DEVELOPMENT OF 14.5 GHZ ELECTRON CYCLOTRON RESONANCE ION SOURCE AT KAERI*

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Abstract

A 14.5 GHz ECRIS has been designed and fabricated at KAERI (Korea Atomic Energy Research Institute) to produce multi-charged ion beam (especially for C^{6+} ion beam) for medical application. The magnet system has cupper conductor solenoid coils and a permanent magnet hexapole. A welded tube with aluminium and stainless steel is used for an ECR plasma chamber to improve the production of secondary electron. A Krystron supplies microwave energy to the plasma. A movable beam extractor with 8 mm aperture covers different species and different charge numbers of the beam. Fabrication and initial experimental results on ECR plasma are discussed in this paper.

INTRODUCTION

A heavy ion accelerator for cancer treatment [1] by a cyclotron or a synchrotron is planned 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 electro-microampere, and to meet this goal key parameters were designed as summarized in Table 1.

In this paper the design and fabrication results of the ion source, and the initial experimental results on the ECR plasma are described. An image camera and an optical sensor with a photo multiplier (PM) tube near the beam extraction aperture, and a NaI(Tl) detector at the outside of a beam extraction chamber with multi-channel analyzer (MCA) system to measure the X-ray spectrum were used to understand the characteristics of the ECR plasma.

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. 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 (B_{min}). There are also three different yokes to make effective and strong axial field at the both ends of the ECR plasma region such as main yokes, hexapole fixing yokes and chamber yokes as shown in Fig. 2. The volume of the chamber yoke at the input side is maximized except the needed openings for microwave injection, vacuum pumping, and gas injection. Their positions and shapes are designed to minimize magnetic reluctance in the magnetic circuit. The hexapole [2] is composed of NdFeB permanent magnet. 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

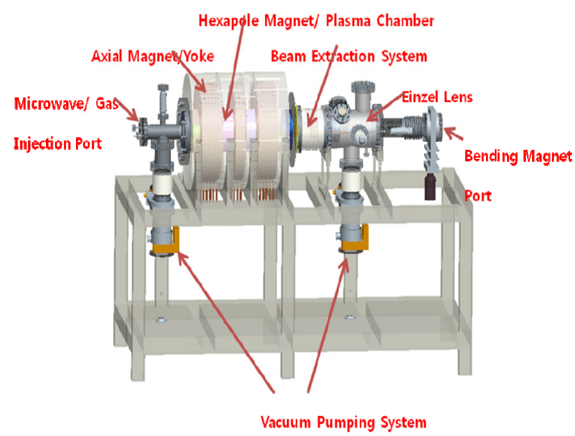


Figure 1. Main structure of KAERI ECR ion source.

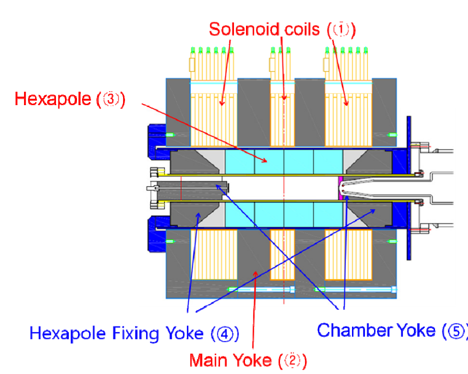


Figure 2. Inner structure of magnets and insulators.

An aluminium tube (5 mm wall thickness) welded with stainless steel (SUS 304) flanges is used for an ECR plasma chamber to improve the production of secondary electrons. A 2 kW Krystron supplies the microwave energy to the plasma. Microwave is injected in an axial direction at the off-axis position from the center to protect RF window from back streaming electrons. A movable beam extractor with 8 mm aperture covers different species and different charge numbers of the beam. And a movable Einzel lens with the beam extraction grid controls beam divergence. To make a simple insulation structure the vacuum chamber and the hexapole including the inner yokes are insulated from other components with G10 cylinder (5.5 mm thickness) and nylon covers at both sides of the chamber as shown with blue colour in Fig. 2. Two pumping system composed of 230 l/sec TMPs at RF input side and beam extraction side maintain the base pressure at the order of 10^{-8} mbar. A shielding box of 10 mm around the solenoid coils and 20 mm around the beam extraction side is installed to shield the high intensity and high energy Bremsstrahlung X-rays from the ECR plasma.

