Development of an RF-carpet gas cell for the chemistry of superheavy elements

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The chemical investigation of superheavy elements (SHEs), with atomic number $Z \geq 104$, is intriguing because of the strong relativistic effects on atomic electrons.[1)] In previous studies, the gas-phase chemical properties of SHEs up to Hs ($Z = 108$) and those of Cn ($Z = 112$), Nh ($Z = 113$), and Fl ($Z = 114$) have been measured[1)] with the help of the He gas-jet system, which allows the deceleration and rapid transport of produced SHEs to gas chromatographic apparatus. However, for the heaviest elements such as Cn, Nh, and Fl, reliable experimental data with sufficient statistics have not been obtained, because of their short half-lives (∼1 s), which are shorter than the transportation time of the He gas-jet system (∼3 s). The RF-carpet gas-cell system, currently used for precise mass measurements of transfermium elements,[2,3)] allows the rapid deceleration and transportation (<100 ms) of SHE ions separated with a gas-filled recoil ion separator (GARIS-II). In this study, we developed a cryogenic RF-carpet gas cell, placed after GARIS or GARIS-II and connected to a gas chromatographic apparatus, for the gas-phase chemistry of short-lived SHEs (<3 s).

Figure 1 shows a schematic view and photograph of the constructed gas cell, which is similar to the one being used in the SHE-Mass-II.[3)] A gas-cell chamber, where He gas for decelerating SHE ions is introduced, is supported by a cryocooler inside a vacuum chamber. The cryocooler can cool the gas cell to ∼70 K, freezing gaseous impurities and preventing SHE ions from reacting with impurities. A DC cylinder and an RF carpet are placed inside the gas-cell chamber. The DC cylinder, consisting of 45 electrodes connected by low-outgas surface-mount resistors, produces a drift field of up to ∼9 V/cm for transporting SHE ions to the RF carpet. The RF carpet consists of many concentric-ring electrodes with 60-μm width and 100-μm spacing. It has a Φ0.32-mm hole at the center for extracting SHE ions. The hole diameter is less than that of SHE-Mass-II (Φ0.74 mm), allowing a lower pressure in the vacuum chamber and lower loss rate of He gas from the gas-cell chamber. A quadrupole

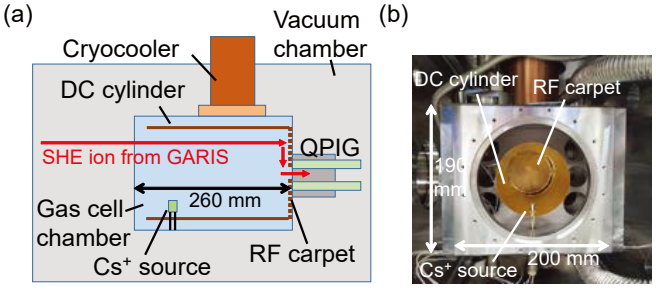

Fig. 1. (a) Schematic view and (b) photograph of the developed cryogenic RF carpet gas cell.

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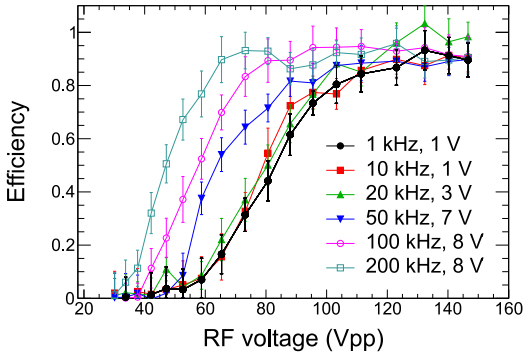

Fig. 2. Transportation efficiency of Cs^+ ions as a function of the RF voltage for combinations of the AF frequency and voltage with a drift field of 6.7 V/cm at a He pressure of 100 mbar and a gas-cell temperature of approximately 75 K.

ion guide (QPIG) is placed close to the hole of the RF carpet to transport extracted ions.

As an evaluation of the apparatus, we measured the transportation efficiency of Cs^+ ions from the surface of the RF carpet to the central hole of the carpet by using a Cs ion source placed inside the gas-cell chamber. First, the current of Cs^+ ions that reached the RF carpet was measured using the carpet as the Faraday cup. Next, Cs^+ ions were transported towards the carpet hole by applying RF fields, on which audio frequency (AF) fields were superimposed,[4)] to the carpet. The current of Cs^+ ions extracted through the hole was measured using the QPIG as the Faraday cup. The transportation efficiency was obtained by dividing the current at the QPIG by that at the RF carpet.

Figure 2 shows an example of the measured transportation efficiency as a function of the RF voltage. For each AF frequency, the AF voltage was fixed to the value that could maximize the transportation efficiency. In Fig. 2, the transportation efficiency is saturated with high RF voltages, indicating that sufficient RF voltages can be applied to the RF carpet with our setup. High maximum transportation efficiencies (more than 80%) were successfully obtained; hence, the constructed gas cell would be applicable to experiments with SHE isotopes at low production rates. Higher AF frequencies are preferable in that lower RF voltages can saturate the efficiency (Fig. 2), and that faster transportation is expected.[5)]

We will measure the transportation efficiency through the QPIG with Cs ions and also with radioisotopes offline and online. In parallel, we will develop the gas chromatographic apparatus connected to the gas cell.

References

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