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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 new 14 GHz Electron-Cyclotron-Resonance Ion Source (ECRIS) has been designed and built over the last two years. The source, which is a modification of the AECR[1,2] at Berkeley, incorporates the latest results from ECR developments to produce intense beams of highly charged ions, i.e. an improved magnetic confinement of the plasma electrons. The aluminum plasma chamber and extraction electrode as well as a biased disk on axis at the microwave injection side donate additional electrons to the plasma, making use of the large secondary electron yield from aluminum oxide. The source will be capable of ECR plasma heating using two different frequencies simultaneously to increase the electron energy gain for the production of high charge states. To be able to deliver usable intensities of the heaviest ion beams, the design will also allow axial access for metal evaporation ovens and solid material samples using the plasma sputtering technique. The main design goal is to produce several eμA of at least $^{238}U^{34+}$ in order to accelerate the beam to coulomb-barrier energies without further stripping. First charge state distributions for ^{16}O and ^{40}Ar have been measured.

Introduction

This 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. 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 set-up of this single stage ECRIS is shown in Fig. 1. It shows the complete ion source assembly including solenoid coils and iron yoke together with a cross sectional view of the microwave injection tank with microwave inputs for two frequencies and a detail of the extraction system assembly. For the production of metallic ions the source allows the installation of high temperature ovens and sample insertion for sputtering, through the magnetic field shaping plug between injection tank and plasma chamber.

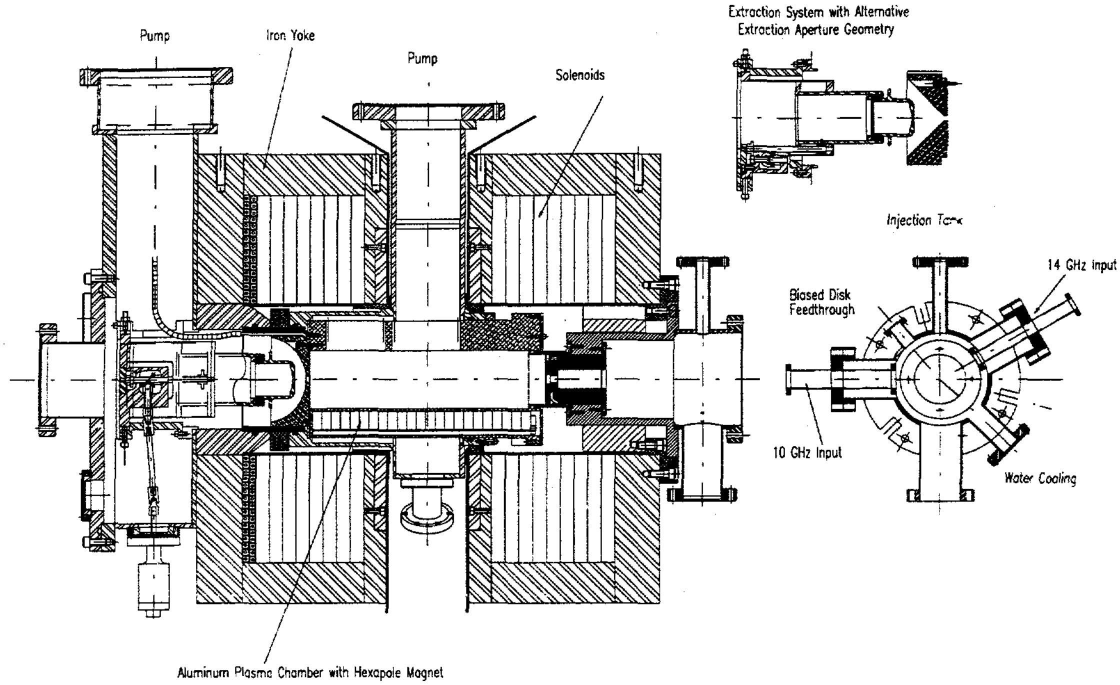

Fig. 1: Schematic overview of the mechanical set up of the 14 GHz ECRIS.

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 chamber are extremely important parameters for improving the performance of high chargestate ECRIS. Fig. 2 shows the calculated (POISSON-code[3]) axial magnetic field on axis produced by two solenoids each consisting of 9 double layer pancake coils with 16 turns per layer and a surrounding iron yoke and plugs at typical coil currents during operation (600 A for the injection solenoid and 520 A for the extraction coil). The power supplies are capable of providing up to 750 A to each pancake. The hexapole magnet mounted into the aluminum plasma chamber consists of 6 double trapezoidal NdFeB magnets and produces a maximum radial field of 1.0 T inside the plasma chamber. This open permanent magnet structure also allows for radial pumping. The total power consumption of the ion source (including solenoid power supplies, Glazer lens and analyzing magnet supplies and RF generators) is expected to be around 115 kW.

