RECENT THE RIKEN 28 GHZ SC-ECRIS RESULT

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Abstract

Highly charged uranium (U) and xenon (Xe) ion beams were produced by the RIKEN superconducting electron cyclotron resonance ion source (SC-ECRIS) using 28 GHz microwaves. The beam intensity of Xe^{25+} was about 250 eμA at an RF power of 1.7 kW. The sputtering method was used to produce a highly charged U ion beam. The beam intensity is strongly dependent on the rod position and sputtering voltage. We obtained ~60 eμA for the U^{35+} ion beam at an RF power of 2 kW.

INTRODUCTION

In the last decade, facilities for the production of radio isotope (RI) beams have been constructed worldwide.[1–4] In these facilities, intense heavy ion beams are needed to produce intense radioisotope (RI) beams. To meet this requirement, several super-conducting electron cyclotron resonance ion sources (SC-ECRISs) have been constructed to produce intense highly charged heavy ions.[5–8]

At RIKEN, we started to construct the new SC-ECRIS, which has an optimum magnetic field strength for 28 GHz microwaves to produce intense highly charged heavy ion beams for the RIKEN RI beam factory project [1]. In the spring of 2009, the RIKEN SC-ECRIS produced its first beam using 18 GHz microwaves.[5] In 2010, 28 GHz microwaves were injected into the new SC-ECRIS and obtained highly charged Xe ion beam. Since then, we have conducted various experiments and modifications to increase the beam intensity. In this paper, we present the modification of the ion source and recent results for highly charged U and Xe ion production.

RIKEN SC-ECRIS

The detailed structure and performance were described in Ref. 5. The RIKEN SC-ECRIS can produce various on axis magnetic field distributions using 6 solenoid coils, which include both the classical B_{min} and the so-called "flat B_{min}"[9]. The liquid He vessel for the ion source is cooled by two refrigerators, (a Gifford-McMahon refrigerator (maximum cooling power of ~1 W) and a Gifford-McMahon + Joule-Thomson refrigerator (maximum cooling power of ~4 W)).

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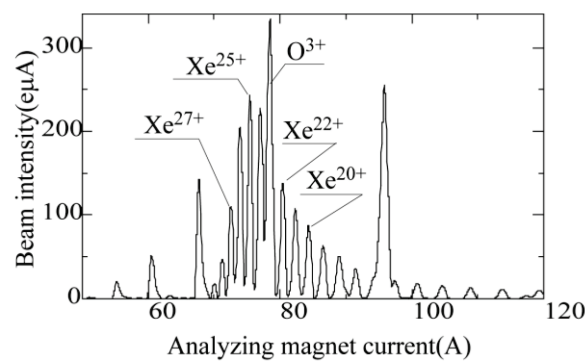

Figure 1: Charge state distribution of highly charged Xe ions at an RF power of 1.7 kW. The ion source was tuned to produce a Xe^{25+} ion beam.

RESULTS AND DISCUSSION

Xe Beam Production

In this test experiment, the maximum strength of the mirror magnetic field at the microwave injection side (B_{inj}), the radial magnetic field strength at the inner surface of plasma chamber (B_r), and the maximum strength of the mirror magnetic field at the beam extraction side (B_{ext}) were fixed to 3.2 T, 1.85 T, and 1.8 T, respectively. The extraction voltage was 22 kV, And the typical gas pressure was ~5 × 10^{-5} Pa. Figure 1 shows the charge distribution of highly charged Xe ions. The ion source was tuned to produce Xe^{25+} ions. Figure 2 shows the beam intensity of Xe^{25+} as a function of RF power.

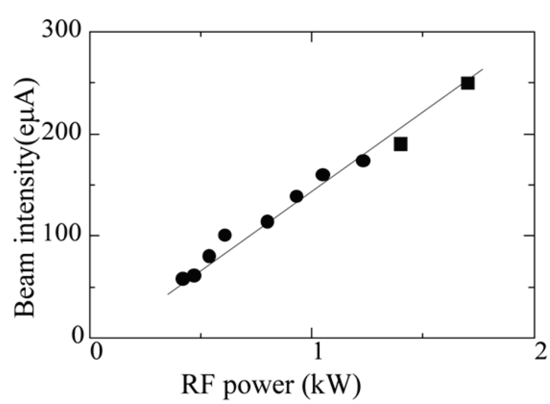

Figure 2: Beam intensity of Xe^{25+} ions as a function of RF power.

The beam intensity increased linearly and we obtained

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250 eμA at an RF power of 1.7 kW. We also measured the emittance and brightness of the Xe ion beam. We observed that the emittance of the Xe^{25+} ion beams were strongly affected by the biased disc voltage. The experimental results are described in Ref.10.

