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A New 14 GHz Electron-Cyclotron-Resonance Ion Source (ECRIS) for the Heavy Ion Accelerator Facility ATLAS

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Abstract

A 14 GHz Electron-Cyclotron-Resonance Ion Source (ECRIS) has been designed and built at Argonne National Laboratory. The source is a modification of the AECR [1,2] at Berkeley and incorporates the latest results from ECR developments to produce intense beams of highly charged ions, including an improved magnetic confinement of the plasma electrons with an axial mirror ratio of 3.5. The aluminum plasma chamber and extraction electrode as well as a biased disk on axis at the microwave injection side donates additional electrons to the plasma, making use of the large secondary electron yield from aluminum oxide. The source is capable of ECR plasma heating using two different frequencies simultaneously to increase the electron energy gain for the production of high charge states. The main design goal is to produce several eμA of at least $^{238}U^{35+}$ in order to accelerate the beam to coulomb-barrier energies without further stripping. First charge state distributions for gaseous elements have been measured and 210 eμA $^{16}O^{7+}$ has been achieved. A normalized, 90% emittance from 0.1 to 0.2 π mm•mrad for krypton and oxygen beam has been found.

DISCLAIMER

Introduction

A new ECR ion source has been constructed as part of an improved high charge state injector for the heavy ion accelerator facility ATLAS, providing the Positive Ion Injector (PII) section with a second, independent ECRIS. The ion source and all associated components are mounted on a high voltage platform designed for 275 kV operation to match the velocity acceptance of the first accelerator section. The design goal of producing usable beam intensities of heavy elements such as uranium, lead or gold in charge states sufficiently high so that acceleration to the coulomb barrier is possible without foil stripping will increase the beam intensity available for experiments by at least an order of magnitude. In addition to that the beam quality should be significantly improved over beams requiring stripping for acceleration.

Source Design

The mechanical configuration of this single stage ECRIS is shown in Fig. 1. For the production of metallic ions, the source allows the installation of high temperature ovens and sample insertion for sputtering, both axially (through the magnetic field shaping plug between injection tank and plasma chamber) and radially (through the slots in the plasma chamber). The magnetic system for confining the hot plasma electrons takes into account the latest understanding that a high axial mirror ratio as well as a strong radial field inside the plasma are extremely important parameters for improving the performance of a high charge state ECRIS. The on-axis magnetic field produced by two solenoids, consisting of 9 pancakes each gives an injection and extraction mirror ratio of 3.5 and 2, respectively. The hexapole magnet mounted into the aluminum plasma chamber consists of 6 double trapezoidal NdFeB magnet bars and produces a maximum radial field of 0.84 T inside the plasma chamber. The open permanent magnet structure also allows for radial pumping. A detailed description of the ion source design and magnetic structure as well as beam line and associated components mounted on a high voltage platform as shown in Fig. 2 is given elsewhere [3,4].

A Glazer lens as the beam-focusing element is located between the ECRIS and the 90° analyzing magnet. The ion beam is focused onto 4-jaw slits at the focal point of the magnet. The ion source and the Glazer lens are mounted on a rail system for better maintenance access. All intensities are measured in an electron suppressed Faraday cup of 25 mm opening diameter directly behind a set of 2-jaw slits at the exit focal point of the dipole magnet.

The ion source features the possibility of heating the plasma with two different frequencies simultaneously to enhance the density of hot electrons in the plasma and improve the production of high charge states. The idea is to create two well-separated ECR zones were the electrons can gain energy [5]. In addition to the confined electrons traveling between the axial magnetic mirrors and passing through the 14 GHz resonance zone, electrons will also be heated as they cross the 10 GHz resonance zone, located much closer to the minimum of the magnetic mirror. The hot electron density enhanced by this additional heating may increase the negative potential well assumed to be responsible for the confinement of the ions and therefore the production of high charge states.

Previous reports on the effect of double frequency heating by the group at LBL [5] and the Grenoble group [6] showed significantly different results. In Berkeley, where two significantly different frequencies of 14 and 10.3 GHz are being used, a shift of the peak in the charge state distribution towards higher charge states, higher intensities for the same charge state and an increase in total RF power applied to the plasma were reported. The French group, using 10 GHz as the main frequency and a second frequency tuned +/- 1 GHz around that, could not find any improvement over single frequency operation.

We have obtained a transmitter, which is tunable over a wide range in the X-band between 8.75 GHz and 10.85 GHz using a magnetron tube. We will study the two frequency heating in order to provide some further understanding of the effect in looking for an optimum difference between the two frequencies.

