (FEBIAD) ion source[2]. In both cases a specific high temperature field is required, mainly to maximize the ionization efficiency, and to obtain short confinement times (with a consequent reduction of particle decay losses). High temperatures are reliably obtained making use of tantalum components, that can be easily resistively heated, showing in the same time a high ductility during operation, and a good machinability in the production phase. In this work the electrical-thermal behavior of both the aforementioned ion sources is studied in detail by means of dedicated coupled field finite element models[3], and taking as a reference the specific ion source versions adopted for the selective production of exotic species (SPES) facility[4]. Since thermal expansions can affect significantly the functioning of FEBIAD ion sources (especially at the cathode-anode interface), a detailed thermal-structural study is also presented for this specific ion source type. Then, numerical results are compared with electric potential difference, temperature, and displacement measurements, allowing for validation of both the electrical-thermal and the thermal-structural models. Finally, ionizing electron current values for the SPES FEBIAD ion source are estimated combining calculated temperatures with the well-known Richardson formula and Child-Langmuir relation, showing a good agreement with the corresponding experimental values. The approach presented in this work can be taken as a reference for the electrical-thermal-structural design of new hot-cavity and FEBIAD ion sources, including the high temperature targets and ovens often related to their functioning. In the specific case of FEBIAD ion sources, the ionizing electron current can also be predicted with a high level of accuracy.

References

[1] M. Manzolaro, G. Meneghetti, A. Andrighetto, Nucl. Instrum. and Meth. Phys. Res. A 623, 1061 (2010).

[2] M. Manzolaro, A. Andrighetto, G. Meneghetti, A. Monetti, D. Scarpa, M. Rossignoli, J. Vasquez, S. Corradetti, M. Calderolla, G. Prete, Rev. Sci. Instrum. 85, 02B918 (2014).

[3] G. Meneghetti, M. Manzolaro, A. Andrighetto, Fin. Elem. Anal. Des. 47, 559 (2011).

[4] A. Andrighetto, C.M. Antonucci, S. Cevolani, C. Petrovich, M. Santana Leitner, Eur. Phys. J. A 30, 591 (2006).

ThuPE31

Charge breeder for the SPIRAL1 upgrade: preliminary results

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In the framework of the SPIRAL1 upgrade under progress at the GANIL lab, the charge breeder based on a LPSC Phoenix ECRIS, first tested at ISOLDE [1] has been modified as to benefit of the last enhancements of this device from the 1+ / n+ community [2].

The modifications mainly concern:

- The injection optics which now include a movable grounded tube and a quadrupole triplet for a more precise control of the 1+ ion beam parameters entering the ECR plasma.
- The use of pure Al components whenever possible (e.g. plasma chamber) to reduce the n+ radioactive beam contamination by stable beams
- Standard UHV techniques (e.g. replacing elastomeric rings by metal rings and optimizing vacuum conductances whenever possible) to reduce the residual gas pressure in and around the plasma chamber
- The injection of the support gas which is now done directly inside the plasma chamber

The latter two modifications aim at reducing charge recombination of the plasma ions with surrounding neutral gas.

Prior to its installation in the midst of the low energy beam line of the SPIRAL1 facility, it has been decided to qualify its performances and several operation modes at the test bench of LPSC lab.

This contribution shall present preliminary results of experiments conducted at LPSC concerning the 1+ to n+ conversion efficiencies for noble gazes as well as for alkali elements and the corresponding transformation times.

[1] P. Delahaye et al, Review of Scientific Instruments. **77**, 03B105 (2006)
[2] R. Vondrasek et al, Review of Scientific Instruments **83** 113303 (2012)

ThuPE32

Progress on the EBIS charge breeder system of RAON in Korea

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A rare isotope beam facility called RAON is under design and construction in Korea and will facilitate an ISOL system to produce rare isotopes using a proton beam accelerated from commercial cyclotron. The ISOL system will include an ISOL target, laser ion source, pre-separator, RFQ-cooler/buncher, and EBIS charge breeder. The charge-bread isotope beam extracted from EBIS will be post-accelerated by a superconducting linear accelerator. An EBIS system has been designed in beam optics using TRAK and PBGUN [1]. Mechanical design was followed along with thermo-mechanical analysis. The maximum electron beam current is set to be 3 A at 20 kV, and the maximum magnetic field in the trap region is 6 T. An electron collector which can has handle up to 20 kW has been designed and will be constructed in this year. An electron gun assembly employing an IrCe cathode was procured from BINP and has been tested. The test results of the electron gun and overall progress of the EBIS system will be presented.

References

[1] Jongwon Kim *et al*., “An EBIS system for Rare Isotope Science Project in Korea” in Proceedings of the XII International Symposium on Electron Beam Ion Sources and Traps, AIP Conf. Proc. 1640, 38-43 (2015).

ThuPE33

Background Reduction in the CARIBU ECR Charge Breeder

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An ECR charge breeder, as part of the Californium Rare Ion Breeder Upgrade (CARIBU) program at Argonne National Laboratory, has been providing beams of highly charged ions to the ATLAS facility for the past several years. The charge breeding efficiency and high charge state production of the source are at the forefront of ECR charge breeders, but its overall performance as part of the accelerator system has been limited by a pervasive stable ion background typically on the order of 10^6 to 10^7 pps even in the cleanest regions of the M/q spectrum. Various steps have been taken to reduce the level of background contamination including precision cleaning with CO_2 ice particles and coating of the plasma chamber with high purity aluminum. The results of these procedures as well as possible further improvements will be discussed.

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ThuPE34

First results on Ge resonant laser photoionization in hollow cathode lamp

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In the framework of the research and development activities of the SPES project regarding the optimization of the radioactive beam production, a dedicated experimental study has been recently started in order to investigate the possibility of laser ionization in-source production of Germanium using a set of tunable dye lasers.

Germanium is in fact one of the candidates beams to be accelerated by the SPES ISOL facility, which is under construction at Legnaro INFN Laboratories.

The three-step, two color ionization schemes have been tested along with a Ge Hollow Cathode Lamp (HCL).
The "slow" and the "fast" optogalvanic signals were detected and averaged by an oscilloscope as a proof of the laser ionization inside the lamp.

As results, several wavelength scans across the resonances of ionization schemes were collected with the "fast" optogalvanic signal. Some comparisons of ionization efficiency for different ionization schemes were made. Furthermore, saturation curves of the first excitation levels have been obtained.

This investigation method and the set-up built in the laser laboratory of the SPES project can be applied for the photo-ionization scheme studies also for the other possible RIB elements.

ThuPS01

High Intensity High Charge State Ion Beam Production with an Evaporative Cooling Magnet ECRIS

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LECR4 (Lanzhou ECR ion source No.4) is a room temperature electron cyclotron resonance ion source, designed to produce high current, high charge state ion beams for the SSC-LINAC injector (a new injector for Sector Separated Cyclotron) at the Institute of Modern Physics. LECR4 also serves as a PoP machine for the application of evaporative cooling technology in accelerator field. To achieve those goals, LECR4 ECR ion source has been optimized for the operation at 18 GHz, with the optimal axial confinement mirror fields of 2.5 T and 1.3 T and 1.0-1.1 T radial field on the plasma chamber wall. In February 2014, the first analyzed beam was extracted. During 2014, LECR4 ion source was commissioned at 18 GHz microwave of 1.6 kW with an injection pumping free system. To further study the influence of injection pumping system to the production of medium and high charge state ion beams, in March 2015, an injection system with pumping system was installed, and some optimum results were produced, such as 2110 euA of O^{6+}, 560 euA of O^{7+}, 580 euA of Ar^{11+}, and so on. The comparison will be discussed in the paper.

ThuPS02

Investigation on the Pulsed Mode Operation of the Frequency Tuned CAPRICE ECRIS

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For the research programs of the currently operational and future accelerator facilities there is an increasing demand for more intense highly charged ion beams. To satisfy such demand, especially for heavy ion beam production, the operational parameters of the Electron Cyclotron Resonance Ion Sources (ECRISs) should be shifted to higher frequencies, higher power and higher magnetic flux densities.

Several techniques have been developed to improve the performance of the existing ECRIS to fulfill this request. Recent experimental results proved that the tuning of the operating frequency of the ECRIS is a promising technique to achieve higher ion currents of higher charge states. On the other hand it is well known that the afterglow mode of the ECRIS operation can provide more intense ion beams in comparison with the continuous wave (cw) operation. These two techniques can be combined by pulsing the variable frequency signal driving the Traveling Wave Tube Amplifier providing the high microwave power to the ECRIS. In order to analyze the effect of these two combined techniques on the ion source performance, several experiments were carried out on the pulsed frequency tuned CAPRICE-type ECRIS. Different waveforms and pulse lengths have been investigated under different settings of the ion source. The results of the pulsed mode have been compared with those for cw operation.

ThuPS03

Producing Multicharged Fullerene Ion Beam Extracted from the Second Stage of Tandem Type ECRIS

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Synthesis of endohedral fullerene has been investigated on tandem type electron cyclotron resonance ion source (ECRIS) in Osaka Univ. Endohedral fullerene is expected to be utilized for such as quantum computing or magnetic resonance imaging contrast agent, because it has various material character.[1] The tandem type ECRIS comprises the first stage, the second stage, beam line, and irradiation stage.[2] The first and the second stage are possible to generate plasma individually, and also they are confined individual ion species by each different plasma parameter. Hence, it is considered to be suitable for the synthesis of materials.

