SUPPLY OF METALLIC BEAMS FROM RIKEN 18-GHz ECRIS USING LOW-TEMPERATURE OVEN

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Abstract

At the RIKEN 18-GHz ECR ion source, in order to enhance the intensity and stability of medium-heavy metallic beams, a low-temperature oven has been put into practical use. The supply methods, operational test results, and operational statuses for several metallic beams are reported herein.

INTRODUCTION

At the RIKEN Radioactive Isotope Beam Factory (RIBF) [1], beams of medium-heavy metals, such as ^{23}Na, ^{24}Mg, ^{27}Al, ^{48}Ca, ^{58}Ni, and ^{70}Zn, are supplied from the RIKEN 18-GHz electron cyclotron resonance ion source (ECRIS) [2]. Until recently, these metallic beams were produced using the rod-insertion method (except for Ni beams, which were produced using the Metal Ions from VOlatile Compounds (MIVOC) method [3]). In this method, a sintered rod of metallic oxide (fluoride for a Na beam) is inserted directly into the plasma generated in the ECRIS. The rod is heated by the plasma, and the metallic atoms are evaporated and fed into the plasma. The typical intensities of the $^{48}Ca^{10+}$ and $^{70}Zn^{15+}$ beams produced using this method were slightly below 20 eμA. However, the ECRIS required frequent tuning to maintain constant beam intensity. Therefore, we had tried to produce beams of medium-heavy metals using a low-temperature oven, which was already in use at several facilities [4-7], with the goal of enhancing the beam intensity and stability.

In this contribution, the supply methods and conditions, operational test results, and operational statuses of beam supplies to the experiments for ^{48}Ca, ^{70}Zn, and ^{27}Al beams are reported. The temperature dependences of the vapor pressures of Ca, CaO, Zn, ZnO, and Al, which are obtained obtained from Ref. [8], are shown in Fig. 1.

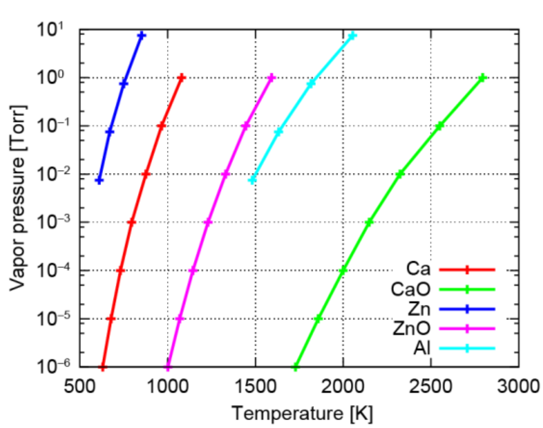

Figure 1: Temperature dependences of vapor pressures of Ca, CaO, Zn, ZnO, and Al (obtained from Ref. [8]).

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STRUCTURE OF LOW-TEMPERATURE OVEN

The details of the structure of the low-temperature oven is described in Ref. [9]. It has been found that the oven temperature can be increased up to about 1000°C without damaging the oven. The crucible and Pt wire are replaced after each operation.

CALCIUM BEAM

For the supply of a ^{48}Ca beam, $CaCO_3$ which is highly enriched with ^{48}Ca (from a natural abundance of 0.2% to 70%-80%) is prepared. $CaCO_3$ is reduced to CaO by heating $CaCO_3$ to above 900°C. A mixture of CaO and Al powders is placed in the crucible. Then, the low-temperature oven is installed in the ECRIS. By heating the material to about 850°C, metallic Ca is produced through the following reductive reaction:

$$3CaO + 2Al \rightarrow 3Ca + Al_2O_3.$$

Ionized helium gas is used to generate the plasma.

Because the material is so expensive, it is quite important to reduce its consumption rate. Therefore, we adopted the so-called "hot liner" method [5,10,11]. In this technique, the inner surface of the plasma chamber in the ECRIS is thermally decoupled from the cooling water jacket to be kept at a high temperature heated by the plasma. Using this method causes the metallic atoms attached to the inner surface to re-evaporate. The details of operational tests that confirm the effectivity of using a hot liner, as well as the effectivity of applying a negative bias to the low-temperature oven itself, are reported in Refs. [9, 12].

The $^{48}Ca^{11+}$ beams produced using a low-temperature oven were first supplied twice to the experiments in the old RIBF facility [12]. After that, the $^{48}Ca^{10+}$ beams produced using a low-temperature oven were supplied to the new RIBF accelerator complex, from November 2014 until December 2014. Figure 3 shows the obtained charge distribution of ^{48}Ca ions. The RF power fed to the ECRIS was 370 W. The beam intensity at the exit of the ECRIS and the oven current are shown in Fig. 4. The beam intensity was adjusted to meet the experimental requirements by changing the slit aperture at the exit of the ECRIS. A beam intensity of about 35 eμA with the maximum slit aperture was maintained throughout the experiments. The status of beam supply is summarized in Table 1.

