STATUS OF RIKEN ECR ION SOURCES FOR INTENSE HEAVY ION BEAM PRODUCTION

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Abstract

To meet the requirement of RIKEN RI beam factory project[1], several high performance ECR ion sources have been constructed. Using these ECRISs, we successfully produced intense heavy ion beams, such as Ar^{8+}(2mA), Kr^{13+}(0.6mA) and Xe^{20+}(0.3mA).

1 INTRODUCTION

At RIKEN, intense beams of multi-charged ions, such as Ar^{8+}, Kr^{18+}, Xe^{20+} and U^{35+}, are strongly demanded for the radioisotope beam (RIB) factory project[1]. For this reason, we have constructed high performance ECRISs (RIKEN 18 GHz ECRIS[2] and the liquid-He-free SC-ECRIS[3]). To increase the beam intensity, many laboratories modified the structure of the ion source and increase the microwave frequency and its power. It is natural to think that the boundary condition of plasma (plasma chamber geometry, property of its surface), magnetic field strength and magnetic field configuration play essential role to increase the beam intensity. In recent our experimental studies, we recognized that the plasma electrode position is key parameter to increase the medium charge state of heavy ions.

RF power is one of the important parameters to evaluate the performance of the ion source. In our case, we used the RF power subtracted from the injected RF power to reflected one. However, this value is strongly dependent on the distance between the RF power supply and ion source, and the number of components used in the RF transmission line. To evaluate the performance of the ion source, it is better to use the RF power absorbed in the plasma chamber. For this reason, we tried to measure the RF power absorbed in the plasma chamber.

In this paper, we report the status of the ECRISs and the effect of the plasma electrode position on the beam intensity of Ar, Kr and Xe ions and the emittance of these ions. We also report the measurements of the RF power absorbed in the plasma chamber.

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2 RIKEN ECRISS

2.1 RIKEN 18 GHz ECRIS

A detailed description of the RIKEN 18 GHz ECRIS and its present performance are described in Ref. 2. In order to increase beam intensities, a negatively biased disc was installed in the plasma chamber and an aluminium cylinder was used to cover the inner wall of the plasma chamber. The diameter of the plasma electrode hole was 10 mm. The distance between the extraction electrode and the plasma electrode was ~15 mm. The hole of the extraction electrode was 12 mm. The detailed description of beam transport system was reported in Ref. 4

Figure 1 shows the beam intensity of Ar^{8+} as a function of RF power. The maximum beam intensity was 2mA at the RF power of 800W. To produce beam intensity of 1mA, we only need 150~200W. In this figure, it should be stressed that the beam intensity is not saturated at the highest RF power (800W). It means that we may obtain higher beam intensity at higher RF power. Figure 2 shows the summary of the beam intensity.

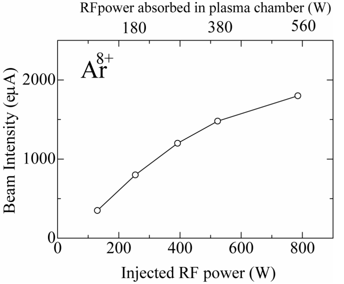

Figure 1: Beam intensity of Ar^{8+} as a function of RF power.

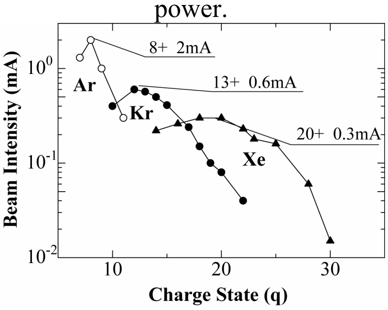

Figure 2: Beam intensity of various charge state heavy ions from RIKEN 18 GHz ECRIS..

2.2 Liquid He-free SC-ECRIS

Main feature of this ion source is to use the G-M refrigerator to cool the solenoid coils instead of liquid-He. It dose not require liquid He to obtain superconductivity in the solenoid coils. To minimize the electrical power consumption for cooling, the high temperature super conducting rods as a power lead are placed between first and second stages. Detailed description is presented in Ref.5. At present, three same type ion sources (RAMSES in RIKEN, SHIVA in University of Tsukuba, and newly constructed one in Dubna) are operated and one ion source is now under construction in Osaka University. Figure 3 shows the beam intensity of Kr ions from RAMSES. As shown in Fig. 3, the beam intensity of Kr^{25+} from RAMSES is higher than that from RIKEN 18 GHz ECRIS. It may be due to the higher magnetic field and longer plasma chamber, which prolong the ion confinement time.

