16th International Workshop on ECR Ion Sources
ECRIS'04

Lawrence Berkeley National Laboratory
September 26-30, 2004

BOOK OF ABSTRACTS

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16th International Workshop on ECR Ion Sources ECRIS'04

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Scientific Program

SUNDAY, SEPT. 26, EVENING

I. Informal Get-Together

19:00-21:00 *NO-HOST GET-TOGETHER*
(DURANT HOTEL SPORTS BAR)

MONDAY, SEPT. 27, MORNING

II. Conference Registration and Welcome Address

08:30-10:00 *BREAKFAST RECEPTION AND REGISTRATION*

09:50-10:00 (10 min.) C. Lyneis (LBNL, Berkeley, USA)
WELCOME ADDRESS

III. Superconducting / Hybrid Sources (Chair: C. Lyneis)

10:00-10:30 (25 + 5 min.) #01: Leitner, D. (LBNL, Berkeley, USA)
FIRST RESULTS OF THE SUPERCONDUCTING ECR ION SOURCE VENUS WITH 28 GHZ

10:30-11:00 (25 + 5 min.) #02: Zhao, H.W. (Chinese Academy of Sciences, Lanzhou, China)
DEVELOPMENT OF IMP ECR ION SOURCES

11:00-11:30 (25 + 5 min.) #03: Gammino, S. (INFN-LNS, Catania, Italy)
PRODUCTION OF HIGHLY CHARGED HEAVY IONS BY MEANS OF A HYBRID SOURCE IN CW MODE AND AFTERGLOW MODE

11:30-12:00 (25 + 5 min.) #04: Kanjilal, D. (NSC, New Delhi, India)
FIRST HIGH TEMPERATURE SUPERCONDUCTING ECRIS

12:00-13:00 *LUNCH*

MONDAY, SEPT. 27, AFTERNOON

IV. Status Reports and Developments (Chair: P. Sortais)

13:00-13:30 (25 + 5 min.) #05: Nakagawa, T. (RIKEN, Saitama, Japan)
PRODUCTION OF INTENSE BEAMS OF MEDIUM CHARGE STATE HEAVY ION FROM RIKEN ECRISS

13:30-13:50 (15 + 5 min.) #06: Biri, S. (ATOMKI, Debrecen, Hungary)
DEVELOPMENTS AND PLASMA STUDIES AT THE ATOMKI-ECRIS

13:50-14:10 (15 + 5 min.) #07: Koivisto, H. (University of Jyväskylä, Jyväskylä, Finland)
RECENT ECRIS RELATED RESEARCH AND DEVELOPMENT WORK AT JYFL

14:10-14:30 (15 + 5 min.) #08: Vondrasek, R. (ANL, Argonne, USA)
ECRIS OPERATION WITH MULTIPLE FREQUENCIES

14:30-14:50 (15 + 5 min.) #09: Beijers, J.P.M. (KVI, Groningen, The Netherlands)
STATUS REPORT OF ECRIS AT KVI

V. Poster Session I

15:00-18:00 Poster Presentations (See Poster Program)
Coffee served during Poster Session

TUESDAY, SEPT. 28, MORNING

VI. Beam Transport (Chair: M. Leitner)

09:00-09:30 (25 + 5 min.) #10: Thuillier, T. (LPSC, France)
HIGH CURRENTS OF MULTICHARGED IONS BEAMS : EXPERIMENT VS SIMULATION

09:30-10:00 (25 + 5 min.) #11: Spaedtke, P. (GSI, Darmstadt, Germany)
USE OF SIMULATIONS BASED ON EXPERIMENTAL DATA

10:00-10:30 (25 + 5 min.) #12: Grote, D.P. (LLNL, Livermore, USA)
THE WARP CODE: MODELING HIGH INTENSITY ION BEAMS

10:30-11:00 *COFFEE BREAK*

VII. Diagnostics and Transport (Chair: H. Koivisto)

11:00-11:30 (25 + 5 min.) #13: Tarvainen, O. (JYFL, Jyvaskyla, Finland)
PLASMA POTENTIAL MEASUREMENTS WITH A NEW INSTRUMENT

11:30-11:50 (15 + 5 min.) #14: Higurashi, Y. (RIKEN, Saitama, Japan)
EFFECT OF PLASMA ELECTRDOE POSITION ON THE BEAM INTENSITY AND EMITTANCE OF THE RIKEN 18 GHZ ECRIS

11:50-12:10 (15 + 5 min.) #15: Ma, L. (Chinese Academy of Sciences, Lanzhou, China)
THE EXPERMENTAL RESEARCH OF SPACE CHARGE COMPENSATION USING NEGATIVE HIGH VOLTAGE ELECTRODE METHOD FOR MULTI-COMPONENTS ION BEAM EXTRACTED FROM ECR ION SOURCE

12:10-12:30 (15 + 5 min.) #16: Stockli, M.P. (ORNL, Oak Ridge, USA)
EMITTANCE MEASUREMENTS AND ANALYSIS

12:30-13:30 *LUNCH*

TUESDAY, SEPT. 28, AFTERNOON AND EVENING

VIII. Poster Session II

13:30-16:30 Poster Presentations (See Poster Program)
Coffee served during Poster Session

IX. 88-Inch Cyclotron Tour and Barbeque

16:30-17:30 Tour of the 88-Inch Cyclotron and its ECR ion sources

17:30-21:00 Conference Barbeque at the 88-Inch Cyclotron

WEDNESDAY, SEPT. 29, MORNING

X. Diagnostics and Applications (Chair: R. Pardo)

09:00-09:30 (25 + 5 min.) #17: Trassinelli, M. (Universite Pierre et Marie Curie, Paris, France)
HIGH RESOLUTION HE-LIKE ARGON AND SULFUR SPECTRA FROM THE PSI ECRIT

09:30-09:50 (15 + 5 min.) #18: Wills, J. (Chalk River Laboratories, Chalk River, Canada)
A MICROWAVE DRIVEN ION SOURCE FOR CONTINUOUS-FLOW AMS

09:50-10:10 (15 + 5 min.) #19: Kidera, M. (RIKEN, Saitama, Japan)
APPLICATION FOR ACCELERATOR MASS SPECTROMETRY BY USING ECRIS

10:10-10:30 (15 + 5 min.) #20: Aguilar, A. (University of Nevada, Reno, USA)
PHOTOIONIZATION OF MULTIPLY CHARGED IONS
AT THE ADVANCED LIGHT SOURCE

10:30-11:00 *COFFEE BREAK*

XI. Techniques (Chair: R. Vondrasek)

11:00-11:20 (15 + 5 min.) #21: Celona, L. (INFN-LNS, Catania, Italy)
ANALYSIS OF THE SERSE ION OUTPUT BY USING
KLYSTRON-BASED OR TWT-BASED MICROWAVE GENERATORS

11:20-11:40 (15 + 5 min.) #22: Alton, G.D. (ORNL, Oak Ridge, USA)
A NEW METHOD FOR ENHANCING THE PERFORMANCES OF
CONVENTIONAL B-GEOMETRY ECR ION SOURCES

12:00-13:00 *LUNCH*

WEDNESDAY, SEPT. 29, AFTERNOON

XII. Optional Alcatraz Excursion

12:00-21:00 Alcatraz Excursion
(Lunch bags provided if selected)

THURSDAY, SEPT. 30, MORNING

XIII. Gyrotrons (Chair: H.W. Zhao)

09:00-09:20 (15 + 5 min.) #23: Golubev, S. (IAP RAS, Nizhny Novgorod, Russia)
PLASMA FORMATION BY MILLIMETER WAVES IN CUSP MAGNETIC TRAP

09:20-09:40 (15 + 5 min.) #24: Vodopyanov, A.V. (IAP RAS, Nizhny Novgorod, Russia)
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09:40-10:00 (15 + 5 min.) #25: Erukhimov, V.L. (IAP-RAS, Nizhny Novgorod, Russia)
INVESTIGATIONS OF ELECTRON DISTRIBUTION FUNCTION IN AN ECR DISCHARGE

10:00-10:30 *COFFEE BREAK*

XIV. New Sources (Chair: T. Nakagawa)

10:30-11:00 (25 + 5 min.) #26: Hitz, D. (CEA-Grenoble, Grenoble, France)
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11:00-11:20 (15 + 5 min.) #27: Hill, C.E. (CERN, Geneva, Switzerland)
GTS-LHC: A NEW SOURCE FOR THE LHC ION INJECTOR CHAIN

11:20-11:40 (15 + 5 min.) #28: Zavodszky, P.A. (NSCL/MSU, East Lansing, USA)
DESIGN OF SUSI – THE NEW SUPERCONDUCTING ECR ION SOURCE AT NSCL/MSU

11:40-12:00 TBD
TBD

12:00-13:00 *LUNCH*

THURSDAY, SEPT. 30, AFTERNOON

XV. Radioactive Ion Beams (Chair: S. Gammino)

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13:30-14:00 (25 + 5 min.) #30: Bricault, P. (TRIUMF, Vancouver, CANADA)
RECENT RESULTS WITH THE 2.45 GHZ ECRIS AT ISAC

14:00-14:20 (15 + 5 min.) #31: Ames, F. (TRIUMF, Vancouver, Canada)
CHARGE STATE BREEDING WITH AN ECRIS FOR ISAC AT TRIUMF

14:20-14:40 (15 + 5 min.) #32: McMahan, M.A. (LBNL, Berkeley, USA)
RADIOACTIVE BEAMS USING THE AECR-U AND THE 88-INCH CYCLOTRON

XVI. Closing Remarks

14:40-14:55 (15 min.) D. Hitz (CEA-Grenoble, Grenoble, France)
CLOSING REMARKS

MONDAY, SEPT. 27, AFTERNOON

Poster Session I

#33: Hitz, D. (CEA-Grenoble, Grenoble, France)
DESIGN STUDY OF A HYBRID ECRIS

#34: Andresen, C. (CERN, Geneva, Switzerland)
CHARACTERISATION AND PERFORMANCE OF THE CERN ECR4 ION SOURCE

#35: Zhao, H.Y. (Chinese Academy of Sciences, Lanzhou, China)
A 2.45 GHZ SINGLY-CHARGED ECR ION SOURCE FOR RADIOACTIVE ION BEAM PRODUCTION

#36: Sun, L.T. (Chinese Academy of Sciences, Lanzhou, China)
THE LATEST RESUTLS OF THE ALL PERMANENT ECR ION SOURCE LAPECR2

#37: Suominen, P. (JYFL, Jyvaskyla, Finland)
A NEW DESIGN FOR THE ECRIS PLASMA CHAMBER USING THE MODIFIED MULTIPOLE STRUCTURE

#38: Kremers, H.R. (KVI, Groningen, The Netherlands)
DESIGN AND CALCULATIONS FOR THE NEW ECRIS AT KVI