In order to supply fullerene vapor in high vacuum, a new evaporator is developed. The evaporator is constructed with Ta ohmic wire heater and crucible filled with the fullerene powder. Fullerene vapor is supplied to the second stage from this evaporator, and we try to produce and extract multichraged fullerene ions. In this experiment, He gas is supplied to the second stage to keep plasma stable. Malticharged fullerene spectrum are successfully observed for the first time in the tandem type ECRIS. In future, we are going to synthesize iron endohedral fullerene by iron ion beam transport to the second stage from the first stage.

References

1. T. Uchida, *et.al*, Rev. Sci. Instrum, **85**, 02C317 (2014) 2. Y. Kato, et.al, Rev. Sci. Instrum. **85**, 02A950 (2014)

ThuPS04

Effect of Axial Magnetic Field on a 2.45 GHz Permanent Magnet ECR Ion Source

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We have built a new 2.45 GHz permanent magnet electron cyclotron resonance ion source at Oshima College (Oshima-ECRIS) [1]. Our target is middle-charged ion beam production for industrial applications, i.e. ion implantation for semiconductors. Therefore, we selected an ECRIS with a 2.45 GHz microwave source and permanent magnets as a low-cost and low-power consumption ion source. However, 2.45 GHz ECRISs generally have low ionization efficiency compared with higher frequency ones. We need to develop the technique to improve the efficiency.

As a first step, we have investigated the optimization of the axial magnetic field. Though magnetic fields on ECRISs is the most important factor, normal permanent magnet ECRIS cannot vary the magnetic field. Since the Oshima-ECRIS has three electric coils for adjusting axial magnetic field, we can adjust the mirror magnetic field, i.e. the strength of injection and extraction side magnetic fields and mirror ratio. We study the variation of ion beams against the axial mirror field configuration. As a result of experiment, the tendency that the production of the multivalent ion changed by adjusting a magnetic field of the beam outlet side was seen.

We will describe the detailed results at the conference.

References

[1] T. Asaji, et al., Rev. Sci. Instrum. 85, 02A940 (2014).

ThuPS05

Experimental Results of Launching Extraordinary Mode Microwaves on ECRIS Plasma

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It has been investigated how to produce multicharged ions efficiently on the tandem-type ECRIS in Osaka Univ.[1] On the 2nd stage of the tandem-type ECRIS, the maximum electron density over cutoff density was observed by Langmuir probe.[2] Therefore, the microwave propagation and accessibility to resonance regions came to be considered. We can estimate accessibility of microwave with the magnetic flux density and the electron density profile based on the previous experimental results. As a result, it was suggested that the upper hybrid resonance (UHR) heating contributes to enhancement of ion beam intensity.[3]

Now we are trying to inject higher frequency microwave with extraordinary(X) mode toward UHR region directly. The effect of additive microwave injection will be investigated experimentally in terms of plasma parameters and electron energy distribution function (EEDF) by Langmuir probe and charge state distribution (CSD). In addition, the application of UHR heating to other sources will be also proposed. Moreover, relativistic mass and Doppler shift effect on resonances will be considered in this paper in brief.

References

1. Y. Kato et al., RSI, **85**, 02A950 (2014).
2. K. Yano, et al., RSI, **85**, 02A937 1-3 (2014).
3. Y. Kato, et al., ICIS2015, contribution.

ThuPS06

Progress of High-Temperature Oven Development for 28 GHz ECR Ion Source

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At the RI-beam factory at RIKEN, uranium is the most frequent requested beams for the experiments, and there is great need for an increase in the beam intensity. U^{35+} ions extracted from a superconducting 28 GHz ECR ion source are used for the acceleration of the uranium beam. The ion source is operated continuously for 1–1.5 months keeping the beam current of U^{35+} at approximately 100 μA. Although we operate the ion source by the sputter method of metal uranium at present, we have been developing a high-temperature oven in parallel with the aim to increase and to stabilize the beam current since the beginning of 2013. Because the oven method uses UO_2, a tungsten crucible with the inside dimensions of ϕ11 mm×13.8 mm is joule-heated to a temperature higher than 2000℃ with DC current of 450–510 A. In the operation of the oven, the UO_2 blocking of the crucible's ejection hole was often observed. This cause was estimated as follows from the ANSYS calculations: the temperature of the cap of the crucible near the ejection hole was low, and the body temperature around the ejection hole may reduce due to the local heating at the rods of the crucible. To resolve the blocking problem, We modified the crucible structure slightly. After the modification, the performance of the oven was dramatically improved. So far we successfully extracted the 100 μA U^{35+} for longer than one week continuously from the 28 GHz ECR ion source by using the high-temperature oven. The beam current was almost the same as that in the operation by the sputter method at the same RF powers. The consumption rate of UO_2 was 2–3 mg/h.

References

1. J. Ohnishi et al., Rev. Sci. Instrum. 85 (2014) 02A941.

ThuPS07

Improvements for Reliability and Lifetime Test of a High-Performance DC Microwave Proton Source

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In order to carry out a long term CW proton source experiment, improvements and modifications were done on Peking University compact permanent magnet 2.45 GHz ECR source(PKU PMECRs), faraday cup and the circumstance on PKU ion source test bench. At the beginning of 2015, a continuous operation of PKU PMECRs for 306 hours with more than 50 mA DC beam was carried out. Total beam availability, which is defined as 35-keV beam-on time divided by elapsed time, was higher than 99%. No plasma generator failure or high voltage breakdown was observed during that running period and the proton source reliability is near 100%[1]. A re-inspect was performance after another additional 100 hours operation (counting time) and no obvious sign of component failure was observed. Counting the previous running time together, this PMECRs longevity is now demonstrated to be greater than 450 hours. Details of the improvements will be given in the paper.

Reference

[1] Shixiang PENG, Ailin ZHANG, Haitao REN, Tao ZHANG, Yuan XU, Jingfeng ZHANG, Jianhua GONG, Zhiyu GUO and Jia'er CHEN, Note: Continuous operation of 2.45 GHz microwave proton source for 306 hours with more than 50 mA DC beam. Accepted by Chinese Physics B on 14 April, 2015.

ThuPS08

Status of Development of the FRIB High Performance Superconducting ECR Ion Source

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Facility for Rare Isotope Beams (FRIB) requires a high performance ECR ion source to produce intense beam of stable ions with the mass up to Uranium. A 28GHz superconducting ECR ion source is being developed at FRIB in collaboration with the Berkeley Superconducting Magnet Group (Supercon). The design of the source cold mass is based on the radial-key clamping scheme developed at Berkeley for high-field, high-performance magnets. In this talk I'll describe projected performance of the source, features of the source design such as the clamping scheme of the cold mass, its benefits for assembly and operation of the cold mass, cryostat design, present status of the project, and discuss future plans.

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

ThuPS09

X-ray Pinhole Camera Setups used in the Atomki ECR Laboratory for Plasma Diagnostics

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Imaging of the electron cyclotron resonance (ECR) plasmas by using CCD camera in combination with a pinhole is a non-destructive diagnostics method to record the strongly inhomogeneous spatial density distribution of the X-ray emitted by the plasma and by the chamber walls. This method can provide information on the location of the collisions between warm electrons and multiple charged ions/atoms, opening the possibility to investigate the direct effect of the ion source tuning parameters to the plasma structure. Studying the bremsstrahlung radiation can give information on the lost high energy electrons and, consequently, on the energy transfer from microwave to electrons.

The first successful experiment with a pinhole X-ray camera was carried out in the Atomki ECR Laboratory more than 10 years ago. The goal of that experiment was to make the first ECR X-ray photos and to carry out simple studies on the effect of some setting parameters (magnetic field, extraction, disc voltage, gas mixing, etc.). Motivated by the unique feature of this method recently intensive efforts were taken to investigate now the effect of different RF resonant modes to the plasma structure. Comparing to the 2002 experiment this campaign used wider instrumental stock: CCD camera with a lead pinhole was placed at the injection side allowing X-ray imaging and beam extraction simultaneously. Additionally, SDD and HpGe detectors were installed to characterize the volumetric X-ray emission rate caused by the warm and hot electron domains.

In this paper detailed comparison study on the two X-ray camera and detector setups and also on the technical and scientific goals of the experiments will be presented.

ThuPS10

Ion Beam Production with Sub-milligram Samples of Material from an ECR Source for AMS

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Current Accelerator Mass Spectroscopy (AMS) experiments at the ATLAS facility at Argonne National Laboratory push us to improve the ion source performance with a large number of samples and a need to minimize cross contamination. These experiments can require the creation of ion beams from as little as a few micrograms of material. These low concentration samples push the limit of our current efficiency and stability capabilities of the Electron Cyclotron Resonance Ion Source. A combination of laser ablation and sputtering techniques coupled with a new multi-sample changer have been used to meet this demand. We will discuss performance, stability, and consumption rates as well as planned improvements.

This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357. This research used resources of ANL's ATLAS facility, which is a DOE Office of Science User Facility

ThuPS11

Design optimization and performances system of 28GHz ECRIS Heavy ion accelerator for multi charge ion implantation

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The implantation beam-line of the 28GHz ECRIS Heavy ion accelerator, in Busan, has been recently completed with a beam monitoring system, and a sample holder system for implantation. The new implantation system converts the multipurpose tool to implant ions, between H and U, in different materials with precise control. The size of the implantation area on target may be as large as 1 _ 10 mm2. The implantation chamber also designed carrying out in situ system on the mass spectrometer line during and the beam is measured by diagnostic system, as well as ion beam analyses. This advancement 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. Implantation of multi-charge ion was carried out on the Copper, Zinc, Cobalt, Chrome substrate and the results of implantation tests and first experiments are shown.