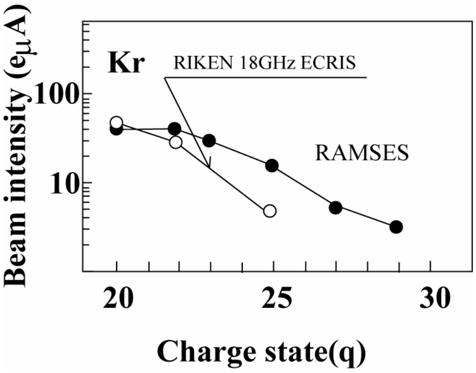

Figure 3: Beam intensity of Kr ions from RIKEN 18 GHz ECRIS (open circles) and RAMSES(closed circles).

3EXPERIMENTAL RESULTS AND DISCUSSION

3.1 PLASMA ELECTRODE POSITION

In a previous study[6], the plasma electrode position for maximizing the beam intensities of the $Ar^{8+,9+}$was found to be at electrode position C (see Fig. 4). For investigating this effect on the beam intensity of Kr and Xe ions, we measured the beam intensities as a function of plasma electrode position. We have chosen four positions as shown in Fig. 4. The other parameters (B_{ext}, gas pressure, biased disc position, and negative bias voltage of the disc) were tuned to maximize the beam intensity.

Figure 4 shows the beam intensity of Ar, Kr and Xe ions as a function of plasma electrode position. It is clearly seen that beam intensities of lower charge state heavy ions increased when moving the plasma electrode toward the ECR zone.

The electrode position affects the density of the plasma electrode hole; the plasma density should be higher near ECR zone. It means that we can obtain higher beam intensity near ECR zone. On the other hand, the confinement time of electron may become shorter, because the magnetic field at the plasma electrode position becomes lower and distance between resonance zone and electrode position becomes shorter. Furthermore, the position also affects the beam trajectory and emittance. Although we have several speculations to explain this mechanism, we need further investigation to figure out this mechanism.

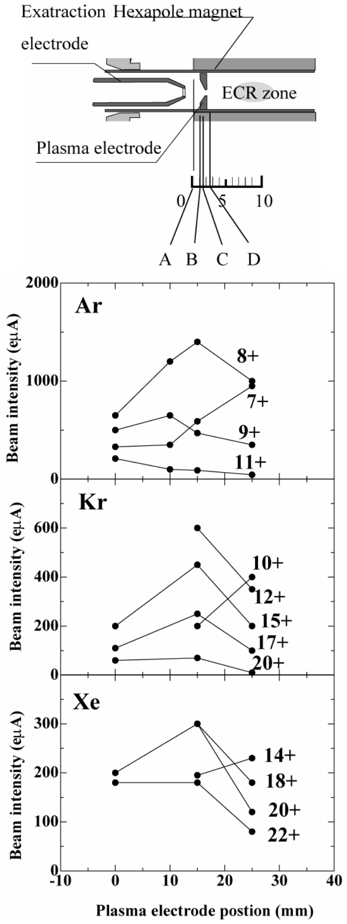

Figure 4: Cross sectional view of the extraction region of RIKEN 18 GHz ECRIS (upper figure) and beam intensities of Ar, Kr and Xe ions as a function of plasma electrode position(lower figure).

3.2 RF power absorbed in the plasma chamber

Figure 5 shows the schematic diagram of the RF power supply and transmission lines. The microwaves emitted from the klystron are injected through several components into the plasma chamber as shown in Fig. 5. Input and reflected RF powers were measured by the input and reflected RF power monitor. In order to measure the absorbed RF power in the plasma chamber, we measured the temperature deference between input and output cooling water of the plasma chamber. The flow rate of the cooling water was 2.2l/min.

Figure 6 shows the absorbed RF power in the plasma chamber as a function of input RF power. In order to minimize the effect of extraction current on the increase (or decrease) of the temperature of the cooling water, we did not supply the extraction voltage. To investigate the effect of gas pressure, we measured the RF power at the Gas pressure from $6x10^{-7}$ to $2x10^{-6}$ torrs. We observed that the absorbed RF power in the plasma chamber was independent on the gas pressure as shown in Fig. 6 and the 70% of input RF power was absorbed in the plasma chamber.

The total length of waveguide (15.8 mm in width 7.9

mm in height) is ~4m. It is estimated that the ~90W of RF power is absorbed in the waveguide at the input RF power of 500W.[7] We also used the flexible waveguide (total length of 20 cm) which has the absorbed RF power of 3.3W/cm. It means that the 66W of RF power have to be absorbed in it. From these results, the total absorbed RF power in the wave guide is estimated to be 161W. The absorbed RF power in the plasma chamber was ~280 W. In transmission line, we used about 10 wave guide flanges. The RF power may be absorbed in these flanges. .