The ion source is mounted on a high voltage platform designed to operate at up to 275 kV. The installation is required to provide a beam velocity of 0.0085c in order to match the required entrance velocity into the superconducting linac. The total power consumption of the source system has been measured to be 190 kVA when operating with single frequency heating. This power will be provided through high voltage isolation transformers with a total power handling capacity of 215 kVA.

First Results

The first analyzed beam from the ion source was obtained in December 1996. Since February 1997 test operation of the ion source is in progress and first charge state distributions for various gaseous elements have been measured. Fig. 3 shows an oxygen spectrum optimized on the 7+ charge state. The 210 eμA current was obtained in single frequency operation (14 GHz, 1100 Watts) at 10 kV extraction voltage using small amounts of He as a mixing gas. The aluminum biased disk, located at the tip of the injection iron plug, was optimized at –90V/2mA. Slits were set to 3x3 cm at both focal points of the analyzing magnet. The magnetic confinement during this performance was such, that the magnetic minimum was only slightly lower than the resonance field for 14 GHz. By tuning the source on the production of $^{16}O^{6+}$ 570 eμA of that charge state was extracted with similar source parameters.

A plot of beam intensities for different gases and charge states measured so far is given in Fig. 4. The graph shows intensities obtained by optimizing on different charge states all at 10 kV extraction voltage. The Krypton beam currents shown in figure 3 were achieved using a natural abundance gas.

First tests heating the plasma electrons with two RF-frequencies simultaneously showed enhanced production of highly charged ions. For ^{16}O the results are shown in Fig. 4 in open symbols. The Intensity for the charge state 7+ increased by more than 25% to 263 eμA at 10 kV extraction voltage. A total microwave power of 1500 watts (1200 watts 14 GHz, 300 watts 10 GHz) to obtain that particular spectrum. The optimum biased disk voltage was found to be –80V, lower than the optimum found for single frequency mode.

The electron current was with 5mA higher than the 2mA observed in single frequency operation. One would expect to lower the minimum of the magnetic field in respect to singly frequency operation to provide a resonance surface for the second frequency. In these tests, the minimum of the magnetic mirror is still higher than the resonance field for 10 GHz. At this point we have not obtained enough data to describe the effect sufficiently.

An emittance measurement system consisting of two movable slits (x,y direction) and a beam profile scanner has been installed behind the exit image of the bending magnet. The first emittance measurements using this system have been performed on krypton and oxygen beams. The normalized 90% emittance, ε_n, for $^{84}Kr^{19+}$ and $^{16}O^{7+}$, was measured to be approximately 0.10 π mm•mrad at 10 kV extraction voltage with a 4 mm radius extraction aperture. The normalized emittance for charge states 5+ and 6+ of ^{16}O was found to be 0.17 π mm•mrad, significantly larger than for the 7+ charge state of ^{16}O. The oxygen results were obtained without any source tuning between measurements and can be viewed as the simultaneous emittance for various plasma species at that time.

These results are qualitatively similar to those obtained in a number of previous measurements on other ECR ion sources showing that high charge-state ions have a smaller normalized emittance than the lower charge states [7,8,9]. The most surprising result comes from comparing the magnitude of the observed emittance to the minimum expected emittance based on angular momentum conservation [9]. The magnetic field in the region of the extraction aperture during these measurements was approximately 1 Tesla. Using this field and an extraction aperture radius of 4 mm, conservation of angular momentum predicts the minimum expected emittance from the source for the 5+, 6+ and

7+ charge states to be 0.81, 0.97, and 1.13 π mm•mrad, respectively. Not only is the expected linear relationship with respect to charge state not observed (as previously reported by other authors), but the absolute magnitude of the emittance is only 10 to 20 % of the expected values compared to this simple estimate. Losses due to the acceptance of the transport and emittance system may account for a portion of the discrepancy, but since approximately 60% of the total extracted beam is accounted for after analysis, such an explanation cannot account for all the difference. In addition the demonstrated acceptance of the transport and emittance measuring system significantly exceeds the observed $^{16}O^{7+}$ emittance. It has been proposed [9] that this effect can be explained if it is assumed the high charge states are strongly concentrated near the center of the extraction aperture and do not uniformly illuminate the aperture. These results are consistent with such an explanation and we hope to test that hypothesis in the coming months.

Future Plans

Tests of beams from solid materials will take place in the next two months. A connecting beam line from the source to the superconducting linac will be completed in the Fall of 1997. Beam acceleration tests using the new ion source will be performed by the end of the year and first beams will be provided to the experimental program by January 1998.

