Metal Ion Production with RIKEN 18GHz-ECRIS

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Abstract At RIKEN, three ECR ion sources (10GHz ECRIS, 18GHz ECRIS and liquid He-free SC-ECRIS) are operated as external ion sources of heavy ion accelerators. In the last year, multi-charged uranium ion beam was produced from 18GHz ECRIS by using UF_6 and the ^{238}U ion was successfully accelerated by the accelerator complex which consists of the RFQ linear accelerator, RIKEN heavy ion linear accelerator (RILAC) and RIKEN ring cyclotron accelerator (RRC). The typical beam intensity of $^{238}U^{14+}$ was about 2pμA on faraday cup after analysing magnet. ^{70}Zn beam was still supplied for the new super-heavy element search experiment with insertion method. Intense beam of $^{70}Zn^{16+}$ was produced for long term (∼43 days) without vacuum break and remarkably low material consumption rate (∼100μgr/h). We already supplied Zn beam longer than 200 days for this experiment. ^{48}Ca ion was also produced by insertion method using ^{48}CaO rod for the nuclear physics experiment. In this contribution, we will present ion source parameter and techniques for production of each of the metal ions.

Key words ECRIS, metal ion, ^{238}U, ^{70}Zn, ^{48}Ca

1 Introduction

In RIKEN radio isotope beam factory project (RIBF project), an intense uranium beam is strongly demanded for production of radio isotope (RI) beams[1]. Because an in-flight fission reaction of the uranium is more effective to produce medium mass RI compared with the projectile like fragmentation of heavy ions[2]. In the early stage of the RIKEN RIBF project, the required beam intensity from the ion source is at least 1pμA of $U^{10+\sim20+}$ ion beams. One of the popular methods for producing ions from a solid material is to use the evaporation from the external furnace set in the plasma chamber of the ion source (so-called oven technique)[3]. However, we need a high temperature to obtain an enough uranium vapor from UO_2, because of its high melting point (2100 deg)[4]. If we can use the uranium compound which has a high vapor pressure at the room temperature, the oven is not required to vaporize the uranium. It is well-known that the uranium hexafluoride (UF_6) has a high vapor pressure (∼100Torr) at the room temperature (25deg.)[5]. When using UF_6, we may produce uranium ions in the same manner as the case of gaseous elements. For these reasons, as a first trial to produce U ion beam at RIKEN, we chose the UF_6.

Recently, intense ^{70}Zn beam was strongly demanded to search the new super-heavy element (atomic number of 113) at RIKEN[6]. One of the popular methods for producing ions from the solid material is the oven technique[3]. Using this method one can produce intense beam of highly charged heavy ions, however the main drawback of this technique is the limit of material volume (∼100mgr) contained in the oven at present. The direct insertion method is

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simplest one to produced metallic ions[7]. The solid rod is directly heated by the plasma in the ion source and evaporated atoms are ionized by electron impact in the plasma. Main disadvantages are the weak beam intensity of highly charged ions and the high consumption rate (∼10mgr/h) compared to those produced with the oven technique. If we can produce the intense beam with low consumption rate (lower than 1mgr/h), this method may meet the requirement. In test experiment by this method, we produced intense beam of Zn ions (2∼3pμA of $^{nat}Zn^{14+\sim16+}$) at low consumption rate (lower than 1mg/h) for several days[8]. And we applied this method to produce the ^{70}Zn ion beam for search of the super-heavy element (Z=113) and successfully produced intense ^{70}Zn ion beam with very low material consumption for long term operation.

In February 2002, we successfully produced ^{48}Ca ions from RIKEN 18GHz ECRIS by using a micro oven method. Typical beam intensity of $^{48}Ca^{11+}$ ion beam was about 25eμA[9]. It was supplied to the accelerator for 50 hour or more. In this experiment, a consumption rate of ^{48}Ca was about 1.2mg/h. One of the problems of our oven is a short period (∼2days) of the beam production. When new sample is installed in the ion source, we take 2days for evacuation and conditioning the ion source. The requirement of the experiment is to generate the intense beam (1∼2pμA) of ^{48}Ca ions from the ion source as long as possible without a break in order to minimize the experimental time. To meet this requirement, we chose the insertion method with ^{48}CaO rod.