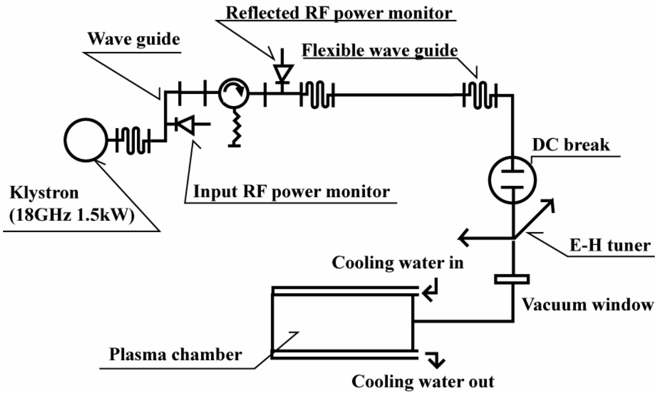

Figure 5: Schematic drawing of the RF power supply and transmission lines.

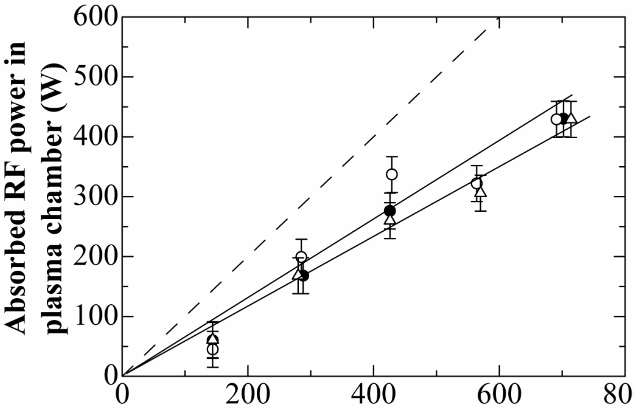

Figure 6: Absorbed RF power in the plasma chamber as a function of input RF power.

3.3 Emittance measurement for intense beams

Measurements of the emittance in both horizontal and vertical were performed in wide range of the drain current of RIKEN 18 GHz ECRIS. Figure 7 shows the normalized 99% emittance of Ar^{8+} as a function of drain current. It is clearly seen that the emittance gradually increased from 0.5 to 1.1πmm mrad with increasing the drain current from 4 to 15 mA. At the highest drain current, the beam intensity of Ar^{8+} was 1.5 emA at the extraction voltage of 17kV. In this case, the unnormalized emittance was 420 πmm mrad, which is 3 times as large as the acceptance of our RFQ linac (Acceptance is 150 πmm mrad.).[8] To accelerate the full beam of 1.5mA Ar^{8+} in this condition, we surly need the extraction voltage of 60 kV. At lower drain current, 90 % of Ar^{8+} beam will be accepted by the RFQ linac at the extraction voltage of 20kV. The emittance of Xe^{20+} were 0.45 and 0.47πmm mrad for the drain current of 3.5 and 1.5 mA, respectively. It seems that the size of emittance is almost constant at lower drain current. In this test experiment, the other effects (beam instability and so on) may be larger than the space charge effect. To understand these phenomena, we need further investigation.

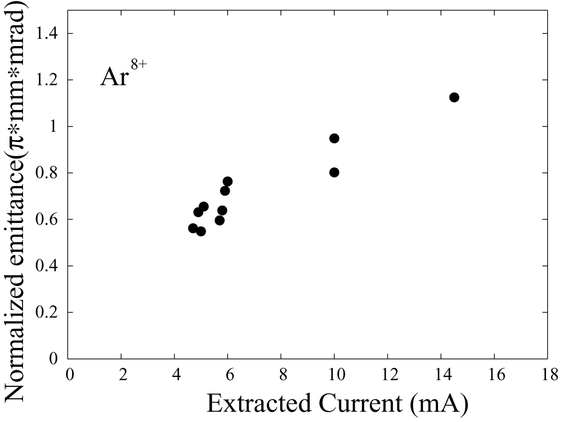

Figure 7: Normalized 99% emittance of Ar^{8+} as a function of drain current

REFERENCES

[1] Y. Yano, J.Phys.**76S**(1),1-7 (2002)
[2]T. Nakagawa and Y. Yano, RSI. 71(2000)637
[3] T. Nakagawa et. al, RSI. 75(2004)1394
[4] T. Nakagawa et al, NIM B226(2004)392
[5]T. Kurita et al, NIM B192(2002)429
[6]Y. Higurashi et al, NIM A510(2003)206
[7] Handbook of ION SOURCES (CRC, New York. 1995) Edited by B.Wolf.
[8] O.Kamigaito et.al. Rev. Sci. Instrum. 70, 4523 (1999)