ThuPS12

Ka-band Microwave Power Transmission System for 28 GHz Electron Cyclotron Resonance Ion Source at KBSI

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A 28 GHz microwave power transmission system is designed to deliver the 10 kW microwave power from a gyrotron oscillator to an electron cyclotron resonance ion source to produce both a high current and highly charged ions. The microwave power produced by the gyrotron oscillator, which is installed in Korea Basic Science Institute (KBSI), is measured using a directional coupler and a dummy load up to 10 kW at the frequency of 28 GHz. The gyrotron microwave power source of the transmission system operates in continuous wave mode with smoothly regulated output power. The whole microwave power transmission system is designed to transfer microwaves to the ion source at low power loss, low mode conversion, and low reflected power. To take account of these issues the transmission line between gyrotron and plasma chamber is comprised of arc detector, dual directional coupler, mode filter, mode converter, 90 degree corrugated bend, high voltage break, and vacuum window, which are arranged in the order named. In this paper, the design of a 28 GHz, 10 kW microwave transmission system and the measured performance of power transmission line will be presented in detail.

ThuPS13

First Results of 28 GHz Superconducting Electron Cyclotron Resonance Ion Source for KBSI Accelerator

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Since 2009, a 28 GHz superconducting electron cyclotron resonance (ECR) ion source was developed to produce high current heavy ion for the compact linear accelerator at KBSI (Korea Basic Science Institute). The aim of this study was to generate fast neutrons with the proton target by p(Li,n)Be reaction. The fabrication of the key parts, which are the superconducting magnet system with the liquid helium re-condensed cryostat and the 10 kW high-power microwave considering for optimum operation at the 28 GHz ECR Ion Source, were completed in 2013. In last year, the waveguide components were connected with a plasma chamber including a gas supply system and the plasma chamber were inserted into the warm bore of superconducting magnet. Also, the high voltage system was installed for bias disk and extraction disk. After installation of ECR ion source, we had reported results about ECR plasma ignition at ECRIS 2014 in Russia. In this year, we were extracted multi-charged ions from various gases that are argon, oxygen, xenon and so on. Also we were obtained some results about beam properties and they are verified by beam diagnostic system of low energy beam transport system. We report about their results and explain about current status of KBSI accelerator project.

ThuPS14

X-ray measurement on 28GHz KBSI ECRIS

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The X-rays of large amount can be produce from Electron Cyclotron Resonance (ECR) ion source. They can be adding an extra heat load to the cryostat, because be absorbed by the cold mass of the superconducting magnet. In addition, the measurements of X-ray spectra can be study about the electron beating process and the electron confinement. The measurements of X-ray spectra were carried out from the 28 GHz ECR ion source at KBSI. RF power dependency of X-ray spectrum is presented. X-ray spectrum with and without beam extraction were compared each other. For the x-ray shielding, while changing the thickness of the Ta-film measured by x-rays and compared with geant4.

ThuPS15

First Operation and Effect of a New Tandem-Type Ion Source Based on Electron Cyclotron Resonance

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A new tandem type source has been constructing on the basis of electron cyclotron resonance (ECR) plasma for producing synthesized ion beams in Osaka Univ.[1] Magnetic field in the first stage consists of all permanent magnets, *i.e.*, cylindrically comb shaped one[2], and that of the second stage consists of a pair of mirror coil, a supplemental coil and the octupole magnets. Both stage plasmas can be individually operated, and produced ions which energy controlled by large bore extractor also can be transported from the first to the second stage. We investigate the basic operation and effects of the tandem type ECR ion source (ECRIS). Analysis of ion beams and investigation of plasma parameters are conducted on produced plasmas in dual plasmas operation as well as each single operation. We describe construction and initial experimental results of the new tandem type ion source based on ECRIS with wide operation window for aiming at producing synthesized ion beams as this new source can be a universal source in future.

References

[1] Y. Kato,Y. Kurisu, D. Nozaki, K. Yano, D. Kimura, S. Kumakura, Y. Imai, T. Nishiokada, F. Sato, and T. Iida, Review of Scientific Instruments, 85 (2014) 02A950-1-3.

[2] T. Asaji, Y. Kato, F. Sato, T. Iida, and J. Saito, Review of Scientific Instruments, 77 (2006)113503-1-6.

ThuPS16

Accessibility Condition on Waves Propagation and Multicharged Ion Production in Electron Cyclotron Resonance Ion Source Plasma

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A new tandem type source on the basis of electron cyclotron resonance (ECR) plasma has been constructing for producing synthesized ion beams in Osaka Univ.[1] Magnetic mirror field configuration with octupole magnets can be controlled to various shape of ECR zones, namely in the second stage plasma to be available by a pair mirror and a supplemental coil. Noteworthy correlations between these magnetic configurations and production of multicharged ions are investigated in detail, as well as their optimum conditions. Interaction between plasmas and waves in magnetized plasma is essential issues for enhancing various kinds of resonance wave heating. We have been considered accessibility condition of electromagnetic and electrostatic waves propagating in ECR ion source (ECRIS) plasma, and then investigated their correspondence relationships with production of multicharged ions. It has been clarified that there exits efficient configuration of ECR zones for producing multicharged ion beams, and then has been suggested that new resonance, *i.e.* upper hybrid resonances, must have occurred. We are planning new advanced experiments inducing actively these additional effects for enhanced furthermore multicharged ion beams with launching extra-ordinary (X) mode waves.

References

[1] Y. Kato, Y. Kurisu, D. Nozaki, K. Yano, D. Kimura, S. Kumakura, Y. Imai, T. Nishiokada, F. Sato, and T. Iida, Review of Scientific Instruments, 85(2014)02A950-1-3.

ThuPS17

Beam Experiments with the Grenoble Test Electron Resonance Ion Source at iThemba Labs

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At iThemba Laboratory for Accelerator Based Sciences (iThemba LABS) a copy of the so-called Grenoble Test Source (GTS) for the production of highly charged ions is installed. The source in combination with the K-200 cyclotron delivers high energy, high intensity beams for nuclear physics experiments.

Because the source is similar to the so-called GTS-LHC at CERN -and therefore named GTS2- a collaboration between the Accelerators and Beam Physics Group of CERN and the ion source group of iThemba LABS was proposed in which the development of high intensity Argon and Xenon beams is envisaged.

In this paper we present experiments in CW and afterglow operation with the GTS2 for Xenon beams at iThemba LABS.

ThuPS18

Measurement of Ion Species in High Current ECR H^+/D^+ Ion Source for IFMIF (International Fusion Materials Irradiation Facility)

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A high current ECR ion source producing 140 mA/100 keV D^+ ion beams [1] for IFMIF accelerator is now under commissioning at Rokkasho in Japan, under the framework of ITER Broader Approach (BA) activities. The ion source for IFMIF is required to produce positive deuterium ion beams with a high D^+ ratio. After the mass separation in a low energy beam transport line (LEBT) consisting of two solenoids, the D^+ ratio should be higher than 95 % with less molecular ions and impurity ions at the entrance of the radio frequency quadrupole (RFQ) linac to be installed downstream.

The ion species have been measured by Doppler shift spectroscopy between the two solenoids. With hydrogen operation in pulsed and CW modes, the H^+ ratio increases with RF power or plasma density and reached 80 % at 160 mA/100 keV. The value was compared with that derived from the emittance diagram for each ion species measured by an Alison scanner installed nearby the viewport for the spectroscopy in the LEBT. It was found that the spectroscopy gives lower H^+ ratio than the emittance measurement. The ion species ratio in deuterium operation will be presented in this paper.

References

[1] R. Gobin *et al.*, Rev. Sci. Instrum. **85**, 02A918 (2014).

ThuPS19

Injection of auxiliary electrons for increasing plasma density in highly charged and high intensity ion sources

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Different electron guns based on cold cathode or hot cathode technology have been developed since 2009 at INFN for operating within ECR plasma chamber as sources of auxiliary electrons with the aim of boosting the source performances. Electron guns have been characterized in terms of duration, stability and impact on the plasma density and successfully tested on the CAESAR source. Their application to Microwave Discharge Ion Source, where plasma is not confined, has required an improvement of the gun design, in order to "screen" the cathode from the plasma particles and enable it to survive in a high energy content plasma environment. The experimental tests carried out on a plasma reactor show a boost of the plasma density, ranging from 10 to 90% when the electron guns are used, depending on the plasma regions (more relevant in the halo). The results will be commented along the paper and interpreted by plasma diffusion models.

ThuPS21

Kinetic Instabilities in Pulsed Operation Mode of a 14 GHz Electron Cyclotron Resonance Ion Source

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The occurrence of kinetic plasma instabilities is studied in pulsed operation mode of a 14 GHz A-ECR type electron cyclotron resonance ion source. It is shown that the temporal delay between the plasma breakdown and the appearance of the instabilities is on the order of 10-100 ms. The most important parameters affecting the delay are magnetic field strength and neutral gas pressure. It is demonstrated that kinetic instabilities limit the high charge state ion beam production in the unstable operating regime.

ThuPS22

Two-Chamber Configuration of Bio-Nano ECRIS for Fullerene Modification

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Modification of fullerenes, such as encapsulation of alien atom(s) into a fullerene cage, functionalization of the external surface of fullerene molecules, atomic substitution of carbon atom(s) in fullerene molecules, etc., is a key technique for the practical applications of fullerenes. We developed an electron cyclotron resonance ion source (ECRIS) aiming at the modification of fullerenes (Bio-Nano ECRIS) [1]. In a special two-chamber configuration of this ECRIS, two collisional modification processes can be performed simultaneously: a vapor-phase one taking place in the ECR plasma, and a surface-type one formed on the plasma chamber surface.

