INTENSE HEAVY ION BEAM PRODUCTION FROM RIKEN ECRIS

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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). We also observed that the beam intensity was strongly dependent on the plasma electrode position and B_{min}

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 and magnetic field configuration are key parameters to increase the medium charge state of heavy ions.

In this paper, we report the status of the ECRISs and how to increase the beam intensity by optimizing these parameters.

RIKEN ECRISS

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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.

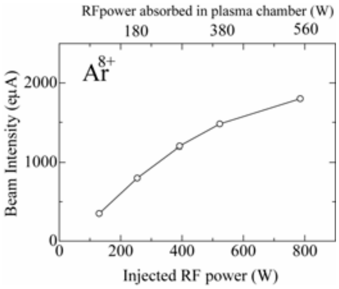

Fig.1. Beam intensity of Ar^{8+} as a function of RF power.

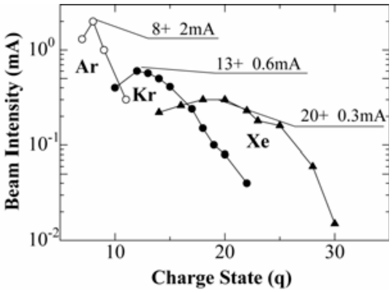

Fig.2. Beam intensity of various charge state heavy ions from RIKEN 18 GHz ECRIS.

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.

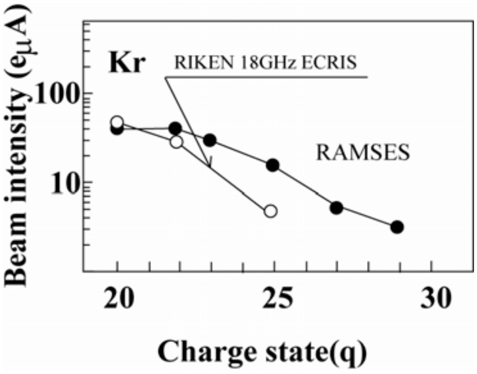

Fig.3. Beam intensity of Kr ions from RIKEN 18 GHz ECRIS (open circles) and RAMSES(closed circles).

KEY PARAMETRES TO INCREASE THE BEAM INTENSITY

By great effort on experimental and theoretical studies, we have recognized several key parameters play essential role in increasing the intensity (magnetic field strength, property of the plasma chamber wall, size of the plasma chamber, negatively biased disc and so an). Very recently, we observed that the magnetic field configuration and plasma electrode position strongly affects the beam intensity.

PLASMA ELECTRODE POSITION

In a previous paper[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.

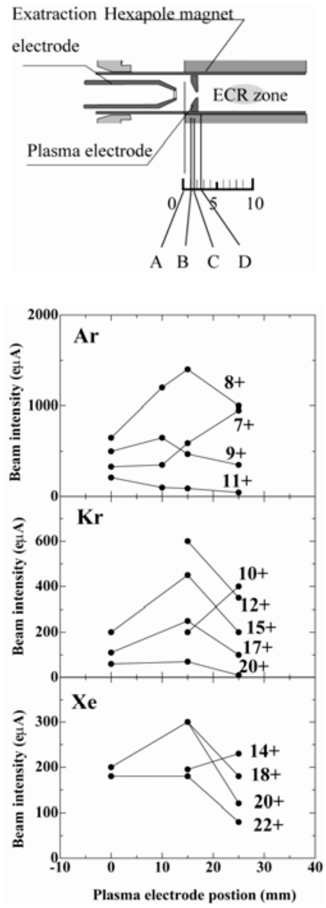

Fig.4. Cross sectional view of the extraction region of RIKEN 18 GHz ECRIS (upper) and beam intensities of Ar, Kr and Xe ions as a function of plasma electrode position(lower).

Magnetic field configuration (B_{min} effect)

It is well known that the magnetic field strength and shape at the beam extraction side and injection side influence the charge distribution and beam intensity. Furthermore it is natural to think that B_{min} should influence to the beam intensity of heavy ions from the ECRIS. Because the magnetic field configuration (or gradient of magnetic field) affects the plasma confinement and the effectiveness of the electron heating at resonance zone.

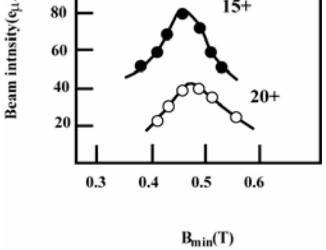

Fig.5. Beam intensities of $Kr^{15+,20+}$ ions as a function of B_{min}.