#39: Hahto, S.K. (LBNL, Berkeley, USA)
PERMANENT MAGNET MICROWAVE SOURCE FOR GENERATION OF EUV LIGHT

#40: Muramatsu, M. (NIRS, Chiba, Japan)
TESTS OF THE NEW NIRS COMPACT ECR ION SOURCE FOR CARBON THERAPY

#41: Liu, Y. (ORNL, Oak Ridge, USA)
TRAVELING WAVE VS. CAVITY RF INJECTION FOR THE ORNL HRIBF VOLUME-TYPE ECR ION SOURCE

#42: Liu, Y. (ORNL, Oak Ridge, USA)
PERFORMANCES OF VOLUME VS SURFACE ECR ION SOURCES

#43: Bilheux, H.Z. (ORNL, Oak Ridge, USA)
TESTING OF THE FLAT-B 6-GHZ ECR ION SOURCE EQUIPPED WITH A RF POLARIZER

#44: May, D.P. (Texas A&M University, College Station, USA)
THE TEXAS A&M ECR ION SOURCES: A PROGRESS REPORT

#45: Stalder, M. (University of Kiel, Kiel, Germany)
DESIGN OF AN ALL - PERMANENT MAGNET, VOLUME TYPE, 10GHZ ECR ION SOURCE WITH FIELD FORMING IRON YOKE

#46: Rashid, M.H. (VECC, Kolkata, India)
IMPROVED SPINDLE CUSP MAGNETIC FIELD FOR ECRIS

#47: You, H.-J. (Hanyang University, Seoul, Korea)
DESIGN OF A 14 GHZ MINIMUM-B ELECTRON CYCLOTRON RESONANCE ION SOURCE WITH OPTIMIZATION CAPABILITY FOR KCCH HEAVY ION ACCELERATOR

TUESDAY, SEPT. 28, AFTERNOON

Poster Session II

#48: Evans, S. (CPI, USA)
THE 28 GHZ, 10 KW, CW GYROTRON GENERATOR FOR THE VENUS ECR ION SOURCE AT LBNL

#49: Schachter, L. (IFIN-HH, Bucharest, Romania)
THE INFLUENCE OF WALL-CURRENT-COMPENSATION AND SECONDARY-ELECTRON-EMISSION ON THE ECR PLASMA PARAMETERS AND ON THE ECRIS PERFORMANCE

#50: Vinogradov, N.E. (ANL, Argonne, USA)
2Q-LEBT PROTOTYPE FOR THE RIA FACILITY

#51: Golubev, S. (IAP RAS, Nizhny Novgorod, Russia)
FORMATION OF ION BEAM FROM HIGH DENSITY PLASMA OF ECR DISCHARGE

#52: Kawai, Y. (ORNL, Oak Ridge, USA)
PLASMA POTENTIAL MEASUREMENT OF VOLUME-TYPE ECR ION SOURCE

#53: Sun, L.T. (Chinese Academy of Sciences, Lanzhou, China)
THEORETICAL AND EXPERIMENTAL STUDIES OF THE EXTRACTED MCI BEAM FROM AN ECR ION SOURCE

#54: Ma, L. (Chinese Academy of Sciences, Lanzhou, China)
THE EXPERIMENTAL RESEARCH OF SPACE CHARGE COMPENSATION USING NEGATIVE CHARGED GAS METHOD FOR MULTI-COMPONENTS ION BEAM EXTRACTED FROM ECR ION SOURCE

#55: Cao, Y. (Chinese Academy of Sciences, Lanzhou, China)
AN ESS SYSTEM FOR ECRIS EMITTANCE RESEARCH

#56: Zhang, Z.M. (Chinese Academy of Sciences, Lanzhou, China)
DEVELOPMENT OF THE TECHNIQE FOR DIAGNOSTIC MULTI-CHARGED ION BEAMS PRODUCED BY ECR ION SOURCE

#57: Tinschert, K. (GSI, Darmstadt, Germany)
EXPERIMENTS ON BEAM EXTRACTION FROM THE CAPRICE ECRIS

#58: Savard, G. (ANL, Argonne, USA)
RADIOACTIVE BEAMS FROM 252CF FISSION USING A GAS CATCHER AND AN ECR CHARGE BREEDER AT ATLAS

#59: Andreev, A. (NSCL/MSU, East Lansing, USA)
SIMULATIONS OF THE LEBT FOR RIA DRIVER LINAC

#60: Marti, F. (NSCL/MSU, East Lansing, USA)
SIMULATION AND COMPARISON OF BEAM EMITTANCE AT VENUS

#61: Kim, J.S. (FAR-TECH, Inc., San Diego, USA)
EFFICIENT PLASMA ION SOURCE MODELING WITH ADAPTIVE MESH REFINEMENT

#62: Qiang, J. (LBNL, Berkeley, USA)
DEVELOPMENT OF THE 3D PARALLEL PARTICLE-IN-CELL CODE IMPACT TO SIMULATE THE ION BEAM TRANSPORT SYSTEM OF VENUS

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Abstracts

#01

FIRST RESULTS OF THE SUPERCONDUCTING ECR ION SOURCE VENUS WITH 28 GHZ

D. Leitner, C.M. Lyneis, S.R. Abbott, R.D. Dwinell, D. Collins, M. Leitner

Lawrence Berkeley National Laboratory, 1 Cyclotron Rd. MS88R0192, Berkeley, CA 94708

VENUS (Versatile ECR ion source for NUclear Science) is a next generation superconducting ECR ion source, designed to produce high current, high charge state ions for the 88-Inch Cyclotron at the Lawrence Berkeley National Laboratory. VENUS also serves as the prototype ion source for the RIA (Rare Isotope Accelerator) front end. The magnetic confinement configuration consists of three superconducting axial coils and six superconducting radial coils in a sextupole configuration. The nominal design fields of the axial magnets are 4T at injection and 3T at extraction; the nominal radial design field strength at the plasma chamber wall is 2T, making VENUS the world most powerful ECR plasma confinement structure. From the beginning, VENUS has been designed for optimum operation at 28 GHz with high power (10 kW).

In 2003 the VENUS ECR ion source was commissioned at 18 GHz, while preparations for 28 GHz operation were being conducted. During this commissioning phase with 18 GHz, tests with various gases and metals have been performed with up to 2000 W RF power. Record ion beam intensities have been extracted at 18 GHz. For example, 1100 eμA of O^{6+}, 180 eμA of Ar^{12+}, 160 eμA of Xe^{20+}, 160 eμA of Bi^{25+} and 100 eμA of Bi^{30+} and 11 eμA of Bi^{41+} were produced.

In May 2004 the 28 GHz microwave power has been coupled into the VENUS ECR ion source. The paper will briefly describe the design of the VENUS ion source, the 28 GHz microwave system, and the VENUS ion beam analyzing system. First results at 28 GHz including first emittance measurements will be presented.

#02

DEVELOPMENT OF IMP ECR ION SOURCES

H. W. Zhao, L. T. Sun , Z. M. Zhang, Y. Cao ,W. He, X. Z. Zhang, X. H. Guo

Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, 730000, China

Development of ECR ion sources at Institute of Modern Physics (IMP) will be presented. Recently IMP 14.5 GHz LECR3 was tested at 18 GHz to produce intense heavy ion beams and more than 1.0 emA of Ar^{8+}, 6.5 eμA of Pb^{37+} were obtained by rf power 800-1000 W. Dependences of beam emittance and focusing image on the operation conditions of an ECR source were studied experimentally at the IMP LECR3 in order to match with the axial injection beam line of the cyclotron SFC. Meanwhile, the beam extraction and compensation of space charge effect were experimentally investigated. Furthermore, an advanced superconducting ECR ion source named SECRAL is being built. The test results of the SECRAL superconducting magnet with sextupole and solenoid coils will be presented. Finally the first test results of a full permanent magnet ECR ion source for highly charged ion beam production will be mentioned.

#03

PRODUCTION OF HIGHLY CHARGED HEAVY IONS BY MEANS OF A HYBRID SOURCE IN CW MODE AND AFTERGLOW MODE

S. Gammino, G. Ciavola, L. Torrisi, L. Andò, L. Celona, S. Manciagli,
F. Consoli, A. Galatà, M. Presti, INFN-LNS, Catania, Italy

A.M. Mezzasalma, A. Picciotto, University of Messina, Italy

J. Krása, L.Láska, M. Pfeifer, K. Rohlena, Inst. Of Physics-ASCR, Prague, Czech Republic

J. Wolowski, P. Parys, E. Woryna, Inst. of Plasma Physics and Laser Microf., Warsaw, Poland

G.D. Shirkov, JINR-Laboratory of Particle Physics, Dubna, Russia

D. Hitz, CEA-DRFMC-SBT, Grenoble, France

The ECLISSE experiment (ECR ion source Coupled to a Laser Ion Source for charge State Enhancement) has been carried out by coupling a Laser Ion Source (based on a Nd:YAG laser (0.9 J / 9 ns, laser power densities $<10^{11}$ W/cm^2) to an electron cyclotron resonance (the SERSE superconducting ECRIS) ion source. Beams of highly charged ions from metal samples without the use of ovens or sputtering technics were obtained in a variety of experimental conditions. The maximum charge states obtained from the ECRIS were 38+ for Ta and 41+ for Au. The peak current was obtained for 25+ and 29+ respectively and it was in the order of some tens of µA.

In this work the analysis of some preliminary results obtained in afterglow mode will be also presented. We employed microwave pulse (length 4 msec) and laser pulse (length 9 nsec) with the same frequency (30 Hz) and variable relative phase. For appropriate phase values, a current enhancement of about one order of magnitude was observed. The afterglow mode will be one of the items to be studied during the next ECLISSE experiment scheduled for the fall of 2004.

#04

FIRST HIGH TEMPERATURE SUPERCONDUCTING ECRIS

D. Kanjilal, G. O. Rodrigues, P. Kumar, C. P. Safvan, U. K. Rao, A. Mandal, A. Roy

Nuclear Science Centre(NSC), Aruna Asaf Ali Marg, New Delhi

C. Bieth and S. Kantas

Pantechnik, 14000 CAEN, France

P. Sortais

Institut des Sciences Nuclaire, INS-IN2P3, Grenoble France

The first High Temperature Superconducting Electron Cyclotron Resonance Ion Source (HTS-ECRIS) called PKDELIS has been developed as a collaborative project. The source has been designed for suitable use on a high voltage platform with minimum requirements of electrical power and water cooling. The design is based on the required A/q of ~7 for the High Current Injector (HCI) of the Superconducting Linear Accelerator (SC-LINAC) at Nuclear Science Centre, New Delhi and to provide relatively higher beam currents of multiply charged ions. High Temperature Superconducting coils (Bi-2223) have been chosen to reduce the power and cooling requirements for obtaining large axial magnetic fields corresponding to a frequency of 18 GHz. The HTS coils are operated in a superconducting mode in a temperature range of about 20 to 22 K using Gifford-McMahon type cryo-refrigerators. A 36 element hexapole was designed using NdFeB to obtain higher fields at the chamber wall. The source is tested thouroughly by producing beams carbon, oxygen, neon, argon, xenon, tantalum and lead at various charge states having analysed current up to 2 emA. The detailed design aspects and test results are presented.