In this paper, we report on the modification of fullerenes with iron and chlorine using two individually controllable plasmas. One of the plasmas is composed of fullerene and the other one is composed of iron and chlorine. The online ion beam analysis allow to investigate the rate of the vapor-phase collisional modification process, while the offline analyses (e.g. time-of-flight mass spectrometry, liquid chromatography mass spectrometry, etc.) of the materials deposited on the plasma chamber can give information on the surface-type process. Both analytical methods show the presence of modified fullerenes such as fullerene-chlorine, fullerene-iron and fullerene-chlorine-iron, etc.

[1] T. Uchida, et al., Rev. Sci. Instrum. **85**, 02C317 (2014).

ThuPS23

Renewal of Control System for Efficient Operation in RIKEN 18 GHz Electron Resonance Ion Source

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To produce beams intensity for medium mass heavy ions, RIKEN 18 GHz electron resonance ion source (18GHz ECRIS) is used as one of the external ion sources of Radioactive Ion Beam Factory (RIBF) accelerator complex. In the majority of components which RIBF is composed, the control systems are integrated by Experimental Physics and Industrial Control System (EPICS). On the other hand, non-EPICS-based system, which has hardwired-controllers, was used in the 18GHz ECRIS control system as independent system. From the view point of efficient and effective operation, the 18GHz ECRIS control system should be renewed as well as RIBF control system by using EPICS. Therefore, we constructed 18GHz ECRIS control system by utilizing programmable logic controllers with embedded EPICS technology. In the renewal system, it is possible to handle the data analysis with each other between the RIBF accelerator complex and 18GHz ECRIS. In this contribution, we report the system design, the unique features of the system, and present status in detail.

ThuPS25

Development Status of a Next Generation ECRIS: MARS-D at LBNL

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Higher performance Electron Cyclotron Resonance Ion Sources (ECRISs) are needed to meet the unprecedented ion beam intensity requirements for the planned heavy ion accelerators and for upgrades to existing facilities. The next generation of ECRISs will operate at substantially higher magnetic fields and heating frequencies than current sources. These increases will require magnet structures using very challenging Nb3Sn superconducting coils, since the "3rd generation ECRISs" all utilize NbTi coils operating at their limits in order to produce magnetic field maxima of 4.0 T on axis and 2.0 T at the plasma chamber walls. A novel Mixed Axial and Radial field System (MARS) utilizes an exotic coil structure, which has a number of advantages over the current designs. The primary advantage is the potential to generate up to 50% higher fields with NbTi coils than the existing magnet structures and this could make MARS the best magnet scheme for the next generation of ECRISs. To validate the MARS' concept, a MARS demonstrator (MARS-D), using NbTi conductor is under development at Lawrence Berkeley National Laboratory. A test winding is in progress with copper wires and it has demonstrated the feasibility of fabricating the exotic shaped coil. To simplify the complexity of magnet cryostat fabrication, the MARS magnet design has been optimized so that this new one-fits-two design can be applied using either NbTi or Nb3Sn coils for production of high Minimum-B fields. TOSCA calculations have shown that the optimized NbTi MARS magnet could extend the range of usefulness of NbTi coils by producing a Minimum-B field with maxima of 5.6 T on axis and 3.2 T at the plasma chamber walls. An ECRIS built with this optimized NbTi MARS magnet would be able to operate with heating frequencies up to 45 GHz. This article will report the status of the MARS-D development, such as the prototyped copper coil, the optimized MARS magnet design and other associated technical challenges.

References

1. D. Z. Xie, Rev. Sci. Instrum. 83, 02A302 (2012).
2. D. Z. Xie *et al.*, Rev. Sci. Instrum. 85, 02A922 (2014).

ThuPS26

A 45 GHz Superconducting ECR Ion Source FECRAL and Its Technical Challenges

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A next generation heavy ion accelerator complex HIAF (High Intensity heavy ion Accelerator Facility) was proposed by IMP and officially approved for nuclear physics and high energy density physics research. HIAF requests ion source capable of delivering 50 pμA of $^{238}U^{34+}$ pulsed beam and 25 pμA of $^{238}U^{34+}$ CW beam for injector of a superconducting heavy ion linac. A 45 GHz superconducting ECR ion source FECRAL (a Fourth generation ECR ion source with Advanced design in Lanzhou) was proposed and got financial support as a key technology R&D for HIAF facility. This paper will present preliminary technical-design of FECRAL ECR ion source such as magnetic field distribution produced by Nb_3Sn superconducting magnet with 6.5 Tesla axial mirror field and 3.4 Tesla sextupole field on the chamber wall, 20 kW@45 GHz microwave coupling system and ion beam transport line. Obviously to build a 45 GHz FECRAL ECR ion source, there will be many technical challenges to be taken, such as engineering and fabrication of the Nb_3Sn superconducting magnet with 12 Tesla maximum magnetic field on the conductor, cryogenic system of the magnet, efficient coupling of 45 GHz microwave power, effective mitigation of the bremsstrahlung thermal radiation to the 4.2 K cryogenics system, intense beam extraction and transmission with good beam quality, integration of the FECRAL ion source system and analyzing beam line onto a high voltage platform.

ThuPS27

Emittance study of an 28GHz ECR ion source for the RISP superconducting linac

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A 28GHz ECR(Electron Cyclotron Resonance) ion source is under development as one of injectors for the RISP(Rare Isotope Science Project) superconducting linac. The KOBRA3D-INP code was adopted to simulate the beam extraction from the ECR ion source. The code can calculate the particle trajectories under the three dimensional complex magnetic field structures which are made by superconducting magnets, four solenoids and a saddle-type sextupole. The beam transport after the ECR ion source is calculated by using the TRACK code to track multiple-charge-state heavy-ion beams. In this study, the beam emittance is simulated to understand the effect of a plasma potential, a charge-to-mass ratio, a charge state distribution and a spatial distribution. The details of numerical and experimental results will be described.

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Electron Cyclotron Resonance Ion Sources

ThuPS28

Production of high current proton beams using complex H-rich molecules at GSI

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The operation of the linear accelerator UNILAC at GSI heavy ion accelerator facility with light ions (M/Q < 8) is strongly limited due to high transmission losses in the low energy beam transport line (LEBT) and RFQ. Another limitation is the low extraction voltage applied at the ion source due to the fixed specific ion energy of 2.2 keV/u at the RFQ entrance. These factors make the operation of the high current injector (HSI) with proton beams extremely inefficient. However the situation can be dramatically improved by production of singly charged molecular heavy (up to M = 50 a.m.u.) ion beams with a high content of hydrogen atoms. These molecular ions can be extracted from ion source and accelerated in the HSI with much lower transmission losses while an intense proton beam is available after conversion in the gas stripper. In this work first experimental results of high intensity proton beam production at GSI UNILAC using CH_3^+ molecular beam from the ion source are presented. The selection of appropriate H-rich molecules and corresponding substances for ion source operation is discussed. The performance of volume type high current ion sources with various gases (methane, ethane, propane and isobutane) as well as with liquid substances (iodoethane) has been investigated and results are summarized. Further steps to improve the ion source performance with molecular beams and to increase the yield of protons behind the gas stripper will be depicted.

ThuPS29

Development of Wien Filter for Small Ion Gun of Analytical Equipment

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The gas cluster ion sources (GCIS) and metal ion sources were required to use ion beam at various analytical equipment, such as X-ray Photoelectron Spectroscopy (XPS) and Secondary Ion Mass Spectroscopy (SIMS). Specially, the small ion source was used for the secondary ion generation and ion etching. The Korea Basic Science Institute is developing small ion source for SIMS from last year. Our first target is the generation of argon gas cluster ion beam using GCIS which consists of cluster generator, ionizer, Wien filter, accelerator, micro lens and target. The clusters are formed using super-sonic nozzle and they insert ionizer through skimmer. The clusters in ionizer are ionized by collisions with emitted electrons and the ionized clusters are sorted using Wien filter. The design of Wien filter was completed using various calculations with initial design of GCIS. The designed Wien filter can distinguish Ar_{2500}^{+} cluster in Ar_{2400}^{+} and Ar_{2600}^{+} through 1 mm aperture. In this paper, results of feasibility studies for development of Wien filter were presented and our development plan for GCIS was introduced.

ThuPS30

The Study about Nozzle Type for Cluster Generation at Gas Cluster Ion Source

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The Korea Basic Science Institute is developing a gas cluster ion source (GCIS) for X-ray Photoelectron Spectroscopy, Secondary Ion Mass Spectroscopy, and Mass Spectroscopy. Specially, argon molecular clusters have received considerable attention to generate secondary ions from samples, such as semiconductor devices and organic light emitting diode. The study about nozzle type at argon GCIS was tried to obtain information for improved cluster formation in nozzles with different geometries. The clusters were formed when a high pressure gas expand into vacuum through a nozzle. The forecast for cluster generation in supersonic expansion was calculated using equivalent sonic nozzle diameter. In this paper, the cluster generation was compared equivalent sonic nozzle type with original nozzle type from simulation results of supersonic transfer using ANSYS. Also, some experiments were performed to verify simulation results. In this paper, we try to solve problem related on lack of the experimental data on argon cluster formation with various nozzles.

ThuPS31

Design and preliminary tests of an external antenna driven cw ion source at IAP Frankfurt

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A filament driven arc discharge proton ion source has been developed for the FRANZ (Frankfurt Neutron Source at Stern-Gerlach-Zentrum) project for many years [1]. The current and emittance requirements for the FRANZ project were reached successfully. But as a tungsten filament is used, the lifetime of the ion source is limited due to the ion bombardment. For improving the lifetime, a radio frequency driven plasma generator with an antenna outside of the plasma chamber was developed at the Institute for Applied Physics (IAP). The frequency of the ion source was set to 13.56 MHz, and a copper coil antenna was installed in a water-cooled channel to feed an inductive discharge inside the plasma chamber. The plasma was separated from the antenna by an Al_2O_3 cylinder. Eight permanent magnets were arranged around the plasma chamber to generate a multi-cusp filed. Preliminary experiments show that the plasma can be ignited easily with a load power higher than 1 kW in pulsed and cw mode. After the optimization of the RF coupling between RF generator and ion source with a 5.5 turn coil antenna, a coupling efficiency of 95% in pulsed mode and 93% in cw mode with a 10 kW input power could be reached. More details of the ion source and the experiments will be reported in this paper.

