PRODUCTION OF HIGHLY CHARGED U ION BEAM FROM RIKEN SC-ECRIS

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Abstract

In 2008, we produced 345 MeV/u beam (~0.4pnA on target) for RIKEN RIBF. To increase the U beam intensity, we produced U^{35+} from RIKEN SC-ECRIS with sputtering method. To maximize the beam intensity, we made various test experiments. We obtained 2~0.7 pμA of highly charged U ion (27~35+) at the RF power of ~1.2kW.

INTRODUCTION

In 2008, we produced 345 MeV/u U beam (0.4 pnA on target) and observed more than 40 new isotopes with in-flight fission reaction for only 4 days experiments [1]. This experiment shows that the intense U beam is strong tool to produce very neutron rich nuclei and to study the r-process in nuclear synthesis. Using 18 GHz RIKEN ECRIS, we only produced 2~4 eμA of U^{35+} beam, which was much lower than the required beam intensity for RIKEN RIBF. For this reason, to meet the requirement, we constructed new SC-ECRIS which has the optimum magnetic field strength for 28GHz.[2] In the autumn of 2009, we obtained first beam of U^{35+} from RIKEN-SC-ECRIS with 18 GHz microwave. Since then, we tried to increase the beam intensity of highly charged U ion beam.

In this article, we report the results of the test experiment for production of highly charged U ion beam.

SC-ECRIS

The detailed structure of the SC-ECRIS and the test experiment was described in refs. 2, 3. For operation of 28 GHz microwaves, the B_{inj}, B_{ext} and B_r are 3.8, 2.2 and 2.2 T, respectively. The main feature of this ion source is that it has six solenoid coils to produce mirror magnetic field at the axial direction. Using this configuration, one can change the magnetic field gradient at ECR zone and ECR zone size independently. To keep the superconductivity, the cryostat is equipped with three small GM refrigerators. The amount of liquid He is about 500 L. The cooling power at 4 K is about 1 W. It was reported that the higher microwave frequency gives stronger heat load. [4] To keep the superconductivity against the heat load, we need stronger cooling power for cryostat. For this reason, we installed GM-JT refrigerator (cooling power of 5 W at 4 K) to increase the cooling power in the end of 2009.

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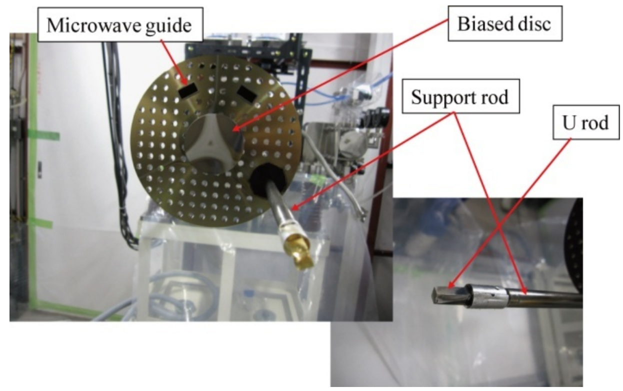

Figure 1: Photograph of the RF injection side and U rod.

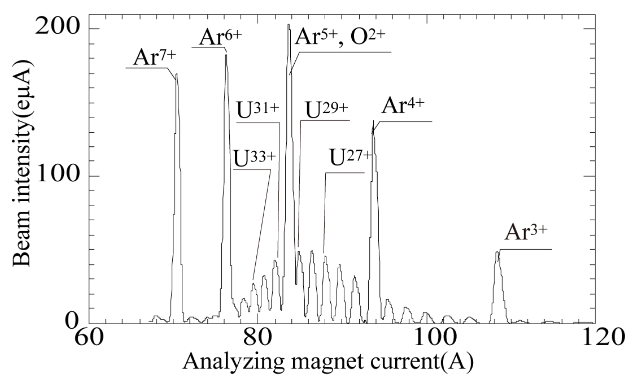

Figure 2: Charge state distribution of the U ion, when using the O2+Ar gas as an ionized gas.

U BEAM PRODUCTION

Fig. 1 shows the photograph of the RF injection side. To produce U ion beam, we used the sputtering method. As shown in Fig. 1, the metal uranium was installed at off-center axis. The metal U was supported by supporting rod. The position of rod was remotely controlled within the error of ~0.2mm. The support rod was water cooled for minimizing the chemical reaction between metal uranium and material of uranium holder at high temperature. The rod position and high voltage for sputtering were optimized for maximizing the beam intensity of highly charged U ions.