#05

PRODUCTION OF INTENSE BEAMS OF MEDIUM CHARGE STATE HEAVY ION FROM RIKEN ECRISS

T. Nakagawa, Y. Higurashi, M. Kidera, T. Aihara, M. Kase and Y. Yano, RIKEN, Saitama, Japan

At RIKEN, the increase of beam intensity, especially medium charge state heavy ions, from ECRIS are important task for RIKEN RI Beam factory project. During improvement of the performance, we observed that the several key parameters play essential role on increasing the beam intensity.

1)The magnetic field strength and configuration strongly affect the beam intensity. Particularly, the minimum magnetic field strength between the magnetic mirror (B_{min}) plays an important role. 2) The plasma electrode position influences the beam intensity, because the plasma density and beam extraction condition are dependent on its position. 3) The plasma conditions are strongly affected by the extraction current.

By optimizing these parameters, we produced 2mA of Ar^{8+}, 0.35mA of Ar^{11+}, 0.6mA of Kr^{13+} and 0.3mA of Xe^{20+} from RIKEN ECRISs at the RF power of ~700 W. To produce 1mA of Ar^{8+}, we only need ~200W.

To investigate the effect of B_{min} and B_{ext} on the beam intensities, we applied the laser ablation method. Using this method, we measured the density and temperature of electrons and ion confinement time as a function of B_{min} and B_{ext}. In this experiment we observed that B_{min} influences the electron density and ion confinement time.

In this paper, we present how to increase the beam intensities by changing these parameters in detail and effect of B_{min} and B_{ext} on the plasma parameters and beam intensities.

#06

DEVELOPMENTS AND PLASMA STUDIES AT THE ATOMKI-ECRIS

S. Biri, A. Valek, ATOMKI, Debrecen, Hungary
L. Kenéz, J. Karácsony, Babes-Bolyai University, Cluj-Napoca, Romania
A. Kitagawa, M. Muramatsu, NIRS, Chiba, Japan
E. Takács, B. Radics, J. Pálinkás, University of Debrecen, Debrecen, Hungary

The 14.5 GHz ECR ion source of the ATOMKI operates as a stand-alone device to produce highly charged ion beams for atomic physics investigations and a variety of low charged plasmas and beams for plasma physics experiments and for practical applications. The ion source also frequently serves as a test-bench for ECRIS developments. The present paper summarizes some recent results obtained in different topics.

The traditional disc-shape biased electrode has been equipped with water cooling while it still can be moved and biased on-line. This allowed to decrease the outgassing of the walls and to increase the microwave power. A comparison with and without cooling will be shown.

In the past few years we performed numerous plasma diagnostics measurements using Langmuir-probes and X-ray cameras. Many results of these measurements were already published. The analyzing of the tremendous measured data was still continued and new information was withdrawn. Langmuir-probe results allowed estimating the plasma potential close to the resonance zone. The studying of X-ray pictures of Xe-Ar mixture plasmas gave new information on the gas-mixing phenomena.

One of our long-term programs is to produce fullerene beams, plasmas and fullerene modifications (carbon clusters, endohedral fullerenes, etc). The results of mixing fullerene plasma with nitrogen and iron will be shown.

#07

RECENT ECRIS RELATED RESEARCH AND DEVELOPMENT WORK AT JYFL

H. Koivisto, P. Suominen, O. Tarvainen, J. Ärje, E. Lammentausta, P. Lappalainen, T. Kalvas, T. Ropponen and P. Frondelius, Department of Physics, University of Jyväskylä, FIN-40014 University of Jyväskylä, Finland

The main focus of the JYFL ion source group has recently been on the development of a new plasma chamber and measurements of the plasma potential with a device developed at JYFL. The new plasma chamber is based on an idea described at ICIS'03 in Dubna. The work is presented elsewhere in these proceedings (Suominen et al.). The plasma potential measurements are based on the use of the decelerating voltage. With the aid of the device information about the plasma potential and the temperature of the ions can be obtained. This work is also described elsewhere in these proceedings (Tarvainen et al.). The radial feeding of the microwave power into the plasma chamber has been studied. According to the first results the beam intensity remains almost unchanged as a function of the power ratio (radial/axial feeding). Practically same intensity was reached when the same microwave power was fed radially or axially into the plasma chamber. The phenomena will be investigated in more detail. Development work for the production of metal ion beams has also been carried out. For example, a new oven has been designed to significantly exceed the maximum temperature of our miniature oven (1300 ˚C). An overview of the work of the JYFL ion source group will be presented.

#08

ECRIS OPERATION WITH MULTIPLE FREQUENCIES

R. Vondrasek, R. Scott, R. Pardo, ANL, Argonne, USA

The usefulness of two-frequency heating for the production of high-charge state high-intensity beams from on ECRIS has been well established. Factors of 2→5 increase in beam currents have been observed accompanied by a shift to higher charge states. The ECRIS at Argonne National Laboratory has been operated utilizing a 14 GHz klystron and a tunable 11-13 GHz traveling wave tube amplifier (TWTA). Recently a third RF generator has become available and tests with three-frequency heating are being conducted on the ECR1 ion source to determine if injection of a third discrete frequency produces a similar increase in beam production. Operating characteristics as well as initial results will be presented.

09

STATUS REPORT OF ECRIS AT KVI

J.P.M. Beijers, I. Formanoy, H.R. Kremers, J. Mulder, J. Sijbring, S. Brandenburg
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ECRIS related work at KVI is focussed on developing new beams and upgrading our present ECRIS for the new TRIμP facility, which is presently under construction. The goal of TRIμP is to build and operate a user facility for trapped radioactive ions in order to perform experiments on e.g. fundamental symmetries in nuclear and elementary-particle physics. This new facility requires high-intensity ECRIS beams, i.e. up to $\approx 10^{14}$ pps, of multiply-charged ions from Li up to Pb with q/m ranging between 0.1 and 0.4. Because such intense beams cannot be produced with our present Caprice-type ECRIS, we are upgrading the ion source following the AECR design of Berkeley. Details of this upgrade including the modifications we have made can be found in a companion contribution. Much effort is devoted to developing metal-ion beams for the KVI facility. With the present ECRIS we succeeded in extracting 5 eμA of $^{208}Pb^{27+}$ ions using an oven based on a GSI design. This oven has a significantly larger diameter (5 mm) compared to the previously used oven from Pantechnique (∅=1.5 mm). A great advantage of the bigger oven is the much larger interval between refills. Another new metal beam developed at KVI is a $^{24}Mg^{10+}$ beam. This beam was produced with the Pantechnique oven and without a radial heat shield in the plasma chamber. The maximum beam current extracted was only 1 eμA, and it was difficult to obtain stable operation. In future runs we will use the GSI-type oven and a radial heat shield. Furthermore, we succeeded in measuring the oven temperature under operating conditions. In addition to these developments we will also discuss other improvements that have been or will be implemented to optimize the production and transport of heavy-ion beams.

#10

HIGH CURRENTS OF MULTICHARGED IONS BEAMS : EXPERIMENT VS SIMULATION

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The PHOENIX 28 GHz source is now running in CW regime at 60 KV on the LPSC (former ISN) high current test bench, in order to qualify multicharged ions beams for the Spiral II project. In this future accelerator, the RFQ is sized to accelerate A/Q=3 heavy ions. In the paper, we will present a typical daily working point of PHOENIX delivering 1 mAe of 06+ under a total ionic current of 6 mAe (oxygen is mixed with helium). The whole charge state distribution of elements included in the total beam have been analyzed through a faraday cup and two new emittancemeters, providing very interesting informations and constraints on the beam formation at the edge of the ECRIS plasma. Thus, experimental datas are used to fit theorical models installed in our “home made” 3D muticharged ions beam transport code. After a recall on the ECRIS and its beam line, the presentation of the experimental results and cross checks with simulations are presented and discussed.

#11

USE OF SIMULATIONS BASED ON EXPERIMENTAL DATA

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Compared to the simulation of classical high perveance extraction systems for high current ion sources, the extraction of typical ECRIS is more complicated because more parameters, partially unknown are involved. To reduce the computational effort, it would be helpful to determine several of these unknown parameters affecting mainly the starting conditions for trajectories in space and in momentum.

The influence of the magnetic field on the beam in the extraction region is studied. Here the magnetic flux density distribution is fixed, but the starting conditions of all particles can be modified in the simulation. By varying the starting conditions of trajectories within reasonable limits the influence of the magnetic field can be investigated.

A comparison of simulation with experiments using a moveable accel-decel extraction system for the most simple case of Helium shows good agreement of the results, indicating the correctness of the applied model.

#12

THE WARP CODE: MODELING HIGH INTENSITY ION BEAMS

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The Warp code, developed for heavy-ion driven inertial fusion energy studies, is used to model high intensity ion (and electron) beams. Significant capability has been incorporated in Warp, allowing nearly all sections of an accelerator to be modeled, beginning with the source. Warp has as its core an explicit, three-dimensional, particle-in-cell model. Alongside this is a rich set of tools for describing the applied fields of the accelerator lattice, and embedded conducting surfaces (which are captured at sub-grid resolution). Also incorporated are models with reduced dimensionality: an axisymmetric model and a transverse “slice” model. The code takes advantage of modern programming techniques, including object orientation, parallelism, and scripting (via Python). It is at the forefront in the use of the computational technique of adaptive mesh refinement, which has been particularly successful in the area of diode and injector modeling, both steady-state and time-dependent. In the presentation, some of the major aspects of Warp will be overviewed, especially those that could be useful in modeling ECR sources. Warp has been benchmarked against both theory and experiment. Recent results will be presented showing good agreement of Warp with experimental results from the STS500 injector test stand. Additional information can be found on the web page http://hif.lbl.gov/theory/WARP_summary.html.

#13

PLASMA POTENTIAL MEASUREMENTS WITH A NEW INSTRUMENT

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An efficient and fast instrument to measure the plasma potential of ECR ion sources has been developed at the Department of Physics, University of Jyväskylä (JYFL). The operating principle of the instrument is to measure the energy of the ion beam by applying a decelerating voltage to a mesh located in the beam line after mass analysis. The plasma potential is determined by measuring the current at the grounded electrode situated behind the mesh as a function of this adjustable voltage. The design of the instrument, the method of determining the plasma potential and the first results will be presented. The measurements were performed with ECR ion sources at JYFL (6.4 and 14 GHz) and at Argonne National Laboratory (14 GHz). The plasma potential was measured as a function of different source parameters such as microwave power, gas feed rate (with different gases), voltage of the biased disk and magnetic field strength. The effects of gas mixing and double-frequency heating were also studied.

