ECR ION SOURCE FOR THE KEK ALL-ION ACCELERATOR*

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Abstract

As a part of KEK-all ion accelerator, a compact 9.4 GHz electron cyclotron resonance ion source (ECRIS) with plasma-confining magnetic field generated by permanent magnets has been designed and fabricated for production of highly charged ions. Microwave power is transmitted from a travelling wave tube (TWT) amplifier and focused into the interaction region with an electromagnetic horn. The geometry of the electrodes has been optimized by beam optics simulations. Preliminary results of each component at the test bench are described.

INTRODUCTION

R & D works to realize an all-ion accelerator (AIA)[1] –capable of accelerating all ions of any possible charge state, based on the induction synchrotron concept, which was demonstrated using the KEK 12 GeV-PS [2], are going on. The AIA, which is depicted in Figure 1, is required to provide many ion species of high-charge state. A possible ion source for the KEK-AIA is an electron cyclotron resonance ion source (ECRIS) or a laser driven ion source, which has been rapidly developed by Okamoto et al [3, 4]. We have decided to construct the ECRIS at first and started its R&D work.

The KEK-AIA never employs a large injector, such as RFQ or DTL: it is an almost injector free synchrotron. From beam dynamical point of view, however, a large velocity is desired because of longer life time, smaller emittance, and relaxed space-charge limitation [5]. In the KEK-AIA, the injection energy of 200 kV is assumed. All the components of the 9.4 GHz ECRIS consisting of a plasma chamber, all power supplies, 9.4 GHz microwave system, and vacuum system etc., are embedded in the 200kV high-voltage terminal. Recently the ECRIS has been assembled and is under microwave test and gas feeding test. Ion extraction tests with 30 kV will start at our ECRIS test stand, soon. In this paper, an outline of the ECRIS design is described and its present status is introduced.

CONCEPUAL DESIGN

The 9.4 GHz ECRIS

The specific mirror magnetic field of the ECRIS is generated with a permanent-magnet system. The main

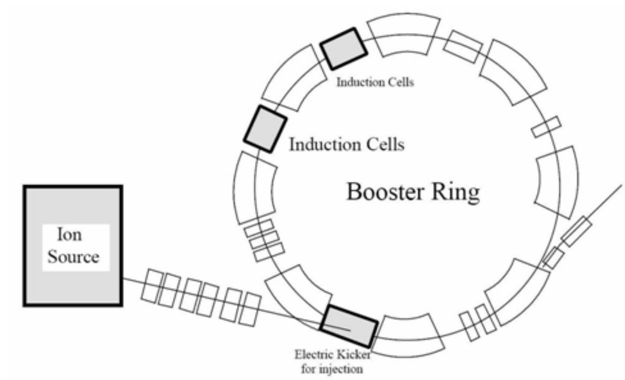

Figure 1: Layout of the KEK-AIA.

advantages of an all-permanent-type ECRIS are (1) no power supply and cooling system because of no electromagnetic coil, (2) compactness of total size.

The magnet system consists of two mirror ring magnets for axial confinement and a sextupole (hexapole) magnet for radial confinement. All the magnets are NdFeB permanent magnets, the total weight of which is 80 kg The mirror magnetic flux density along the centre axis is 0.686 T at the upstream region, 0.152 T at the minimum B region, and 0.541 T at the extraction side, respectively, as shown in Figure 2. From the cyclotron resonance frequency of 9.4 GHz, the resonant flux density of 0.336 T is evaluated

The plasma chamber of stainless steel, which has inner diameter of 40 mm, is inserted into the above magnet system. The chamber is water-cooled to prevent the permanent magnets from being demagnetized due to conducting heat. The diameter of the anode orifice's hole is 2 mm. The extraction electrode of molybdenum is electrically isolated with a ceramic chamber of alumina from ground. The distance between these two electrodes s 20 mm. The maximum extraction voltage is 30 kV. A 300 l/s turbo molecular pump is connected to the

Table 1: Specifications of the designed ECRIS

Microwave frequency	9.4 GHz
The maximum power of microwave	750 W
The maximum acceleration voltage	30 kV
The material of the permanent magnets	NdFeB
The weight of the permanent magnet complex	80 kg
The 1st peak of magnetic flux density (B_{inj})	0.686 T
The 2^{nd} peak of magnetic flux density(B_{ext})	0.541 T
The minimum of magnetic flux density(B_{min})	0.152 T

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upstream chamber with the microwave injection port. The base pressure in the vacuum pumping chamber is actually 8×10^{-6}Pa.

The 9.4 GHz microwave is fed into the plasma chamber thorough a rectangular horn antenna from the axial direction. The TWT amplifier can be operated both in CW and pulse mode with the maximum output power of 750 W. To protect the vacuum window of alumina from being hit by plasma, an E-bend is placed just after the window.

The photograph of the ECRIS, which is under testing, is shown in Figure 3 and its main specifications are listed in Table 1.