References

[1] W. Schweizer, U. Ratzinger, B. Klump, and K. Volk, *Rev. Sci. Instrum.* **85** 02A743, 2014.

ThuPS32

Operation Modes of Hydrogen Ion Beam Source Based on Pulsed Penning Discharge with Hollow Cathode

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We report on an experimental study of the ion source based on a Penning discharge with a hollow cathode [1] that was transferred to high current (tens A) pulse (tens µs) mode to produce intense beam of hydrogen ions. With operating gas of molecule hydrogen H_2 the ion beam contains the three ion species: H^+, H_2^+ and H_3^+. For all experimental conditions ion beam fraction of the H_2^+ was about 10-15% of the total ion beam current and it did not change much with ion source parameters. From the other hand, ratio of H^+, and H_3^+ strongly depends on discharge current, especially on distribution the discharge current between planar cathode and hollow cathode. The higher discharge current the more protons in the ion beam present. Maximum part of H^+ was as high as 80% of the total ion beam current. Forced redistributing the discharge current between the cathodes so that the current increase in the hollow cathode can dramatically increase the proportion of H_3^+ions in the ion beam. For optimal parameters part of the H_3^+ions reached 60% of the total ion beam current.

References

1.Low-energy dc ion source for low operating pressure / Efim Oks, Maxim Shandrikov, Cecilia Salvadori and Ian Brown //Rev. Sci. Instrum. 85, 083502 (2014);

ThuPS33

Ar/N2 Plasma Treatment of High Density Polyethylene via Atmospheric Microwave Plasma Pencil Ion Source Device

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High density polyethylene substrates were treated with argon-nitrogen plasma via the Atmospheric Microwave Plasma Pencil ion source device. Optical emission spectroscopy results indicated the presence of Nitrogen and Oxygen molecular ions and Argon ions in the plasma. The device's microwave power configuration was varied at an increment of 20W from 40 to 100W and the treatment time was varied from 5 to 60s. Surface free energy (**γ**) values were calculated by using the van Oss - Chaudhury – Good equation from the contact angle measurement results of three test liquids namely water, glycerol and ethylene glycol. Generally, higher power and longer treatment time yielded higher **γ** which is an indication of enhanced adhesion properties. The highest **γ** obtained is 51.89 mJ/m2 at 100 W and 60s treatment time. The increase in **γ** is attributed to the formation of the polar functional groups amine (C-N, N-H) and carbonyl (C=O), which was observed through Attenuated Total Reflectance -Fourier Transform Infrared Spectroscopy. Also, **γ** is significantly correlated to the root mean square surface roughness and approximated surface area values which were calculated from the Atomic Force Microscopy data.

ThuPS34

Study on the D/Ti ion ratio of metal deuteride cathode vacuum arc ion source

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Based on the violence vacuum arc discharge mode, we can simply and easily obtain a large number of ions and atomics compositions. When the discharge cathode is made of metal deuteride, it can generate high current pulsed deuterium ion beam, which have been widely studied and used in neutron generators, accelerators and other fields. The ions compositions that produced by metal deuteride cathode vacuum arc discharge are analyzed in this paper by the magnetic analysis technology. We study the metal deuteride electrode discharge and the D/Ti ion ratio with different deuterium content. The effects of the TiDx cathode deuterium content (x) on the D/Ti ion ratio in vacuum arc ion source are analyzed in this paper. In addition, the metal deuteride electrode discharge with different TiDx cathode surface roughness is studied and the effect of the TiDx cathode surface roughness on the stability of ion ratio is analyzed. The experimental results show that the increase of deuterium content on the TiDx cathode can significantly improve the D/Ti ions ratio in the vacuum arc discharge. Besides, the results indicate that suitable cathode surface roughness can increase the stability of the vacuum arc discharge.

Key words: vacuum arc discharge, TiDx cathode, magnetic analysis, D/Ti ion ratio, surface roughness

Friday
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FriM01

Recent Development of Plasma-Optical Systems

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This is the brief review of recent development and ongoing research of plasma optical systems based on the fundamental plasma optical idea magnetic electron isolation, equipotentialization magnetic field line and the axial-symmetric cylindrical electrostatic plasma lens (PL) configuration. The electrostatic PL is well-explored tool for focusing and manipulating large area, intense, positive light and heavy ion beams, where the concern of beam space charged compensation is critical. The crossed electric and magnetic fields inherent the PL configuration provides a suitable method for establishing a stable discharge at the low pressure. Using PL configuration in this way several low maintenance and high reliability plasma generation devices were developed. These kind of devices are part of a large class plasma devices (hall-type plasma accelerators, jet propulsions, magnetically insulated diodes) that use a discharge in crossed electric and magnetic fields with closed electron drift for the generation, formation and manipulation of intense ion beams and ion plasma flows. This background development opened up a new possibility to use PL configuration with a positive space charge cloud for focusing high current negative charged particles beams (electrons and negative ions).. Here briefly describes the results of wide-aperture (6 cm) non-relativistic (up to 20 keV) intense (from 100 mA up to 100 A) electron beam focusing by the positive space charge PL. The experiments have been carried out in the Tomsk (HCEI SB RAS) with using plasma lens produced by IP NASU. These experimental results demonstrate an agreeable possibilities application positive space charged plasma lens with magnetic electron insulation for focusing and manipulating wide aperture, high-current, no relativistic electron beams.. We describe also the original approach for effective additional elimination of micro droplets in a density flow of vacuum arc plasma. This approach is based on application the cylindrical PL configuration for introducing at volume of propagating along axis's dense low temperature plasma flow convergent radially energetic electron beam generated by ion –electron secondary emission from electrodes of plasma optical tool. The theoretical appraisals and experimental demonstrations that have been carried out at the IP NASU provide confidence and optimism that proposed idea for removal and clearing the micro droplet component from dense metal plasma has the high practical potential for elaboration novel state-of-the-art plasma processing for the filtering of micro droplets (or their reduction to the nanoscale) from the plasma formed by erosion plasma sources like vacuum arc and laser produced plasma. Note also, these energetic electrons could be attractive for additional stripping ions at the MEVVA ion source.

References

Alexey Goncharov Invited Review Article: The Electrostatic Plasma Lens, Rev. Sci. Instrum. 84, 021101 (2013)

A.A.Goncharov, A.N.Dobrovolsky, S.N. Dunets, I.V.Litovko, V.I. Gushenets and E.M. Oks, Rev.Sci. Instr. 83, 02B723 (2012)

A.A.Goncharov, V.I. Maslov, A.Fisk 55th SVC Annual Techn. Conference Proceedings, pp.441-444, Santa Clara, CA (2012),

FriM02

Correlations between density distributions, optical spectra and ion species in a hydrogen plasma

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An experimental study of plasma density distributions in a 2.45 GHz hydrogen plasma source operated at 100 Hz is presented. Ultrafast photography, time integrated visible spectra, time resolved Balmer-alpha emission, time resolved Fulcher Band emission, ion species mass spectra and time resolved ion species currents have been implemented as diagnostics tools for a broad range of plasma conditions. Preliminary results of density distributions and optical emissions correlated with H+, H2+ and H3+ ion currents by using a Wien Filter system with optical observation capability are presented. The magnetic field distribution and strength is reported as the most critical factor for transitions between different plasma patterns and ion populations. The breakdown study of typical plasma distributions for visible, Balmer-alpha and Fulcher Band is also presented showing the atomic and molecular distribution evolution where some unexpected structures are observed. The use of visible light emissions as a valuable diagnostic tool for tuning ion sources plasmas is proposed on the base of obtained results.

FriM03

Industrial Applications of ECR-Based Neutron Generators

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Phoenix Nuclear Labs' (PNL) high yield deuterium-deuterium (DD) neutron generator, with measured yields greater than 3×10^{11} n/s, is based upon a proprietary gas target coupled with a custom 300 kV accelerator and a high-current microwave ion source (MWS). The ion injector is comprised of a MWS for deuterium ion generation and an extractor to produce a low emittance beam from the ion source for transport to a subsequent accelerating column. The PNL ion source utilizes 2.45 GHz microwaves and an 875 Gauss magnetic field to produce high plasma densities by generating electron cyclotron resonance (ECR) interactions. As no filaments are required to ignite the plasma, the microwave ion source can operate with long lifetimes, on the order of years. The ion extractor, which is biased negatively with respect to the plasma chamber, pulls deuterium ions from the ion source into the accelerator. PNL ion sources have been operated with extracted deuteron currents as high as 90 mA as measured by a calibrated calorimeter located downstream of the extraction aperture.

Three prototype neutron generators have been delivered: one to the US Army for neutron radiography, one to Ultra Electronics' Nuclear Control Systems for neutron flux monitor calibration, and one to SHINE Medical Technologies for medical isotope production. Experiences operating and optimizing the various subsystems (ion source, accelerator, focus element, differential pumping stages, and gas target) for each application will be described. System requirements and tradeoffs for these diverse applications, including thermal neutron radiography, medical isotope production, nuclear instrumentation testing and calibration, and explosives detection, will be presented, along with preliminary results. Multiple next-generation systems are presently being designed and constructed at PNL with an emphasis on further increasing neutron yield and reliability and on decreasing physical size, weight, and price of the system. Modifications currently underway include further increases in voltage and current, the use of a solid target (e.g. for fast neutron radiography), and transitioning to a mixed deuterium-tritium beam in the gas target system. The latter modification will result in a neutron yield increase of approximately 50X. PNL is targeting delivery of three generators with neutron yields of 5×10^{13} DT n/s in 2018 to SHINE's molybdenum-99 production facility.