For investigating the support gas effect, we used the O_2 , Ar and Ar+O_2 gas as an ionized gas. Fig. 2 shows the charge distribution of the highly charged U ion with using O_2+Ar gas. The RF power was 980 W. The extraction voltage was 17 kV.

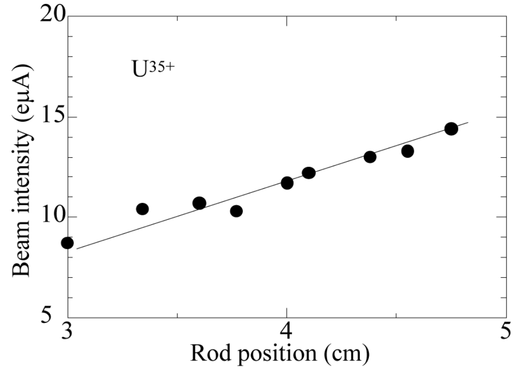

Figure 3: Beam intensity of U^{35+} as a function of rod position.

Beam intensity of U^{35+} as a function of rod position and high voltage are shown in fig.3 and 4, respectively. The RF power was ~900 W. The extraction voltage was 15 kV. B_{inj}, B_{min}, B_{ext} and B_r were 2.3 T, 0.46 T, 1.1 T , 1.3 T respectively. The beam intensity was increased linearly with increasing high voltage for sputtering. The beam intensity is very sensitive to the rod position as shown in Fig.3. The beam intensity increased linearly when moving the rod toward the ECR zone.

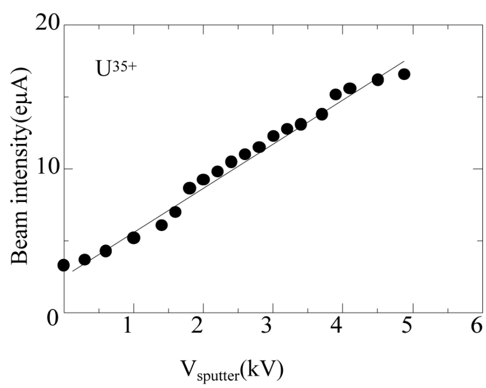

Figure 4: Beam intensity of U^{35+} ion as a function of sputtering voltage.

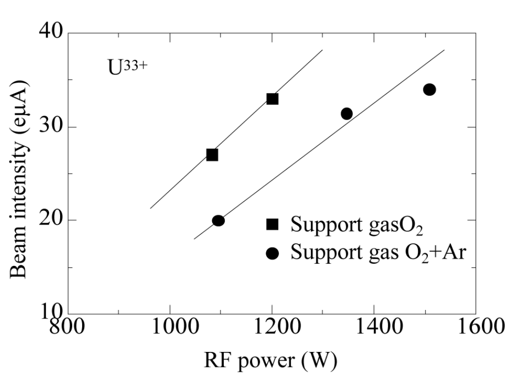

Figure 5: Beam intensity of U^{33+} as a function of RF power, when using O_2(closed squares) and O_2+Ar (closed circles)gases as an ionized gas

Fig. 5 shows the beam intensity of U^{33+} as a function of RF power in case of O_2+Ar gas. The beam intensity for O_2 gas was always higher than those for O_2+Ar at the same RF power. However, for lower charge state of heavy ions(<31+), the beam intensity for O_2+Ar gas was higher. Fig. 6 shows the beam intensity of U^{33+} and U^{35+} as a function of RF power in case of O_2 gas. In Fig. 7, the beam intensity for lower charge state of U ions (31+,33+) are shown. We obtained ~50 eμA of U^{31+} at the RF power of 1.2 kW.

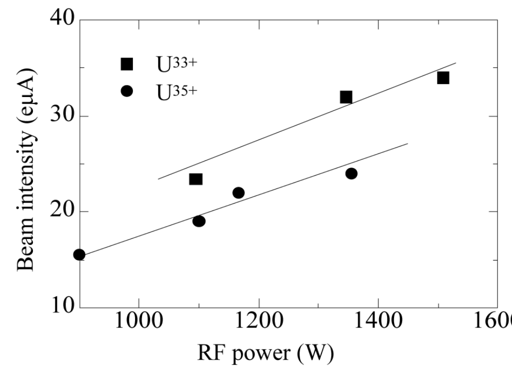

Figure 6: Beam intensity of $U^{33+}$and U^{35+} as a function of RF power, when using O_2 gas.

