Production of highly charged calcium-ion beam using high-temperature oven

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The calcium-48-ion beam is one of the indispensable beams for studying light nuclei with excess neutrons. Before the upgrade of RILAC with superconducting (SC) acceleration cavities[1] to provide calcium (Ca) beams for experiments at RIBF, a Ca^{11+} beam was extracted from a normal-conducting electron-cyclotron-resonance ion source (ECRIS) with a low-temperature oven as an evaporator of Ca,[2] accelerated by RILAC, following which a Ca^{16+} beam was produced through a carbon-foil charge stripper. However, due to the upgrade of RILAC, the charge stripper is no longer available, because the materials sputtered from the stripper into the beam pipe are adsorbed on the cryogenic surface of SC cavities, resulting in a serious reduction in the acceleration voltage. Meanwhile, the ECRIS for RILAC was also upgraded with the SC technology, and the performance of the ion source has been improved significantly. Therefore, we conducted a test to directly extract Ca^{16+} ions from the new SC-ECRIS.

It is also necessary to reduce the consumption of the Ca sample as much as possible because of the recent worldwide shortage of ^{48}Ca samples. Various ovens to evaporate Ca[2–4] were developed worldwide, but we selected a high-temperature oven (HTO)[5] because it was able to achieve a high enough temperature to directly decompose the CaO sample. We tested whether a Ca^{16+} beam of sufficient intensity can be obtained with a small Ca consumption using the HTO as the evaporator.

The experiment was conducted using an SC-ECRIS for RILAC (R28G-K).[6,7] The magnetic mirror was set to the same field as that for the uranium-beam production, which is suitable for producing multiply charged ion beams. An ion-extraction voltage of 9.99 kV was applied to fit to the case of ^{48}Ca-ion acceleration. A tablet-shaped CaO (natural Ca) sample, which was calcined at 1000°C for 2 h in the ambient atmosphere, was placed directly into a tungsten crucible of HTO, which was surrounded by a molybdenum heat shield. In addition, by calcining with an HTO heating power below 200 W for 6 h in vacuum ($\sim 10^{-4}$ Pa) in R28G-K, H_2O and CO_2, which were contained in the CaO sample, were completely eliminated.

High-intensity $^{40}Ca^{16+}$-ion beams were successfully extracted from R28G-K as a function of the total power of microwaves at frequencies of 18 and 28 GHz to heat the ECR plasma, as shown in Fig. 1. The ECR plasma was stabilized by the O_2 support gas. The heating power of HTO (P_{HTO}) was changed from 300 W to 720 W, and the corresponding consumption rates (C.R.) are summarized in Table 1. The results clearly indicate that C.R. depends on the transmission efficiency through the accelerators and the beam lines, and we expect to provide a Ca-ion beam of more than 0.5 particle μA on the target with a Ca consumption of 0.5 mg/h. Furthermore, we plan to study other support gases such as N_2 and different crucible shapes to improve the ionization efficiency to reduce the Ca consumption further.

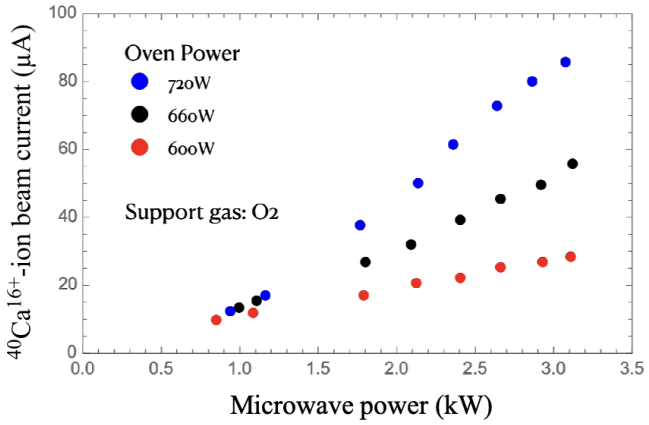

Fig. 1. Obtained $^{40}Ca^{16+}$-beam currents as a function of the total power of the 18- and 28-GHz microwaves. The red, black, and blue points show HTO heating powers of 600, 660, and 720 W, respectively.

Table 1. Total consumption of the CaO sample ΔW as a function of the HTO heating power P_{HTO} and the operation time Δt. The consumption rate (C.R.) was estimated from the ratio of the atomic weights of Ca and O.

P_{HTO}(W)	Δt(hours)	ΔW(CaO, mg)	C.R.(Ca, mg/h)
300.	167.0	6.	0.03
600.	71.3	23.	0.23
660.	40.6	29.	0.51
720.	18.6	20.	0.78

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