EMITTANCE MEASUREMENT FOR U ION BEAMS PRODUCED FROM RIKEN 28 GHZ SC-ECRIS

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Abstract

In order to investigate the ion optical parameters of the beam line of a new injector system for RIKEN RIBF, we measured the emittance of heavy ion beams from the RIKEN 28 GHz SC-ECR ion source. In the test experiments, we observed that the emittance of the U^{35+} beam was ~100π mm-mrad (4 rms emittance). The emittance with 28 GHz was almost the same as that with 18 GHz and independent of the injected RF power. The size of the emittance increased with the decreasing charge state. We also observed that the brightness of the U^{35+} ion beam increased with the increase in the negative bias voltage of the disc installed in the plasma chamber.

INTRODUCTION

At RIKEN, we commenced the construction of the new superconducting electron cyclotron resonance ion source (SC-ECRIS), which has the optimum magnetic field strength for the operational microwave frequency of 28 GHz to produce an intense beam of highly charged heavy ions for RIKEN RI beam factory project [1]. In the spring of 2009, RIKEN SC-ECRIS produced the first beam with 18 GHz microwaves [2]. Since then, we have conducted various test experiments with the aim of increasing the beam intensity of highly charged heavy ions [2]. In 2010, we started the injection of 28 GHz microwaves into the ion source and produced intense Xe and U ion beams [3]. For the external ion source of the heavy ion accelerator, it is important to not only increase the beam intensity but also improve the beam quality (emittance, brightness, etc.). Accordingly, several laboratories have systematically studied the effect of the main parameters (magnetic field distribution, gas pressure, RF power, etc.) of the ECRIS on the emittance. A simple method to increase the beam intensity is the "biased disc" method [4]. We employed this method and successfully increased the beam intensity of highly charged heavy ions [2]. Although it is natural to assume that a negatively biased disc would affect the beam quality, few experiments have so far been conducted for understanding the effect of a biased disc on beam quality. Hence, we started studying the effect of the biased disc.

In this paper, we report the experimental results of emittance measurements for the U ion beam produced from the RIKEN 28 GHz SC-ECRIS. The effect of a biased disc on the emittance is also described.

RIKEN 28 GHZ SC-ECRIS

The detailed structure and performance of the RIKEN SC-ECRIS with 28 GHz microwaves have been described in Refs. [2, 3]. Using six solenoid coils, RIKEN SC-ECRIS can produce various magnetic field distributions on the axis, which are both of the classical B_{min} and the so-called "flat B_{min}" [5]. The microwaves were generated by the 28 GHz gyrotron (Max. power of 10 kW) and injected into the RIKEN 28 GHz SC-ECRIS.

EXPERIMENTAL RESULTS AND DISCUSSION

In this experiment, the maximum mirror magnetic field strength at the RF injection side (B_{inj}), minimum strength of mirror magnetic field (B_{min}), the maximum mirror magnetic field strength at the beam extraction side (B_{ext}), and radial magnetic field strength at the inner wall of the plasma chamber (B_r) were fixed to 3.3, 0.6, 1.8, and 1.8 T, respectively, with 28 GHz microwaves. The extraction voltage was 22 kV. To produce a U ion beam, we used the sputtering method. Figure 1 shows the schematic illustration of the RF injection side of the plasma chamber. The sputtering voltage and the position of the U rod (L) were optimized to maximize the beam intensity of highly charged U ions. The typical sputtering voltage and L were 5 kV and ~140 mm, respectively. Figure 2 shows the typical charge distribution of the highly charged U ions. The RF power was ~1 kW.

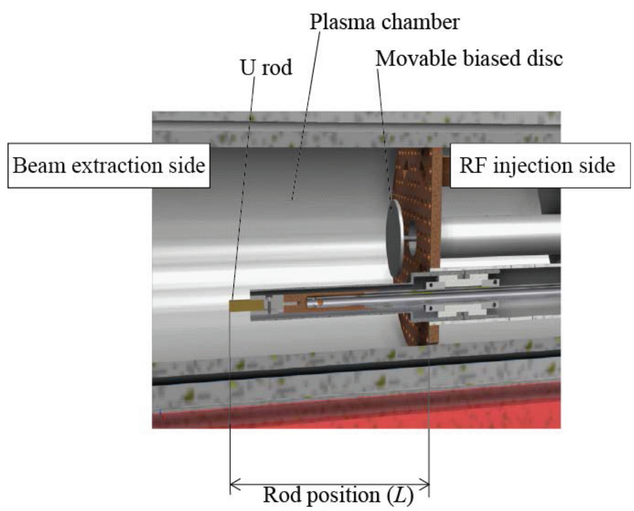

Figure 1: Schematic illustration of the RF injection side of the plasma chamber.

