Production of U beam from RIKEN 18GHz ECR Ion Source

Yoshihide Higurashi[1,A)], Takahide Nakagawa[A)], Masanori Kidera[A)]
Mistuhiro Haba[A)], Toshimistu Aihara[B)]
Masayuki Kase[A)], Akira Goto[A)]and Yasushige Yano[A)]

[A)] RIKEN Nishina Center
2-1 Hirosawa, Wako, Saitama, 351-0198
[B)]SHI Accelerator Servie Ltd.
1-17-6 Osaki, Shiganagawa-ku, Tokyo, 141-0032

Abstract

For RIKEN radio isotope factory (RIBF) project, we produced the multi-charged uranium beam with two methods. For producing lower charge state U ions beams (14+~20+) we used the UF_6 gas as an ionized gas. Typical beam intensity of U14+~20+ was 2~1 pμA at the extraction voltage of 14kV. For production of higher charge state U ion beam (U^{35+}), we chose the sputtering method. The beam intensity was 70pnA at the extraction voltage of 5.4kV. Using this method, we successfully produced multi-charged U beam continuously for one month without break for RIBF commissioning.

理研ECRイオン源での多価ウランイオンの生成

1. Introduction.

For RIKEN radio isotope beam factory (RIBF) project, intense beam of U ions is strongly demanded.[1] It is mainly due to the high production rate of radio isotope beam by in-flight fission reactions compared to the projectile like fragmentation with heavy ions. For this reason, we intensively studied how to produce the multi-charged U ion beams from RIKEN 18 GHz electron cyclotron resonance (ECR) ion source.

For acceleration, we have two choices.

1) We produce U10+~20+ ion beam from ECRIS and accelerate it by RIKEN heavy ion linear accelerator and change the charge state of U ions from 14+ to 35+ by thin carbon foil charge stripper and then inject the beam into RIKEN ring cyclotron.

2) We produce U^{35+} beam from ECRIS directly and accelerate it by accelerator complex.

For these requirements, we chose two methods (use of UF_6 gas and sputtering the metal U) to produce multi-charged U ion beam.

In this paper, we report the results of the test experiment for production of U beam with these two methods.

2. UF_6

When using UF_6, it does not require an oven nor an insertion system for solid rods to be vaporized under plasma sputtering. Because the UF_6 has a high vapor pressure (~60 Torr) at the room temperature. For this reason, it is possible to produce U ions in the same manner as in the case of gaseous elements. Figure 1 show a cross-sectional view of the RIKEN 18GHz ECRIS and a schematic drawing of a UF6 bottle. Details of the description of the RIKEN 18GHz ECRIS and its performance are described in ref. 2. The UF_6 bottle (50 cm^3 in volume) was connected to a gas-feeding tube via a variable slow-leak valve to control the flow rate of UF_6 vapor. About 10 g of UF_6 was filled in the UF_6 bottle. The gas pressure of UF_6 in the bottle was measured by

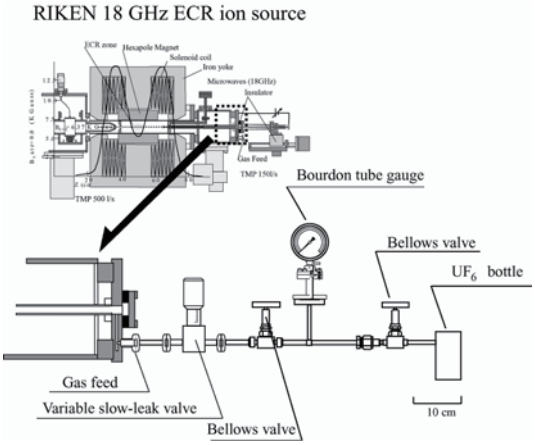

Fig.1. Cross-sectional view of RIKEN 18 GHz ECRIS and schematic drawing of UF_6 bottle.

[1] E-mail: higurasi@riken.jp

the diaphragm sealed Bourdon tube gauge. The gas flow rate was controlled by the slow leak valve. To avoid the erosion of the gas feeder with UF_6, all of the parts were made of stainless steel and metal seals were used for avoiding the leakage. To minimize the contamination, the plasma chamber wall was covered with a thin aluminum tube (of 1 mm thickness), which is easily replaceable. Furthermore, the aluminum surface emits several secondary electrons per primary electron impact, which increases the plasma density.[3]

We also used the Fomblin oil to minimize the chemical reaction of UF_6 with the oil of rotary pump. To prevent UF6 from escaping into the atmosphere, the exhaust gas from the rotary pump of the ion source flowed into the chemical trap.