We succeeded in supplying ^{48}Ca beams twice as intense as those using the rod-insertion method, with nearly one-tenth of the material consumption rate.

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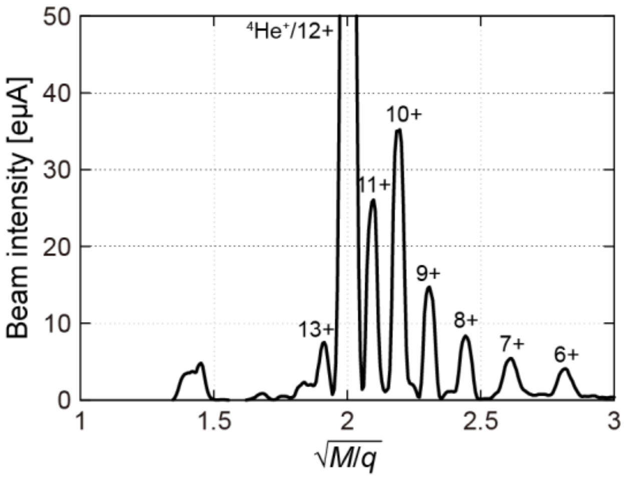

Figure 3: Charge distribution of ^{48}Ca ions.

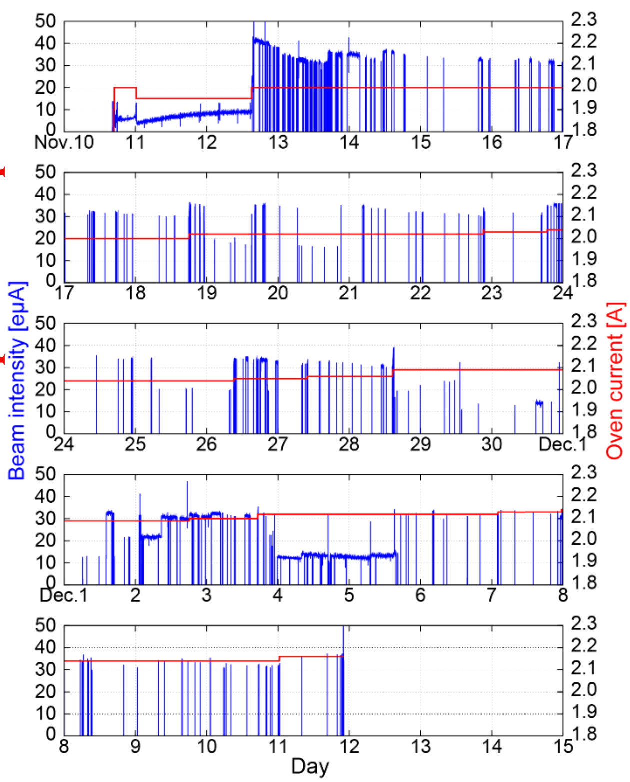

Figure 4: Long-term supply of $^{48}Ca^{10+}$ beam for experiments in new RIBF facility. Intensity of $^{48}Ca^{10+}$ beam (blue) and oven current (red) are shown.

Table 1: Status of $^{48}Ca^{10+}$ Beam Supply

Averaged beam intensity [eμA]	35
Amount of material prepared [mg]	299
Amount of material consumed [mg]	98
Consumption rate of material [mg/h]	0.13

ZINC BEAM

For the supply of a ^{70}Zn beam, ZnO which is highly enriched with ^{70}Zn (from a natural abundance of 0.6% to more than 80%) is prepared. In contrast to the procedure for the Ca beam, only the powder of ZnO is placed in the crucible because of the sufficiently high ZnO vapor pressure. Ionized helium gas is used to generate the plasma. The hot liner is not used because a high RF power of 550 W is required to produce an adequate intensity of highly charged Zn^{15+} ions. In an operational test in which the hot liner was installed in the ECRIS and the RF power fed to the ECRIS was limited to 400 W, the beam intensity hit a peak at an inadequate level even if the oven current was increased.

When the oven current is gradually increased, following the evaporation of the water, Zn beam production is observed at an oven current lower than that at which the Ca beam is produced. The production of the Zn beam at a lower oven current is likely due to the evaporation of the traces of metallic Zn which exist in ZnO. The Zn beam production at this oven current rapidly ceases. By further increasing the oven current, Zn beam production is observed again at an oven current higher than that at which the Ca beam is produced.

A $^{70}Zn^{15+}$ beam produced using the low-temperature oven was first supplied to the experiment in the RIBF from May 2014 until June 2014. Figure 5 shows the obtained charge distribution of ^{70}Zn ions. The RF power fed to the ECRIS was 550 W. The beam intensity at the exit of the ECRIS and the oven current are shown in Fig. 6. In order to reduce material consumption, the oven current was decreased when the beam was not in use. Because there was a break period (from May 27th until May 29th in Fig. 6), the material was replaced as a precaution. The statuses of beam supplies before and after the break are summarized in Table 2. The consumption rate throughout the experiment was 0.14 mg/h.