The root-mean-square (rms) emittance is defined as

$$\varepsilon_{x-rms} = \sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2}$$
$$\varepsilon_{y-rms} = \sqrt{\langle y^2\rangle\langle y'^2\rangle - \langle yy'\rangle^2}.$$

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In these formulae, the averages of the phase-space coordinates of the position (x, y) and the divergence (x', y') were weighted by the beam intensity [6].

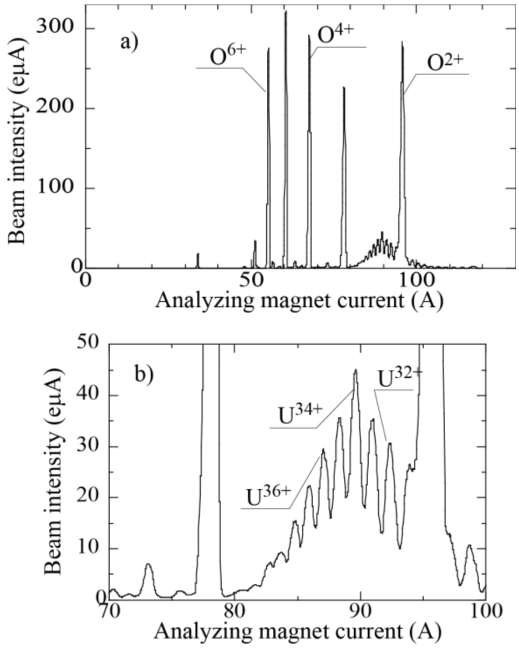

Figure 2: Charge state distributions for O and U ion beams.

Figure 3 shows the normalized *x*-emittance (rms) for U and O ions as a function of M/q, where M and q are, respectively, the mass and charge state of heavy ions. The emittances for these ions were measured at the same plasma and beam extraction conditions. The RF power was 1 kW. The gas pressure was ~4×10^{-7} Torr. The emittance for U ions gradually increased with the increase in M/q; on the other hand, the emittance for O ions is constant or even decreased. Furthermore, the emittance for O ions is significantly larger than that for U ions, which agrees with the results obtained at other laboratories [7]. According to the simple model calculation [8], the emittance is inversely proportional to M/q. In order to understand the difference between the model calculation and experimental results, further investigation is required.

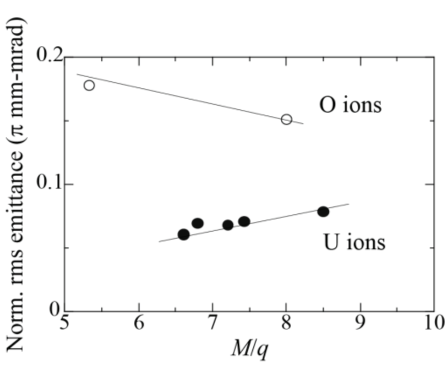

Figure 3: Normalized rms *x*-emittance for O and U ion beams.

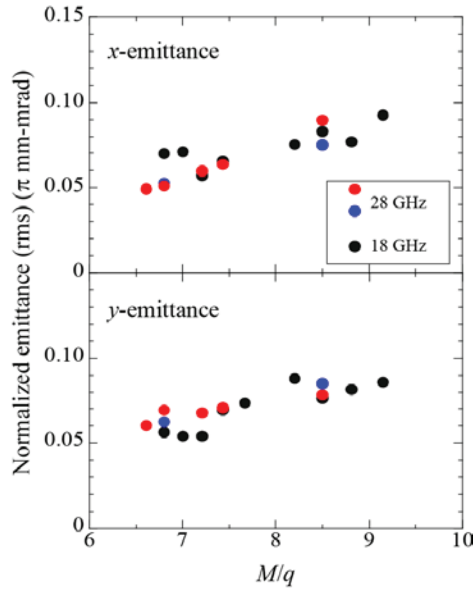

Figure 4: 4 rms emittance for highly charged U ion beams for 28 and 18 GHz microwaves (red and blue circles indicate the value obtained for 28 GHz microwaves for different measurement runs).

According to Ref. [8], the emittance becomes larger with the increase in B_{ext}. Practically, we use a high B_{ext} for a high microwave frequency to produce an intense beam of highly charged heavy ions. In this experiment, we set B_{ext} ~1.8 T for 28 GHz microwaves and ~1.2 T for 18 GHz microwaves. This implies that the emittance for 28 GHz may be 1.5 times larger than that for 18 GHz. For investigating this effect on the emittance of highly charged U ions, we measured the emittance for 28 and 18GHz microwaves. B_{inj}, B_{min}, B_{ext}, and B_r were fixed to 2.3, 0.5, 1.2, and 1.3 T, respectively, for 18 GHz microwaves. Figure 4 shows the emittance of U ion beams with 18 and 28 GHz microwaves as a function of the charge state of U ions. The emittances in the case of 28 GHz microwaves were almost the same as those in the case of 18 GHz microwaves. Increasing the beam brightness is advantageous, because, a high microwave frequency generally results in high intensity of the highly charged heavy ions. Figure 5 shows the emittance of U ions as a function of RF power. From this figure, it appears that the emittance is almost constant.