FIELD MEASUREMENT RESULTS

The field components of B_r, B_θ and B_z have been measured by a three dimensional probe to certificate the magnetic structure of the fabricated ECRIS system. The measured B_θ components after fixing the hexapole structure at the chamber wall position (r=34 mm) with the angle resolution of 15° is shown in Fig. 3. It shows that the measured value (about 1.3 T) is higher than the estimated one (1.2 T) by a field calculation code. The difference between the measured and the calculated one comes from the position shift of a θ–component sensor in a three dimensional probe. The measured and calculated results of the axial field with the chamber yokes along the center line are shown in Fig. 4. The mirror field at the entrance region could be increased higher than 1.7 with a proper cooling. At the exit region, mirror field of more than 1.1 T also could be possible.

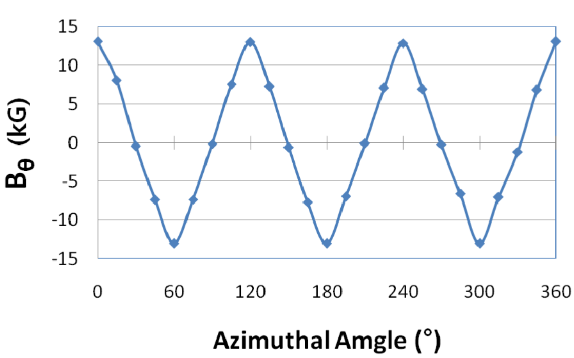


Figure 3. Measured B_θ at the chamber wall position (r = 34mm) with a hexapole structure.

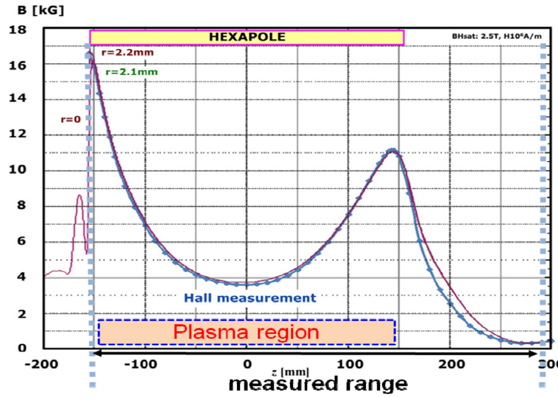


Figure 4. The magnetic field at the beam center (r=0 mm) with complete magnet structure of KAERI ECRIS. The coil currents are 700A, 300A, 700A for coil A, trim coil and coil B respectively.

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. Three different tools such as image camera, optical sensor and X-ray detector are used to check the characteristics of the ECR plasma.

Camera Image

There are limited apertures through which ECR plasma could be seen. A small image camera is inserted instead of the beam extraction grid of the ion source, and ECR plasma is observed by the camera through the beam extraction hole. Fig. 5 shows the images of the ECR plasma through the hole (8 mm diameter) depending on the current value of the trim coil. The current changes B_{min} value and the layer structure of the ECR zone, and it changes the characteristics of the ECR plasma. They show that as B_{min} is approached to the ECR resonance frequency by increasing the current of the trim coil the light intensity is decreased, but on the other hand X-ray intensity is increased.

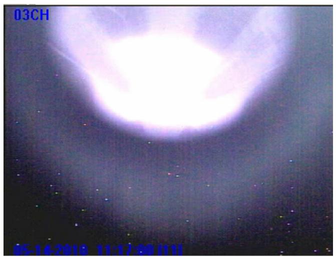
Optical sensor and PM Tube

An optical sensor is installed instead of the camera to measure the light intensity of the ECR plasma. The signal is amplified by a PM tube. Fig. 6 shows the measured result of the light intensities from the argon ECR plasma depending on gas pressure and microwave input power. The light intensity increases as pressure and microwave power are increased.

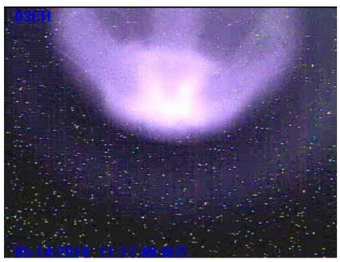
Bremsstrahlung X-ray

X-ray shielding was not considered seriously at the first design of the 14.5 GHz ECR ion source, but the X-ray dose from the ECR plasma was very high during some operation conditions even with 6 mm lead shielding around the beam extraction system (Fig. 1). Therefore X-ray spectrum and radiation dose were measured with

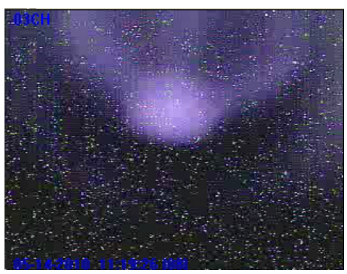
NaI(Tl) detector to estimate the needed shielding thickness around the ion source.



(a) When trim coil current is 0 A ($B_{z\,min}$ = 0.22 T).



(b) When trim coil current is 200 A ($B_{z\,min}$ = 0.31 T).



(c) When trim coil current is 500 A ($B_{z\,min}$ = 0.48 T).

Figure 5. Camera images of the ECR plasma that are seen through the beam extraction hole.

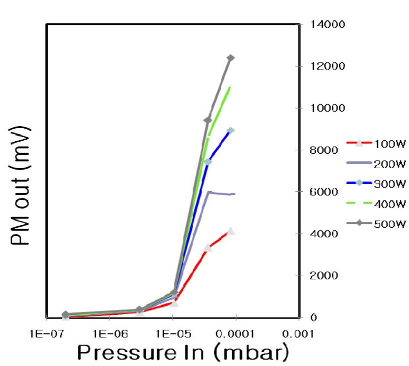


Figure 6. Light intensities from the ECR plasma depending on Argon gas pressure and input power.

A detector without collimator is positioned at the outside of the ion source near the beam monitoring chamber, which is fabricated with 3 mm thickness stainless steel (Fig. 1). The dimension of the NaI(Tl) detector is 50 mm(D) x 50 mm(L) and the pulse shaping time is 1 μsec. Energy calibration was made by a Cs-137 gamma ray source, which has 0.031 MeV and 0.661 MeV energy peaks. Gas was not supplied during this measurement but discharges could be started even at the base pressure of ~10^{-8} mbar. The pressure increases up to ~10^{-6} mbar with the plasma ignition.

The energy distribution of Bremsstrahlung X-ray from the ECR plasma [3, 4] is closely related with the electron energy distribution function. The spectrum change with trim coil current is shown in Fig. 7 when the microwave input power is 100 W. It clearly shows that electron heating efficiency changes with the field strength of B_{min}. 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 B_{min} is 0.45 T (0.87*B_{ECR}). Fig. 8 and Fig. 9 show another X-ray spectrums when microwave input power is 250W and 500W respectively. X-rays, whose energies are higher than 2 MeV, were detected when trim coil current is 450 A at 250 W input power. And the peak energy of the X-ray decreases again with the microwave input power. It looks like there is an optimum value of input power for the KAERI ECR ion source between 250 W to 500 W. This value is relatively small compared with the results of other sources [5].