Table 2: Status of $^{70}Zn^{15+}$ Beam Supply

	Before	After
Averaged beam intensity [eμA]	30	33
Amount of material prepared [mg]	1007	835
Amount of material consumed [mg]	59	22
Consumption rate of material [mg/h]	0.16	0.10

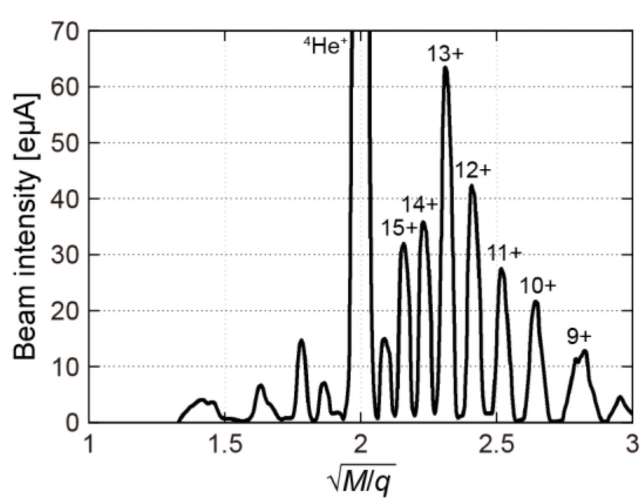

Figure 5: Charge distribution of ^{70}Zn ions.

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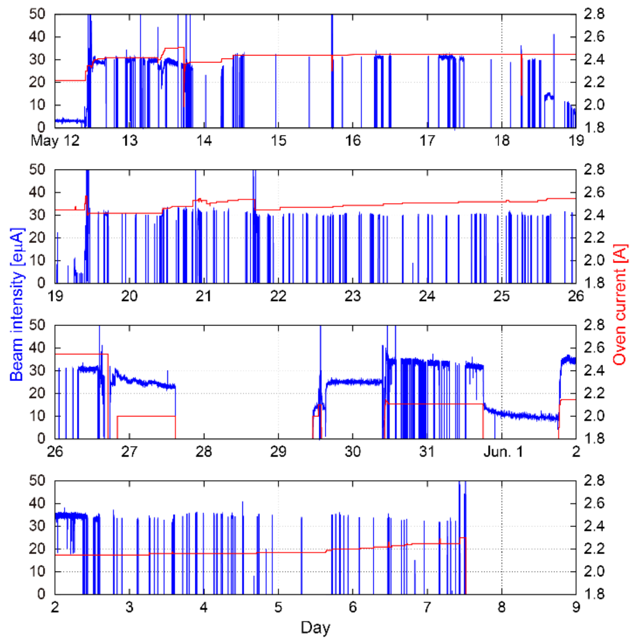

Figure 6: Long-term supply of $^{70}Zn^{15+}$ beam for experiment in RIBF. Intensity of $^{70}Zn^{15+}$ beam (blue) and oven current (red) are shown.

As shown in Fig. 1, since the vapor pressure of ZnO is lower than that of Ca, ZnO requires an oven temperature higher than that required by Ca. However, after ZnO is decomposed into Zn and O by the plasma, the vapor pressure of Zn is higher than that of Ca, enabling the beam to be supplied with a sufficiently low consumption rate, even if a hot liner is not used.

ALUMINIUM BEAM

As Fig. 1 shows, the vapor pressure of Al is slightly lower than that of ZnO. Thus, Al atoms should be evaporated at a slightly higher oven temperature. In the Al beam production test conducted using the low-temperature oven, metallic Al was placed in the crucible, and the hot liner was not used. The maximum RF power fed to the ECRIS was 500 W. Ionized helium and oxygen gases were tested to generate the plasma. Unfortunately, the obtained $^{27}Al^{8+}$ beam had an intensity of no more than a few eμA, even when the oven current was increased to a level at which previous empirical evidence had indicated that Pt wire should burn out within one week.

At the RIKEN 28-GHz superconducting ECRIS [13,14], a high-temperature oven for the production of a highly intense ^{238}U beam is currently under development [15]. The temperature of this oven can be increased to above 2000°C. Therefore, it is expected that an Al beam can be produced using this high-temperature oven without any difficulty.

SUMMARY

At the RIKEN 18-GHz ECRIS, a low-temperature oven has been put into practical use to supply highly intense and stable beams of medium-heavy metals. Ca and Zn beams have been successfully produced, and supplied to the long-term experiments in the RIBF. The upper temperature limit of the low-temperature oven seems to be slightly lower than the temperature at which an Al beam can be produced with an adequate intensity.

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