INTENSE BEAM PRODUCTION FROM RIKEN ECRISS

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Abstract

We have constructed several high performance ECRISs in RIKEN and produced intense beam of heavy ions.(e.g., 2mA of Ar^{8+}, 0.6mA of Kr^{13+}, 0.3mA of Xe^{20+}) During the improvement of their performance, we found that the several key parameters play essential role to increase the beam intensity (plasma electrode position, magnetic field configuration, property of the chamber wall material. position of the biased disk and so on).

INTRODUCTION

ECR ion sources have been widely used as the external ion sources for heavy ion accelerators. Especially, ECRISs became one of the key devices for production of radioisotope beam (RI beam). Since middle of 1990s, RIKEN has undertaken construction of new accelerator facility so-called RI Beam Factory.[1] In this project, the production of intense heavy ion beams is an important task to produce the intense RI beam. For this reason, at RIKEN, several high performance ECRISs have been constructed (RIKEN 10 GHz ECRIS[2], 18 GHz ECRIS [3]and liquid He–free Super conducting ECRIS[4]) in the last decade.

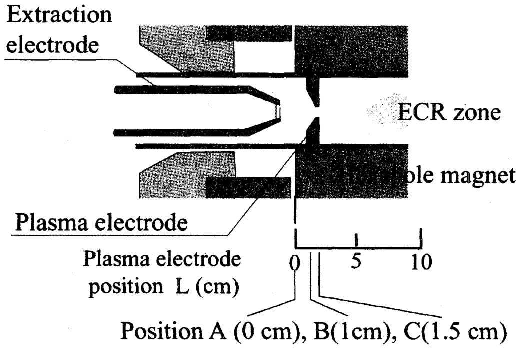

Figure 1: Schematic drawing of the plasma chamber around the plasma electrode position.

Since the first beam was extracted from RIKEN 18 GHz ECRIS in 1995, several methods have been applied to increase the beam intensity of highly charged heavy ions(e.g., optimization of plasma electrode position [5] and Al_2O_3 plating[6]). The solenoid coils of liquid He-free SC ECRIS is cooled by small refrigerator instead of liquid He. This feature allows us to avoid the complicated operation and bulkiness of ordinary super conducting magnets using liquid He.[4] After one year of construction, we have successfully extracted the first beams of highly charged heavy ions, such as Xe and Kr ions. During the increase of the beam intensity, we have recognized that it is important for increasing the beam intensity not only to increase the magnetic field strength, but also to optimize magnetic field configuration[7]. Applying these methods, the beam intensities from RIKEN ECRISs have been dramatically increased. For example, the beam intensity of Ar^{8+} has been increasing from several 10 eμA to 2 emA during the past decade.

RIKEN 18GHZ ECRIS

A detailed description of the RIKEN 18 GHz ECR ion source and performances are described in ref. [3]. The mirror ratio has a nominal value of 3.0 with the maximum of mirror magnetic field ~1.4 T. The field strength at the surface of magnets (B_r) is ~ 1.4 T. To increase the beam intensity, we used the negatively biased electrode installed in plasma chamber and the aluminum cylinder to cover the inner wall of plasma chamber [3]. For production of highly charged Ar ions (Ar^{11+}, Ar^{12+}), we used the Al_2O_3 plating method. [6] Furthermore, the position of plasma electrode and magnetic field configuration play essential roles to improve the performance.

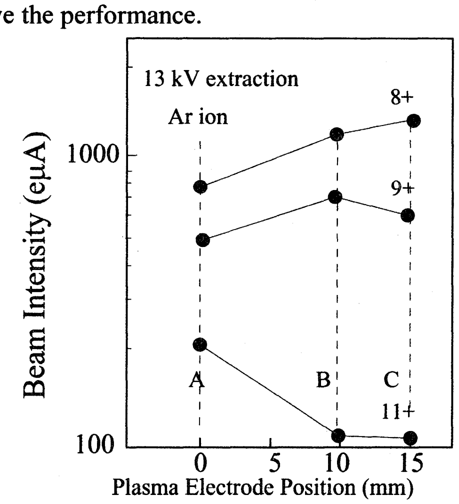

Figure 2: Beam intensity of Ar ions as afunction of plasma electrode position.

