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Production of vanadium-ion beam from RIKEN 28 GHz SC-ECRIS

Y. Higurashi,[*1] J. Ohnishi,[*1] and T. Nakagawa[*1]

Following the last super-heavy element (SHE) (Z = 113) search experiment[1)] in 2012, an experiment to search for new SHEs (Z = 119 and 120) was planned for which intense beams of vanadium (V) and chromium (Cr) ions were strongly required. Therefore, we started test experiments to produce a V-ion beam from RIKEN 28 GHz SC-ECRIS.[2)] The main feature of the ion source is that it has six solenoid coils for producing a mirror magnetic field. By using this ion source, we can produce magnetic-field distributions of various shapes from classical B_{min} to flat B_{min}.[3)]

To produce V vapor, we used a high temperature oven[4)] of the same type as that used for the production of uranium (U) vapor. The metal V was installed in the crucible of the high-temperature oven and heated by resistance heating up to ~1900°C. This temperature to obtain sufficient vapor. To avoid the chemical reaction between the metal V and W crucible at the high temperature, we used a ceramic crucible (Y_2O_3) as the W crucible as shown in Fig. 1.

Figure 2 shows the charge state distribution of the highly charged V-ion beam. To produce plasma, we used oxygen gas as an ionized gas. B_{inj}, B_{min}, Br, and B_{ext} were 2.3, 0.5, 1.4, and 1.5 T, respectively. The extraction voltage was 12.6 kV, which is the required extraction voltage to obtain a V-ion beam of 6.0 MeV/nucleon with the RIKEN ring cyclotron for the experiment. The injected microwave power and gas pressure were ~1.0 kW and ~7.1×10^{-5} Pa, respectively. We used the two-frequency (18 and 28 GHz) plasma heating method[5)] to stabilize the beam intensity. The electric power of the high-temperature oven was ~720 W. Under this condition, we produced V^{13+} of ~100 eμA. In our recent experiment, we observed that the emittance of the ion beam was strongly affected by the aberration of the analyzing magnet. To minimize this effect, we need to provide a focused ion beam. For this reason, to minimize the emittance, we optimized the beam size in the analyzing magnet with a focusing solenoid coil installed after the ion source, and we obtained beam parameter products of 200 mm mrad (four rms x-emittance) and 188 mm mrad (four rms y-emittance) after the analyzing magnet.

In December 2017, a stable V^{13+} beam of ~85 eμA was successfully produced for 15 days without break for the experiment. The average consumption rate of the material was ~1.9 mg/h. Using the present crucible of the high-temperature oven, metal V of ~1.6 gr can be installed. Therefore, it is estimated that one can produce an intense beam (V^{13+} of ~85 eμA) for longer than one month without break under the present condition.

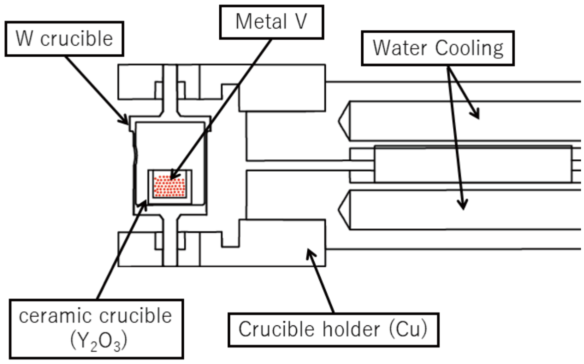

Fig. 1. Schematic of the high-temperature oven.

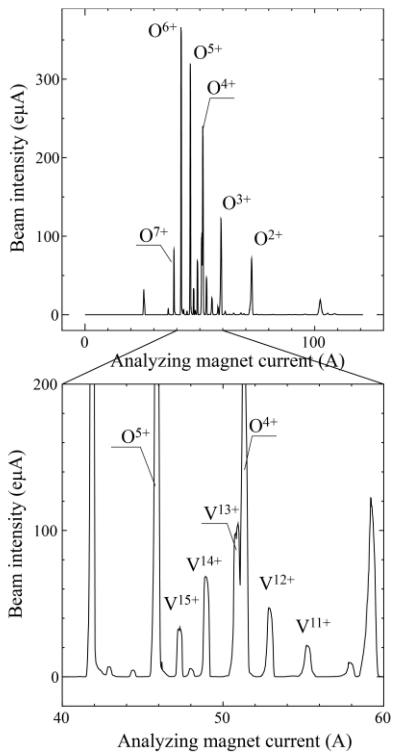

Fig. 2. Charge-state distribution of the highly charged V ion beam.

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*1 RIKEN Nishina Center