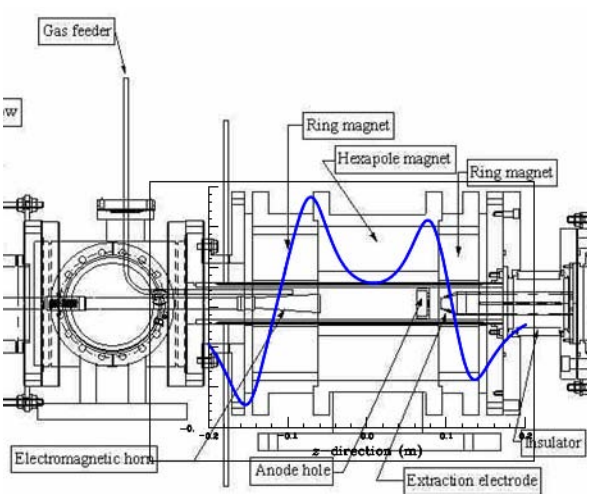

Figure 2: Cross-sectional view of the ECRIS.

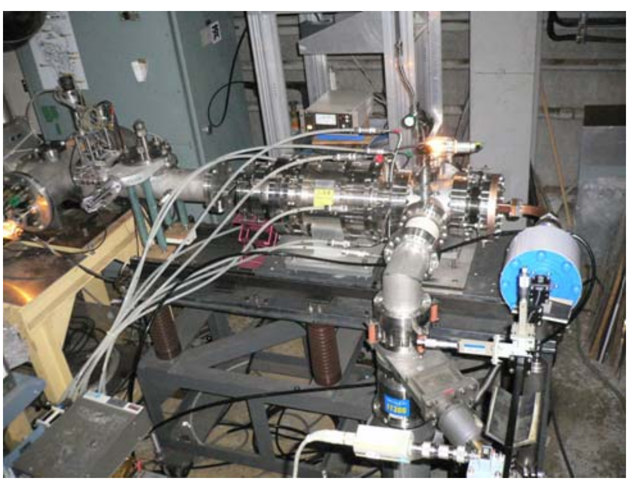

Figure 3: The ECRIS at the test stand.

Microwave Transport

The electromagnetic horn is employed to increase the effective power density in the interaction region, because the directive horn antenna improves impedance matching between the waveguide and free space in the chamber. The HFSS (High-frequency structure simulator) code simulations, where the microwave power of 1 W is emitted into the assumed chamber through the straight cut waveguide and the optimized horn, are shown in Figure 5. The cylindrical tube corresponds to the plasma chamber. Since the edge of cylindrical tube is shorted, a standing wave is generated.

These simulations predict that the optimized horn can provide an effective power density in the interaction region twice as high as the straight cut waveguide. According to the existing data [5], where the intensity of highly charged ions is linearly proportional to the microwave power density, a large production rate of highly charged ions is expected.

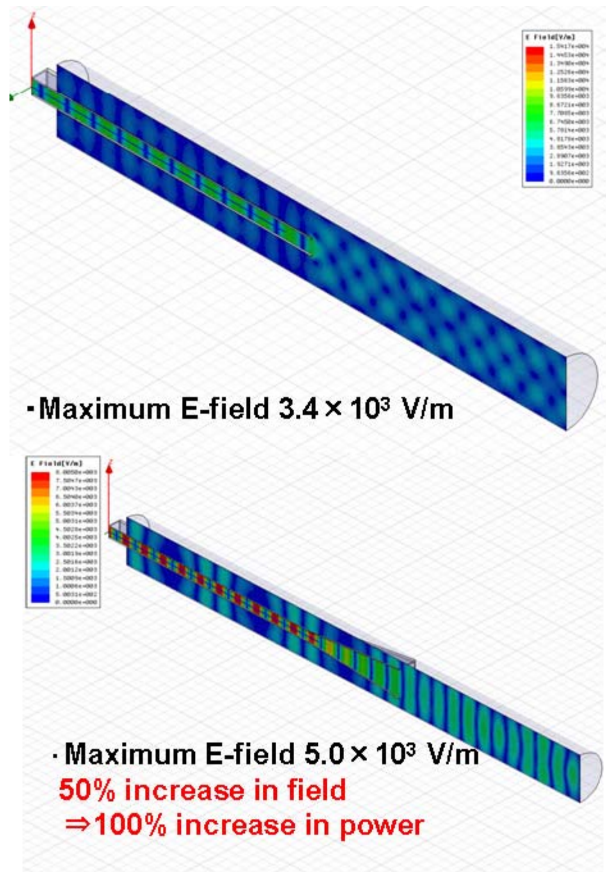

Figure 4: Comparison of a straight cut waveguide (upper) and the optimized horn (lower) by HFSS code simulation.

