Recent development of RIKEN 28-GHz superconducting electron cyclotron resonance ion source[†]

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Over the past several years, we have endeavored to improve the performance of the RIKEN superconducting electron cyclotron resonance ion source using several methods.[1,2] For the production of U vapor, we employed the sputtering method, although the beam intensity in this method is assumed to be weaker than that in the oven technique. We also used an aluminum (Al) chamber instead of a stainless steel (SS) one. It is possible to observe the so-called "wall-coating effect."[3] Using these methods, we successfully produced ~180 eμA of U^{35+} and ~230 eμA of U^{33+} at the injected radio frequency (RF) power of ~4 kW (28 GHz). Very recently, with the aim of further increasing the beam intensity of U^{35+}, we have the development of high-temperature oven and have successfully produced a highly charged U ion beam.

In this paper, we present a detailed report on the effect of the Al chamber on the beam intensity of highly charged U ion beams. We also report the effects of the two-frequency injection method on the U ion beam intensity.

For this experiment, the maximum mirror magnetic field strength at the RF injection side (B_{inj}), minimum strength of the mirror magnetic field (B_{min})[4], maximum mirror magnetic field strength at the beam extraction side (B_{ext}), and minimum magnetic field strength at the surface of the plasma chamber (B_r) were fixed at 3.2, 0.65, 1.8, and 1.85 T, respectively. The microwave frequency generated by the gyrotron was 28 GHz. The diameters and lengths of both plasma chambers (Al and SS) were 150 and 575 mm, respectively. The typical sputtering voltage was approximately −5.5 kV. We used oxygen as the ionized gas. The gas pressure was (4–5) × 10^{-5} Pa. The extraction voltage was fixed at 22 kV in these experiments. Figure 1 shows the charge state distributions of the highly charged U ion beams. The open and closed circles denoted the results in the cases where SS and Al chambers, respectively were used. The injected RF power was 2 kW for both cases. The ion source was tuned to produce U^{35+}. As shown in Fig. 1, the intensity of the highly charged U ion beam produced with the Al chamber was higher than that produced with the SS chamber. For example, the intensity of the U^{35+} beam produced with the Al chamber was 110 eμA, which was almost twice the value (60 eμA) obtained with the SS chamber.

Ever since enhancement of the beam intensity of the highly charged heavy ions was achieved by injecting power at two frequencies simultaneously,[5] this mechanism has been investigated and used at several laboratories to increase the beam intensity. At RIKEN too, we employed this method to increase the beam intensity. Figure 2 shows the beam intensity of U^{35+} as a function of B_{min}. The opencircles represent the beam intensity of the U ions under a single frequency operation (28 GHz [1.5 kW]). At the lower B_{min}, we added an RF power of 500 W (18 GHz). The closed circles denote the results obtained with 28 GHz (1.5 kW) + 18 GHz (500 W). The beam intensity at a B_{min} of 0.57 T (18 + 28 GHz) was slightly higher than that at a B_{min} of 0.66 T (28 GHz). On comparing results with those at B_{min} of 0.66 T with a 2 kW injection (28 GHz), we did not find any beam enhancement in this experiment. However, as shown in Fig. 2, the X-ray heat load with a B_{min} of 0.57 T is lower than that with a B_{min} of 0.66 T; this is mainly due to the magnetic field gradient effect. As we obtained nearly the same beam intensity with a lower X-ray heat load, this result indicates that the two-frequency injection could be advantageous for our SC-ECRIS.

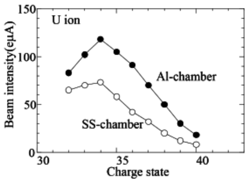

Fig. 1. Charge state distribution of the U ions with the Al chamber (closed circles) and SS chamber (open circles).

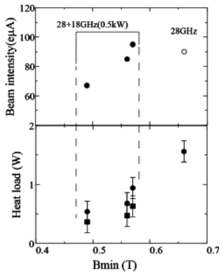

Fig. 2. Beam intensity of U^{35+} with two frequencies (18 + 28 GHz) for several B_{min} values and with a single frequency (28 GHz) for B_{min} = 0.66 T (upper panel). X-ray heat load in the cryostat with two frequencies (18 + 28 GHz) (closed circles) and a single frequency (28 GHz) (closed squares) for several B_{min} values (lower panel).

References
1) Y. Higurashi, et al.:Rev. Sci.Instrum. 83, 02A308 (2012).
2) T. Nakagawa et al.: Rev. Sci. Instrum. 81, 02A320 (2010).
3) T. Nakagawa: Jpn. J. Appl. Phys. 30, L930 (1991).
4) G. D. Alton and D. N. Smithe, Rev. Sci. Instrum. 65 (1994) 775
5) Z. Q. Xie and C. Lyneis: in Proceedings of the 12th International Workshop on ECRIS, Wako, INS-J-182 (University of Tokyo, 1995), p. 24.

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