The energy of the ions extracted from an ECRIS plasma comes from the source potential, plasma potential and the thermal energy of the ions. In order to distinguish the effect of the ion temperature on the measured curve simple computer simulations were performed. With the aid of the simulation and assuming a certain potential profile and maxwellian velocity (energy) distribution of the ions, it was seen that the ion temperature should affect the shape of the measured curve in the region where the adjustable deceleration voltage is close to the value of the plasma potential. In the measurements it was observed that the shape of the curve in this region changed dramatically when gas mixing was used. However, the effect was typical only for low charge states of the heavier element while the curves measured with higher charge states remained almost unchanged. The effect of gas mixing on the ion temperature will be discussed based upon the obtained results.

#14

EFFECT OF PLASMA ELECTRDOE POSITION ON THE EBAM INTENSITY AND EMITTANCE OF THE RIKEN 18 GHZ ECRIS

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In previous studies, we observed that the beam intensities of Ar ions were strongly dependent on the plasma electrode position. In these experiments, the lower charge state Ar ions were strongly enhanced when moving the plasma electrode toward the ECR zone. To investigate this effect in detail, we measured the beam intensity of various charge state of Ar, Kr and Xe ions as a function of plasma electrode position. From these experimental results, we confirmed that the beam intensities of lower charge state heavy ions were dramatically increased when setting the plasma electrode near the resonance zone. For example, beam intensity of Kr10+ increased from ~150 to 400 eμA when moving the plasma electrode from 50 to 30 mm far from the edge of ECR zone. Emittance of the intense beam should be influenced by the space charge of the beam, which is one of the main component to enlarge the emittance. To investigate this effect, we measured the emittance of the beam of various heavy ions. In this experiment, we observed that the emittance of the beam is strongly affected by the extraction current of the ion source.

In this paper, we report the effect of plasma electrode position on the beam intensities and the results of emittance measurements for various heavy ions.

#15

THE EXPERMENTAL RESEARCH OF SPACE CHARGE COMPENSATION USING NEGATIVE HIGH VOLTAGE ELECTRODE METHOD FOR MULTI-COMPONENTS ION BEAM EXTRACTED FROM ECR ION SOURCE

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Compensation of the space charge of multi-components, low energy and intense ion beam extracted from ECR ion source has been investigated. A new method of using negative high voltage anode to compensate space charge field of multi-components ion beam extracted from ECR will be discussed. A series of experiments have been done in IMP, some valuable results and data have been gotten. The radical results are the beam current of O^{6+} increasing 37.8%(for negative electrode voltage of -8KV), O^{7+} increasing 23.1%(for negative electrode voltage of -8kv), Ar^{8+} increasing 13.5%(for negative electrode voltage of -5kv) and Ar^{16+} increasing 32.5%(for negative electrode voltage of -2kv) after space charge compensation using negative gas detected in experimental termination when extracting voltage is 15kv.

#16

EMITTANCE MEASUREMENTS AND ANALYSIS

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An LBNL designed Allison type emittance device is used to study ion beam emittances. The desired resolution is obtained with a pair of 0.5 mm slits that only let pass a tiny fraction of the total beam current. This makes the measured signals susceptible to noise and bias. Especially the rms emittance is sensitive to bias due to the x^2, x'^2 and $x{\cdot}x'$ weighing. To eliminate this source of error we assume the data averaged outside certain exclusion boundaries to represent the average bias, and therefore we subtract this value from all raw signals before evaluating the emittance from the data within the boundary. The inclusion of all real signals, even those buried in the noise, can be confirmed if the emittance results do not significantly change when the exclusion boundary is uniformly increased. Most accurate and reliable estimates are obtained with exclusion boundaries that fit the measured signals tightly. The variable exclusion method is compared with results obtained with traditional methods.

#17

HIGH RESOLUTION HE-LIKE ARGON AND SULFUR SPECTRA FROM THE PSI ECRIT

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We present new results on X-ray spectroscopy of multicharged Argon and Sulfur obtained with the Electron Cyclotron Ion Trap installed in Paul Scherrer Institut (Villigen, Switzerland). A Johann type Bragg spectrometer with spherically bent crystal was used with an energy resolution of about 0.4 eV. The ECRIT itself is of a hybrid type with a superconducting split coil magnet plus a special iron inserts providing the mirror field and a permanent magnetic hexapole. The High frequency was provided by a 6.4 GHz microwave emitter.

We obtained high intensity multicharged F-like to He-like Argon and Sulfur X-ray spectra with one *1s* hole. In particular we observe the $1s2s\ ^3S_1 \rightarrow 1s^2\ ^1S_0$ M1 and $1s2s\ ^3P_2 \rightarrow 1s^2\ ^1S_0$ transitions on He-like Argon and Sulfur with unprecedented statistic and resolution. All observed lines energy are being determined with good accuracy, using the heliumlike M1 line as a reference.

Moreover we scanned the plasma by focusing the spectrometer to different points in the plasma chamber. We surveyed the heliumlike M1 transition intensity as a function of the ECRIT working conditions. In particular we observed the M1 intensity dependencies on the superconducting coil current and the injected microwave power.

#18

A MICROWAVE DRIVEN ION SOURCE FOR CONTINUOUS-FLOW AMS

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A microwave-driven, gas-fed ion source originally developed as a high-current positive ion injector for a Tandem accelerator at Chalk River has been the subject of a three-year development program at the Woods Hole Oceanographic Institution NOSAMS facility. Off-line tests have demonstrated positive carbon currents of 1 mA and negative carbon currents of 80 μA from CO_2 gas feed. This source and a magnesium charge-exchange canal were coupled to the recombinator of the NOSAMS Tandetron for on-line tests, with the source fed with reference gasses and a combustion device.

The promising results obtained have prompted the redesign of the microwave source for use as an on-line, continuous-flow injector for a new AMS facility under construction at NOSAMS. The new design is optimized for best transmission of the extracted positive-ion beam through the charge-exchange canal and for reliable operation at 40 kV extraction voltage. Other goals of the re-design include improved lifetime of the microwave window and the elimination of dead volumes in the plasma generator that increase sample hold-up time.

This talk will include a summary of results obtained to date at NOSAMS with the Chalk River source and a detailed description of the new design.

#19

APPLICATION FOR ACCELERATOR MASS SPECTROMETRY BY USING ECRIS

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We have developed the new analytical system which consists of electron cyclotron resonance ion source (ECRIS) and heavy ion linear accelerator. ECRIS-AMS (Accelerator Mass Spectrometry using Electron Cyclotron Resonance Ion Source) has several advantages described below.

1) The production of positive ions in the ECRIS is not influenced by ionization selectivity.
2) We can analyze many trace elements simultaneously in the material with very low background.
3) We can minimize the spectroscopic interference by using the high temperature ECR plasma.

Using this system, we have measured elemental compositions in reference samples (JB, JG etc). From our experimental results, it is considered that the further development and establishment of this method will play an important role in the trace element analysis. For this application, we just need small heavy ion linear accelerator which has acceleration energy of ~ 1MeV/u.

In this contribution, we will present the procedure of analysis in detail and several experimental results for trace element analysis in the materials.

#20

PHOTOIONIZATION OF MULTIPLY CHARGED IONS AT THE ADVANCED LIGHT SOURCE

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A 10-GHz compact all-permanent-magnet ECR ion source is used in conjunction with an ion-photon-beam (IPB) merged-beams endstation to study photoionization of multiply charged ions at undulator beamline 10.0.1 of the Advanced Light Source at LBNL. Absolute cross sections are determined by recording the yield of photoions with a single-particle detector as the photon-beam energy is scanned. The accessible range of photon energies is 17-340 eV with a maximum spectral resolving power of 30,000. The spatial overlap of the ion and photon beams over their 30-cm common path of interaction is determined using two commercial rotating-wire beam-profile monitors and a translating two-slit scanner. Recent photoionization cross-section measurements for F^{2+}, Ne^{3+}, Xe^{3+}, Fe^{3+}, Fe^{5+}, Fe^{7+}, C_{60}^{+}, C_{60}^{2+} and C_{60}^{3+} exemplify the capabilities of the endstation, as well as the fundamental physics issues that may be explored by conducting systematic investigations along isoelectronic or isonuclear sequences of ions.

#21

ANALYSIS OF THE SERSE ION OUTPUT BY USING KLYSTRON-BASED OR TWT-BASED MICROWAVE GENERATORS

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A complete set of measurements has been carried out in order to confirm the previously observed enhancement of the SERSE source performances, when microwaves are fed by means of a TWT generator instead of a Klystron generator, which has been commonly used. An increase in the extracted currents takes place for the highest charge states by using a TWT at 14 GHz, while higher extracted currents were obtained for every charge state by using a TWT at 18 GHz. A description of the experimental set-up and of the obtained results is given in the following. The data will be analysed and an explanation in terms of ECRIS plasma model will be proposed.

#22

A NEW METHOD FOR ENHANCING THE PERFORMANCES OF CONVENTIONAL *B*-GEOMETRY ECR ION SOURCES

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The viability of the "volume"-affect for enhancing the high charge-state populations and intensities of beams extracted from ECR ion sources has been clearly demonstrated at several laboratories. Enlarged ECR zones have been achieved by engineering the central magnetic field so that it is flat and in resonance with single-frequency *rf* power or alternatively, by using multiple frequency techniques to enlarge the ECR volumes within these sources. The performances of conventional *B*-geometry sources have been ameliorated at several laboratories through the use of multiple frequency *rf* power sources. However, the practical application of this technique is very costly, requiring an inventory of independent single-frequency *rf* power supplies and serious modification to the *rf* injection systems of these sources. Broadband sources of *rf* power offer a low-cost and more affective alternative method for increasing the physical sizes of the ECR volumes within these sources without the need to modify the *rf* injection systems of these sources. However, here-to-fore, broadband power sources have not been made available for use in the ECR ion source community. A special programmable additive white Gaussian noise generator (AWGNG) system for injecting broad-band *rf* power into these sources has been conceived and developed, in conjunction with a commercial firm, for such applications. The noise generator, in combination with an external local oscillator, can be used to generate broadband microwave radiation for amplification with a TWT without requirements of modifying the injection system of these sources. The unit has the ability to select internal noise filters and "tune" the noise pass-band over a range of center frequencies. Units can be purchased for use with 6, 10, 14, and 18 GHz ECR ion sources. In this presentation, the AWGNG and its applications for enhancing the performances of conventional *B*-geometry ECR ion source will be described in detail.

