DEVELOPMENTS OF RIKEN NEW SUPERCONDUCTIONG ECR ION SOURCE

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Abstract

We constructed new SC-ECRIS for RIKEN RIBF project. To improve the performance, we investigated the effect of ECR surface size and magnetic field gradient at ECR point on the beam intensity of highly charged heavy ions. We produced U^{35+} beam with sputtering method and obtained 24 eμA of U^{35+} and 43 eμA of U^{31+} at the RF power of 1.2kW.

INTRODUCTION

In the past decade, the interest in the radio isotope beam leads us to increase the beam intensity and charge state of heavy ions from ECRIS for increasing the energy and intensity from the heavy ion accelerators.[1)] For this reason, recently, the several high performance superconducting ECR ion sources (SC-ECRIS) have been constructed.[2-4)] Since middle of the 1990s, RIKEN has undertaken construction of new accelerator facility so-called Radio Isotope Beam Factory (RIBF)[1)] and successfully produced 345MeV/u U beam (~0.1 pnA on target) in 2007. In 2008, we increased the beam intensity with improving the transfer efficiency in the accelerator to 0.4 pnA. However, to meet the requirement of the RIBF (primary beam intensity of 1pμA on target), we still need to increase the beam intensity. Therefore, we started to construct the new SC-ECRIS which has an optimum magnetic field strength for 28 GHz microwave in the summer of 2007. In the end of 2008, we obtained the 102% of the designed value for the magnetic field strength. In the spring of 2009, the SC-ECRIS produced first beam with 18GHz microwaves. Since we obtained the first beam form the ion source, we made various test experiments to increase the beam intensity of highly charged heavy ions. In this article, we present the experimental results and future plan to meet the requirements.

DESIGN OF SC-ECRIS

Detailed design of the ion source was described in refs.5 and 6. The main feature is that it has six solenoid coils for producing mirror magnetic field. Figure 1 shows the schematic drawing of the SC-coils. Inner radii of the hexapole and solenoid coils are 102 mm and 170 mm, respectively. Four coils (SL2 ~SL5) are used for creating a flat magnetic field region between the mirrors. The hexapole magnetic field in the central region is increased by using iron poles, which is same structure as the VENUS.[2)] A NbTi-copper conductor is used for coils and these are bath-cooled in liquid helium. Figure 2 shows the typical axial magnetic field distributions along the beam axis ("Flat B_{min}" configuration (solid line) and "Classical B_{min}" configuration (dashed line)). The maximum axial magnetic fields are 3.8 T at the RF injection side (B_{inj}) and 2.2 T at the beam extraction side (B_{ext}). The maximum hexapole magnetic field (B_r) is 2.1 T on the inner surface of the plasma chamber (r = 75 mm). Two turbo-molecular pumps (1100L/sec) are placed at the RF injection side and beam extraction side to keep the high vacuum of the plasma chamber. The inner diameter and outer diameter of the plasma chamber are 150 and 164 mm, respectively. The chamber is made of double wall stainless steel tube with the water cooling channel in between. To keep the high voltage, the kapton sheets (total thickness of 1.2 mm) covers the plasma chamber. The negatively biased disc is placed in the axial direction and its position is remotely controlled with the accuracy of 0.1 mm.

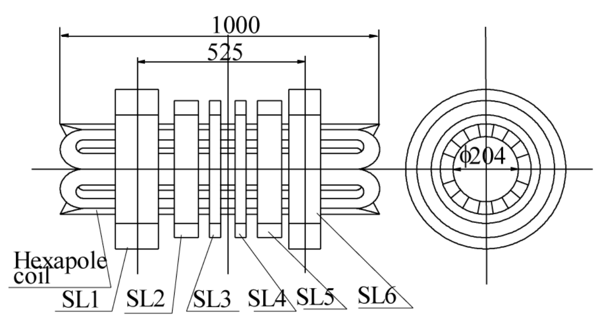

Figure 1: Schematic drawing of the SC-coils of RIKEN SC-ECRIS.

EXPERIMENTAL RESULTS

One of the strong interests for increasing the beam intensity of highly charged heavy ions is the effect of the resonance surface size and field gradient at the resonance

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point. As described in the previous section, the ion source has six solenoid coils to create the mirror magnetic field.