The ion source features the possibility of heating the plasma with two different frequencies simultaneously (cross sectional view of the injection tank in Fig.1) 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[4]. In addition to the confined electrons traveling between the axial magnetic mirrors and passing through the 14 GHz resonance zone, there will be those electrons only heated at the 10 GHz resonance zone, located much closer to the minimum of the magnetic mirror. The 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[4] and the Grenoble group[5] showed significantly different results. The Berkeley group used

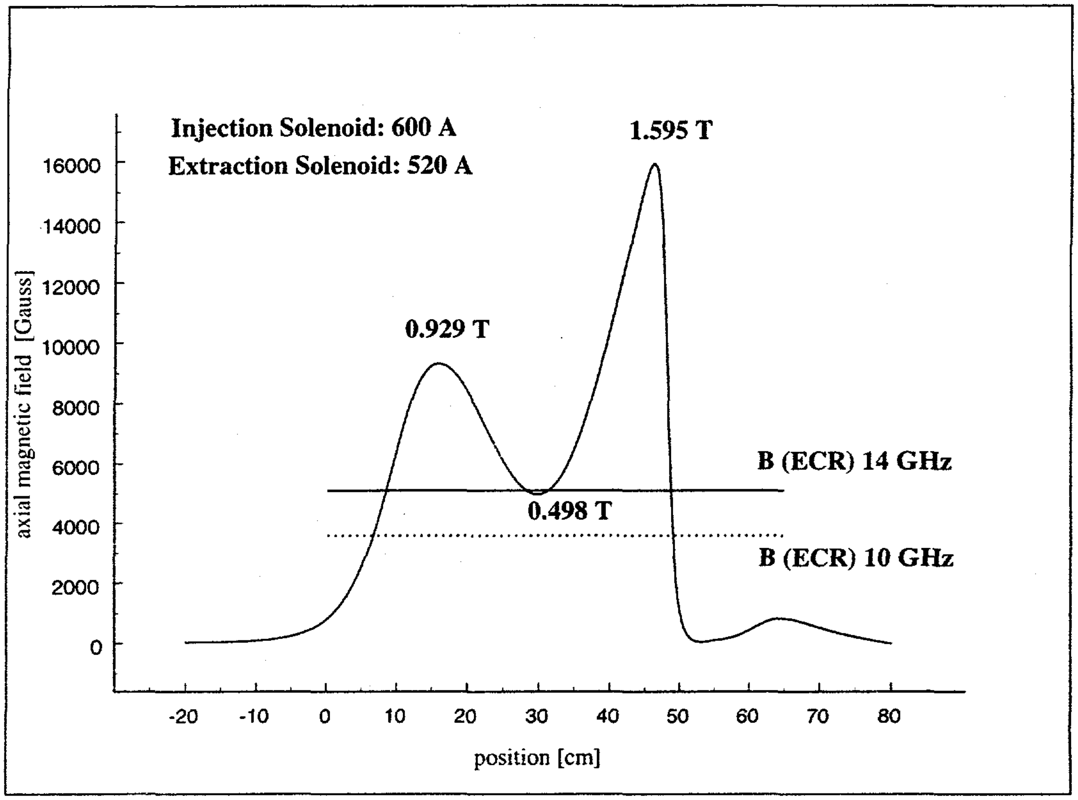

Fig. 2: Calculated (POISSON[3]) axial magnetic field on axis at typical coil currents during operation.

two significantly different frequencies 10.3 GHz and 14 GHz, creating well separated resonance zones and reported 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. The French group using a fixed frequency at 10 GHz and a second frequency tunable between 9.6 GHz and 11 GHz could not find any improvement over single frequency operation. We have obtained a transmitter which allows us to tune the second frequency over a wide range in the X-band between 8.75 GHz and 10.85 GHz using a magnetron tube. We will study the 2 frequency heating in order to provide some further understanding of the effect in looking for an optimum difference between the two frequencies.

Two different extraction aperture geometry's (both with 8mm aperture hole) will be tested for optimizing efficient extraction of high charge state ion beams. The Accel-Decel puller electrode assembly (shown in detail in Fig. 1, 9mm hole diameter) is movable along the beam axis allowing adjustment of the extraction system for operation with different ion species. The Accel- or screening electrode is introduced into the main extraction gap and biased to a sufficiently low potential (up to -4 kV) so as to create a negative potential well and form an electron trap to reduce the space charge influence of the ion beam[4]. The estimated normalized emittance of an extracted $^{238}U^{30+}$ ion beam using the IGUN code[5] with typical ECR plasma parameters ($n_p = 1x10^{11}\ cm^{-3}$, $T_i = 5$ eV, total extracted current $I_t = 1$ mA) is $\varepsilon_{n90\%} = 0.2\ \pi$ mm mrad at 12.5 kV extraction voltage.

