A COMPACT 14.5 GHz ECR ION SOURCE AT TOHOKU UNIVERSITY

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Abstract

A 14.5 GHz ECR ion source at Tohoku University was installed in 2001. This ion source is made of permanent magnet but the magnetic field strength along the chamber axis is adjustable by using the additional side magnets. The ion source has been upgraded to increase the beam intensity of the higher charge state. The plasma chamber has been modified to adjust its inner length by the movable panel. The frequency of the microwave is also tunable by using a travelling wave tube amplifier (TWTA). Therefore it can effectively optimise these parameters of the resonator to transmit the power of the microwave into the ECR plasma effectively. In addition, to realize the high-B mode ECRIS, the magnetic fields have been increased not only the axial magnetic field but also the radial magnetic field. As a result, more than 20 eμA of Oxygen 6+ beam can be obtained by the present ECR ion source.

INTRODUCTION

An electron cyclotron resonance (ECR) ion source was installed in 2001[1]. The light ion, such as Oxygen, Neon, Argon . . ., have been supplied from this ion source and have been accelerated by the K=110 MeV CYRIC AVF cyclotron. But the beam intensity of higher charged ions was not sufficient for accelerating by the cyclotron. Therefore, several improvements have been planned and carried out.

Improvements of ECRIS

Figure 1 illustrates the modified design of the ion source. It consists of two main ring magnets, a hexapole magnet, and three additional ring magnets, which are made of Nd-FeB permanent magnets.

The first improvement is the frequency tuning for the optimum operation of microwave. This ion source is originally operated by the 14.5GHz microwave frequency with the 2kW klystron amplifier. In order to find out the optimum condition, a travelling wave tube amplifier (TWTA) of Ku-band (12.0-18.0GHz) is prepared; furthermore, the movable tuning panel in the plasma has been installed.

The second improvement is the optimisation of the magnetic field.

CAVITY RESONATOR

For ECR ion source, one of the important thing is the electron cyclotron heating. Therefore, the injection of microwave requires careful handling. Although the wave-guide for the microwave has been designed for the TM_{01} mode, the microwave inside the plasma chamber has various modes. This come from the impedance miss-matching between the wave-guide and the plasma chamber. So the additional microwave tuning panel has been installed (see no.5 in Fig. 1); it can adjust the length of the plasma chamber and tune the microwave mode.

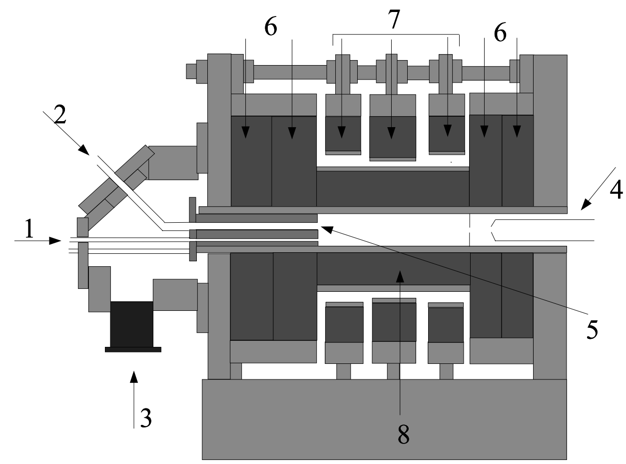

Figure 1: Schematic view of ion source. (1) gas injection (2) microwave injection (3) 150 l/sec TMP (4) extraction electrode (5) microwave tuning panel (or magnetic stainless steel cylinder + bias electrode) (6) main ring magnet (7) additional ring magnet (8) hexapole magnet

The tuning panel is remotely controlled from the ground voltage by the telemetry devices. Figure 2 shows the extraction ion current to the plasma chamber length controlled by the position of tuning panel. The microwave frequency was adjusted at 14.0GHz and 14.5GHz by using TWTA. Figure 2 clearly shows the resonance pattern of the extracted Ar^{4+} ion current to the plasma chamber length. The peak positions of the current are dependent on the TM_{01} microwave mode for each frequency in plasma chamber. This positions are consistent with a result of Maxwell equations. As a result, we have obtained the increased ion current of 10$\sim$20$\%$ by the optimum tuning of cavity length.