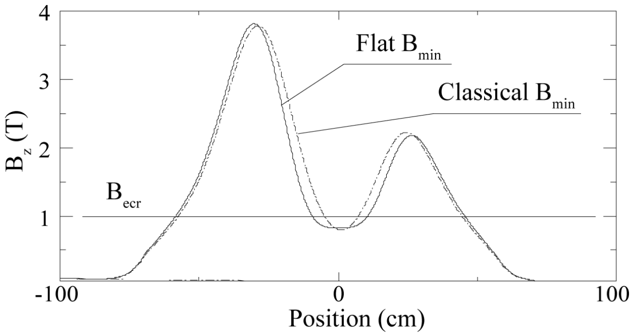

Figure 2: Typical axial magnetic field strength.

Using these coils, the ECR surface size can be changed without changing the B_{min}.

To investigate the effect of the magnetic field gradient at the resonance zone and the size of the ECR zone, we did not change the radial magnetic field strength (B_r) at the inner surface of the plasma chamber (diameter of 150mm), the maximum magnetic field strength at the RF injection side (B_{inj}) and the extraction side (B_{ext}). B_{inj}, B_{ext} and B_r were kept at 2.3, 1.2 and 1.3T, respectively. The extraction voltage was fixed to 15kV. Figure 3 shows the beam intensities of Xe^{20+} on four conditions. The injected RF power was 500W. The ion source was tuned to maximize the beam intensity of Xe^{20+} ions. The experimental results in the group I and II (see fig. 3) give us the information of the average field gradient effect and the ECR zone size effect, respectively. The zone size and the average field gradient on the ECR zone were calculated with the three dimensional code OPERA[7)].

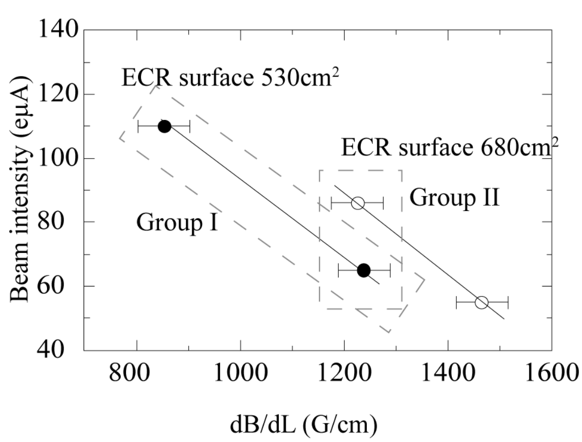

Figure 3: Beam intensity of Xe^{20+} ions for several average magnetic field gradient at ECR zone.

In fig. 3, we can clearly see that the gentler average field gradient (dB/dL) gives higher beam intensity of Xe^{20+} for same ECR zone size (Secr~530cm2). The beam intensity increased from 55 to 110 eμA with decreasing the average field gradient from 1220 to 850 G/cm. Figure 4 shows the charge distributions of Xe ions at the average field gradient of 854 and 1220G/cm (group I in fig.2), respectively. The slope of the charge distribution (charge state higher than 20+) for dB/dL~850G/cm is gentler than that for dB/dL~1220G/cm. It may be due to the effect of the electron temperature. The electrons in the plasma obtain larger kinetic energy at the gentler magnetic field gradient. As a result, the electron temperature becomes higher. Generally the production rate of the higher charge state heavy ions increases with increasing the electron temperature. Figure 5 shows the charge distributions of Xe ions for ECR zone size (S_{ecr}) of 680 and 530 cm^2, respectively (group II in fig. 2). The average field gradient at resonance zone (dB/dL) was fixed to ~1220G/cm. The slope of the charge distribution for S_{ecr} ~680cm^2 is almost same as that for 530cm^2. The ratio between Xe^{20+} beam intensity for the surface size of 680 cm^2 and 530cm^2 is ~1.35, which is almost same as the ratio of the ECR zone size (~1.3). This experimental result may indicate that the ECR zone size affects the production rate of the ions in the plasma.

Figure 6 shows the beam intensity of Ar^{11+} as a function

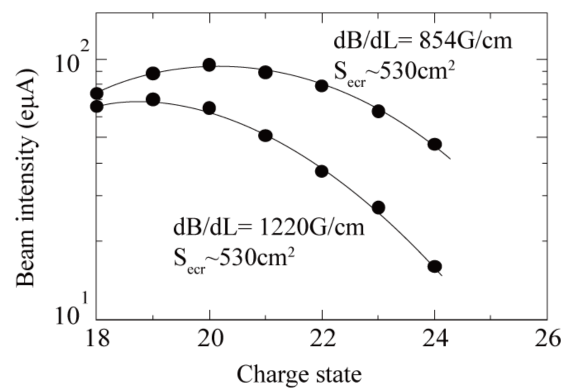

Figure 4: Charge distributions of Xe ions for the average magnetic field gradient *dB/dL* ~ 850 and 1220G/cm.

of dB/dL at three ECR zone sizes. In this experiment, the RF power and extraction voltage were fixed to 600W and 15 kV, respectively. The beam intensity increases linearly with deceasing field gradient.