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

#23

PLASMA FORMATION BY MILLIMETER WAVES IN CUSP MAGNETIC TRAP

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Modern way of ECR multicharged ion sources development is defined with increasing of microwave frequency up to tens of GHz. Millimeter wave gyrotrons are used now by a few laboratories in the world. Traditional mirror magnetic traps with min B configuration for suppressing of MHD instabilities became too expansive, because very strong magnetic field (more 2 T) with complicated structure must be created. So prospection of cheaper axisymmetric plasma trap with MHD stabilization is quite relevant subject of modern plasma physics. The simplest trap of such kind is CUSP one. Low magnetic field in the center of the trap doesn't allow to achieve a good confinement in classical (Pastulhov) regime. If plasma density is high enough that gasdynamic (collisional) regime of plasma confinement may be realized then central low magnetic field area doesn't play any role in confinement.
A small cusp trap was designed for confinement of plasma created by pulsed 37.5 GHz, 100 kW gyrotron radiation under ECR conditions. Temporal evolution of plasma parameters in experiments were quite smooth and stable. Experimental ion charge state distribution in beam corresponds with calculated one for optimal plasma parameters.
The experiments showed that CUSP traps looks promising as high current multicharged ion source for light ions of medium charge. Agreement between calculations and experiments allows to design bigger CUSP trap with better plasma confinement time. Calculations showed that maximum on Nitrogen +4 in ion charge state distribution and very high ion current density can be achieved if modified CUSP trap and 75 GHz gyrotron are used.

#24

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

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A joint research and development effort has been initiated, whose ultimate goal is the enhancement the mean ion charge states in vacuum arc metal plasmas by a combination of a vacuum arc discharge and an electron cyclotron resonance (ECR) heating. Metal plasma was generated by a special vacuum arc mini-gun and injected into mirror magnetic trap. Plasma was pumped by high frequency gyrotron-generated microwave radiation (frequency 37.5 GHz, max power 100 kW, pulse duration 1.5 ms). Using of powerful microwaves makes it possible to sustain sufficient temperature of electrons needed for multiple ionizations at high plasma density (more then 10^{13} cm^{-3}). Parameter of multiple ionization efficiency $N\tau$, where N is plasma density, τ is ion lifetime, in such a case could reach rather high value $\sim 10^9$ $cm^{-3}\cdot s$. In our situation $\tau = L/V$, where L is trap length, V is plasma gun flow velocity. The results have demonstrated substantial multiple ionization of metal ions (including metals with high melting temperature). For a metal (lead, platinum) plasma, ECR heating shifted the average ion charge up to 5+. Further increase of the ion charge states will be attained by increasing the vacuum arc plasma density and optimizing the ECR heating conditions.

#25

INVESTIGATIONS OF ELECTRON DISTRIBUTION FUNCTION IN AN ECR DISCHARGE.

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The formation of the Electron Distribution Function (EDF) plays an important role in physics of ECR ion sources. Electrons with high energy provide ionization while cold electrons define the losses from the trap. The task of analyzing the EDF is challenging due to many reasons. There is a wide variety of processes that are important for the profile of the EDF including microwave heating, collisions, ionization, ambipolar losses and it is usually hard to construct a theoretical solution that takes all of them into account. On the other hand the available diagnostics for experimental observations of EDF is very poor. Recent investigations of cyclotron instability in ECRIS that generated bursts of high energy electrons on the detectors outside of the trap are among few examples promising to be powerful tools for EDF analysis. In this work we present initial results for theoretical analysis of EDF in the ECR discharge and compare them with experiments.

#26

An all-permanent magnet ECR ion source for the ORNL MIRF upgrade project

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A new high voltage platform has been installed at the ORNL Multicharged Ion Research Facility (MIRF) to extend the energy range of multicharged ions available for experiments studying their collisional interactions with electrons, atoms, molecules, and solid surfaces. For the production of the multiply charged ions, a new all-permanent magnet ECRIS has been designed and fabricated at CEA/Grenoble. After a brief overview of the basic features of the new platform, associated beam transport, and control system, a detailed description of the new ion source design and performance is provided, together with some typical Ar, Xe, and O beam intensities obtained during source commissioning prior to shipment to ORNL.

#27
GTS-LHC: A NEW SOURCE FOR THE LHC ION INJECTOR CHAIN

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The ion injector chain for the LHC has to be adapted and modified to reach the design beam parameters. Up to now an ECR4 delivered the ion beam for the SPS fixed target physics programme. This source will be replaced by a higher intensity source to produce the Pb^{27+} ion current required to fill the Low Energy Ion Ring (LEIR).

The new ion source will be based on the Grenoble Test Source (GTS) which was itself is based on empirical scaling laws derived from the Framework 5 Innovative ECRIS collaboration.

This paper will describe the design principle, the commissioning timetable and the present status of the source development.

#28
DESIGN OF SUSI – THE NEW SUPERCONDUCTING ECR ION SOURCE AT NSCL/MSU

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An ECR ion source is being designed to initially serve as a test bench for development and later will replace the existing 6.4 GHz SC-ECRIS. This ECRIS will operate at 18+14.5 GHz microwave frequencies. The radial magnetic field will be produced by six superconducting hexapole coils, capable to reach 1.5 T at the aluminum plasma chamber wall (R=50 mm). The axial trapping will be produced with six superconducting solenoids enclosed in an iron yoke. The maximum magnetic field at the injection end will be 2.6 T and 1.5 T at extraction. The two central solenoids polarized in the opposite direction between the injection and extraction coils will be used to decrease the minimum value of the axial magnetic field to produce magnetic mirror ratios as high as 20. We will present the Flexible Axial Magnetic Field Concept, introduced for the first time in this design, which will allow tuning the distance between the plasma electrode and resonant zone in the plasma, as well as the plasma chamber length and the bias disc position. The distance between the two axial magnetic maxima will be also tunable in the range of 330 to 480 mm. We will present comparisons of 3D magnetic and electric field calculations as well as charged particle trajectory calculations performed with computer codes based on the Finite Element Method (OPERA-3D and KOBRA-3D) and computer codes based on the Boundary Element Method (AMPERE and LORENTZ).

#29

Radioactive ion beam production at GANIL: the present and the future

Renan Leroy and the Ion Production group.

The GANIL ion production group has in charge the production of stable and radioactive ion beams on the SPIRAL facility. On this facility, the radioactive elements are produced by fragmenting a high energy heavy ion beam in a thick target. The radioactive atoms are stopped inside the target, diffuse and effuse to an ecr ion source before being ionised, extracted and accelerated with a cyclotron. This machine is now under operation since 3 years and numerous radioactive ion beams have been delivered for nuclear physics experiments. A short overview of the delivered beams will be given.
The fragmentation process is well adapted for le production of neuton defficient elements. However,for very heavy and neutron rich elements, a new production process is under studies that consists in bombarding a carbon wheel with a high power deuton beam in order to produce a high intensity neutron beam. This neutron beam iradiates then a uranium carbide target inducing fissions and creating heavy radioactive elements. These radioactive elements are therefore ionised in different sources and extracted. The production of the radioactive ion beam is one of the major challenge of a new big project that is called SPIRAL2. A description of the project and an overview of the different development in ion sources as well as for stable and radioactive ion beam production will be presented.

#30

RECENT RESULTS WITH THE 2.45 GHZ ECRIS AT ISAC

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A 2.45 GHz ECRIS was built at TRIUMF for on-line applications at the ISAC facility. The ISAC facility utilizes a 500 MeV proton beam driver with intensity that can reach 100 µA on the isotope production target. In such an environment special care during the design phase had to be taken, all the ECRIS components specially the two coils had to be radiation hard. The source cavity is a single mode TE11 that operates at 2.45 GHz. In order to avoid large containment time the plasma volume was limited using a 12 mm diameter quartz tube located at the centre of the cavity.

The source was installed at the ISAC target station last summer and first on-line tests were performed. The first measured yield for all noble gases from a Ta foil target were quite low compared to the results from the alkali elements from a similar target combined with a surface ion source. The ionization efficiency was adversely affected by the pressure increase when the proton beam hit the target. For example the Neon ionization efficiency of a calibrated leak dropped by two orders of magnitude when the proton beam was raised from 0 to 10 µA on target.

Following the disappointing run with the Ta foil target we decide to conduct intensive studies of the relation between the ionization efficiency and the pressure. Tests were conducted with a well know quantity of gases of Kr and Xe that were injected into the ECR while monitoring the ionization efficiency. The Neon ionization efficiency decreased from 2% to 0.01% when the tank pressure increased from $1.5x10^{-6}$ to $3x10^{-6}$ Torr. This corresponds to approximately 10^{14} Xe/s.

In May 2004 on-line tests this time with a SiC target were undertaken. The goal was to produce ^{18}Ne for a high precision half-live determination. The ECRIS was operated with the same tune developed during the off-line tests, where a 2% Neon ionization efficiency was obtained. Helium at a flow of 1 SCCM was used as the support gas. The ^{18}Ne yield was measured with 1 µA to 5 µA and follow the proton beam. Above 7 µA the yield did not increase and at 10 µA it was lower than at 5 µA. The Neon ionization efficiency was measured and it decreased from 1% at 5 µA to 0.05% at 10 µA.

Furthermore, due to carbon coating of the quartz liner in the plasma chamber, the ECRIS had to run with an Ar-He. The Ar provides some way to reduce the carbon on the quartz tube. Unfortunately, the addition of Ar also reduces the ionization efficiency by a factor 3. A better solution was to change the support gas from He to Ar. Even though, the Ne ionization efficiency is lower, about 1% instead of 2%, the net effect is that the efficiency is much less pressure dependent. In those conditions we were able to operate the ECRIS with a proton beam up to 30 µA on the SiC target and the ^{18}Ne yield just scale with the proton beam. This paper will give the results of the Ne ionization efficiency as a function of the pressure and will describe in detail how we manage to improve the on-line ionization efficiency of the 2.45 GHz ECRIS.

#31

CHARGE STATE BREEDING WITH AN ECRIS FOR ISAC AT TRIUMF

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For the acceleration of radioactive ions the usable mass range is limited by the A/q acceptance of the first accelerator stage. At the ISAC facility the maximum A/q value is at 30. Since an efficient primary ion source normally produces singly charged ions charge state breeding is necessary if higher masses are to be accelerated. At TRIUMF an ECR source has been chosen as a breeder due to its potential high efficiency in producing intermediate A/q values. To minimize the necessity for further stripping an A/q around 6 is desirable.
A 14 GHz "PHOENIX" booster from Pantechnik has been set-up at a test bench. The singly charged ions are produced from an ion source mounted in a standard ISAC target-ion-source set-up, which can be equipped with different ion sources. For the first tests an ECR source to produce noble gas beams has been chosen.
The aim of the measurements at the test bench is to find the optimum operation conditions of the charge state booster and the injection and extraction ion optics. Working with radioactive ions always means that the system should aim for high efficiency, as the production of such species is limited. Therefore, special emphasis has to be put on the highest yield for the production of the desired charge state. To improve the injection efficiency the injection line at the test bench can accommodate a gas filled RF quadrupole cooler. A second point is the analysis of the extracted beam quality in order to optimize the following mass separation and transport efficiency. This will also reduce the background due to neighboring high intensity A/q values or scattered ions in the beam lines. Additionally, as the access to the source at its final destination in a highly radioactive environment will be limited, a stable operation is essential.
First results on the optimization of the extraction ion optics and the charge breeding will be presented.