Gas Feeding

The diagram of the gas feeding system is shown in Figure 5. Flow rates of gaseous materials are regulated with a mass flow controller at maximum rate of 1cc/min. The grounded gas cylinder is electrically insulated with a 2 m long plastic tube. The rotary pump is prepared to purge residual gas in the pipe for purification of the beam. When the gas flow rate of argon is 0.04cc /min, the vacuum in the plasma chamber is actually 5.7×10^{-4} Pa. In the production of Ar^{8+}, this vacuum corresponds to the cut off density at 9.4 GHz ,which is estimated to be 1.1×10^{12}cm^{-3}.

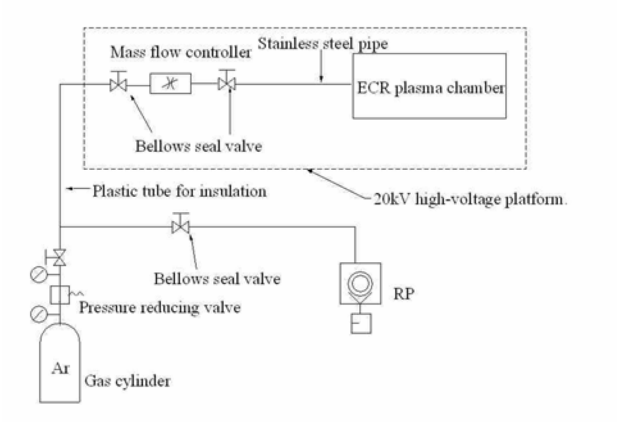

Figure 5: Gas feeding system for the ECRIS.

Beam Optics and Transport System

To optimize the geometries of electrodes, beam extractions and trajectories considering solenoid magnetic field are simulated by IGUN code [7]. Figure 6 shows the result assuming a single ion species of Ar^{8+}. The z-axis full scale is equivalent to 220 mm. The potential of the plasma chamber with the anode orifice (green) is 30 kV and the extraction electrode (red) remains grounded. Under this optimized configuration, the envelope of a beam is insensitive to focusing by the solenoid magnetic field of - 0.5 T and divergence by the self field of the beam of 7.4 mA

The existing beam transport system, which is used only for the test of the ECRIS itself, is depicted in Figure 7. The analysing magnet has a bending angle of 45 degree, edged angles of 11.7 degree for both ends, and radius curvature of 0.6 m. The maximum magnetic rigidity is 0.6 Tm. In redesigning the beam transport system not only a Faraday cup, but also an emittance monitor will be prepared in the vacuum chamber as the endstation.

SUMMARY

In summary, we have designed and constructed a 9.4 GHz ECRIS with all-permanent magnets, where the extraction voltage is 30 kV in maximum.

We have found that an electromagnetic horn should be promising as a microwave feeder, instead of a rectangular waveguide, from HFSS simulations. The gas feeding has been constructed and the gas flow rate can be controlled successfully in order to perform a bench test using argon gas.

The geometries of the electrodes have been optimized using the IGUN simulation results.

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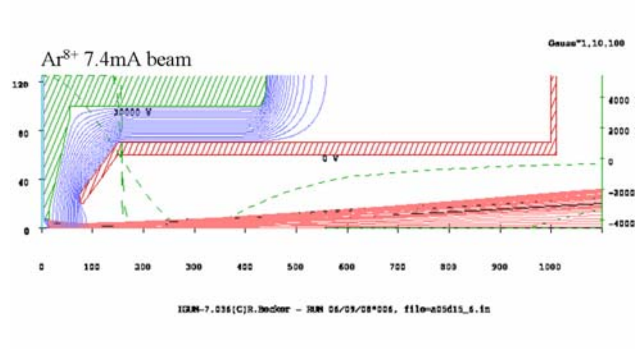

Figure 6: IGUN simulation of the 7.4 mA Ar^{8+} for the assumed electrode with a mesh unit of 0.2 mm.

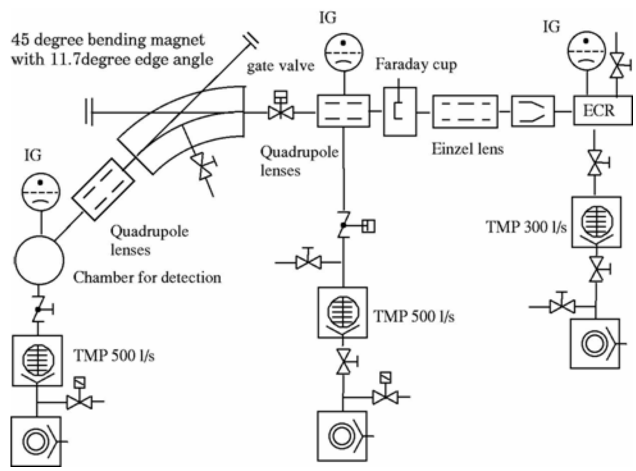

Figure7: Diagram of the beam transport system at the test stand including analysing system and vacuum system.

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