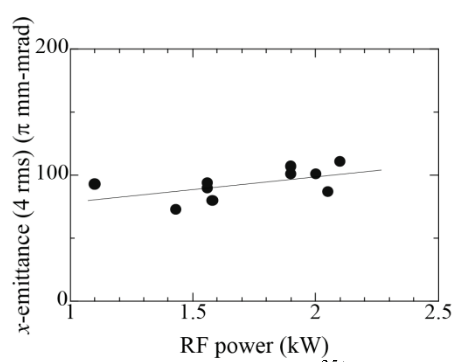

Figure 5: 4 rms *x*-emittance for U^{35+} ion beams as a function of RF power.

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Figure 6a) shows the beam intensity as a function of biased disc voltage. Two cases of the biased disc position are shown. The beam intensity increased with the increase in the negative disc voltage. Figure 6b) shows the brightness of the Xe^{19+} beam as a function of disc voltage. We observed that the brightness was almost constant and independent of the disc voltage. For example, the 4 rms *y*-emittance (non-normalized) changed from 140 to ~170π mm-mrad with the increase in the negative bias voltage from 0 to –500 V. We also measured the beam intensity of U^{35+} as a function of disc voltage. The beam intensity increased from 20 to 35 eμA with the increase in the negative bias voltage from 0 to –300 V (see Fig. 7a)). We observed the same tendency for the beam intensity as that for Xe^{19+} ions. However, the brightness of the U^{35+} beam increased with the increase in the negative voltage, as shown in Fig. 7b). The 4 rms *y*-emittance decreased from ~150 to ~100π mm-mrad with the increase in the negative bias voltage from 0 to –300 V. Although the mechanism of this phenomenon is unclear so far, practically, it is advantageous to increase the brightness of the beam. We require further investigation to understand the phenomenon.

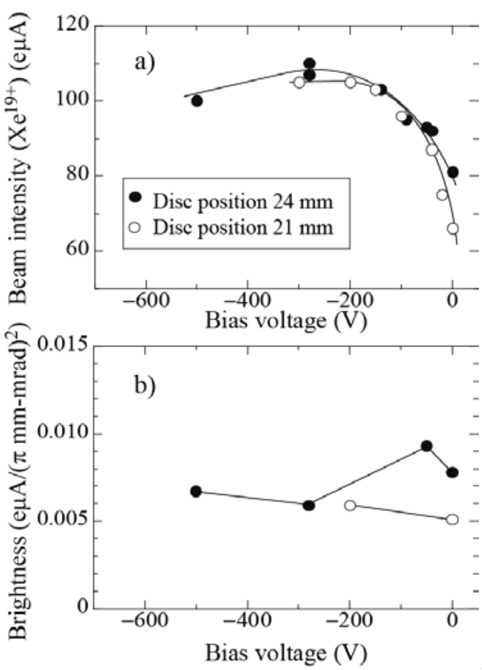

Figure 6: a) Beam intensity and b) brightness of Xe^{19+} ion beams as a function of disc voltage.

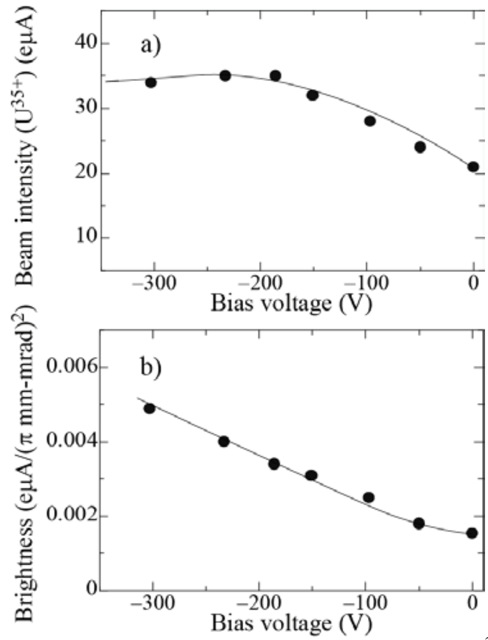

Figure 7: a) Beam intensity and b) brightness of U^{35+} ion beam as a function of disc voltage.

CONCLUSIONS

We measured the emittance of the RIKEN 28 GHz SC-ECRIS. The emittance of a highly charged U ion beam was smaller than that for an O ion beam at the same *M*/*q*. The emittance of the highly charged U ions for 28 GHz microwaves was almost the same as that for the 18 GHz microwaves and was independent of the RF power. We observed that the brightness for U^{35+} ion beam increased with the increase in the negative bias disc voltage.

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