The energy of X-ray from ECR plasma chamber has been measured by a CdZnTe detector. A CdZnTe detector has the volume of $10 \times 10 \times 3mm^3$ and is placed

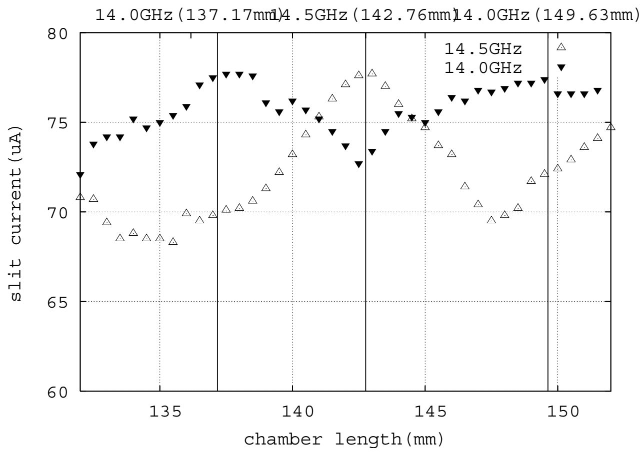

Figure 2: Dependence of the plasma chamber length for the extracted Ar^{4+} ion current with varying microwave frequency (14.0 and 14.5 GHz) of TWTA

along to the plasma chamber axis. Since the X-ray is the Bremsstrahlung of hot electrons in ECR plasma chamber, the end-point energy of X-ray is equivalent to the maximum energy of hot electron. Figure 3 shows the end-point energy of X-ray and the extracted Ar^{8+} ion current to the plasma chamber length. The end-point energy of X-ray is clearly related to the cavity resonator(chamber length). Consequently, the careful tuning of cavity resonator is very important for ECR ion source.

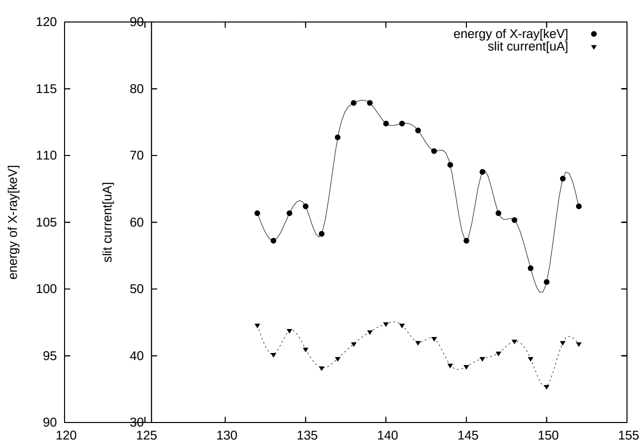

Figure 3: Dependence of extracted Ar^{8+} ion current and end-point energy of X-ray to the Plasma chamber length. Since the tuning has been for the Ar^{8+} ion extraction, this figure shows the different pattern of cavity resonator mode from fig.2.

MAGNETIC FIELD CONFIGURATION

The magnetic field configuration at the microwave frequency of 14.5GHz was modified. According to the scaling rule of the magnetic field for ECR ion source which was proposed by R.Geller[2], magnetic field should fulfill the following condition.

$$B_{axial(ext)}/B_{resonance} \geq 2 \tag{1}$$

$$B_{radial}/B_{resonance} \geq 1.6 \approx 2.0 \tag{2}$$

$$B_{axial(inj)}/B_{axial(ext)} \approx 2.0 \tag{3}$$

This rule was empirically considered using superconducting ECR ion source, which frequency is from 2.45GHz to 18.0GHz[3, 4, 5]. Although our ion source was made of all permanent magnet, we have modified the magnetic field configuration without adding new electromagnet devices.

The magnetic field strength of radial direction has been increased from 6726G to 8764G by opening up the radius of the plasma chamber from 16mm to 18mm; the extend has been compensated by the thinner cooling water space (Fig.4). Therefore, the magnetic field strength of radial direction close to the wall of plasma chamber was increased without the additional of hexapole magnet.