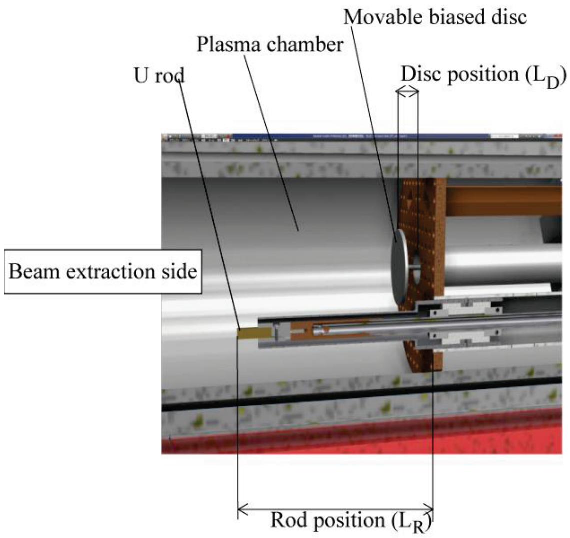

Figure 3: Schematic drawing of the RF injection side for the sputtering method.

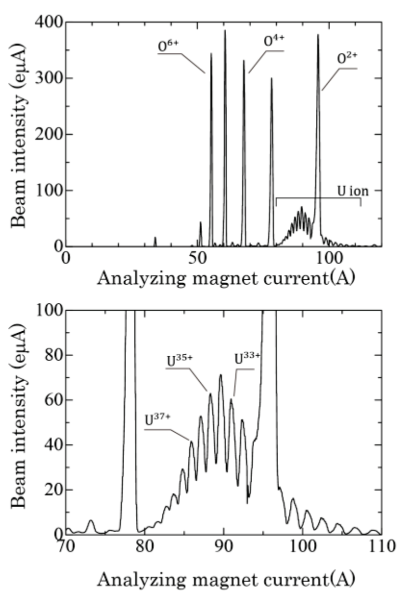

Figure 4: Charge state distribution of U ions. The ion source was tuned to produce a U^{35+} ion beam.

U Beam Production

To produce the U ion beam, we used the sputtering method. The detailed method is described in Ref. 11. Figure 3 shows the schematic drawing. The sputtering voltage and U rod position (L_R) were optimized to maximize the beam intensity of highly charged U ions. The rod position is shown in Fig. 3. The typical sputtering voltage and rod position (L_R) were ~5.5 kV and ~140 mm, respectively. Figure 5 shows a typical charge distribution of the highly charged uranium ions. The RF power was ~2 kW. The ion source was tuned to produce U^{35+} ions. The typical gas pressure was 3-5.5 × 10^{-5} Pa.

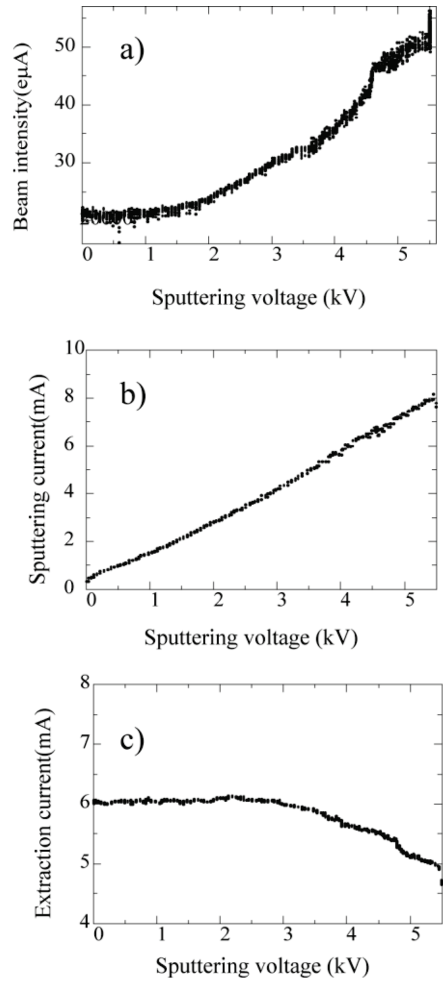

Figure 5: (a) Beam intensity of U^{35+} ions, (b) sputtering current, and (c) extraction current as a function of sputtering voltage.

The beam intensity of the highly charged U ions was strongly dependent on therod position, and sputtering voltage. In order to investigate the effect of these parameters on the beam intensity of U^{35+} ions, we measured the beam intensity as a function of rod position and sputtering voltage. Figure 5-(a) shows the beam intensity of U^{35+} ions as a function of sputtering voltage. The beam intensity increased with increasing voltage up to 5.5 kV. The sputtering current also increased linearly with increasing sputtering voltage as shown in Fig. 5-(b). However, the extraction voltage gradually decreased with increasing voltage as shown in Fig. 5-(c). Figure 6-(a) shows the beam intensity as a function of rod position