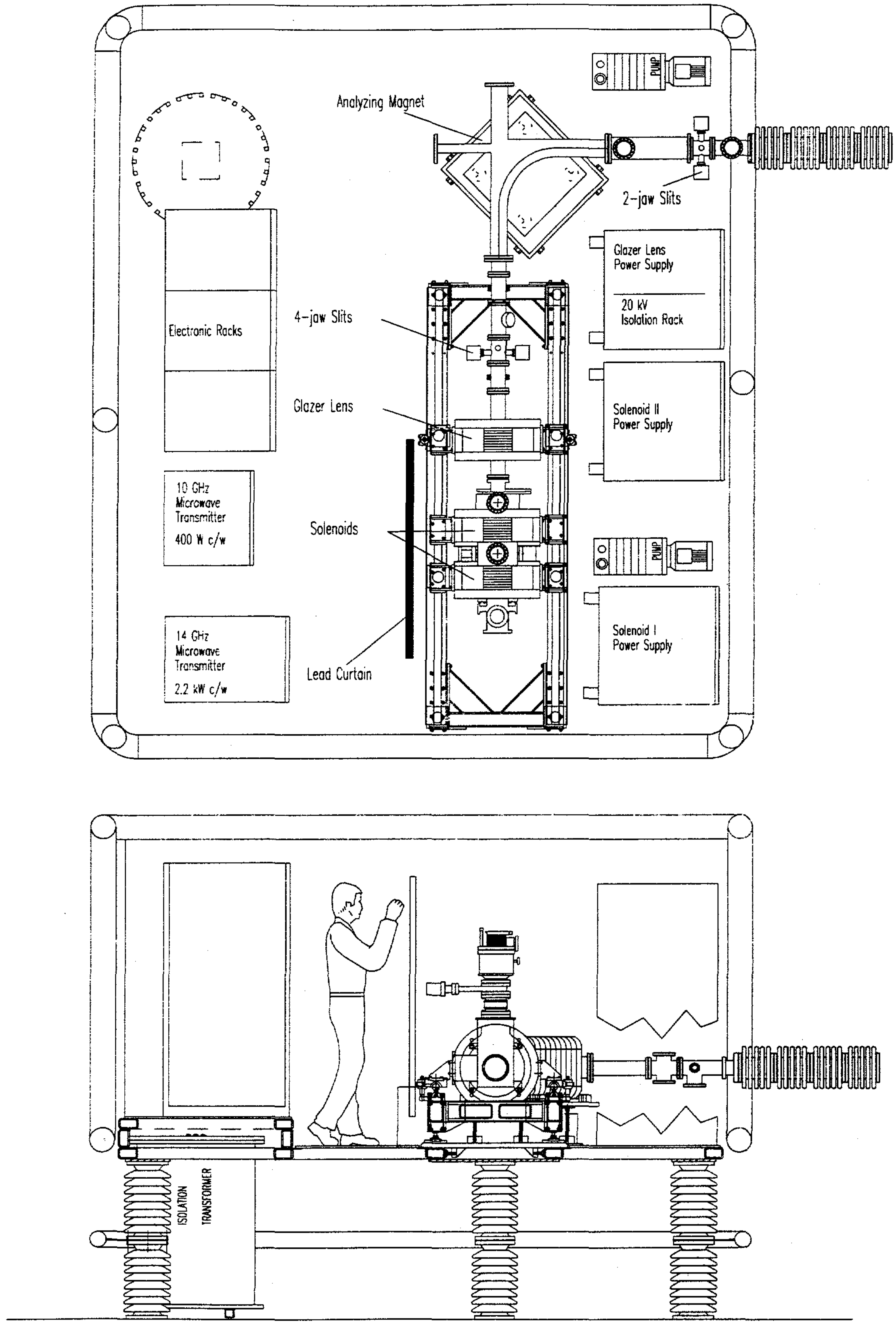

Fig. 3: Layout of the ion source including analyzing magnet and acceleration tube on the high voltage platform.