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References:

1. D.J. Clark, C.M. Lyneis and Z.Q. Xie, 14th Particle Accelerator Conference (PAC), IEEE Conf. 91CH3038-7, 2796 (1991)
2. C.M. Lyneis, Z.Q. Zie, D.J. Clark, R.S. Lam and S.A. Lundgren, 10th International Workshop on ECR Ion Sources, Oak Ridge, ORNL CONF-9011136, 47 (1990)
3. M. Schlapp et al., 13th International Workshop on ECR Ion Sources, Texas A&M, USA (1997) (in print)
4. M. Schlapp et al., 17th Particle Accelerator Conference (PAC), Vancouver, B.C. (1997) (in print)
5. Z.Q. Xie and C.M. Lyneis, 12th International Workshop on ECR Ion Sources, Riken, Japan, 24 (1995)
6. R. Geller et al., 8th International Conference on ECR Ion Sources and their Applications, East Lansing, NSCL Report #MSUCP-47, 1 (1987)
7. K. A. Harrison and T. A. Antaya, Rev. Sci. Instum. **65**(4), 1138(1994)
8. P. Sortais et al., 10th International Workshop on ECR Ion Sources, Oak Ridge, ORNL CONF-9011136, 35 (1990)
9. R. Geller, "Electron Cyclotron Resonance Ion Sources and ECR Plasmas", (Inst. of Physics, Bristol, UK, 1996)

Fig. 1: Cross section of the mechanical set-up of the ECR ion source

Fig. 2: ECR ion source and associated components mounted on a high voltage platform designed for 275 kV operation.

Fig. 3: Analyzed spectrum of ^{16}O at 10 kV extraction voltage. The numbers represent Oxygen charge states. The spectrum was obtained ramping the Glazer lens together with the analyzing magnet to focus the beam for every charge state.

Fig. 4: Charge state distributions for various gases. Shown with filled symbols are the results in single frequency operation (14 GHz), whereas the open symbols represent the results obtained in the double frequency mode. ^{84}Kr was measured using gas with natural isotope distribution. For Xenon an enriched gas bottle with 57% ^{128}Xe has been used.

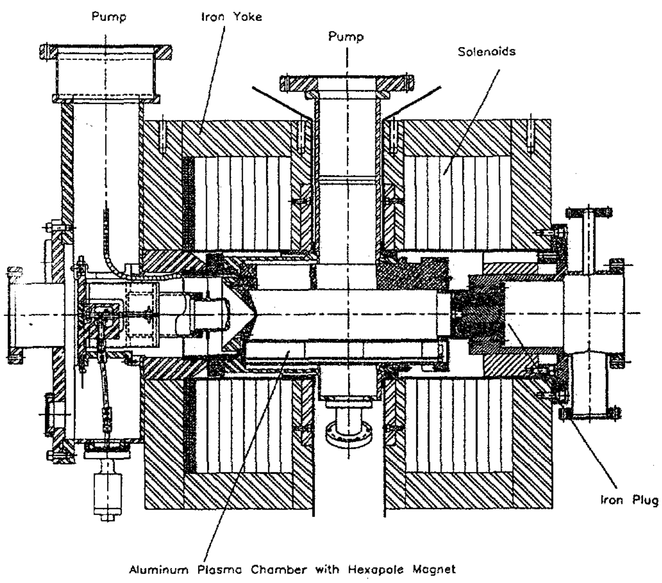
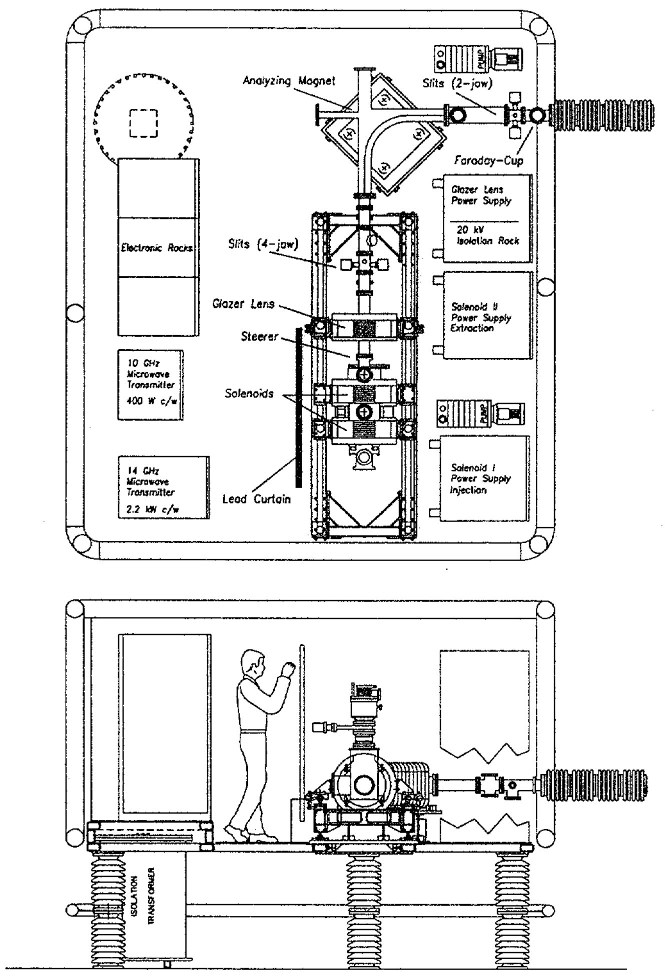

