ECR plasma characteristics of 14.5 GHz electron cyclotron resonance ion source at KAERI

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1. Introduction

Ion sources to make multi-charged ion beam based on the electron cyclotron resonance (ECR) principle [1] have played major role in many areas [2] of applied science and technology. Since the final energy of an ion beam is directly proportional to the charge state of the ion during acceleration, ion sources which are capable of producing high charge state ion beams become a crucial component of the ion accelerator system. A heavy ion accelerator for cancer treatment [3] with a superconducting magnet cyclotron is being studied in Korea. As an important activity of this project a 14.5 GHz ECRIS has been designed and fabricated. The main design goal of the ion source is to produce C^{6+} ions with a current level of several tens of electronic-microampere, and to meet this goal key parameters were designed as summarized in Table 1.

In this study the design and fabrication results of the ion source, and the measurement results with ECR plasma depending on trim coil current, that determine the structure of ECR magnetic field configuration, are described.

2. Source Design and Fabrication

To get high current for the fully striped carbon ions with 14.5 GHz frequency strong-field ECR ion source, as shown in Fig. 1, was designed with the magnet system of solenoid coils made with cupper conductor and hexapole made with permanent magnet. The solenoid coils are composed of two axial coils to make mirror fields in both sides of the chamber and one trim coil at the center to control the layer of the resonance region. There are also three different kinds of yokes to make effective and strong axial field around the chamber region such as main yokes, hexapole fixing yokes and chamber yokes. The volumes of the chamber yokes are maximized except the needed openings for microwave input, vacuum pumping, gas injection and a bias disc at the microwave input side, and an aperture for beam extraction at the other side to increase the peak value of the mirror fields. Their positions and shapes are designed to minimize magnetic reluctance in the magnetic circuit. The hexapole[4] is composed of NdFeB permanent magnet to make radial mirror field and ECR region around the wall of the ECR chamber. The sector number and outer diameter are optimized to make a strong hexapole field with a fixed inner diameter.

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Table 1: Design Parameters of KAERI ECRIS

Parameters	Values
Microwave Max. Power	2.0 kW
B_{inj}	1.65 T
B_{ext}	1.1 T
B_r max	1.1 T
Max. Mirror Ratio	3.3
Chamber Inner Diameter	68 mm
Chamber Length	320 mm
Beam Extraction Diameter	8 mm
Beam Extraction Voltage (Max.)	30 kV
I_{C6+}	> 20 μA

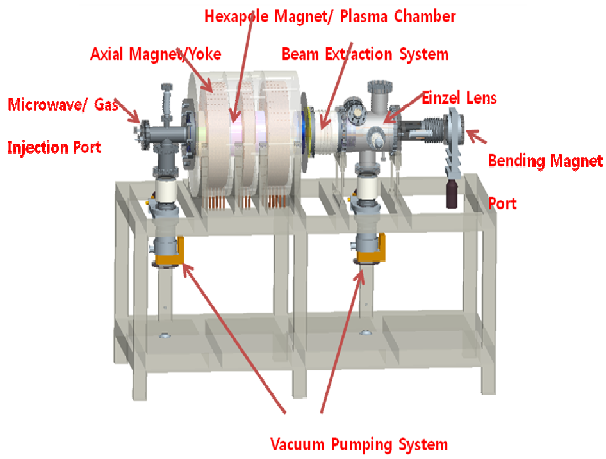

FIGURE 1. Main structure of KAERI ECR ion source.

3. ECR Plasma Experiment

The charge state and the current of the beam from the ion source are closely related with the electron temperature and density of the ECR plasma. To check the characteristics of the ECR plasma of the KAERI ion source, three different tools are tried such as image camera, optical cable and X-ray detector.

3.1 Camera Image

There are limited apertures that can see the ECR plasma in the plasma chamber. A small image camera is inserted from the beam extraction port instead of beam extraction grid, and ECR plasma is observed by the camera through the beam extraction hole. Because of the heating effect by the diffused plasma through the hole, enough distance was necessary from it.

We have investigated the image of the ECR ion source plasma seen through the extraction hole as function of the current of the trim coil. The current changes the layer structure of the ECR zone, and it changes the characteristics of the ECR plasma. The light intensity inferred from the images (refer to Fig. 2 as an example) taken by the camera decreased with increasing the trim coil current, by which the minimum axial magnetic field is approaching to the ECR resonance frequency.