For studying the effect of B_{min} on the beam intensity produced from RAMSES, we changed B_{min} from 0.25T to 0.6 T without changing B_{ext} and B_{inj}. Figure 5 shows the beam intensity of $Kr^{20+,15+}$ as a function of B_{min}. In this experiment, B_{ext} and B_{inj} were fixed to 1.15 and 1.9 T, respectively. The injected microwave power was 600 W. The extraction voltage was 12 kV. The gas pressure, the position of electrode and its negative bias voltage were changed to maximize the beam intensity. The typical gas pressure at B_{min}=0.5 T was $3x10^{-7}$ Torr for Kr^{15+} ions. We did not use the gas mixing method for simplifying the experiment. The beam intensity gradually increased with increasing B_{min} up to ~0.49T and then gradually decreased. Above 0.6 T of B_{min}, the extracted beam became unstable. The value of B_{min} (optimum B_{min}) for maximizing the beam intensity of Kr^{15+} was almost same as that for Kr^{20+} ions.

Figure 6 shows the summary of the experiment (optimum B_{min} for multi charged O, Ar, Kr and Xe ions). We measured the optimum B_{min} at several conditions (B_{ext} = 0.9~1.25 T, B_{inj} =1.72 ~1.9 T) for various heavy ions.

In these experiments, we observed that the existence of optimum value for B_{min} to maximize the beam intensity and it is not dependent on the charge state of heavy ions. The optimum value for B_{min} was 0.47~0.49 T for 18 GHz for production of various multi-charged heavy ions as shown in Fig.6.

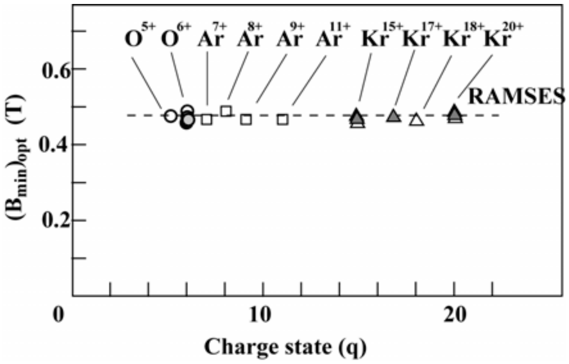

Fig.6. Optimum value for B_{min} for various heavy ions.

RIKEN 18 GHz ECR ion source has only two sets of solenoid coils for producing the mirror magnetic. It means that we cannot control B_{min} and B_{ext} independently. For most of the experiments, we kept the B_{inj} ~1.40T, which is the maximum magnetic field strength of RIKEN 18 GHz ECRIS. For production of O^{5+}, the B_{min} is significantly lower than the optimum B_{min} , which is expected from the experiment with RAMSES. This is likely one of the reasons why we obtained only 1.5mA of O^{5+}. For production of heavier ions, such as Xe^{20+}, the B_{min} is slightly higher than the optimum value. It means that if we can set the optimum value for B_{min} without changing B_{ext}, we may increase the beam.

New SC-ECRIS

The requirement of the beam intensity of U^{35+} for RIKEN RI beam factory project is 15pμA. To produce such high intensity of highly charged heavy ions, we have to increase the plasma chamber volume, magnetic field strength and to use higher microwave frequency. Furthermore, to obtain lager plasma volume, we will use special geometrical arrangement of solenoid coils as shown in Fig.7. Using this arrangement, we will obtain 3~4 times large volume as that for classical magnetic field configuration (dashed line in Fig.7). The maximum magnetic field strength of mirror magnetic field and radial magnetic field strength are 4 and 2 T, respectively. The expected extraction voltage is higher than 60kV to reduce the space charge effect at the extraction region.

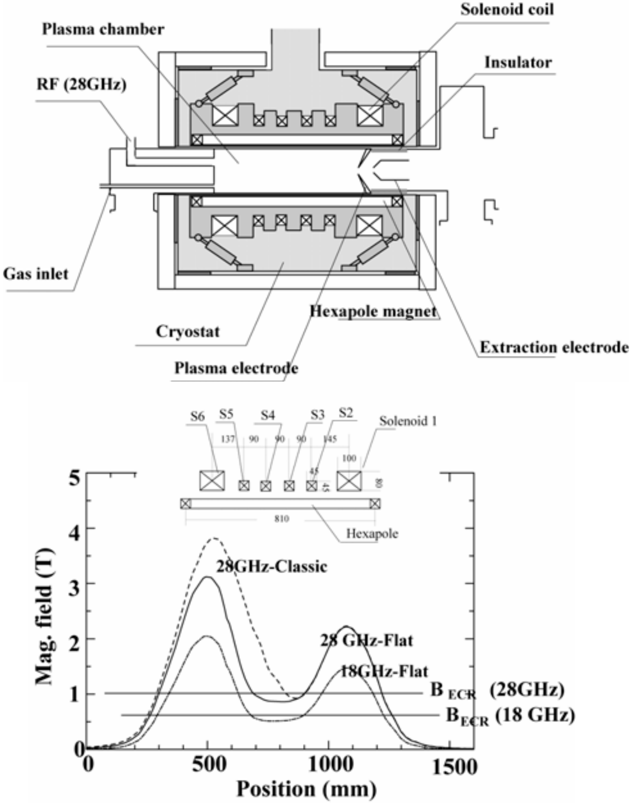

Fig. 7. Schematic drawing of the new SC-ECRIS (upper) and magnetic field configuration (lower).

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