In this paper, we report the results of U, ^{70}Zn and ^{48}Ca ion beam production with the methods described above.

2 Uranium ion production

We contained ∼3gr of UF_6 in the bottle (5cm in diameter and 10cm in length). The gas pressure of UF_6 in the bottle was measured by 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. We also used the Fomblin oil to minimize the chemical reaction of UF_6 with the oil. To prevent UF_6 from escaping into the atmosphere, the exhaust gas from the rotary pump of the ion source flowed into the chemical trap.

Figure 1(a) and (b) show charge state distributions of the uranium ions. The ion source was tuned to produce U^{21+} ions (a) and U^{16+} ions (b). When producing U^{21+} ions, the gas pressure and microwave power were 9×10^{-7}Torr and 260W, respectively. To produce U^{16+} ions, we set the gas pressure of 1×10^{-6}Torr and microwave power of 160W. 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 0.53T, respectively. It is clearly seen that we need higher microwave power and lower gas pressure to produced higher charge state uranium ions.

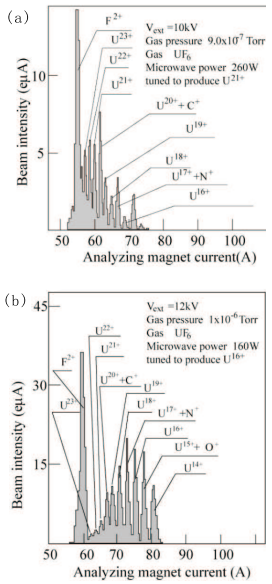

Fig. 1. Charge state distribution of uranium ions. The ion source was tuned to produce U^{21+} (a) and U^{16+}(b).

Figure 2 shows the charge distribution of uranium ions at the microwave power of 160 and 260W. The extraction voltage was 10kV. The gas pressure was 1×10^{-6}Torr. The B_{inj}, B_{ext} and B_{min} were 1.4, 1.25 and 0.5T, respectively. The average charge state was shifted to higher side with increasing the microwave power.

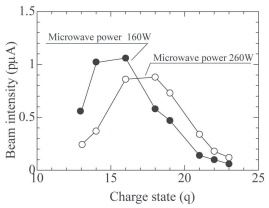

Fig. 2. Charge distributions of uranium ions at the microwave power of 160 (closed circles) and 260W (open circles). The extraction of voltage was 10kV.

The total measured beam intensities were 3.6 and 3.7pμA at microwave power of 160 and 260W, respectively. It means that the number of produced ions was almost constant, which was same tendency as the MIVOC method described in Ref. [10].

Figure 3 shows the summary of the beam intensity of uranium ions. The extraction voltage was 14kV. 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 14kV, the gas pressure and RF power were 1×10^{-6}Torr and 250W, respectively. The gas pressure and microwave power were 9×10^{-7}Torr and 500W 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 $B_{\rm inj}$, $B_{\rm ext}$ and $B_{\rm min}$ were 1.4, 1.4 and 0.53T, respectively, which is maximum magnetic field strength of RIKEN 18GHz ECR ion source.

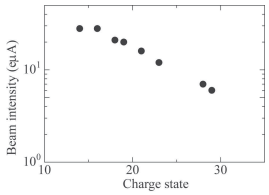

Fig. 3. Beam intensity of multi-charged uranium ions at the extraction voltage of 14kV.

In order to obtain 350MeV/u uranium beam from the accelerator complex of RIKEN RIB factory project[4], the extraction voltage of the ion source for U^{14+} ion beam has to be set at 14kV to match the acceleration condition. In this condition (extraction voltage of 14kV 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 up to 11MeV/u.

3 ^{70}Zn ion production

To produce ^{70}Zn ion beams, we used the rectangular rod ($4\times4\times43$mm^3) of ^{70}ZnO (enrichment of 95%). A position of the rod was remotely controlled with the accuracy of 0.1mm. To check the effect of ionized gas (base gas for production of plasma) on the beam stability and intensity, we chose He gas and O_2 gas as ionized gases. Usually, for production of heaver ions such as Zn ions, O_2 gas is better than He gas[11]. However, in this experiment, beam intensity of Zn ions using He gas is more stable than that using O_2 gas. For this reason, we used He gas as an ionized gas.