FIGURE 2. Camera image of the ECR plasma that are seen through the beam extraction hole, when trim coil current is 200 A ($B_{z\,min}$ = 0.31 T).

3.2 Optical cable and PM Tube

To measure the light intensity of the ECR plasma an optical cable is installed instead of the camera position explained in the above session. The signal is amplified by PM tube and analyzed. Fig. 3 shows the light intensities, measured by the optical cable and PM tube set, from the ECR plasma depending on gas pressure and microwave input power. A discharge could be made even from the base pressure of ~10^{-8} mbar. The light intensity is increased with the increase of pressure and microwave power.

3.3 Bremsstrahlung X-ray

It would be very interesting to measure the X-ray spectra emitted by the lost electrons from the ECRIS magnetic trap, allowing more quantitative characterization of the ECRIS plasma as compared to the previous measurements. It should reflect the temperature of the ECRIS plasma, although the spectra would be modified by the lead shielding (6mm) around the insulator of the beam extraction system (Fig. 1).

The detector without any collimator is positioned at the outside of the beam monitoring chamber, which is fabricated by 3 mm thickness stainless steel. The position is the highest X-ray dose point around the ion source. The dimension of the NaI(Tl) detector is 50 mm(D) x 50 mm(L) and the pulse shaping time 1 μ sec for a photon. Energy calibration of the system was made by a Cs-137 gamma ray source (0.661 MeV).

The spectrum change of the X-ray with trim coil current is shown in Fig. 4 when the microwave input power is 250 W. It clearly shows that electron heating efficiency (consequently the temperature of plasma electrons) changes with the layer structure of the ECR zone. The optimum condition for the electron heating is supposed to be made around the trim coil current of 450 A . At this current the value of the minimum axial field in the center of the chamber is 0.45 T (0.87*B_{ECR}).

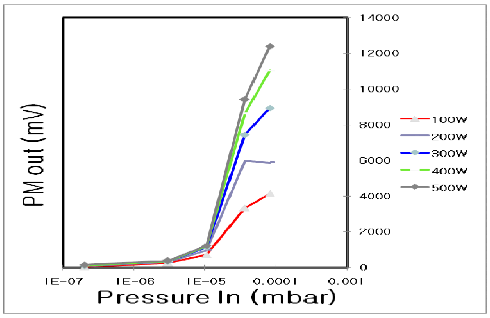

FIGURE 3. Light intensities from the ECR plasma depending on gas pressure and input power.

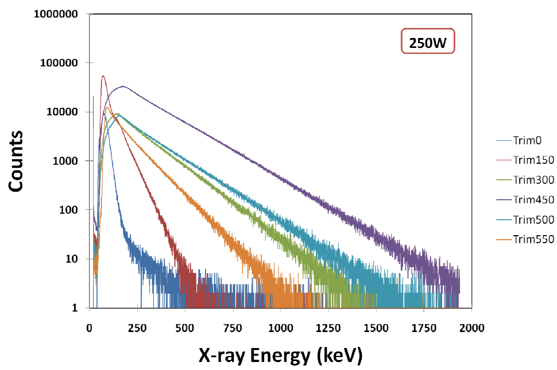

FIGURE 4. X-ray spectrums depending on trim coil currents when microwave input power is 250 W.

4. Summary

The fabrication of KAERI ECR ion source had been finished, and the test was started. During the initial ECR plasma experiments we observed very high energy X-ray with high intensity passing through the lead shield, and there needed to add an adequate X-ray shielding. As the shielding structure is completed recently, more detailed measurements on X-ray spectrum and beam extraction experiments will be started.

REFERENCES

[1] R. Geller, *Electron Cyclotron Resonance Ion Soruce and ECR Plasma* (Institute of Physics, Bristol, 1996).

[2] A. Girard, D. Hitz, and G. Melin, Rev. Sci. Instrum, **75** (2004) 1381

[3] A. Kitakawa, M. Muramatsu, T. Fujita, W. Takasugi, S. Wakaesami, S. Biri, A.G. Drentje, *Proceeding of ECRIS*, Chicago (2008) 88

[4] Byung-Hoon Oh, Chang Seog Seo, Sang-Ryul In, and Tae-Seong Kim, Rev. Sci. Instrum. **81, 02A317** (2010)