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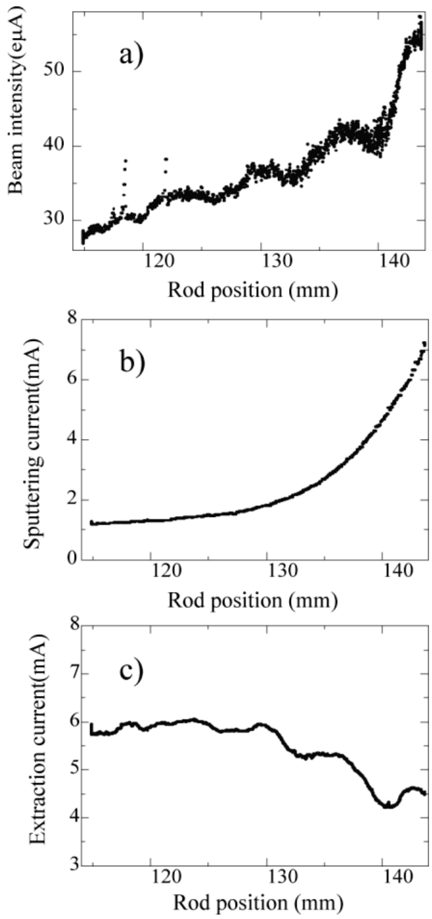

Figure 6: Beam intensity of U^{35+} ions (a), sputtering current(b) and extraction current(c) as a function of rod position.

(L_R). The sputtering voltage was fixed at 5.5 kV. The beam intensity increased with moving the rod toward the ECR zone and oscillated slightly as a function of rod position. Figure 6-(b) shows the sputtering current as function of rod position. The current suddenly increased at the rod position of $L_R \approx 135$ mm. We observed that the extraction current decreased with moving the rod toward the ECR zone.

The beam intensity was also strongly affected by the biased disc position as shown in Fig. 7. The disc position was defined in Fig. 3. The beam intensity of U^{35+} ions is strongly fluctuated by moving the disc. Figure 8 shows the beam intensity as a function of RF power which was calculated from the chamber cooling water temperature. The beam intensity increased linearly with increasing RF power up to 2 kW. We obtained ~60 eμA of U^{35+} and ~80 eμA of U^{33+} at an RF power of 2 kW. The emittance of the U^{35+} ion beam was measured under various conditions. We observed that the emittance of U^{35+} ions was ~100 πmm mrad (4 rms emittance) and independent of the RF power (1–2 kW). Furthermore, we observed that the brightness of the beam increased with increasing disc bias voltage. The detailed experimental results are described in Ref. 10.

Long-term stable beam production is a very important issue for the ion source at RIKEN RIBF. When producing a U^{35+} ion beam for a long time, we observed that the beam intensity fluctuated regularly which is mainly due to changing output power from the gyrotron. We found that the current to power supply for the solenoid coils fluctuated slightly with changing room temperature, and as a result, the output power of the gyrotron changed. To minimize this effect, we replaced the power supply with a more stable one. Using it, we obtained a stable beam with less than 10% fluctuation in long-term operation. The detailed results are described in Ref. 12.

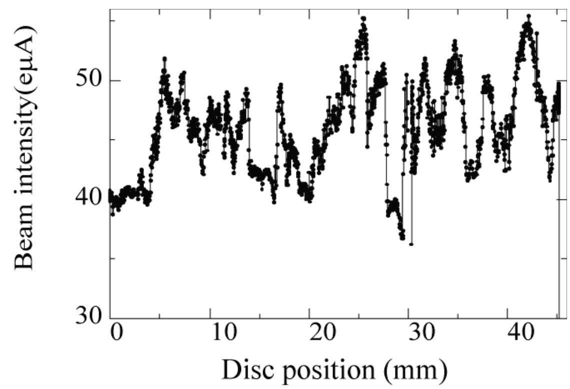

Figure 7: Beam intensity of U^{35+} ions as a function of biased disc position.

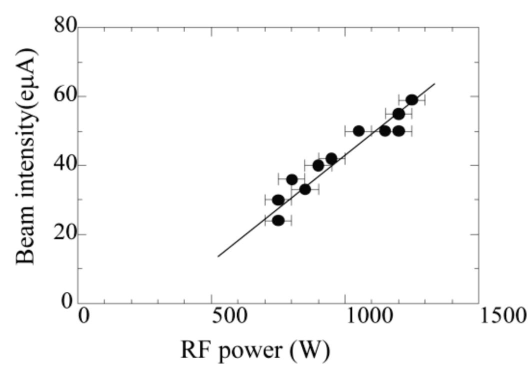

Figure 8: Beam intensity of U^{35+} ions as a function of RF power as calculated from chamber cooling water temperature.

CONCLUSIONS AND FUTURE PLANS

We measured the beam intensity of highly charged U and Xe ions with 28 GHz microwaves under various conditions. The sputtering method was used to produce U ion beams. The beam intensity of U^{35+} ions was strongly dependent on the rod position and sputtering voltage. The beam intensity of U^{35+} ions increased with increasing

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sputtering voltage and proximity of the rod to the ECR zone. The biased disc position strongly affected the beam intensity. Using the sputtering method, we obtained ~60 eμA of U^{35+} and ~80 eμA of U^{33+} at an RF power of 2 kW.

To increase the beam intensity, we will attempt to increase the injected RF power in a future work. Furthermore, we plan to use a high-temperature oven to obtain a higher vapor pressure of U next spring.

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