Because of the shield layers between the ECR plasma and the detector such as chamber wall, extraction grid and/or other components of the ECR ion source, the X-ray distribution at low energy region should be deformed much by the attenuation by the shields. But the distribution at higher energy region can have relatively useful information on the electron distribution function of the ECR plasma. The electron temperatures estimated by the high energy tails of the measurement data are summarized in Fig. 10. We are planning to make more detailed measurement form the pure ECR plasma with proper collimators [3] in a near future.

SUMMARY

The fabrication of KAERI ECR ion source had been finished, and the test was started. During the initial test of the ECR plasma energy spectrums at the outside of the ion source depending on different operation condition were measured. It was found that the measured spectrums at the outside of the ion source without collimator also give some information on the KAERI ECR ion source. As the installation of the shielding structure of the source has been finished recently, next experiments on ECR plasma and multi-charged ion beam will be started.

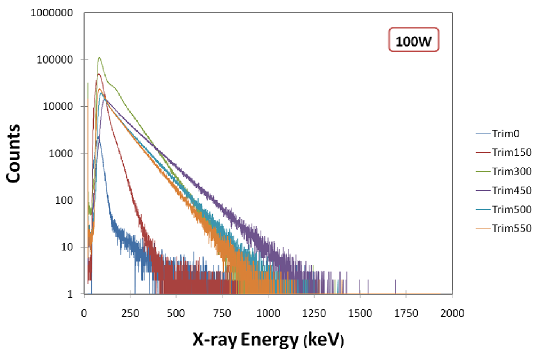


Figure 7. X-ray spectrums depending on trim coil currents when microwave input power is 100 W.

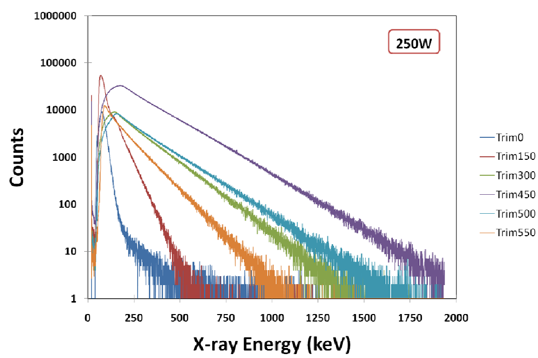


Figure 8. X-ray spectrums depending on trim coil currents when microwave input power is 250 W.

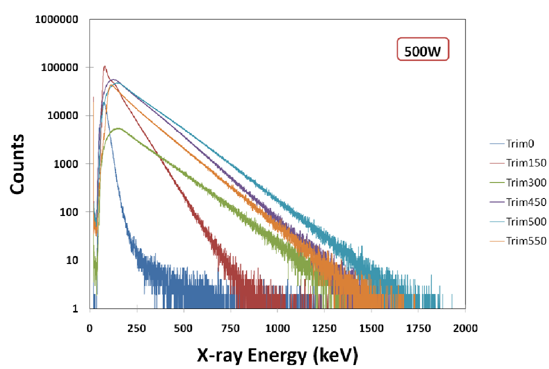


Figure 9. X-ray spectrums depending on trim coil currents when microwave input power is 500 W.

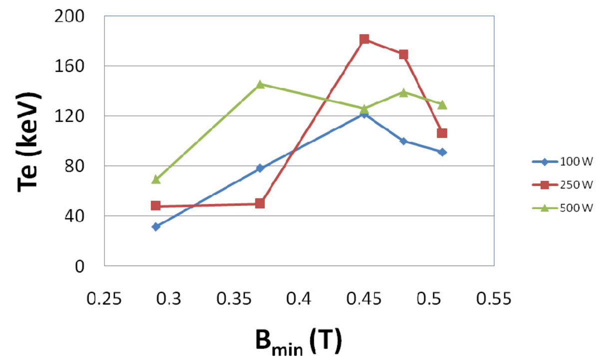


Figure 10. Calculated electron temperature of the ECR plasma based on the X-ray spectrum of high energy tail.

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