Measurement of extraction time and efficiency of ^{220}Rn ions using a cryogenic RF-carpet gas cell for the chemistry of superheavy elements

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We have been developing a cryogenic RF-carpet gas cell for the gas-phase chemistry of superheavy elements (SHEs) with short half-lives (<5 s) such as ^{283}Cn (Z = 112), ^{284}Nh (Z = 113), and ^{289}Fl (Z = 114).[1] We designed and constructed the gas cell, and measured the transportation efficiency of ions from the surface of the RF carpet to its central hole (>80%) using Cs^+ ions emitted from a Cs ion source.[1] In this work, we measured the extraction time and efficiency of ions to the outlet of the quadrupole ion guide (QPIG) using ^{220}Rn ($T_{1/2}$ = 55.6 s) ions emitted from a ^{224}Ra source with recoil energy from alpha decay.

The ^{224}Ra source (45 kBq) was prepared by collecting ^{224}Ra ions recoiling out of a ^{228}Th source to the surface of a Cu foil (diameter 10 mm).[2] As shown in Fig. 1, ^{220}Rn ions recoiling out of the ^{224}Ra source placed 50 mm from the RF carpet were decelerated by the He buffer gas, extracted from the RF carpet, and transported to an Al foil (thickness 0.8 μm) via QPIG. The number of ^{220}Rn ions on the Al foil was measured by alpha-particle spectrometry using a Si detector. The extraction efficiency against a variety of voltages applied to the RF carpet and QPIG was obtained by dividing the number of ^{220}Rn ions extracted on the Al foil by that emitted from the ^{224}Ra source.

The extraction time measurement was performed by synchronously applying a pulsed voltage to the ^{224}Ra source (55 V, width 2–10 ms) and a pulsed RF voltage to the QPIG (1.6 MHz, 74 V_{pp}, width 2–100 ms). The pulsed voltage to the source creates a pulse of ^{220}Rn ions, which reach the QPIG with some delay. The extraction time can be obtained by searching the pulse

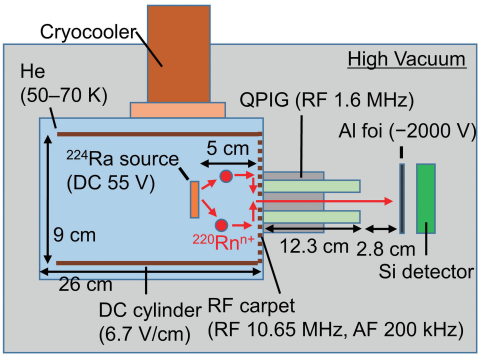

Fig. 1. Setup of the measurement of extraction time and efficiency of ^{220}Rn ions.

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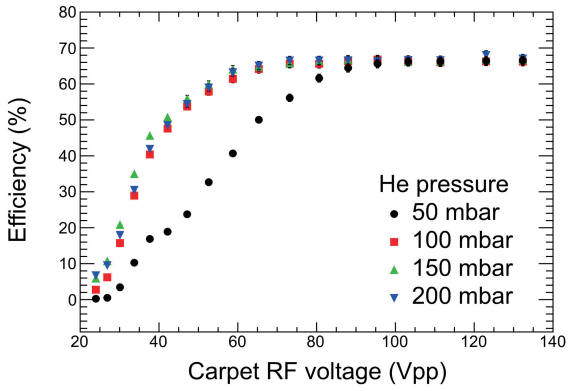

Fig. 2. Extraction efficiency of ^{220}Rn ions as a function of the RF voltage applied to the RF carpet.

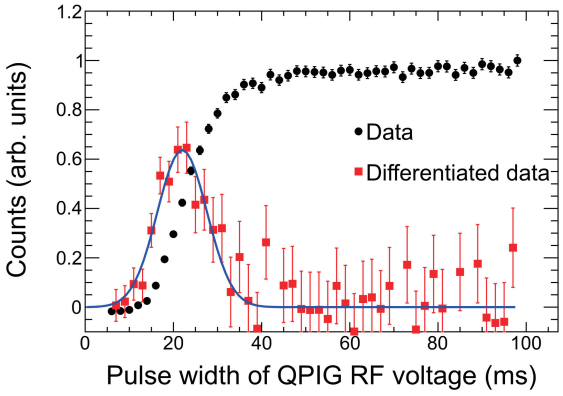

Fig. 3. Counts of ^{220}Rn ions as a function of the pulse RF voltage applied to the QPIG for a He pressure of 100 mbar (black circle). The differentiated data (red square) is fitted with a Gaussian function (blue line).

width of the QPIG RF voltage at which the ^{220}Rn counts increase.

Figure 2 shows the extraction efficiency as a function of the RF voltage applied to the RF carpet, where we find that the maximum efficiency is obtained with an RF voltage of 88 V_{pp} for every He gas pressure (50, 100, 150, and 200 mbar, room temperature equivalent). Similarly, we determined the best values for the audio-frequency voltage of the RF carpet, and the RF and DC voltages of the QPIG. We obtained an extraction efficiency of ~66% even for a He pressure of 200 mbar (Fig. 2), which is higher than the value for the RF-funnel type gas cell (5% at 70 mbar).[3]

Figure 3 shows an example of the results of the ex-

traction time measurement, where the counts of ^{220}Rn ions increase and saturate with an increase in the pulse width of the QPIG RF voltage. The differentiated data was fitted with a Gaussian function, yielding a mean extraction time of 22.0(6) ms for 100 mbar. The mean extraction times for 50, 150, and 200 mbar were determined in the same way as 6.7(4), 30.1(11), and 33.8(9) ms, respectively.

The high extraction efficiency (∼66%) and fast extraction time (<40 ms) indicate that the developed gas cell is applicable to the chemistry of SHEs with half-lives of less than 100 ms at low production rates. We plan to develop a gas chromatographic apparatus connected to the gas cell, and perform online experiments.

References

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