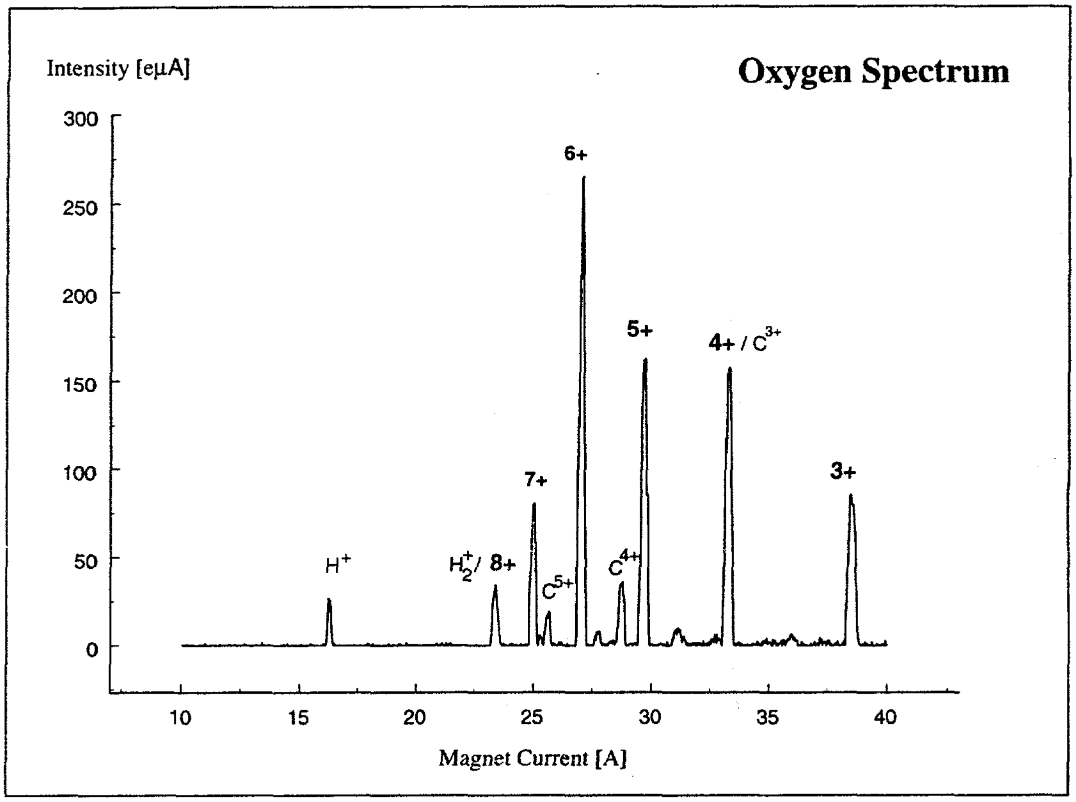

Fig. 4: ^{16}O spectrum extracted at 15 kV. During the scan the Glazer lens was scaled in respect to the magnetic field of the analyzing magnet to obtain a real spectrum.

High Voltage Platform

A layout of the ion source, beam line and associated components mounted on a high voltage platform is shown in Fig. 3. A Glazer lens as the beam focusing element is located between the ECRIS and the 90° double focusing 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 a Faraday cup directly behind a set of 2-jaw slits at the exit focal point of the dipole magnet. The ECR II beam line will be connected to the PII section of the Linac by the end of 1997.

First Results

The ion source produced the first extracted ion beam by the end of 1996. The test runs so far were done by using ^{16}O and ^{40}Ar as operating gases. All spectra to this point were obtained using one gas only. A second gas inlet valve for the operation of mixed gases will be installed shortly. The ion source operates in a single frequency mode (14.25 GHz) applying up to 750 watts of microwave power to the plasma. A first test of the double frequency mode is expected in March 1997. For this the minimum of the axial mirror has to be decreased by at least 30% to produce a resonance zone for 10 GHz. The oxygen spectrum shown in Fig. 4 was obtained using the magnetic field configuration shown in Fig. 2 at 15 kV extraction voltage and 750 watts RF power.

^{40}Ar: q	7	8	9	10	11	12	13	14	15	16
I [eμA]	15	45	61	*	46	18	5.3	1.2	*	.03

Tab. 1: Charge state intensities of ^{40}Ar at 10 kV extraction voltage optimized on Ar^{12+}. Other operating parameters are: U_{puller}: -2.57 kV, $U_{biased\ disk}$: -860 V, P_{14GHz}: 727 watts. The charge states labeled with * are contaminated by ^{16}O and ^{12}C peaks.

The biased disk was optimized to -550 V during this run. One can still observe relatively large carbon peaks (32 eμA of C^{4+}), which limits the output of high charge states. The production of high argon charge states is still limited by the lack of a mixing gas. Tab.1 shows an argon charge state distribution obtained at 12.5 kV extraction voltage and source parameters as shown. Tests of the source performance for heavy elements, i.e. ^{238}U are expected in the Spring 1997 after all features of the ion source stated in the abstract have been implemented.

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