FriM04

The RHIC Polarized Ion Source

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The high-intensity polarized H^- ion beam for RHIC produced in multi-step charge –exchange process. A high brightness primary proton beam of a 6.5 keV energy (from the surface of the plasma emitter with a low transverse ion temperature ~0.2 eV) is produced by four-electrode spherical multi-aperture ion-optical system with geometrical focusing. The converging proton beam immediately converted to neutral atomic hydrogen beam in a pulsed hydrogen gas cell. The atomic hydrogen beam injected into the superconducting solenoid (3.0 T) where it is ionized in the He-gas cell. The protons produced in the He-cell decelerated to 2.5 keV by three-grid deceleration system and neutralized again by capture of polarized electrons from optically pumped Rb-vapor (Optically Pumped Polarized Ion Source –OPPIS-technique). In such a way, beam at entrance and exit of solenoid field is neutral to avoid emittance growth in charge-exchange process in high-magnetic field. The electron polarization transferred to protons by Sona-transition and then beam is ionized in the sodium-jet ionizer cell. The H^- ion beam produced in the cell (ionizer cell is isolated and -32.5 kV pulsed HV applied to the cell) is accelerated to 35.0 keV which is transported and injected for further acceleration in RFQ. The use of high-brightness primary beam and large cross-sections of charge-exchange cross-sections resulted in production of very high intensity (up to 4.0 mA) H^- ion beam of 85% polarization. This beam intensity is much higher then RHIC acceptance and extra beam intensity is scraped by collimation after the Booster to reduce beam emittance. This reduces depolarization in AGS and RHIC and increase luminosity for polarized beam collisions in RHIC. Siberian snakes used in AGS and RHIC to prevent depolarization during acceleration. The use of high-intensity and 85% polarization source beam resulted in 75% polarization at 23 GeV out of AGS and 60-65% beam polarization at 100-250 GeV beams colliding in RHIC.

FriM05

Intense Beam Transport and Space Charge Compensation Strategies

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The transport of intense ion beams is affected by the collective behavior of this kind of multi particle and multi species system. The space charge expressed by the generalized perveance dominates the dynamical processes of thermalisation, which leads to an emittance growth. To prevent changes of intrinsic beam properties and to reduce the intensity dependent focusing forces space charge compensation seems to be an adequate solution.

In a case of positively charged ion beam electrons, produced by residual gas ionization and secondary electrons provide the space charge compensation. The influence of the compensation particles on beam transport and the local degree of space charge compensation is given by different beam properties as well as the ion beam optics.

Especially for highly charged ion beams space charge compensation in combination with poor vacuum conditions leads to recombination processes and therefore increased beam losses. Strategies for providing a compensation electron reservoir at very low residual gas pressures will be discussed.

FriM06

Hall Thruster for Space Applications: Advanced Concepts and Research Challenges

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The Hall thruster is a plasma propulsion device that holds considerable promise for many space applications, including near-Earth orbital missions and space exploration missions. Unmagnetized ions (usually Xenon) are accelerated electrostatically to energies of 0.1-1 keV in a quasineutral plasma (10^{11}-10^{12} cm^{-3}) with a closed electron $E \times B$ drift. This thruster concept was invented in early 60's to overcome the limitations of a gridded ion thruster, in that the Hall thruster produces neutral plasma flow that is not space-charge limited, but is instead limited by the attainable magnetic fields in the thruster magnetic circuit. Over the years, more than 100 Hall thrusters have been flown in space mainly for station keeping and orbit transfer of satellites. Future space applications, including micropropulsion with the input power of less than 100 W and the thruster level of not exceeding and high power electric propulsion (50-200 kW), can take Hall thruster technology to its technological limit. With recent advances in understanding of Hall thruster physics, further improvements of Hall thrusters were suggested by controlling plasma-wall interaction and electron cross-field transport. This talk will review fundamentals and potential applications of several advanced Hall thruster concepts, including a thruster with reduced plasma-wall interaction effects on the plasma due to the use of engineered wall materials with surface micro-architecture, and novel plasma thrusters with advanced magnetic field topologies including plasma thrusters with cusp-type and mirror-type magnetic field topologies, magnetically-filtered and shielded plasma thrusters proposed for low and high power applications.

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Guobiao	**Gu**	MonPS03				
Haase	**M.**	TueM07				
Haba	**T.**	WedM03				
Hafalia	**Aurelio**	WedM02	ThuPS08			
Hagino	**Shogo**	MonPE33	MonPS07	ThuPS05	ThuPS15	ThuPS16
		ThuPS03				
Hamm	**Robert**	TuePS31				
Han	**Baoxi**	MonPS29	MonPS35	TueM08	TuePE36	
Hanada	**Masaya**	TuePE21	TuePE16	ThuPE10	ThuPE08	ThuPE07
Hansen	**J.**	TueM07				
Harada	**K.**	MonPE16				
Harrault	**F.**	MonPS05	MonPS04	WedM04		
Hashida	**Masaki**	TuePS12				
Hatanaka	**Kichiji**	TuePS37				
Hatayama	**Akiyoshi**	MonPE10	MonPS31	TueM07	TuePE21	TuePE23
		TuePE25	TuePE28			
Hayamizu	**T.**	MonPE16				
He	**Yuan**	TuePS35				
Heidinger	**R.**	WedM04				
Heinemann	**Berndt**	MonA01	MonA03	TuePS35	ThuPE11	
Hemsworth	**Ronald Stepher**	MonA03	ThuPE15			
Henares	**Jose Luis**	TuePS05				
Heo	**Jeongil**	MonPS08	MonPS09	MonPS15		
Hershcovitcl	**Ady**	MonM04	TuePS06			
Heymach	**Frank**	ThuPS28				
Hiasa	**Toshikazu**	MonPS31				
Higurashi	**Yoshihide**	WedM03	WedM09	ThuPS23	ThuPS06	
Hijazi	**Lara**	TuePS05				
Hirano	**Yoichi**	MonPE09	MonPE27			
Hiratsuka	**Junichi**	TuePE16	ThuPE07	ThuPE08	ThuPE10	
Hitobo	**Takeshi**	MonPS01				
Hodgkinson	**A.**	TuePE15	ThuPS25			
Hojo	**Satoru**	MonPE33	ThuPE29			
Hollinger	**Ralph**	MonPE05	TuePE20	TuePS28	ThuPS02	ThuPS28
Hong	**In-Seok**	MonPE11	MonPE13	MonPS08	MonPS09	MonPS15
		ThuPS27				
Hong	**Jonggi**	MonPE18	ThuPS11	ThuPS12	ThuPS13	ThuPS14
		ThuPS29	ThuPS30			
Horioka	**Kazuhiko**	TuePS04				
Hu	**Chundong**	TuePS32	ThuPE09	ThuPE21		
Huang	**QingHua**	ThuPE28				
Hwang	**Y. S.**	MonPS27	MonPS28			
Ichikawa	**Masahiro**	MonPS10	ThuPE10	ThuPE08		
Ichimiya	**Ryo**	WedM04	ThuPS18			
Ihara	**Akira**	WedM04	ThuPS18			
Ikeda	**Katsunori**	MonPE11	MonA04	MonPS32	TueM06	TuePS34
Ikeda	**Shunsuke**	TuePS07	TuePS08	TuePS13	TuePS14	TuePS03
		TuePS04	TuePS09	TuePS10		
Ikeda	**Yukiharu**	WedM04	ThuPS18			
Ikegami	**Kiyoshi**	TueA04	TuePE32	TuePE24		
Imai	**Youta**	ThuPS15				