Pump
Iron Yoke
Pump
Solenoids
Iron Plug
Aluminum Plasma Chamber with Hexapole Magnet

Fig. 1:



Analyzing Magnet
Slits (2-jaw)
Faraday-Cup
Glazer Lens Power Supply
20 kV Isolation Rack
Electronic Racks
Slits (4-jaw)
Glazer Lens
Solenoid II Power Supply Extraction
Steerer
10 GHz Microwave Transmitter 400 W c/w
Solenoids
Solenoid I Power Supply Injection
14 GHz Microwave Transmitter 2.2 kW c/w
Lead Curtain
ISOLATION TRANSFORMER

Fig. 2:

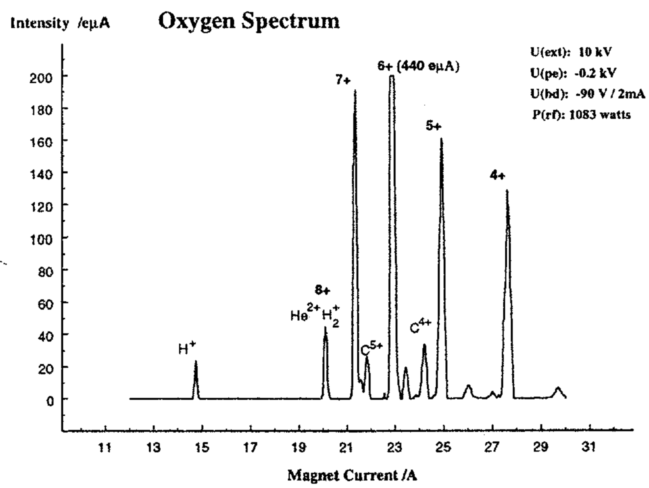
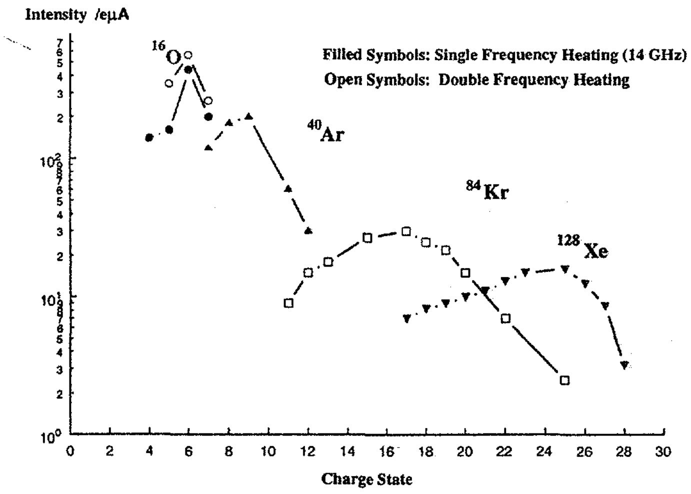

Intensity /eμA
Oxygen Spectrum
U(ext): 10 kV
U(pe): -0.2 kV
U(bd): -90 V / 2mA
P(rf): 1083 watts
6+ (440 eμA)
7+
5+
4+
8+
He2+ H2+
H+
C5+
C4+
200
180
160
140
120
100
80
60
40
20
0
11
13
15
17
19
21
23
25
27
29
31
Magnet Current /A

Fig. 3:



Intensity /eμA
Filled Symbols: Single Frequency Heating (14 GHz)
Open Symbols: Double Frequency Heating
16O
40Ar
84Kr
128Xe
Charge State

Fig. 4: