II. 3. Present Status of the 14.5GHz all Permanent Magnet Type ECRIS at CYRIC

Miyashita Y., Fujita M.*, Yamazaki A.*, Tanaka E.*, and Shinozuka T.*
Department of physics, Tohoku University
Cyclotron and Radioisotope center, Tohoku University*

A 14.5 GHz electron cyclotron resonance ion source (ECRIS) has been installed in February, 2001\(^1\). This ion source is made of permanent-magnet and has advantages of simple structure and easy handling. The light ions, such as Helium, Carbon, Nitrogen and Oxygen, have been supplied from this ion source and have been accelerated by the K=110MeV cyclotron. But, in the case of light heavy ion, such as Argon, it was not sufficient to obtain the intensities at higher charged ions for the acceleration by the cyclotron. Therefore, several improvements have been performed.

As the first improvement, the plasma chamber has been modified to for adjustable inner length by the movable panel. This made cavity resonator of plasma chamber, and it can effectively optimize these parameters of the resonator to transmit effectively the power of the microwave into the plasma chamber. Figure 1 shows the variation of the extracted ion current to the inner length of plasma chamber. In addition to optimize its length, microwave frequency was optimized at 14.0GHz and 14.5GHz by using a Traveling Wave Tube Amplifier. In comparison with slit current of each frequency, a resonance pattern of cavity resonator was observed in Figure 1. As a result, the extracted ion current has increased by 10~20%, and the reflected power of microwave was decreased. At the same time, the energy of X-ray from ECR chamber was measured by CdZnTe detector. Figure 2 shows the shift of the end-point energy of X-ray and extracted ion current to the plasma chamber length. The end-point energy of X-ray also was affected by cavity resonator, and electron heating in ECR plasma chamber was enlarged. This shows the important properties for the turning of cavity resonator at ECRIS.

The second object of the upgrade is to optimize the magnetic field distribution.
The scaling rule of the magnetic field distribution in ECRIS was proposed by R. Geller\textsuperscript{2)}. According to this rule, magnetic field should fulfill the following condition\textsuperscript{3)}:

\[ \frac{B_{\text{axial(ext)}}}{B_{\text{resonance}}} \geq 2, \quad \frac{B_{\text{radial}}}{B_{\text{resonance}}} \geq 1.6 \quad \text{and} \quad B_{\text{axial(inj)}} \approx 2B_{\text{axial(ext)}} \] (1)

Magnetic field intensity of radial direction was increased from 6726G to 8764G by enlarging the diameter of the plasma chamber in 2001\textsuperscript{4)}. Furthermore, the magnetic field intensity of axial direction at injection side was increased from 9800G to 12461G by inserting the magnetic stainless steel cylinder (SUS 403) in the plasma chamber. Figure 3 shows the calculated magnetic field of axial direction. Magnetic field was calculated using OPERA-3D codes. In calculation, \[ B_{\text{radial}} / B_{\text{resonance}} \] increased from 1.3 to 1.7, \[ B_{\text{axial(inj)}} / B_{\text{axial(ext)}} \] increased from 1.1 to 1.3 and \[ B_{\text{axial}(\text{ext})} / B_{\text{resonance}} \] is 1.7. As a result, the beam intensity of the Ar\textsuperscript{8+} and Ar\textsuperscript{9+} has increased to 15.1eµA and 2.53eA, the magnetic field distribution has gotten closer to the scaling rule for ECRIS. The extracted ion current is summarized in Table 1. The extracted ion current of \textsuperscript{12}C and \textsuperscript{16}O is sufficient, but that of Ne\textsuperscript{7+} and Ar\textsuperscript{9+} is still insufficient. For the improvement of the source performance, it is planed for several ideas. They are the installment of bias electrode in cylinder and the more precise gas flow system.

References

Table 1. Extracted ion current for each charge state eµA. Operating conditions for any ions are as follows; microwave power is 200W, extraction voltage is 10kV, no gas mixing method is used.

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Fig. 1. Plasma chamber length dependence of extracted Ar$^{4+}$ ion current with varying microwave frequency (14.0 and 14.5GHz) of TWTA.

Fig. 2. Plasma chamber length dependence of extracted Ar$^{8+}$ ion current and energy of X-ray. In comparison with Fig. 1., extraction condition is difference with Fig. 1. Therefore Fig. 2. was observed many mode of cavity resonator pattern.

Fig. 3. The calculated magnetic field distribution of axial direction in the plasma chamber using OPERA-3D code.