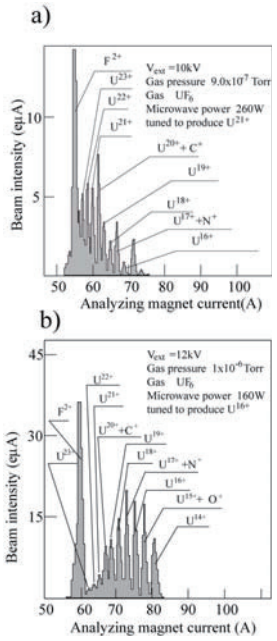

Fig.2. Charge state distributions of U ions. The ion source was tuned to produce U^{21+} ions (a) and U^{16+} ions (b).

Figure 2 a) and b) show charge state distributions of the uranium ions. The ion source was tuned to produce U21+ ions (a) and U^{16+} ions (b). When producing U^{21+} ions, the gas pressure and microwave power were $9x10^{-7}$ Torr and 260 W, respectively. To produce U^{16+} ions, we set the gas pressure of $1x10^{-6}$ Torr and microwave power of 160 W. In this experiment, we did not use the support gas. Typical magnetic field strength of the microwave injection side (B_{inj}), the beam extraction side (B_{ext}) and the minimum field of mirror magnetic field (B_{min}) were 1.4, 1.4 and 0.53 T, respectively. It is clearly seen that we need higher microwave power and lower gas pressure to produced higher charge state uranium ions.

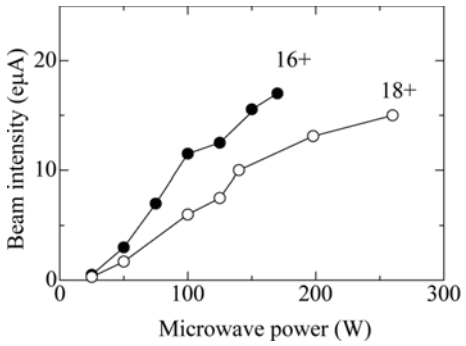

Fig.3. Beam intensity of $U^{16+,18+}$ ions as a function of microwave power

Figure 3 shows the beam intensity of $U^{16+,18+}$ ions as a function of microwave power. We just changed the microwave power without changing any other parameters (gas pressure, magnetic field configuration, extraction voltage etc). The gas pressure and the extraction voltage were $1.0x10^{-6}$ Torr and 12 kV, respectively. The beam intensity was increased with increasing the microwave power. The beam intensity of U^{16+} ions was almost saturated at the microwave power of ~200 W.

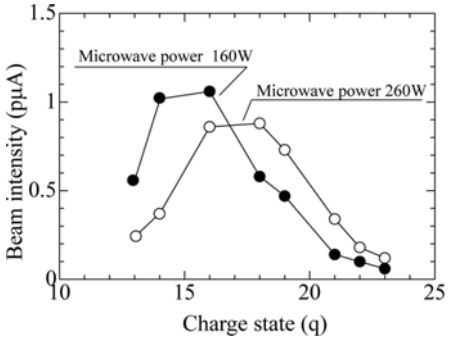

Fig.4. Charge distribution of uranium ions at the microwave power of 160 and 260 W.

Figure 4 shows the charge distribution of uranium ions at the microwave power of 160 and 260 W. The extraction voltage was 10 kV. The gas pressure was $1x10^{-6}$ Torr. The B_{inj}, B_{ext} and B_{min} were 1.4, 1.25 and 0.5 T, respectively. The average charge state was shifted to higher side with increasing the microwave power. The total measured beam intensities were 3.6 and 3.7 pμA at microwave power of 160 and 260 W, respectively. It means that the number of produced ions was almost constant, which was same tendency as the MIVOC method described in ref. [4].