As the plasma electrode makes the part of the boundary of ECR plasma, it is natural to think that the position of plasma electrode affects the condition of plasma. It also affects the beam extraction conditions. Then, the beam intensity may be increased finding the most suitable position of the plasma electrode. Based on this assumption, we tried to

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optimize the plasma electrode position to increase the beam intensity of highly charged heavy ions. We have chosen different points (see Fig. 1) and measured the beam intensity of Ar, Kr and Xe ions. Figure 2 shows the beam intensity of Ar ions as a function of the plasma electrode position. The beam intensity gradually increases when moving the plasma electrode toward the ECR zone and then decreases as shown in this figure. It seems that an optimum electrode position exists to maximize the beam intensity. The optimum plasma electrode position moves toward the ECR zone when the charge state becomes lower. The same tendency can be seen in case of Kr and Xe ions.

Figure 3 shows the typical beam intensities produced from gaseous elements at the extraction voltage of 13~17kV and RF power of 700 W. We obtained 0.3emA of Xe^{20+}, 0.6 mA of Kr^{13+} and 2mA of Ar^{8+} at only 700 W of RF power.

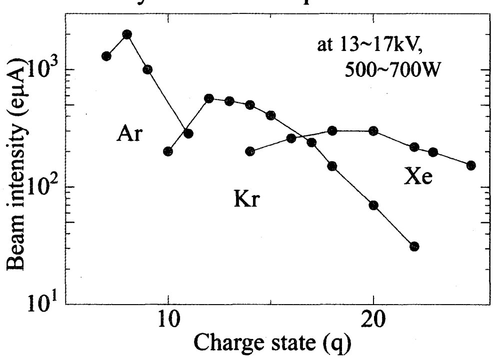

Figure 3: Charge distribution of Ar, Kr and Xe ions produced from RIKEN 18GHz ECRIS.

LIQUID HE−FREE SC-ECRIS

The detailed design of the ion source was described in ref.[4]. The RF injection side coils generate a maximum field of 3T. The beam extraction side coils generates a maximum field of 2T. The solenoid coils are cooled by small refrigerator. The radial magnetic field strengths on the surface of plasma chamber is 1.2T. The operational microwave frequency is 18 GHz. It should be stressed that the plasma chamber volume (1.5 L) is much smaller than those of other SC-ECRISs.

To investigate the effect of magnetic field strength and plasma chamber volume, we compared the beam intensities from the RIKEN 18 GHz and liquid He-free SC-ECRIS. Figure 4 shows the beam intensities of Kr ions. Open and closed squares are the beam intensities of Kr ions from RIKEN 18 GHz and liquid He-free SC-ECRIS.

The obtained beam intensities of $Kr^{20+,27+}$ from the SC-ECRIS were 40 and 5 eμA at 12 kV of the extraction voltage and 600 W of the microwave power. In this experiment, the typical magnetic filed strengths of B_{inj}, B_{min} and B_{ext} of the SC-ECRIS were 2.0, 0.5 and 1.2T, respectively. The beam intensities of highly charged Kr ions (25+, 27+) extracted from the SC-ECRIS are much higher than those from RIKEN 18 GHz ECRIS. Though both ECRISs have the almost same chamber diameter (~7.2 cm in diameter) and the RF power was also almost same, there are two essential differences between two sources, i.e., the plasma chamber length and its magnetic field strength. The ion confinement time is strongly dependent on the volume of the plasma chamber and the mirror ratio of mirror magnetic field. It may conclude that the different confinement time of ions in plasma in the two ion sources brings the different results of the beam intensity.

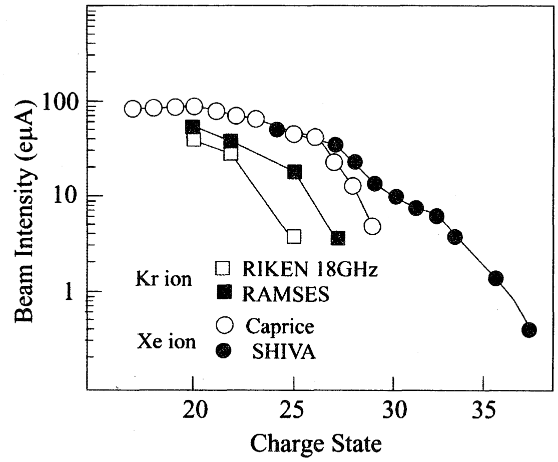

Figure 4: Beam intensities of Xe ions from SHIVA (closed circles) and CAPRICE (open circles) and Kr ion from RAMSES (closed squares) and RIKEN 18GHz ECRIS.

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.[8] Furthermore it is natural to think that B_{min} should influence to the beam intensity of heavy ions from the ECRIS[9]. Because the magnetic field configuration (or gradient of magnetic field) affects the plasma confinement and the effectiveness of the electron heating at resonance zone.