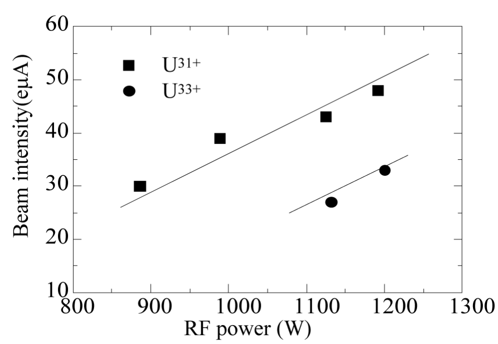

Figure 7: Beam intensity of U^{31+} and U^{33+} as a function of RF power, when using O_2+Ar gas.

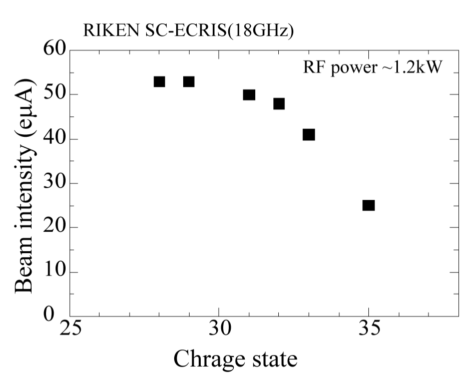

Figure 8: Beam intensity of highly charged u ion at the RF power of ~1.2 kW.

Fig. 8 shows the beam intensity of highly charged U ions at the RF power of ~1.2 kW. It is noted that the beam intensities were not saturated in this test experiment as shown in Figs.3~7. Because the power density of RF power in this experiment was very low (~100 W/L). We may obtain higher beam intensity at the higher sputtering voltage and RF power.

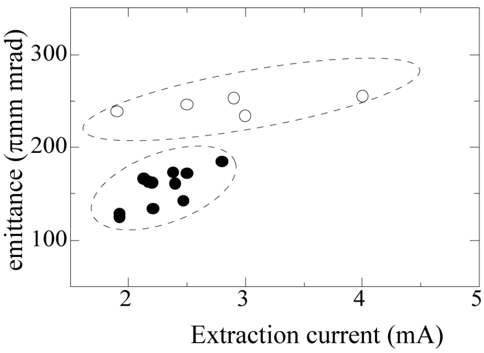

Figure 9: Y emittance (4 rms), when using O_2 gas(closed circles) and O_2+Ar gas (open circles).

Fig. 9 shows the 4 rms emittance as a function of extracted current, when using O_2 gas (open circles) and O_2+Ar gas (closed circles). The values of the 4 rms emittance are calculated with:

$$\varepsilon_{rms} = 4\sqrt{<x^2><x'^2> - <xx'>^2}$$

The emittance was increased with increasing the extracted current. Furthermore, it seems that the emittance for O2+Ar gas was smaller than that for O2 gas at the same extraction current. To understand it, we may need more systematic study.

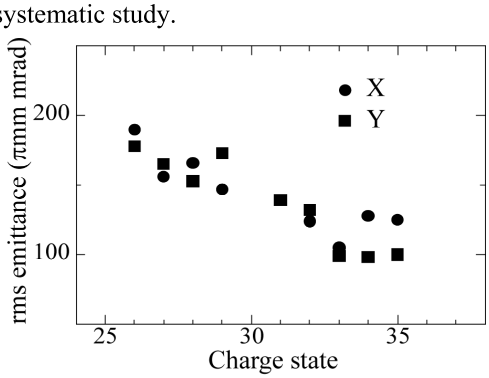

Fig.10: Rms emittance for highly charged U ion.

Fig. 10 shows the X and Y emittance (4 rms) for highly charged U(26~35+) ions. The emittance decreased with increasing the charge state at same extraction voltage. In this experiment, we obtained the 4 rms emittance of ~ 120 πmm mrad for U^{35+}. This is smaller than the acceptance of the accelerator of the RIKEN RIBF (~160 πmm mrad). It means that we can accelerate almost of the U^{35+} beam (~20 eμA) produced form RRIKEN SC-ECRIS at present. This intensity is ~10 times as high as the intensity from RIKEN 18 GHz ECRIS. From these results, we may obtain ~4 pnA of U ion beam at the energy of 345 MeV/u on target for production of RI beam.

CONCLUSIONS AND FUTURE PLAN

We obtained 0.7~2 pμA of highly charged U ion beams (35~27+) from RIKEN SC-ECRIS with sputtering method. For higher RF power and sputtering voltage, we may obtain higher beam intensity, because the beam intensity was not saturated in the test experiment. We observed that the emittance for O_2+Ar gas was smaller than those for O_2 gas. To confirm it, we need further investigation.

From this autumn, we will use the 28 GHz gyrotron to increase the beam intensity of U^{35+}. To produce U vapour, we will make a test experiment with high temperature oven.

REFERENCES

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