The magnetic field strength of axial direction at the gas and RF injection side has been increased by inserting the magnetic stainless steel cylinder (SUS 403) in plasma chamber[6]. The SUS 403 is high μ value material. So the value of maximum magnetic field at injection side was increased 9800G to 12460G and value of maximum magnetic field at extraction side was not changed. Figure 5 shows the calculated magnetic field of axial direction using the OPERA-3D code.

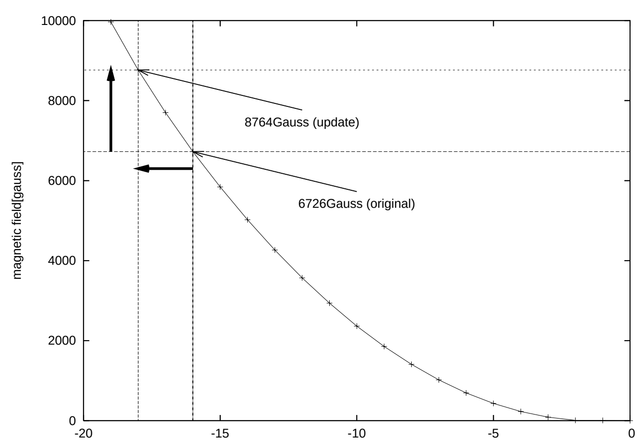

Figure 4: The calculated magnetic field distribution of radial direction in the plasma chamber using the OPERA-3D code.

In calculation, the values of $B_{radial}/B_{resonance}$, $B_{axial(inj)}/B_{axial(ext)}$ and $B_{axial(ext)}/B_{resonance}$ are improved as following values,

$$B_{axial(ext)}/B_{resonance} \approx 1.7 \rightarrow 1.7 \tag{4}$$

$$B_{radial}/B_{resonance} \approx 1.3 \rightarrow 1.7 \tag{5}$$

$$B_{axial(inj)}/B_{axial(ext)} \approx 1.1 \rightarrow 1.3 \tag{6}$$

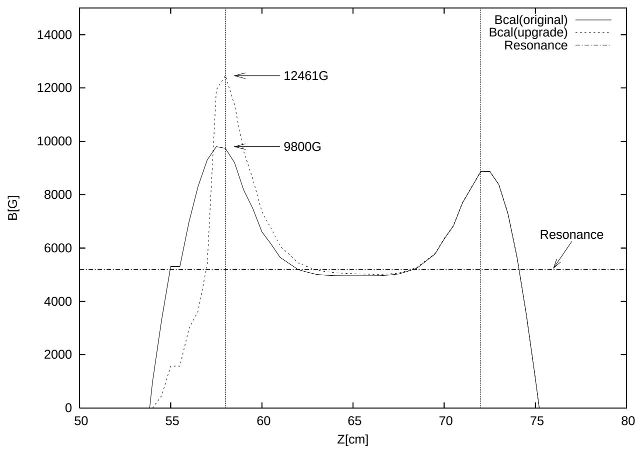

Figure 5: The calculated magnetic field distribution of axial direction in the plasma chamber using the OPERA-3D code.

The value of the $B_{radial}/B_{resonance}$ has been sufficiently improved, but the strength of axial direction need the larger value.

As a result, the extracted ion current was increased to 10 or more times for the case of the Ar^{9+}. Table 1 summarise the extracted ion current by the present improvements.

Table 1: Extracted ion current for each charge state in $e\mu A$. Operating condition for any ions are as follows; microwave power is 200W, extraction voltage 10kV, gas mixing method is not used

	2^+	3^+	4^+	5^+	6^+	7^+	8^+	9^+
^{12}C	68		37	4				
^{16}O	134	129	125	61	23			
^{20}Ne	78	95	78	39	11	2		
^{40}Ar	52	56	54	52	38	24	15	2.5

SUMMARY

After the improvement of compact ECR ion source with all-permanent magnets, we have obtained the sufficient results for the extracted ion current of ^{12}C and ^{16}O ; this shows the sufficient ability of present ion source for practical uses at cyclotron. However, for the Ne^{7+} and Ar^{9+}, we still need the more improvements such as the new bias electrode in the plasma chamber and the more precise gas flow system for gas mixing as well as the reinforcements of stronger axial magnetic field.

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