Kayama	**Takamasa**	MonPE34				
Kenmotsu	**T.**	TuePE35				
Kester	**Oliver**	TuePS28				
Khursheed	**Anjam**	TuePS29				
Kidera	**Masanori**	ThuPS23				
Kikuchi	**T.**	WedM04				
Kim	**Byoung-Chul**	ThuPS14				
Kim	**Deok-Min**	MonPS09				
Kim	**Dae-Il**	MonPE31				
Kim	**Eun-San**	MonPE18				
Kim	**Hye-Jin**	MonPS09				
Kim	**Jongwon**	ThuPE32				
Kim	**Jin-Soo**	TuePS21				
Kim	**J. S.**	MonPE17	TuePS02			
Kim	**June-Young**	MonPS27	MonPS28			
Kim	**Seong-Jun**	MonPE18	ThuPS11	ThuPS12	ThuPS13	ThuPS14
Kim	**Yong-Hwan**	MonPS08	MonPS09	MonPS15	ThuPS27	
Kim	**T. S.**	MonPE17				
Kimura	**Daiju**	ThuPS15				
Kisaki	**Masashi**	MonA04	MonPS32	TuePS35	TueM06	
		TuePS34	TuePE35			
Kitagawa	**Atsushi**	MonM02	MonPE33	MonPS07	ThuPS03	ThuPS22
Kitagawa		ThuPE29	ThuPS05			
Kitami	**Hisashi**	MonPE35				
Kitano	**Toshihiko**	WedM04	ThuPS18			
Kiyama	**Satoru**	MonPE09	MonPE27			
Klump	**B.**	ThuPS31				
Knaster	**J.**	MonPS05	WedM04			
Koester	**Petra**	TuePS19				
Koguchi	**Haruhisa**	MonPE09				
Köhler	**L.**	MonPE16				
Koivisto	**Hannu**	MonPS13	MonPS11	MonPS12	MonPS16	MonPS37
		TuePE08	WedM06	ThuM07	ThuPS21	ThuM05
		FriM02				
Kojima	**Atsushi**	TuePE21	TuePE16	ThuPE07	ThuPE08	ThuPE10
Kolhinen	**V.**	ThuM07				
Kolmogorov	**Vyacheslav**	ThuPE16				
Kolmogorov	**Anton**	ThuPE04				
Komata	**Masao**	TuePE16				
Komiyama	**Misaki**	ThuPS23				
Komppula	**Jani**	MonPS13	MonPS12	MonPS11	MonPS16	MonPS37
		TuePE08	WedM06	ThuM05	ThuPS21	
Kondakov	**Alexey**	TueA01	ThuPE16			
Kondo	**Keitaro**	ThuPS18				
Kondo	**K.**	WedM04				
Kondo	**Kotaro**	TuePS11				
Kondrashev	**Sergey**	ThuPS02				
Konstantino	**Sergey**	MonPS21				
Korepanov	**Sergey**	ThuPE16				
Koszar	**I.**	TueM07				
Kozlov	**Alexander V**	MonPE29				
Kraus	**Werner**	MonA01	ThuPE11			
Kravchuk	**Konstantin S.**	MonPE29				
Kron	**Tobias**	TuePS05				
Kronholm	**Risto**	MonPS13	MonPS11	MonPS16	MonPS12	TuePE08
		WedM06	ThuM05	ThuPS21		
Küchler	**Detlef**	TuePS25	TuePS26	ThuPS17		
Kuibeda	**Rostislav P.**	MonPE29				
Kulevoy	**Timur V.**	MonA02	MonPE29			
Kumaki	**Masafumi**	TuePS07	TuePS08	TuePS13	TuePS14	TuePS03
		TuePS09	TuePS10	TuePS11		
Kumakura	**Sho**	ThuPS15	ThuPS16			
Kundrapu	**Madhusudhan**	TuePE33				
Kushwah	**Mahesh**	ThuPE15				

Nagatsu	**Koutaro**	ThuPE29				
Nagaya	**Tomiki**	ThuPS16				
Nagaya		MonPS07	ThuPS03	ThuPS05	ThuPS15	
Naiko	**Lylia**	TuePE07				
Naiko	**Irina**	TuePE07				
Naito	**F.**	TuePE28				
Nakagawa	**Takahide**	MonPE20	WedM09	WedM03	ThuPS23	ThuPS06
Nakahara	**Yuta**	MonPS01				
Nakamiya	**Akihisa**	MonPE27				
Nakamura	**Tsubasa**	MonPS01	ThuPS04			
Nakano	**Haruhisa**	MonA04	MonPS32	TuePS35	TueM06	TuePS34
		TuePE35				
Nakao	**Masao**	ThuPE29				
Nayuki	**Tetsuo**	MonPE34				
NB Heating Technology Grou		ThuPE10				
NB Heating Technology Grou		ThuPE08				
Nemoto	**Shuji**	TuePE16				
Nemoto	**Kenji**	MonPE34				
Neri	**Lorenzo**	TuePS27	TuePE11	TuePE05	WedM07	ThuM08
		ThuPS19	ThuPE27			
Nicolosi	**Dario**	MonPE21	TuePE05	TuePS27		
Nicolosi	**P.**	ThuPE34				
Nikitin	**Alexander A.**	MonPE29				
Nikolaev	**Alexey**	TueM03	TuePS22	TuePS16		
Nisbet	**D.**	TueM07				
Nishida	**K.**	TuePE23	TueM07	TuePE28		
Nishikiori	**Ryo**	ThuPE10	ThuPE08			
Nishioka	**Shu**	MonPE10	TuePE21			
Nishiokada	**Takuya**	MonPS07	MonPE33	ThuPS15	ThuPS03	ThuPS05
		ThuPS16				
Nishiura	**Masaki**	TuePE35				
Nishiyama	**S.**	TueM06				

NNBI-team		ThuA02				
Nocentini	**Riccardo**	MonA03	MonA01			
Noda	**Akira**	ThuPE29				
Noda	**Koji**	ThuPE29				
O'Hara	**James F.**	MonPS24				
O'Neil	**M.**	TueM07				
Odorici	**Fabrizio**	ThuM04	ThuPS19			
Oguri	**Hidetomo**	TueA04	TuePE32	TuePE24	TuePE28	
Ohira	**S.**	WedM04				
Ohkoshi	**Kiyonori**	TueA04	TuePE32	TuePE24	TuePE28	TuePE28
Ohnishi	**Jun-ichi**	ThuPS06				
Ohnishi	**J.**	WedM09	WedM03			
Ohzeki	**Masahiro**	TuePE16				
Ok	**Jung-Woo**	MonPE18	ThuPS11	ThuPS12	ThuPS13	ThuPS14
Okajima	**Yuki**	TuePE10				
Okamura	**Masahiro**	TuePS07	TueM01	TuePS08	TuePS13	TuePS14
		TuePS03	TuePS04	TuePS09	TuePS10	TuePS12
		TuePS11				
Oks	**Efim**	MonPE29	TueM03	TuePS22	TuePS16	ThuPS32
Okumura	**Yoshikazu**	MonPS05	MonPS31	WedM04	ThuPS18	
Onai	**Moriaki**	MonPS31	TuePE25			
Orlov	**Nikolay N.**	MonPE29				
Osakabe	**Masaki**	MonA04	TueM06	TuePS35		
Osin	**Dmitry**	ThuPE16				
Osmond	**Benoit**	ThuPE31	TuePS05	WedM05		
Ostroumov	**Peter**	ThuM09				
Otsuka	**Takuro**	MonPS07	ThuPS15	ThuPS16	ThuPS03	ThuPS05
Owens	**James**	WedM02				
Ozeki	**Kazutaka**	ThuPS23				
Palchan-Haz	**Tala**	ThuPS10				
Pálinkás	**József**	WedM07	ThuPS09			
Palla	**Daniele**	TuePS19				

Raparia	**Deepak**	MonPE23				
Ratzinger	**U.**	ThuPS31				
Ravarotto	**D.**	MonA02				
Razin	**Sergey**	ThuM02				
Recchia	**M.**	MonA02				
Ren	**Haitao**	MonPE24	MonPS34	TuePS38	WedM02	ThuPS07
Riaby	**Valentin**	TuePE12				
Riedl	**Rudolf**	MonA03	MonA01	ThuPE11		
Rifuggiato	**D.**	MonPE21				
Ritter	**John**	TueM01				
Rizzolo	**Andrea**	MonA03	MonPE22	ThuPE13	ThuPE23	
Roger	**A.**	MonPS05				
Roger	**Arnaud**	WedM05				
Rogozhkin	**Sergey V.**	MonPE29				
Romano	**Paolo**	WedM07	ThuPS09			
Romé	**M.**	ThuPE25				
Romero	**Camile Faith**	TuePE10				
Romero-Ron	**E.**	MonPE32				
Roncolato	**C.**	ThuPE26				
Rosario	**L. D.**	ThuPS33				
Rosenkranz	**André**	MonM06				
Roser	**Thomas**	MonM01				
Rossetto	**Federico**	ThuPE05				
Rotti	**C.**	ThuM03				
Roux	**Kevin**	MonA03	ThuPE15			
Ruan	**Lin**	ThuPS01				
Rutter	**Theo**	TueM09				
Rutter	**Theo**	TuePE27				
Rybarcyk	**Lawrence J.**	MonPS24				
Sakabe	**Shuji**	TuePS12				
Sakakita	**Hajime**	MonPE09	MonPE27			
Sakamoto	**K.**	MonPE16	WedM04			

Sakamoto	**Yukio**	MonPE33				
Sakemi	**Y.**	MonPE16				
Sako	**Takayuki**	MonPE34				
Sakuraba	**Junji**	MonPE35	MonPS31			
Sanin	**Andrey**	MonPS20	MonPS21	MonPS22	TueA01	
Santana	**Manuel**	MonPS29	MonPS35	TueM08	TuePE36	
Saquilayan	**Glynnis**	TuePS15				
Saratovskyh	**Mikhail**	MonPE04				
Sarstedt	**Margit**	MonM06				
Sartori	**Emanuele**	MonPE25	MonPE26	MonA02	MonPE28	TuePE26
		ThuPE14	TuePS24	ThuPE20	TuePS34	ThuPE23
Sasa	**Mamiko**	ThuA01				
Sasaki	**K.**	TueM06				
Sasaki	**Noriyuki**	MonPE33				
Sasaki	**Shunichi**	TuePE16				
Sasano	**Toshinobu**	MonPE33				
Satir	**Mert**	MonPE12				
Sato	**Fuminobu**	MonPS07	ThuPS15	ThuPS16	ThuPS03	ThuPS05
Sato	**Kiyokazu**	MonPE34				
Sattin	**M.**	MonA02				
Savalle	**A.**	ThuPE31				
Savard	**Guy**	ThuPE33				
Savkin	**Konstantin**	TuePS16				
Scantamburl	**F.**	WedM04				
Scarpa	**Daniele**	ThuPE34				
Schaefer	**T.**	ThuPS31				
Schenkel	**Thomas**	TueM05				
Schiesko	**Loic**	ThuPE11	ThuA02	ThuA02		
Schillaci	**Francesco**	TuePS19	TuePS01			
Schlei	**B. R.**	ThuA02				
Schneider	**Fabian**	TuePS05				
Schoepfer	**Roberto**	TueM01				

