Development of a spin polarized RI atomic beam apparatus the using atomic resonance method

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We are currently developing a spin-polarized radioactive isotope (RI) atomic beam apparatus using the atomic beam magnetic resonance (ABR) method to apply RIs to nuclear structure study and material sciences. The apparatus mainly consists of the following two parts: i) An RI ion neutralizer based on a radio frequency (RF) trap and laser cooling technique for generating a low-energy RI atomic beam. ii) An ABR apparatus consisting of a sextupole magnet, dipole magnet, quadrupole magnet, and RF cavity for producing a highly polarized RI atomic beam.[1)] In our method, RI and laser-cooled ions are simultaneously trapped in a linear Paul trap at first. Then, the energy of trapped RI ions is sympathetically decreased by the Coulomb interaction between laser-cooled and trapped RI ions (sympathetic cooling).[2)] After cooling the RI ions, an ion neutralization gas is blown against the trapped ions. An RI atomic beam produced by the above neutralization process is delivered to the ABR apparatus. In the ABR apparatus, spin polarization is achieved by a combination of double spin selection using a magnetic field gradient generated by a sextupole and quadrupole magnet and single spin flip by magnetic resonance with an RF cavity assembled in a uniform magnetic field generated by a dipole magnet. In the development process, establishing highly efficient RI ion neutralization and RI atomic beam transport method is crucial because the ABR method itself is a well-established technique in the field of measuring nuclear electromagnetic moment of stable isotopes. In this study, we report on an offline laser cooling experiment conducted using singly charged ^{88}Sr ions toward sympathetic cooling for developing the neutralizer.

Figure 1 shows (a) the schematic of the setup and (b) corresponding energy levels of the $^{88}\mathrm{Sr}^{+}$ ion in the experiment. Laser pulses from a Nd: YAG laser (wavelength: 1064 nm, repetition rate: 1 Hz, pulse duration: 5 ns, intensity: ~2.5 mJ) were focused on a $\mathrm{SrTiO_3}$ plate (width × hight × thickness = 10 × 10 × 0.5 mm^3) using a convex lens with a mm focal length of 350 mm. The $^{88}\mathrm{Sr}^{+}$ ions produced by laser ablation were trapped at the center electrode (denoted as "C" in Fig. 1) in our linear Paul trap. For ion trapping, we introduced He as the buffer gas whose pressure was approximately 2.0×10^{-2} Pa for buffer gas cooling. After 200 s of buffer gas cooling, the buffer gas was quickly pumped out and pressure was maintained in the range of 10^{-6}–10^{-7} Pa. To produce laser-cooled $^{88}\mathrm{Sr}^{+}$ ions, we prepared two lasers. One was the cooling laser with

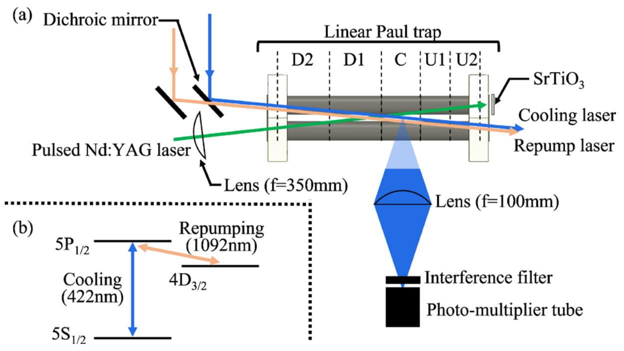

Fig. 1. (a)The schematic of the experimental setup. (b) The related energy levels of Sr ion in the experiment.

awavelength of 422 nm corresponding to the D1 ($5S_{1/2}$–$5P_{1/2}$) transition of the $^{88}\mathrm{Sr}^{+}$ ion. The other was the repump laser (wavelength: 1092 nm) used to pump $^{88}\mathrm{Sr}^{+}$ ions de-excited in the $4D_{3/2}$ metastable state to the $5P_{1/2}$ excited state. We irradiated the trapped ions with both lasers in a co-propagation configuration. The optical paths of the lasers were spatially combined using a dichroic mirror (Thorlabs, DMLP650). The laser powers of the cooling laser and the repump laser were 1.5 mW and 5 mW, respectively. The laser induced-fluorescence (LIF) emitted from $^{88}\mathrm{Sr}^{+}$ ions was collected using a convex lens with a focal length of 100 mm and detected using a photo-multiplier tube (Hamamatsu photonics, H16721-50). In order to reduce the background stray light, an interference filter with a bandwidth of 435 ± 20 nm (Edmund optics, Fluorescence band-pass filter) was mounted in front of the PMT. We obtained the LIF spectra by scanning the laser frequency of the cooling laser. So far, we have confirmed the onset of laser cooling effect by observing the narrowing of the line width and change of line shape under different RF voltages applied to the trap electrodes. Further optimization of the experimental parameters, such as the applied laser power, number of trapped ions, and so on, is under investigation.

Along with the development of the neutralizer, an RF cavity is being developed. We have designed the RF cavity, whose resonance frequency is approximately 3 GHz, as a prototype. Currently, preparations to evaluate the performace of the cavity using an Rb vapor enclosed glass cell is in progress now.

References
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