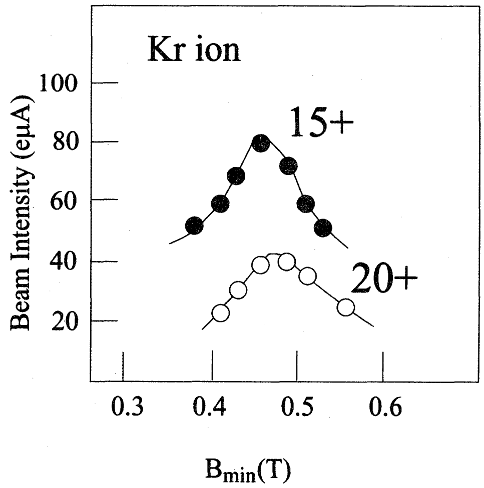

Figure 5: Beam intensities of $Kr^{15+,12+}$ as a function of B_{min}.

For studying the effect of B_{min} on the beam intensity produced from the SC-ECRIS, we changed B_{min} from 0.25T to 0.6 T without changing B_{ext} and B_{inj}.[7] 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} = 0.9~1.25T, B_{inj} =1.72 ~1.9T) for various heavy ions.

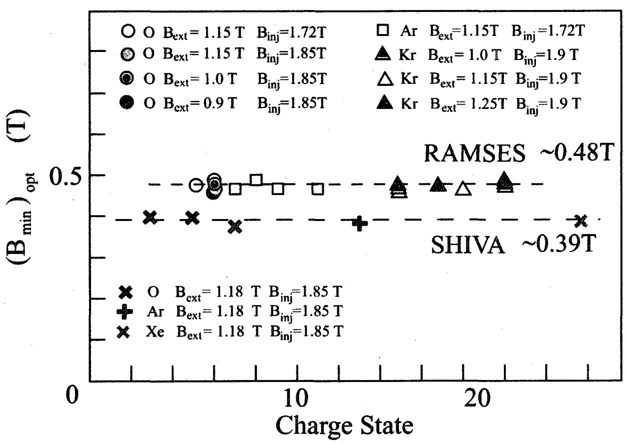

Figure 6: Optimum B_{min} for various charge state of heavy ions.

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 0.47~0.49T for production of various multi-charged heavy ions as shown in Fig.6.

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. Figure 7 shows the magnetic field strength of B_{ext} and B_{min} for maximizing the beam intensity of various heavy ions. For most of the experiments, we kept the B_{inj} ~1.40T, which is the maximum magnetic field strength of RIKEN 18 GHz ECRIS. The dashed line is the optimum B_{min} obtained from the experiment using RAMSES. 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.

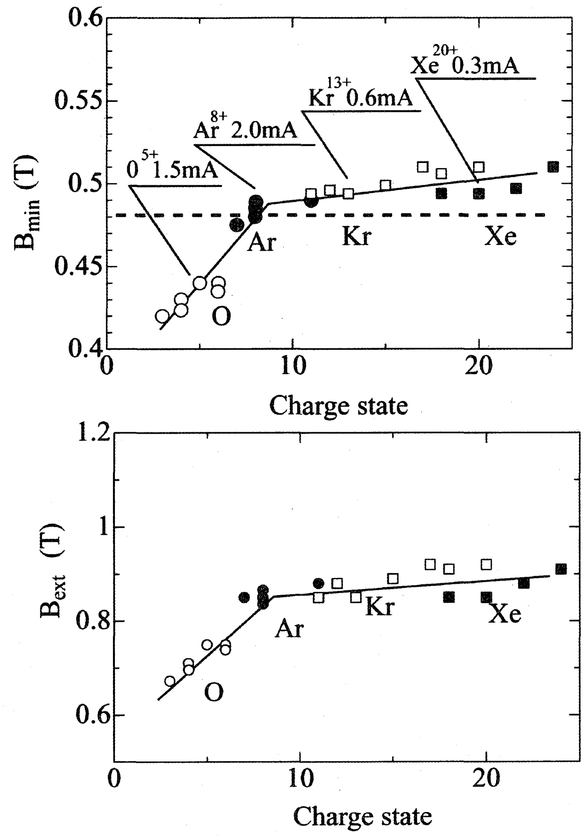

Figure 7: B_{min} and B_{ext} of RIKEN 18GHz ECRIS for production of various charge state of heavy ions.

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