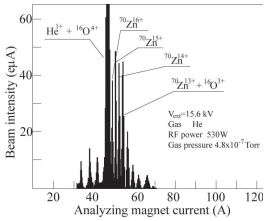

Fig. 4. Charge state distribution of the ^{70}Zn ions from RIKEN 18GHz ECR ion source with direct insertion method.

Figure 4 shows the charge state distribution of the ^{70}Zn ions. The RF power was 530W. The gas pressure was 4.8×10^{-7} Torr. The maximum magnetic field strength on the microwave injection side, the minimum strength of mirror magnetic field, and the maximum magnetic field strength on the beam extraction side were 1.4, 0.49 and 1.2T, respectively. The extraction voltage was 15.6kV. Before producing Zn ions, we cleaned up the inner wall of the aluminum cylinder by the oxygen plasma for 2 days. And then we inserted the rod into the plasma chamber. Usually, we have to set the rod near the ECR zone to obtain enough vapor pressure from the high melting point material such as ZnO (The melting point of ZnO is ∼1970℃.). However, remarkably, the position of the rod tip was 1.5—2.5cm from the flange surface of injection side, which was ∼11cm from the ECR zone, to obtain 40eμA of ^{70}Zn^{15+} ion beam. To understand this phenomenon, we need further inves-

tigation. Practically, it was advantageous to obtain stable beam. Because the solid rod was done not cause the instability of the plasma.

Figure 5 shows the beam intensity of $^{70}Zn^{16+}$ as a function of time. We successfully produced average beam intensity of 35.5eμA for 43 days for the superheavy element search experiment without break. The total consumption was 115mg of ^{70}Zn. The consumption rate was 0.11mgr/h. It is expected that the evaporation rate is not so high at the rod tip position of 1.5∼2.5cm from injection flange, because of the low temperature of the plasma at this position. It may be one of the reasons why the consumption rate was so low.

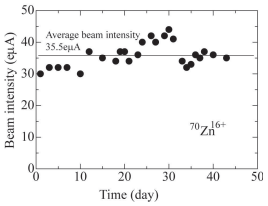

Fig. 5. Beam intensity of $^{70}Zn^{16+}$ as a function of time.

Even if we assume the 100% transport efficiency of the beam from the ion source to the faraday cup, production efficiency of $^{70}Zn^{16+}$ is 6.3%, which is almost same or even higher efficiency compared to the oven method for production of ^{48}Ca ion beam[12]. The production efficiency was defined as the number of extracted ions divided by the number of evaporated atoms from the material.

In case of $^{70}Zn^{15+}$, the production efficiency is about 10%. It is estimated that the total production efficiency of ^{70}Zn ions from solid rod is at least ∼30%.

4 ^{48}Ca ion production

To produce ^{48}Ca ion beams, we made the rectangular rod ($4\times4.5\times39.25mm^3$) of ^{48}CaO (enrichment of over 90%). Weight of this rod was 1.305gr. After the test experiment with ^{nat}CaO rod to search the optimum condition to produce Ca^{11+}, we used ^{48}CaO rod. Typical beam intensity of $^{48}Ca^{11+}$ ions during the experiment was about 15∼20eμA. We successfully produced $^{48}Ca^{11+}$ beam for 19 days without exchanging the rod. In this experiment the consumption rate of ^{48}Ca was 1.1mgr/h.

5 Summary

We produced multi-charged uranium ion beams from RIKEN 18GHz ECR ion source by feeding UF_6. The beam intensity increases with increasing the extraction voltage and microwave power. To produce higher charge state uranium ions, the lower gas pressure and higher microwave power were needed. The beam intensities of multi-charged uranium ions (U^{14+} ∼U^{20+}) were 2∼1pμA.

We successfully produced intense beam of highly charged ^{70}Zn ions for long term (43 days) without break using the direct insertion method. The average consumption rate of ^{70}Zn was 0.11mg/h. By using the direct insertion method, it is possible to provide about 20000h of the target irradiation using one rod (∼2.2g) of ^{70}ZnO.

The ion production of ^{48}Ca was done by the insertion method with the ^{48}CaO rod. The consumption rate of ^{48}Ca was 1.1mgr/h, which is same as our oven method. The duration of beam supply with rod method is ten times as long as that with our micro oven method.

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