Ion extraction from linear Paul trap via axially swinging field

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Spin-polarized radioactive isotope (RI) beams have been used for the measurements of nuclear electromagnetic moments and spins to investigate nuclear structure. In many experiments, the polarization of nuclear spin is generated via projectile fragmentation reaction.[1)] The reaction mechanism has been well studied so far. However, the achievable spin polarization is typically as low as several percentage points. Laser optical pumping can realize spin polarization of more than a few tens of percentage points but the method is element-limited. A highly efficient and universal method for producing spin-polarized RI beams is desired. For this purpose, we are developing a spin-polarized beam production apparatus using the atomic beam magnetic resonance (ABMR) method. In this method, the spin polarization of neutral atomic beams is generated by two-step spin selection using multi-pole magnets and one magnetic resonance.[2)] The ABMR method itself has high spin selectivity. However, the efficient production of a neutral RI atomic beam using thermal energy is a significant technical challenge. We propose a new ion neutralization system based on a multi-segmented linear Paul trap.

In the proposed neutralization system, RI ions are simultaneously trapped with laser-cooled ions. The kinetic energy of trapped RI ions will decrease due to mutual Coulomb interaction between RI ions and laser cooled ions. After the cooling of RI ions, RI ions are neutralized using a neutralization gas. In a general linear Paul trap, an RF electric field is only used to confine the radial motion of trapped ions. However, neutralized ions are scattered around in the above situation because the axial component of the trapped ion motion is much smaller than the radial component of the motion. In order to extract neutral RIs from a linear Paul trap efficiently, we apply an additional alternating electric field in the axial direction (swinging field) to induce axial ion motion. We constructed a five-segmented linear Paul trap to demonstrate ion extraction using an axially swinging field. The setup of the experiment is shown in Fig. 1(a). Rubidium ions emitted from a surface ionization ion source were guided to the trap operated at a frequency of 1.18 MHz and 532 V_{pp} using a quadrupole mass separator. In order to trap Rb ions, helium buffer gas of the pressured at a 1×10^{-4} Torr was filled in the trap chamber. The kinetic energy of Rb ions decreased because of collision between the ions and the He buffer gas, following which Rb ions were confined in the center electrode of the trap, denoted as "C" in Fig. 1(a). After ion trapping, we superimposed sinusoidal voltages (frequency: 1 Hz, amplitude: 2 V) to each trap electrode as the swinging field. The phase difference of the each sinusoidal voltage was 45°. The time variation of the applied voltage of each trap electrode is schematically shown in Fig. 1(b). We turned off all the voltages including that of the end electrode at a given time after applying the swinging field. The ions extracted toward the downstream direction were detected using channel electron multiplier (CEM) detector.

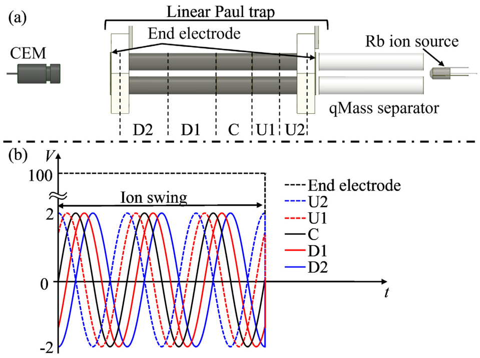

Fig. 1. (a) Schematic view of the experimental setup. The time variation of the applied voltages of each electrode during ion swinging is schematically shown in (b).

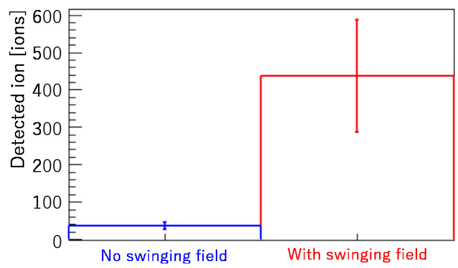

Fig. 2. Number of detected ions at the CEM position with/without an ion swinging field.

The number of ions detected using the CEM detector with/without the swinging field is shown in Fig. 2. The detected ion number shown in Fig. 2 is the average value of 25 measurements. The error was calculated as the standard deviation of the number of detected ions in each measurement. As shown in Fig. 2, approximately 450 ions were detected at the CEM position when we applied a swinging field, while the signal rate decreased almost to the background level in the case of no swinging field. This result indicates that the trapped ions obtain an axial momentum component sufficient to eject in the axial direction using the swinging field before ion neutralization: that is ions neutralized using a gas are delivered to the downstream spin-selection magnet as a neutral atomic beam. In a rough estimation, the extraction efficiency of the trapped ions reached approximately 10% so far. Further investigation and development are in progress now.

References

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