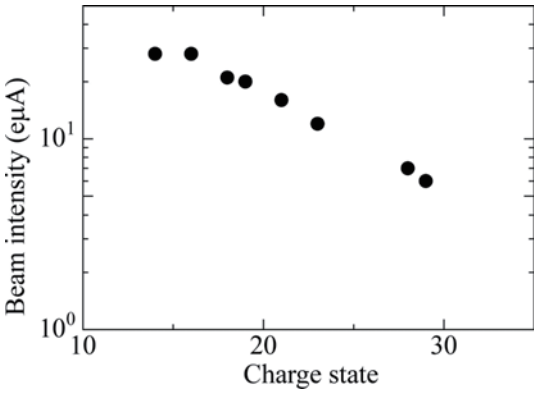

Fig.5. Summary of the beam intensity of U ions

Figure 5 shows the summary of the beam intensity of uranium ions. The extraction voltage was 14 kV. The gas pressure, microwave power and magnetic field configuration were optimized to maximize the beam intensity. To produce 30eμA of U^{16+} ion beam at the extraction voltage of 14 kV, the gas pressure and RF power were $1x10^{-6}$ Torr and 250 W, respectively. The gas pressure and microwave power were $9x10^{-7}$ Torr and 500 W to obtain 12eμA of U^{23+} ion beam. Furthermore, we have to add oxygen gas to maximize the beam intensity of U^{23+} ions. The B_{inj}, B_{ext} and B_{min} were 1.4, 1.4 and 0.53 T, respectively, which is maximum magnetic field strength of RIKEN 18 GHz ECR ion source.

In order to obtain 350MeV/u uranium beam from the accelerator complex of RIKEN RIB factory project, the extraction voltage of the ion source for U^{14+} ion beam has to be set at 14 kV to match the acceleration condition. In this condition (extraction voltage of 14 kV from the ion source), the beam intensity of U^{14+} was 30eμA (2pμA) which was two times as high as required beam intensity. Using this method, 2pμA of U^{14+} beam was successfully to the accelerator and accelerated by the accelerator complex

Using this method, we successfully produced an intense beam of U^{14+} ions (~1.5 pμA) continuously for one week for RIBF commissioning.

3. Sputtering method

A U^{35+} ion beam is required from an ion source, unless we use the first charge stripper which is placed at downstream of the RIKEN heavy ion linear accelerator. To produce U^{35+} ions, we used the sputtering method. The size of the rod was 6 x 3 x 25 mm. The rod was placed near the wall of RF injection side as shown in fig. The position of rod tip was L~3cm. The position L is defined in Fig. 6 . To check the effect of ionized gas (base gas for production of plasma) on beam stability and intensity, we chose N_2, O_2, and Ne gases as ionized gases.

In this experiment, the beam intensity of U ions using O_2 gas is more stable than that using N_2, or Ne gas. However, the beam intensity of U ions produced using Ne gas is higher than that using N_2 or O_2 gas, because the sputtering effect of Ne ions is much better than that of N or O ions. Figure 7 shows the charge state distribution of U ions. The ion source was tuned for the production of U^{35+} ions. The ionized gas was O2, the injected microwave power was 500 W, the sputtering voltage was 1.5 kV, the gas pressure was 1.0 x 10-6 Torr, and the extraction voltage was 5.6 kV. In order to obtain 350MeV/u uranium beam from the accelerator complex of RIKEN RIB factory project, the extraction voltage of the ion source for U^{14+} ion beam has to be set at 5.6 kV to match the acceleration condition.

Using this method, we successfully produced a beam of U^{35+} ions (~60 pnA) for one month without the vacuum break.

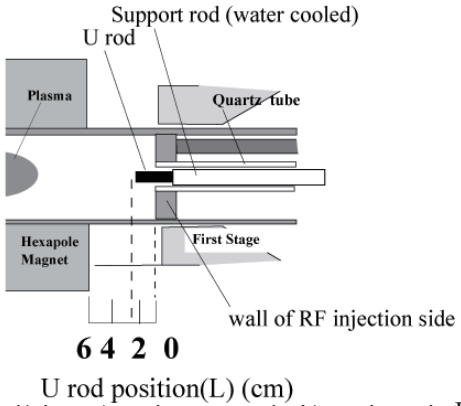

Fig.6. Schematic drawing of U rod and RF injection side of the RIKEN 18 GHz ECRIS

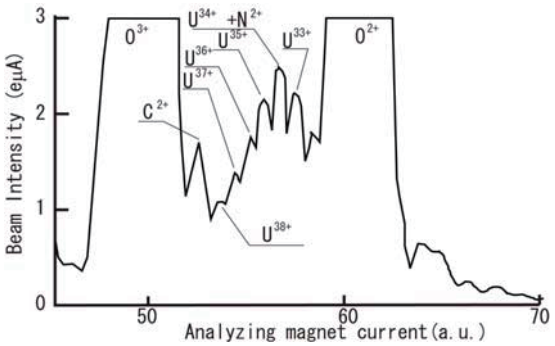

Fig.7. Charge state distribution of the U ion produced with sputtering method

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[4]T. Nakagawa et al, Nucl. Instrum. Methods A396(1997)9