#32

RADIOACTIVE BEAMS USING THE AECR-U AND THE 88-INCH CYCLOTRON

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The high ionization efficiency of an Electron Cyclotron Resonance (ECR) ion source combined with the mass resolution of a cyclotron is ideal for the generation of some ISOL-type radioactive ion beams (RIBs). In two separate projects at the 88-Inch Cyclotron at LBNL – BEARS [1] and the Recyclotron [2] – we have developed techniques to efficiently ionize and accelerate beams of gaseous species of ^{11}C ($t_{1/2}$ = 20 min), $^{14,15}O$ ($t_{1/2}$ = 20 sec, 2 min) and $^{76,79}Kr$ ($t_{1/2}$ = 14, 35 hours).

Measurements of the ionization efficiency and hold-up times will be discussed, along with issues of source contamination and poisoning encountered in running both RIBs and high-intensity stable beam experiments using the same ion source, the LBNL AECR. Methods to tune clean, low intensity RIBs through the cyclotron with high efficiency will also be discussed, including the use and limitations of analog beams (beams with nearly the same charge to mass ratio as the RIB).

[1] J. Powell, et al, Nucl Instr Meth. **A455**, 452 (2000)
[2] J. Cooper, et al, Nucl. Instr Meth., in press (2004)

#33

DESIGN STUDY OF A HYBRID ECRIS

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For some applications like the installation on a compact high voltage platform, a new ion source is under study. The purpose of this machine is to deliver very high charge states, which requires long ion lifetimes and then a large plasma volume. On the other hand, to deliver intense beams, the highest frequency compatible with the magnetic confinement has been chosen.

Due to the room available for this source, the magnetic system is chosen hybrid: the radial field is created by permanent magnets, while the axial field is produced by 4K superconducting coils placed in a cryostat filled with LHe.

This presentation gives the major parameters of this ion source, with a special emphasis on the magnetic system and its cryogenic features.

#34

CHARACTERISATION AND PERFORMANCE OF THE CERN ECR4 ION SOURCE

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To optimise the heavy ion injector for the LHC a good knowledge of the parameters of the ECR4 ion source and the beam transport in the Low Energy Beam Transport (LEBT) for a lead ion beam is necessary.

Results of the emittance measurements of the full Pb^{27+} lead beam using a scanning slit and profile monitor will be presented. Furthermore, the emittance of a single charge state after the source has been measured using a solenoid scan coupled to a guillotine and spectrometer. The results are compared to beam simulations.

Also the results for last years operation for the SPS fixed target physics with indium will be presented.

#35

A 2.45 GHZ SINGLY-CHARGED ECR ION SOURCE FOR RADIOACTIVE ION BEAM PRODUCTION

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A 2.45 GHz electron cyclotron resonance (ECR) ion source has been developed in IMP. This ECR ion source is dedicated to the production of singly-charged radioactive ion beams. The magnetic field is supplied by two permanent magnetic rings. The main features of this ion source are presented in this article. Some preliminary tests of the ionization efficiency have been done, and the results are presented.

#36

THE LATEST RESUTLS OF THE ALL PERMANENT ECR ION SOURCE LAPECR2

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Abstract

A high performance all permanent **E**lectron **C**yclotron **R**esonance **I**on **S**ource (ECRIS) LAPECR2 (**L**anzhou **A**ll **P**ermanent **ECR** ion source No. **2**) has been under construction in IMP for one year. This ECRIS is running at 14.5GHz. The magnetic field configuration is designed according to the famous magnetic scaling laws: B_{inj} = 1.4T (2.2T with a iron yoke at the injection side), B_{ext} = 1.1T, B_{min} = 0.43T and B_{rad} = 1.2T. According to the final design, the source body is ϕ650mm×610mm in dimension and about 900kg in weight. The source turns out to be the largest all permanent ECRIS in the world. To fabricate such an ion source is really very difficult, however we have succeeded in overcoming the many difficulties and the source has been set up recently. In this article, the typical parameters of the constructed ion source and the preliminary commissioning results with some gaseous elements are presented.

#37

A NEW DESIGN FOR THE ECRIS PLASMA CHAMBER USING THE MODIFIED MULTIPOLE STRUCTURE

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Recent hexapole upgrades have shown that an increase of about 10 % in the radial magnetic field strength can improve the production of high charge states even by a factor of 2. Unfortunately methods to increase the radial magnetic field are quite limited. We have studied a new method, called the Modified Multipole Structure (MMPS), where the magnetic field is increased only at the locations where the plasma flux hits the plasma chamber wall. According to the magnetic field simulations a high permeability material (for example a small cross section iron block) at the magnetic pole can boost the radial magnetic field inside the plasma chamber to a value of over 2 T. The effect is very local, only a few millimeters wide, and strongly depends on the shape and the size of the iron block. In the ECRIS the iron is also influenced by a relatively high solenoid field. Consequently, optimization of the design has to be made using a 3D-simulation code. We have performed extensive simulations and designed a new MMPS - plasma chamber for the JYFL 6.4 GHz ECRIS. The results of the simulations and new features of the plasma chamber will be presented.

In the new design the plasma chamber consists of two parts. The outer part holds the magnet array and the inner part is a separate vacuum vessel. The magnet array consists of 12 NdFeB - permanent magnet bars. The radial position of each magnet can be adjusted by 8 mm, which allows the multipolar magnetic field inside the plasma chamber to be changed between values of 0.4 T and 0.55 T. Between every second magnet there is an iron block, which can boost the magnetic field up to 0.9 T. The position of these “iron poles” can be changed online allowing the strength of the magnetic field to be adjusted without breaking the vacuum.

#38

DESIGN AND CALCULATIONS FOR THE NEW ECRIS AT KVI

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New experimental requirements at KVI make a significant upgrade of our present Caprice-type ECRIS mandatory. We have chosen for a modification following the AECR design of LBL-Berkeley. This successful source is also in operation in Jyväskylä, Argonne, NSCL-Michigan and Texas A&M. In the present contribution we will discus our new design in detail, which is based on the Jyväskylä ECRIS. Important changes are the better high-voltage insulation, enabling the new source to operate at a maximum extraction voltage of 35 kV, and a completely redesigned extraction region. Also the magnetic circuitry is modified, with stronger hexapole bars, a slightly different iron yoke for the existing solenoids and central iron plugs. The longitudinal magnetic field extrema on axis are B_{in}=1.8 T, B_{ex}=0.95 T and B_{min}=0.36 T, dtailed magnetic field calculations will be presented at the conference. The new Al plasma chamber housing the 6 magnet bars for the hexapole has also been modified with respect to the original design and will be built in Jyväskylä. The oven for metal beam production, the biased disk and a new isolated radial screen will be integrated in the new design. The source is now under constuction and we hope to extract the first beam in the beginning of 2005.

#39

PERMANENT MAGNET MICROWAVE SOURCE FOR GENERATION OF EUV LIGHT

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Extreme ultraviolet (EUV) lithography is considered to be the most favored technique for manufacturing integrated circuits at 65 nm node and beyond. Producing high power of 13.5 nm EUV light is needed in order to meet the throughput requirement for mass production. In particular, Xenon ions with charge state of ten are found to be responsible for the production of the 13.5 nm line in electromagnetic spectrum. To obtain reasonable concentration of Xe^{10+} ions in the plasma, a permanent magnet Electron Cyclotron Resonance (ECR) based plasma generator using 6.4 GHz microwave frequency has been developed by the Plasma and Ion Source Technology Group at Lawrence Berkeley National Laboratory (LBNL). In this presentation, the initial results of the experiment are shown and proposed improvements for the plasma source and EUV measurement setup are presented.

#40

TESTS OF THE NEW NIRS COMPACT ECR ION SOURCE FOR CARBON THERAPY

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Ion source for medical facilities should have characteristics of easy maintenance, low electric power, good stability and long operation time without maintenance (one year or more). Based on the proto type compact source, a 10 GHz compact ECR ion source with all permanent magnets has been developed. Peaks of the mirror magnetic field along the beam axis are 0.59 T at the extraction side and 0.87 T at the gas injection side, respectively, while the minimum B strength is 0.25 T. The source has a diameter of 320 mm and a length of 295 mm. The result of beam tests shows that a C^{4+} intensity of 530 μA was obtained under an extraction voltage of 45 kV. This paper describes the design detail and the experimental results for the new source.

#41

TRAVELING WAVE VS. CAVITY RF INJECTION FOR THE ORNL HRIBF *VOLUME-TYPE* ECR ION SOURCE

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The all-permanent, 6-GHz ECR ion source at the Oak Ridge National Laboratory (ORNL) Holifield Radioactive Ion Beam Facility (HRIBF) was originally designed with an rf injection system consisting of a tapered rectangular-to-circular transition, starting from a rectangular WR137 waveguide and terminating with a cylinder whose diameter matched the dimension of the plasma chamber. High rf power reflection was often observed with this traveling wave structure. A major modification has been made to the source by adding a small iron plug on axis close to the peak of the injection side axial magnetic field and shifting the rf injection to an off-axis position. The new rf injection system consists of a transition from WR137 waveguide to a WRD580 double-ridge waveguide which penetrates the magnetic plug mounting plate sufficiently off-axis to avoid parasitic resonances inside the waveguide. The plasma chamber thus becomes a cavity structure instead of a traveling wave structure for the injected rf radiation. The performance of the source has been significantly enhanced with the new rf injection system: the charge-state-distribution was moved to higher charge states and the intensities of the charge-states $>Ar^{7+}$ were increased more than a factor of two. Details on the source improvement will be discussed.

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

#42

PERFORMANCES OF *VOLUME* VS *SURFACE* ECR ION SOURCES

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An all-permanent, 6-GHz ECR ion source has been evaluated at the Oak Ridge National Laboratory (ORNL) Holifield Radioactive Ion Beam Facility (HRIBF) for two different magnetic configurations: a traditional minimum-*B* configuration where the ECR zones are surfaces and a flat central-field (flat-*B*) magnetic profile which forms a large, on-axis ECR volume. Comparisons are made of the performance of the source when operated in the *volume* and *surface* ECR configurations. The studies show that the *volume* ECR configuration produced higher charge states and higher intensities for high charge states than the conventional minimum-*B* configuration. Much higher *X*-ray intensities and energies were also measured with the *volume* ECR configuration, suggesting the presence of more hot electrons in the *volume-type* ECR source.

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

#43

TESTING OF THE “FLAT-B” 6-GHZ ECR ION SOURCE EQUIPPED WITH A RF POLARIZER

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The all-permanent magnet, 6-GHz “flat-B” (or “volume”-type) ECR ion source at the Holifield Radioactive Ion Beam Facility of the Oak Ridge National Laboratory can be equipped with a RF polarizer for injection of right-hand circularly polarized (RHCP) or left-hand circularly polarized (LHCP) microwave radiation into the plasma chamber. Testing of the source with the polarizer is made using *Ar* as the operating gas. Comparison of the source performance with and without the polarizer will be given in this report.

