Development of Resonant-Extraction Charge Breeder (RECB)

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In the RUNBA project,[1)] RI ions from ERIS[2)] are accelerated in the storage ring (RUNBA) for nuclear reaction experiments. For efficient acceleration, RI ions should be a highly charged ion beam. Although an EBIT type charge breeder (CB) is widely used to increase the charge state, an efficiency of only 20% hase been achieved do far because of finite spread in charge state distribution.[3)] We developed a prototype of a resonant-extraction charge breeder (RECB) to improve the efficiency, the RECB can selectable extract only the desired charge state ions.

In a RECB, a longitudinal electrostatic potential for ion trapping is designed as a quadratic shape on an electron beam axis (Fig. 1). The longitudinal motion of ions in the potential is a simple harmonic oscillation for which the frequency depends on the mass-to-charge ratio. Thus, the ion motion is excited by adding an oscillation to the electrostatic potential at the resonant frequency. Then, ions of a selected charge state are extracted from the trapping regions, and the others are left in the RECB. When we apply a time-dependent potential $V_{\mathrm{trap}}(z,t) = (a + b\sin(\omega t))z^2$ (z, ω, and a and b represent the position, frequency of the potential oscillation, and constants, respectively), the ion motion is described by Mathieu's differential equation.

As shown in Fig. 1, RECB consists of an electron gun, a solenoid coil, an electron beam collector, and 20 electrodes that form the trapping potential $V_{\mathrm{trap}}(z,t)$ using a DC power supply and a function generator. In the trapping region, the energy, current, and beam radius, of the electron beam were −32 keV, 10 mA, and 0.06 mm, respectively. Collection efficiency at the electron beam collector was more than 99.5% when the solenoid magnetic field was 0.13 T. Extracted ions with an energy of 10 keV/q from the RECB were separated by the analyzing magnet, and then, they were detected with a channeltron.

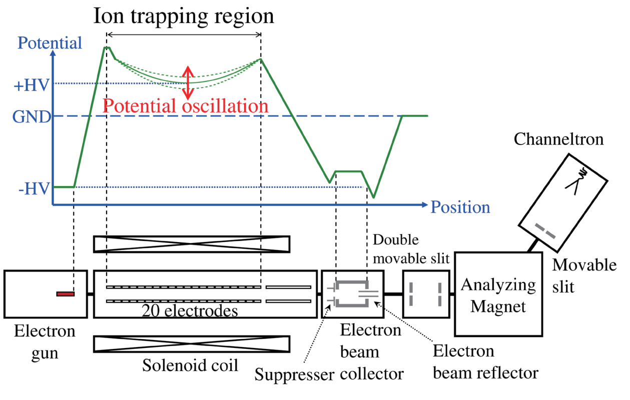

Fig. 1. The schematic diagram of the prototype RECB.

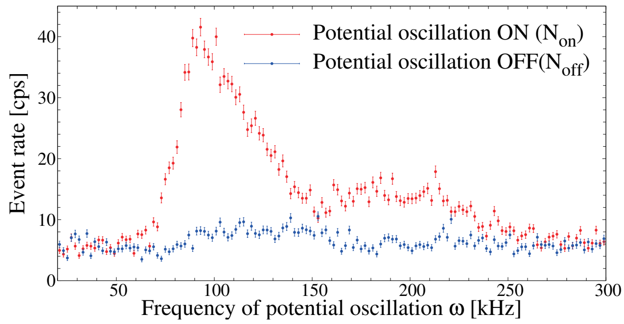

Fig. 2. Spetrum of extracted $^{12}C^{4+}$ ions.

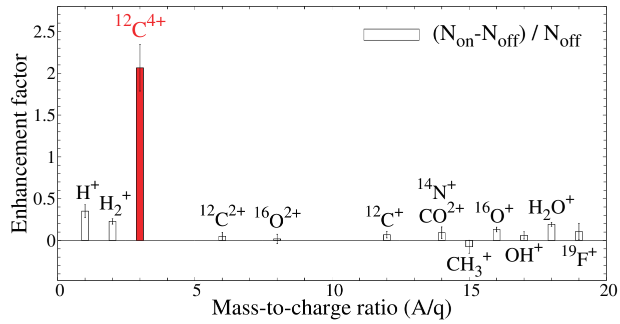

Fig. 3. Enhancement factors of extracted of $^{12}C^{4+}$ ions.

We evaluate the performance of the potential oscillation by measuring the extracted residual gas ions (vacuum pressure $= 5 \times 10^{-6}$ Pa). Figure 2 shows an example of a $^{12}C^{4+}$ ion extraction where the depth of the quadratic shape potential is 150 V and the function generator supplies a 1.0 V_{pp} sine wave for a short duration of 0.5 ms with a repetition rate of 500 Hz. The red and blue plots indicate the spectrum of the extracted $^{12}C^{4+}$ ions from the RECB with and without the potential oscillation (N_{on} and N_{off}), respectively. We confirmed that $^{12}C^{4+}$ ions were extracted at their fundamental frequency (90 kHz) and second order harmonic frequency (180 kHz). The spread of the spectrum was attributed to a distortion of the electrostatic potential produced by the space charge of trapped ions. Figure 3 shows the enhancement factor estimated by the event rate for ($N_{\mathrm{on}} - N_{\mathrm{off}}$) divided by that for N_{off} at a frequency of 90 kHz. The enhancements for the $^{12}C^{4+}$ ions were 30, 42, and 9.0 times greater than those for the $^{12}C^{+}$, $^{12}C^{2+}$, and H_2^+ (same A/q of $^{12}C^{6+}$) ions, respectively. In future work, we will optimize the electrostatic potential form to improve charge state selectivity for extraction.

References

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