Figure 7 shows the beam intensity of Ar^{11+} as a function

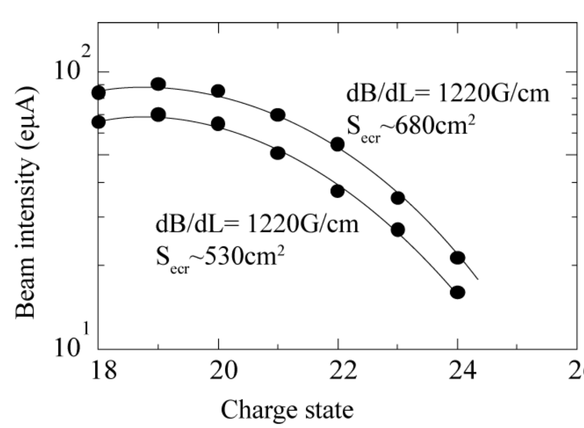

Figure 5: Charge distribution of Xe ions for the ECR surface size of 686 and 530 cm^2.

of RF power at two conditions (A and B in Fig.6). The beam intensities at the condition of A were always lower than those at the condition B. It is mainly due to the effect of the magnetic field gradient and ECR zone size. At the RF power of 1.9kW, we obtained ~500eμA of Ar^{11+}.

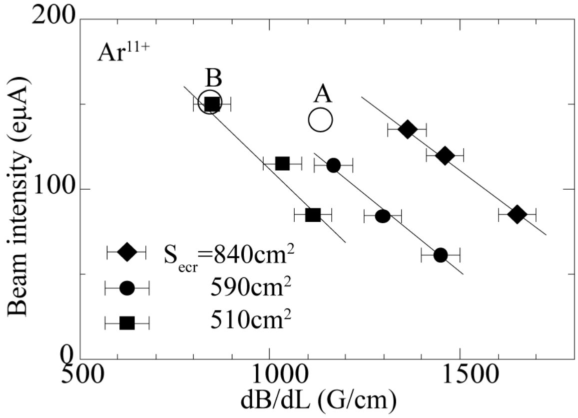

Figure 6: Beam intensity of Ar^{11+} ions for several average magnetic field gradient at ECR zone.

PRODUCTION OF U BEAM

In the autumn of 2009, the few tens μA of U^{35+} beam from the new superconducting ECR ion source was required to increase the U beam for producing the radio isotope beam. To meet this requirement, we made the test experiment for production of U beam with sputtering method. The maximum beam intensity of 24eμA was obtained at the RF power of 1.2kW. We used the oxygen gas as an ionized gas. We observed that the emittance was reduced using O_2+Ar gas as an ionized gas. The minimum rms emittance was ~90πmm mrad at the extraction voltage of 15kV, which is smaller than the acceptance of the accelerator (~200πmm mrad). We also observed that the intensities of lower charge state U ion beam (< 34+) were enhanced with O_2+Ar gas. The beam intensity of U^{31+} was 51 eμA at the RF power of 1.2kW.

FUTURE PLAN

In the summer of 2010, we will operate the new SC-ECRIS with 28GHz microwaves after moving the ion source to the ion source room for new heavy ion linear accelerator. The 28GHz gyrotorn was installed in the spring of 2010. After installation, we will make various test experiments with 28GHz microwaves to meet the requirement of the RIKEN RIB factory project.

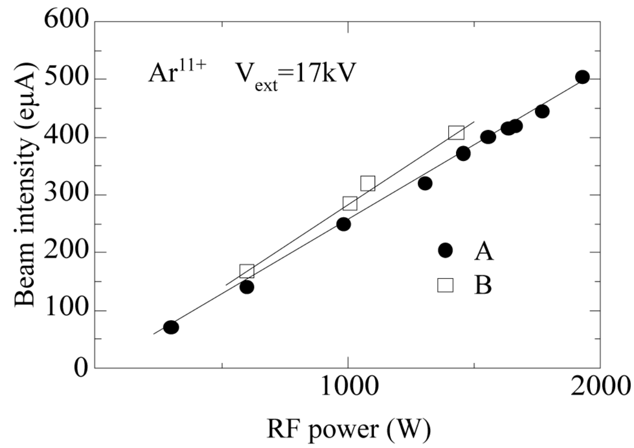

Figure 7: Beam intensity of Ar^{11+} as a function of RF power at two conditions (A and B).

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