Suzuki	**Taku**	MonM02	MonPE33			
Svensson	**Lennart**	ThuPE15				
Taccogna	**Francesco**	MonA02	TueA02	TuePE30		
TAE Team		ThuPE16				
Takagi	**Akira**	TueA04	TuePE32	TuePE24	TuePE28	
Takahashi	**Hiroki**	MonPS05	WedM04	ThuPS18		
Takahashi	**Katsuyuki**	MonPE33	MonM02			
Takahashi	**Kazumasa**	TuePS04				
Takahashi	**Nobuaki**	MonPE35	MonPE33			
Takakuwa	**Jeff**	TueM05				
Takasugi	**Wataru**	MonM02				
Takeiri	**Yasuhiko**	MonA04	MonPS32	TuePS35	TueM06	TuePS34
Takeuchi	**Takeshi**	MonPE34				
Tamura	**Jun**	TuePS11				
Tan	**Cheng-Yang**	TuePE29				
Tan	**X. H.**	TuePS20				
Tang	**Bing**	ThuPE28				
Tarnev	**Khristo Ts.**	ThuPE06				
Tarvainen	**Olli**	MonPS13	MonPS11	MonPS12	MonPS37	MonPS16
		MonPS14	TuePE08	WedM06	ThuPS21	ThuM07
		ThuM05	FriM02			
NNBI Team		MonA01				
Ter-Avetisya	**Sargis**	TuePE31				
Terunuma	**Yuto**	TuePE16				
Thaus	**N.**	TueM07				
Theroux	**J.**	TuePE20				
Thomae	**Rainer**	TuePS17	ThuPS17			
Thuillier	**Thomas**	MonPS16	TuePE15	WedM05	ThuM07	
Tikhonchuk	**V.**	TuePE31				
Ting	**J. S.**	ThuPS33				
Tinschert	**Klaus**	WedM08	ThuPS02			
Tobari	**Hiroyuki**	MonA03	ThuPE10	ThuPE08		

Tobos	**Larry**	WedM02				
Todd	**D. S.**	TuePE15	ThuPS25			
Todorov	**Dimitar T.**	ThuPE18				
Toigo	**Vanni**	MonA03	MonPE28			
Toivanen	**Ville**	TuePS26	TuePS25	WedM06	ThuPS17	
Tollin	**Marco**	MonPE22				
Tomaselli	**A.**	ThuPE34				
Tongu	**Hiromu**	MonPS10	TuePS12			
Torrisi	**Giuseppe**	TuePS27	TuePE11	WedM07	ThuPE27	ThuM08
Touzery	**Robert**	WedM05				
Traykov	**E.**	ThuM07				
Trevisan	**Lauro**	MonA03				
Triplett	**Kent**	MonPE06				
Tsumori	**Katsuyoshi**	MonA04	MonPS32	TuePS35	TueM06	TuePS34
Tudisco	**Salvatore**	TuePS19	TuePS01	ThuM04		
Tumlos	**R. B.**	ThuPS33				
Turner	**David**	TuePE27				
Tuske	**Olivier**	MonPS04	WedM05			
Tuunanen	**J.**	MonPS16				
Tyagi	**Himanshu**	ThuM03				
Tzoganis	**Vasilis**	MonPE20				
Uchida	**Takashi**	MonPS01	MonM02	MonPE33	ThuPS22	ThuPS03
Uchiyama	**Akito**	MonPE16	ThuPS23			
Ueno	**Akira**	TueA04	TuePE32	TuePE24	TuePE28	
Uhlemann	**Reinhard**	ThuPE04				
Ullmann	**Cathrina**	MonPE05	TuePS28			
Umeda	**Naotaka**	TuePE16	ThuPE07	ThuPE08	ThuPE10	
Usami	**H.**	WedM04				
Useinov	**Alexey S.**	MonPE29				
Uy	**J. Y.**	ThuPS33				
Vakhrushev	**Roman**	ThuPE16				
Valente	**Matteo**	ThuPE13				

SYNOPTIC TABLE

23-Aug

Time	Session
3:00-6:30	Registration
6:30-8:30	Reception

MONDAY 24-Aug

Time	Session
	Registration
8:30	Opening Remarks
	Chair: T. Nakagawa
9:00	Ion Source requirements for high energy accelerators (Roser)
9:30	Recent developments of ion sources for life science studies at the Heavy Ion Medical Accelerator in Chiba (Kitagawa)
10:00	High density plasmas and new diagnostics: an overview (Celona)
10:30	*Coffee Break*
	Chair: A. Kitagawa
11:00	Molecular ion sources for semiconductor ion implantation (Hershcovitch)
11:30	Ambient ionization, ion transport and ion mobility-based detection... (Guharay)
11:50	Ion beam sources for surface modification (Rosenkranz)
12:10	*Conference photo*
12:30	*Lunch (on your own)*
14:00	*Poster Session / Exhibitors*
	Chair: K. Tsumori
16:00	Towards 20A negative hydrogen ion beams for up to 1 Hour; achievements of the ELISE Test Facility (Fantz)
16:30	First experiments with the negative ion source NIO1 (Cavenago)
16:50	Final design of the beam source for the MITICA injector (Marcuzzi)
17:10	Improvement of accelerator of N-NBI on LHD (Kisaki)

TUESDAY 25-Aug

Time	Session
	Chair: R. Pardo
8:30	Intense pulsed heavy ion beam production by EBIS and its future development (Beebe)
9:00	New development of laser ion source for highly charged ion beam production (Zhao)
9:30	High charge states heavy metal ion source based on vacuum spark (Oks)
9:50	Design steps towards a high brightness electron impact ion source (DeCastro)
10:10	Development and testing of a pulsed helium ion source for probing... (Ji)
10:30	*Coffee Break / Exhibitors*
	Chair: M. Bacal
11:00	Production and extraction processes of H- ions in a large scaled negative ion source (Tsumori)
11:30	Linac4 H– ion sources (Lettry)
11:50	Recent performance of and plasma outage studies with the SNS H-... (Stockli)
12:10	Commissioning the RAL scaled Penning surface plasma source (Faircloth)
12:30	*Lunch (on your own)*
14:00	*Poster Session / Exhibitors*
	Chair: B. Schunke
16:00	Inductively driven surface-plasma negative ion source for N-NBI use (Belchenko)
16:30	Particle model of full scale ITER-relevant negative ion source (Taccogna)
16:50	Physics of negative ion beam formation and extraction from the... (Fubiani)
17:10	Fine-tuning to minimize emittances of J-PARC RF-driven H^- ion source (Ueno)

WEDNESDAY 26-Aug

Time	Session
	Chair: S. Gammino
8:30	Advancement of highly charged ion beam production by superconducting ECR ion source SECRAL (Sun)
9:00	Status of ECR ion sources for the Facility for Rare Isotope Beams (Machicoane)
9:30	Further improvement of RIKEN 28GHz SC-ECRIS for production of ... (Nakagawa)
9:50	Operation and commissioning of IFMIF LIPAc Injector (Okumura)
10:10	Status of the SPIRAL2 injector commissioning (Thuillier)
10:30	*Coffee Break / Exhibitors*
	Chair: H. Zhao
11:00	Limitation of the ECRIS performance by kinetic plasma instabilities (Tarvainen)
11:30	Electron density and temperature measurements in ECR plasma by... (Mascali)
11:50	Ion beam emittance from an ECRIS (Spädtke)
12:10	Emittance measurement for RIKEN 28GHz SC-ECRIS (Higurashi)
12:30	*Free afternoon (enjoy NYC)*

THURSDAY 27-Aug

Time	Session
	Chair: M. Loiselet
8:30	In gas-jet isomer selective laser ion source (Lecesne)
9:00	New progress of high current gasdynamic ion source (Skalyga)
9:30	Overview of ion source characterization diagnostics in Indian Test... (Badyopadhayay)
9:50	Effects of advanced nanowire-based targets for nanosecond laser driven acceleration (Lanzalone)
10:10	VUV-diagnostics of inelastic collision processes in low temperature hydrogen plasmas (Komppula)
10:30	*Coffee Break / Exhibitors*
	Chair: R. Leroy
11:00	Innovation in EBIS charge state breeders for stable and radioactive elements (Schwarz)
11:30	Optimizing charge breeding techniques for ISOL facilities in Europe: conclusions... (Delahaye)
11:50	Advanced numerical modelling of the PHOENIX-SPES charge breeder (Galata)
12:10	Off-line commissioning of EBIS and plans for its integration into ATLAS and CARIBU (Ostroumov)
12:30	*Lunch (on your own)*
14:00	*Poster Session / Exhibitors*
	Chair: M. Stockli
16:00	Optimum plasma grid bias for a negative hydrogen ion source operation with Cs (Bacal)
16:20	Investigation of the boundary layer during the transition from volume to surface... (Wimmer)
16:40	Brightness Award presentation
17:00	Brightness Winner Talk
18:30	**Banquet 6:30 - 9:00**

FRIDAY 28-Aug

Time	Session
	Chair: A. Ivanov
8:30	Recent development of plasma optical systems (Goncharov)
9:00	Correlations between density distributions, optical spectra and ion species in a hydrogen plasma (Cortazar)
9:30	Industrial applications of ECR-based neutron generators (Christensen)
9:50	The RHIC polarized ion source (Zelenski)
10:10	*Coffee Break*
	Chair: P. Spaedtke
10:40	Intense beam transport and space charge compensation strategies (Meusel)
11:10	Hall thrusters for space applications: advanced concepts and research challenges (Raitses)
11:40	*Summary talk*
12:00	*Closing Remarks*
12:30	*Post-conference BNL Tour (return after 9:00 PM)*