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

#44

THE TEXAS A&M ECR ION SOURCES: A PROGRESS REPORT

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The Texas A&M Cyclotron Institute has two ECR ion sources, ECR1 and ECR2. ECR1 operates at 6.4 GHz and has high-B containment fields. ECR2 operates at 14.5 GHz. Both plasma chambers are aluminum, are large with similar dimensions and incorporate biased disks on the injection end. The large chamber size has been convenient in allowing a number of sputtering feeds to be used. In ECR1 an eight-lead, high-voltage feedthrough is used for sputtering, enabling the beam to be switched rapidly and easily between eight different metallic elements, some of which are refractory. Many of the metallic elements up through uranium can be sputtered. Sputtering as well as other methods used for generating beams will be described, and the operation of the two ion sources will be described and compared.

#45

DESIGN OF AN ALL - PERMANENT MAGNET, VOLUME TYPE, 10GHZ ECR ION SOURCE WITH FIELD FORMING IRON YOKE

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A new ECR ion source (ECRIS) using permanent magnets only has been developed for the use in a solar wind calibration laboratory at the University of Kiel. The main goal of the new ECRIS is to produce high charged ions like Fe^{20+} to simulate the solar wind. The ECRIS and an 90° sector magnet are placed on a high voltage platform, allowing the static acceleration of the ions in the energy rage of 1keV/q .. 450keV/q.
We designed an all - permanent magnet system using additional iron rings to shape the magnetic field. A plateau in the axial magnet field strength B_z leads to a big resonance volume. The form of the B_z-field plateau can be adjusted moving the iron rings in axial direction. Changing the iron rings leads to resonance frequencies in the range of 10GHz to 14GHz. Our magnet design leads to a simple magnet geometry and a high axial mirror field strength of $B_{z\,Max} = 1T$. With the inner plasma camber diameter of $d_i = 45mm$ and the length of $l = 140mm$ we built up one of the biggest permanent magnet systems operating at 10GHz. Empirically ECRIS with big plasma cambers diameter have a good performance producing highly charged ions.
The magnet system can be equipped with either a hexapole or a 12-fold multipole for the radial plasma confinement. Therefore we can experimentally compare the well known ECRIS with hexapole and the multipole concept. Simulations of the electron tracks in the ECRIS show clear a difference using different confinement systems. A hexapole leads to the well known triangular deformations of the magnetic flux surfaces at the mirror field points. The central region, where electrons move mainly axially is very small $r < 3mm$. Most electrons are reflected axially and radially at the increasing field of the hexapole. The confinement of the electrons seams to be strongly affected by the field strength at the plasma chamber wall which is dominated by the hexapole. With the 12-fold multipole the deformations of the flux surfaces are small compared to the hexapole system. Within a radius of $r < 10mm$ the electrons are axial reflected. This leads to a confinement of the electrons dominated by the axially mirror field strength $B_{z\,Max}$. Outside the central region the confinement is rather weak as the field strength at the plasma camber with a 12-fold multipole is weaker than with the hexapole. Experiments will show if the multipole system leads to higher currents of highly charged ions.

#46

IMPROVED SPINDLE CUSP MAGNETIC FIELD FOR ECRIS

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Magnetic field of minimum-B configuration is very important for achieving robust plasma confinement and closed surface for electron cyclotron resonance zone for electron heating and plasma discharge. It is employed for designing efficient ion source for producing and extracting highly charged heavy stable or radioactive ions. The spindle cusp magnetic field configuration also forms the modified minimum-B configuration. Earlier this type of field was used for 2.45 or 9.6 GHz frequency of microwave. They were little successful to be dismantled and it was attributed to the huge constant loss of plasma on the cusp ring at the middle length because of insufficient magnetic field for providing mirror reflections of charged particles and little field at the center.

The absolute magnetic field in the new configuration has been optimized and improved sufficiently and symmetrized to the absolute field at the point cusp positions on the central axis at the ends. It was done using a technique of properly shaped disk of high permeability material in between the oppositely energized co-axial coil pair. Otherwise, a single ring with special pole surface made of permanent magnet with radial magnetization can be used either. Properly shaped plugs made of highly permeable material are also used. The coil configuration can achieve magnetic field corresponding to 2.45 to 28 GHz or higher for high-B mode operation. Similarly, the permanent magnet configuration can achieve magnetic field for 2.45 to 14.4 GHz as of now. The property of mirror reflection in the improved cusp field was investigated also by electron simulation. The electrons get bounced back constantly due to the symmetric and sufficient magnetic field at the cusp positions. The low energy electrons passing through the center of the cusp field also get reflected several times and are lost at the cusp positions only due to the non-adiabatic effect on electron magnetic moment there. Their reflection is enhanced using negatively biased electrodes at the cusp positions. Thus, density of plasma as well as confinement will be boosted. The improved spindle cusp geometry does not need any multipole magnet. The length of the loss-line in this configuration is much less than the multipole cusps in a corresponding conventional ECRIS. The system becomes simpler, more compact and cost-effective compared to the conventional one. International cooperative and collaborative effort is needed, indeed, to achieve the goal of constructing and testing such conceived new ECRIS.

#47

DESIGN OF A 14 GHZ MINIMUM-B ELECTRON CYCLOTRON RESONANCE ION SOURCE WITH OPTIMIZATION CAPABILITY FOR KCCH HEAVY ION ACCELERATOR

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A 14 GHz minimum-B ECR ion source has been designed to be used firstly as an ion source for heavy ion accelerator being upgraded in Korea Cancer Center Hospital. Secondly, this ion source plans to be used for applications in atomic physics research and for further physical understandings of electron cyclotron resonance (ECR) plasmas. The designed ion source is featuring operating flexibility as a research facility rather than a specified ion source optimized to its application. To meet various requirements for the above applications, the source has been designed to be flexibly operated by variable magnetic structures, movable extraction system, biased disc, and the real-time plasma diagnostics.
(1) By using the additional central coil and by axially shifting the whole magnet system, the magnetic field structure can be changed to different profiles. (2) Beam extraction system, three electrode acel-decel type extractor and einsel lens, has made to be movable. (3) The biased disc has been shaped triangular, made to be movable and rotatable for controlling the particle flux entered it. (4) The plasma chamber has been carefully designed to include 6 radial diagnostic ports, which are positioned between 6 poles of the hexapole magnet so that the plasma parameters and its time and space resolved profiles can be measured by electrical probe and LIF (Laser Induced Fluorescence) method. (5) The rectangular waveguide is directly inserted to the source to make its radial position lie along the resonance surfaces so that it can ensure the maximum power coupling.

#48

THE 28 GHZ, 10 KW, CW GYROTRON GENERATOR FOR THE VENUS ECR ION SOURCE AT LBNL

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The VIA-301 Heatwave™ gyrotron generator was specifically designed to meet the requirements of the Venus ECR Ion Source at the Lawrence Berkeley National Laboratory (LBNL). VENUS (Versatile ECR ion source for NUclear Science) is a next generation superconducting ECR ion source, designed to produce high current, high charge state ions for the 88-Inch Cyclotron at the Lawrence Berkeley National Laboratory. VENUS also serves as the prototype ion source for the RIA (Rare Isotope Accelerator) front end [1].
This VIA-301 Heatwave™ gyrotron system provides 100 watts to 10 kW continuous wave (CW) RF output at 28 GHz. The RF output level is smoothly controllable throughout this entire range. The power can be set and maintained to within 10 watts at the higher power end of the power range and to within 30 watts at the lower power end of the power range. A dual directional coupler, analog conditioning circuitry, and a 12-bit analog input to the embedded controller are used to provide a power measurement accurate to within 2%. The embedded controller completes a feedback loop using an external command set point for desired power output. Typical control-loop-time is on the order of 500 mS. Hard-wired interlocks are provided for personnel safety and for protection of the generator system. In addition, there are software controlled interlocks for protection of the generator from high ambient temperature, high water temperature, and other conditions that would affect the performance of the generator or reduce the lifetime of the gyrotron. Cooling of the gyrotron and power supply is achieved using both water and forced circulation of ambient air. Water-cooling provides about 80% of the cooling requirement. Input power to the generator from the prime power line is less than 60 kW at full power. The Heatwave™ may be operated locally via its front panel or remotely via either RS-232 and/or Ethernet connections. Through the RS-232 the forward power, the reflected power, the interlock status and crucial operating parameters are transmitted and tied into the VENUS PLC control system.
The paper describes the gyrotron system, control software, the user interface, the main system parameter, and performance in respect to output power stability.

[1] D. Leitner, C.M. Lyneis, D.G. Collins, R.D. Dwinell, M.A. Leitner, D.S. Todd, First results of VENUS with 28 GHz, this conference

#49

THE INFLUENCE OF WALL-CURRENT-COMPENSATION AND SECONDARY-ELECTRON-EMISSION ON THE ECR PLASMA PARAMETERS AND ON THE ECRIS PERFORMANCE

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Axial and radial diffusion processes determine the confinement time in an ECR ion source. As it has been demonstrated a biased disk redirects the ion and electron currents in the source in such a way that the source performance is improved. This effect is due to a partial cancellation of the compensating wall currents.

In this contribution we present the effects of suppressing the compensating wall currents by using a metal-dielectric (MD) disk instead of a metallic disk in the IKF 14-GHz-ECRIS.

Lower values of the plasma potential values (measured by means of a Langmuir probe) and higher average charge states were observed in the presence of the MD disk as compared with the case of the standard metallic biased disk. The measurements were performed with the MD disk (the metallic plate) on the plasma chamber potential. Due to its insulating properties, the MD disk obviously is a better blocker of the compensating currents than the metallic biased disk.

A comparison with results from experiments with a MD liner in the source clearly demonstrates that the beneficial effect of the liner on the performance of the ECRIS is much stronger than that observed with the MD-disk. The “liner-effect” certainly has to be ascribed to the different physics based on the strong secondary electron emission of the liner as compared to the MD disk, the function of which may be interpreted simply as a blocker of the compensating wall currents.

#50

2Q-LEBT PROTOTYPE FOR THE RIA FACILITY

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The Rare Isotope Accelerator (RIA) facility utilizes the concept of simultaneous acceleration of two charge states from the ion source. We are building a prototype two charge-state (2Q) injector of the RIA Driver Linac, which includes an ECR ion source, a LEBT and one-segment of the prototype RFQ. Currently, the 2Q-LEBT Facility consists of Berkeley Ion Equipment Corporation BEI-100 ECR ion source. The rf transmitters, high voltage power supplies, turbo pumps and other related equipment were received with the source. BEI-100 is an all-permanent-magnet source utilizing NdFeB magnetic material, grade N45H, and has the highest magnetic field strengths for an ECR ion source of this type ever built. The magnetic field achieves a maximum strength of 11 kG at the plasma chamber surface and 13 kG on the axis. The source operates with two-frequency plasma heating of 12.75 and 14.5 GHz. We have made some modifications of the plasma chamber injection assembly to increase the beam production performance. The assembling of the source have been basically completed and the beam production is expected in the June 2004. This report will include measured beam current and emittance for a variety of beams from the source. Detailed design of the 2Q-LEBT will also be presented and the current project status will be reported.

#51

FORMATION OF ION BEAM FROM HIGH DENSITY PLASMA OF ECR DISCHARGE

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One of the most promising directions of ECR multicharged ion sources evolution is related with increase in frequency of microwave pumping. During last years microwave generators of millimeter wave range - gyrotrons have been used more frequently. Creation of plasma with density 10^{13} cm^{-3} with medium charged ions and flux density from trap plug along magnetic field lines on level of a few A/cm^2 is possible under pumping by powerful millimeter wave radiation and quasigasdynamic (collisional) regime of plasma confinement in the magnetic trap. Such plasma has great prospects for application in plasma based ion implantation systems for processing of surfaces with complicated and petit relief. Use it for ion beam formation seams to be difficult because of too high ion current density. This paper shows possibility to arrange ion extraction in zone of plasma expansion from the magnetic trap along axis of system and magnetic field lines.

Plasma was created at ECR gas breakdown by means of millimeter wave radiation of a gyrotron with frequency 37.5 GHz, maximum power 100 kW, pulse duration 1.5 ms. Two and three electrode quasi-Pierce extraction systems were used for ion beam formation.

It is demonstrated that there is no changes in ion charge state distribution along expansion routing of plasma under collisional confinement. Also ion flux density decreases with distance from plug of the trap, it allows to control extracting ion current density. Multicharged ion beam of Nitrogen with total current up to 3 mA at diameter of extracting hole 1 mm, that corresponds current density 320 mA/cm^2, was obtained. Magnitude of total ion current was limited due to extracting voltage (60 kV). Under such conditions characteristic transversal dimension of plasma equaled 4 cm, magnetic field value in extracting zone was about 0,1 T at axesymmetrical configuration, that is important for formation of ion beams with low emittance.

#52

PLASMA POTENTIAL MEASUREMENT OF "*VOLUME*"-TYPE ECR ION SOURCE

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The "volume"-type ECRIS based on flat central-field (flat-*B*) concept has been developed at the Holifield Radioactive Ion Beam Facility, Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee. It has been demonstrated that the "volume-type" ECRIS is superior to the conventional minimum-*B* source; the flat-B can provide better coupling of RF to the electrons, which results in enhancement of energetic electrons, therefore, higher ionization rate. In this report, we present the plasma potentials measured at various pressures, rf power, and gas mixing ratio for further evaluation of the flat-B source. X-ray emission is monitored as an indicator of the change of electron energy distribution.

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#53

THEORETICAL AND EXPERIMENTAL STUDIES OF THE EXTRACTED MCI BEAM FROM AN ECR ION SOURCE

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With the development of **E**lectron **C**yclotron **R**esonance **I**on **S**ource (ECRIS), very high performance ECRIS nowadays have been set up one by one around the world, such as the GTS in Grenoble, SERSE in Catania, LECR3 in Lanzhou and etc, which can produce very intense **M**ultiply **C**harged **I**on (MCI) beam. But till now, the study of the extracted MCI beam from an ECRIS remains open. In this article, we present a theoretical and experimental study of the extracted MCI beam. In the theoretical part, the influences of the extraction system on the extracted ion beam quality are mainly analyzed. The aspects that have influences on the extracted ion beam quality have been analyzed. With the instruction of the analysis, the PBGUNS code is used to simulate the influences of some important aspects concerning the extraction system. The influences of the extraction system geometry design, magnetic field, and the space charge effect will be detailedly presented in this article. In the experimental part, with an Electric-Sweep Scanner (ESS) emittance detection system, the influences on the extracted ion beam emittance of some typical parameters of ECRIS have been researched, such as the injected RF power, the RF frequency, the magnetic field and etc. The obtained results and the corresponding explanations are presented. Some of the results are well in accord with some empirical laws, but some other results seem to be disputed.

#54

THE EXPERIMENTAL RESEARCH OF SPACE CHARGE COMPENSATION USING NEGATIVE CHARGED GAS METHOD FOR MULTI-COMPONENTS ION BEAM EXTRACTED FROM ECR ION SOURCE

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Compensation of the space charge of multi-components, low energy and intense ion beam extracted from ECR ion source has been investigated. A new method of using negative charged gas to compensate space charge field of multi-components ion beam extracted from ECR will be discussed. Full compensation and overcompensation will been considered too. A series of experiments have been done in IMP, some valuable results and data have been gotten. the radical result is the beam current of O^{7+} increasing from 250µA to 285µA after space charge compensation using negative gas detected in experimental termination.

#55

AN ESS SYSTEM FOR ECRIS EMITTANCE RESEARCH

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Abstract

An emittance scanner named Electric-Sweep Scanner (ESS) had been designed and fabricated in IMP. And it has been set up on the LECR3 beam line for the ion beam quality study. With some development, the ESS system has become a relatively dependable and reliable emittance scanner. Its experiment error is about 10 percent. We have done a lot of experiments of emittance measurement on LECR3 ion source, and have researched the relations between ion beam emittance and the major parameters of ECR ion source. The reliability and accuracy test results are presented in this paper. And the performance analysis is also discussed.

#56

DEVELOPMENT OF THE TECHNIQE FOR DIAGNOSTIC MULTI-CHARGED ION BEAMS PRODUCED BY ECR ION SOURCE

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A new diagnostic system and its preliminary experimental results had been reported last year on ICIS'03 . This year the system has been improved and some new test results have been obtained successfully.

#57

EXPERIMENTS ON BEAM EXTRACTION FROM THE CAPRICE ECRIS

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Classical compact ECRIS of small volume operating at 14 to 18 GHz provide an ion current density of several mA/cm^2 at the extraction aperture (e.g. CAPRICE at 14.5 GHz). This is considerably less than typical values for high current ion sources which are in the order of 100 mA/cm^2 for ion beams of lowly charged ions.

However, the present development of powerful ECRIS with large volumes and higher plasma densities working at 28 GHz (or even higher frequencies) will lead to higher current densities which may approach the values of high current sources. Therefore a careful beam formation within the extraction which provides space charge compensation downstream behind the extraction system will be essential. The GSI CAPRICE ECRIS was equipped with a movable accel-decel extraction system in order to investigate the influence of electric field gradient and space charge compensation as well as further effects of ion extraction. First results will be presented and will be compared with computer simulations.

#58

RADIOACTIVE BEAMS FROM 252CF FISSION USING A GAS CATCHER AND AN ECR CHARGE BREEDER AT ATLAS

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A proposed upgrade to the radioactive beam capability of the ATLAS facility has been proposed using 252Cf fission fragments thermalized and collected into a 1+ particle beam using a helium gas catcher. In order to reaccelerate these beams the ATLAS ECR-I will be reconfigured as a charge breeder source. A 1Ci 252Cf source is expected to provide sufficient yield to provide beams of up to 5x105 ions far from stability per second on target. The facility description will be presented and more complete expected performance information will be provided in this report. This work is supported by the U.S. Department of Energy, Office of Nuclear Physics, under contract W-31-109-ENG-38.

#59

SIMULATIONS OF THE LEBT FOR RIA DRIVER LINAC

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In the low energy beam transport (LEBT) system of the Rare Isotope Accelerator (RIA), a 100KV platform is employed to pre-accelerate the ion beam extracted from the Electron Cyclotron Resonance (ECR) ion source followed by an achromatic charge selection system. The selected beam is then bunched and matched into the entrance of a Radio Frequency Quadrupole (RFQ) with a multi-harmonic buncher and other beam elements. To meet the beam power requirements for heavy ions, high current (several mA), multi-species beams will be extracted from the ECR. Therefore, the control of space charge effect is crucial to obtain a low emittance beam. PARMELA code is used to perform the low energy beam simulations with 3D space charge calculations, which also include simultaneously tracking the multi-type-particle, multi-charge-state ion beams. The result of the beam dynamics simulations are presented, and the key issues of the emittance increase and its possible compensation are discussed.

#60

SIMULATION AND COMPARISON OF BEAM EMITTANCE AT VENUS

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The transverse emittance is one of the most important beam parameters for many accelerator applications. It would be very helpful to know the phase space of the ion beams right after the extraction of an ion source so that one can use it as an initial parameter to design the successive transport line, especial to minimize the emittance growth for a space-charge dominated beam, and to improve the performance. However, this information can't be directly obtained by measurements. Based on the experimental data (such as: beam current, charge-state distribution, phase space at emittance scanner, and settings of beam elements) from VENUS, we used PARMELA code to simulate the ion beam from the ECR source through the analyzing magnet to the emittance scanner. In the simulation, we tried different initial emittances (both value and orientation of the phase space) at ECR and simultaneously tracked the extracted multi-species, multiple charge-state ion beams with 3D space charge calculations down to the position of measurement in order to fit the measured one. We will discuss the simulation results with respect to the experimental measurements.

#61
EFFICIENT PLASMA ION SOURCE MODELING WITH ADAPTIVE MESH REFINEMENT

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Ion beam drivers for high energy density physics and inertial fusion energy research require high brightness beams, so there is little margin of error allowed for aberration at the emitter. Thus, accurate plasma ion source computer modeling is required to model the plasma sheath region and time-dependent effects correctly.

A computer plasma source simulation module that can be used with a powerful heavy ion fusion code, WARP, or as a standalone code, is being developed. In order to treat the plasma sheath region accurately and efficiently, the module will have the capability of handling multiple spatial scale problems by using Adaptive Mesh Refinement (AMR). We will report on our progress on the project.

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#62
DEVELOPMENT OF THE 3D PARALLEL PARTICLE-IN-CELL CODE IMPACT TO SIMULATE THE ION BEAM TRANSPORT SYSTEM OF VENUS

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The superconducting ECR ion source VENUS serves as the prototype injector ion source for the Rare Isotope Accelerator (RIA) driver linac. The RIA driver linac requires a great variety of high charge state ion beams with up to an order of magnitude higher intensity than currently achievable with conventional ECR ion sources. In order to design the beam line optics of the low energy beam line for the RIA front end for the wide parameter range required for the RIA driver accelerator, reliable simulations of the ion beam extraction from the ECR ion source through the ion mass analyzing system are essential. The RIA low energy beam transport line must be able to transport intense beams (up to 10 mA) of light and heavy ions at 30 keV.

For this purpose, LBNL is developing the parallel 3D particle-in-cell code IMPACT to simulate the ion beam transport from the ECR extraction aperture through the analyzing section of the low energy transport system. IMPACT, a parallel, particle-in-cell code, is currently used to model the superconducting RF linac section of RIA and is being modified in order to simulate DC beams from the ECR ion source extraction. By using the high performance of parallel supercomputing we will be able to account consistently for the changing space charge in the extraction region and the analyzing section.

A progress report and early results in the modeling of the VENUS source will be presented.