Measuring the stopping position of the energetic radioactive Rb beams in superfluid helium

M. Ito,[*1,*2] K. Imamura,[*1] S. Akimoto,[*1,*2] A. Takamine,[*1] K. Kikuchi,[*1,*2] R. Mitsuyasu,[*1,*2] T. Miwa,[*1,*2] A. Gladkov,[*1] M. Tajima,[*1] S. Go,[*1] M. Mukai,[*1] H. Endo,[*1,*2] S. Sasamori,[*1,*2] S. Takahashi,[*1,*2] Y. Fukuzawa,[*1,*2] M. Hase,[*3] K. Kawata,[*1,*4] A. Kitagawa,[*5] T. Wakui,[*5] H. Ueno,[*1] and Y. Matsuo[*1,*2]

We are developing a laser spectroscopy technique called OROCHI (Optical RI-atom Observation in Condensed Helium as Ion-catcher) to study the nuclear structure of short-lived and low-yield radioisotopes produced at accelerator facilities.[1)] In OROCHI, ion beams are injected into superfluid helium (He II), where the ions are slowed down, stopped in a small volume, and neutralized with nearly 100% efficiency. Nuclear spins/moments are derived from the measurements of the Zeeman/hyperfine splitting energy using the laser-radio frequency (RF)/laser-microwave (MW) double resonance. The feasibility of this method for measuring the hyperfine splitting energy with an accuracy of six orders of magnitude was demonstrated in off-line experiments conducted with Cs atoms.[2)] Therefore, this method is expected to be promising for short-lived unstable nuclei applications.

In previous online experiments,[1)] our group observed laser-RF double resonance spectra for $^{84\text{–}87}$Rb ion beams provided by the RIKEN RIPS at ∼60 MeV/nucleon. In the future, we plan to conduct measurements on low-yield unstable nuclear atoms, such as Ag, which are provided at energies as high as ∼300 MeV/nucleon at the RIKEN BigRIPS facility. To demonstrate the applicability of our method to high energy beams, we conducted experiments at the QST-HIMAC SB2 beamline, which can deliver a beam in excess of 350 MeV/nucleon. Among the single-valence-electron alkali atoms, Rb is one of the atoms whose behavior in superfluid helium is well studied. Furthermore, ^{84}Rb is estimated to be produced with the highest yield with a primary beam of ^{84}Kr according to the LISE++ simulation. This is why we employed ^{84}Rb as the target atom in our experiments. Because the number of atoms stopped in the observation region in He II is small, a LIF (laser-induced fluorescence) detection mechanism with high efficiency is needed. Therefore, the accurate measurement of the beam stopping position at HIMAC SB2 beamline is one of the important developments for the future double resonance measurement of atoms with unstable nuclei.

So far, in FY2019, we measured the beam yields of a high-energy ^{84}Rb beam at the HIMAC SB2 beamline using liquid nitrogen as a stopping material to estimate the number of stopped atoms in the possible LIF observation region.[3)] Then, in FY2021, we successfully observed the LIF of ^{84}Rb atoms in superfluid helium (He II) at the HIMAC SB2 beamline.[4)]

In FY2022, the number of measurement points was increased compared to the beam experiment conducted in FY2021 to more precisely determine the beam stopping position. Two measurement methods were performed as shown in Fig. 1. (1) measurement of the number of injected ions that penetrated the plastic scintillator placed in the center of the cryostat in normal fluid liquid helium and (2) measurement of LIF from atoms stopped in superfluid helium in the cryostat. A taper-amplified laser light[5)] was used for the irradiation of the cryostat center with a cross section size of 3 mm × 6 mm. These two types of measurements were performed while varying the thickness of the Al degrader every 100 μm to optimize the degrader thickness for efficient LIF collection from ^{84}Rb atoms. We are currently in the process of data analysis.

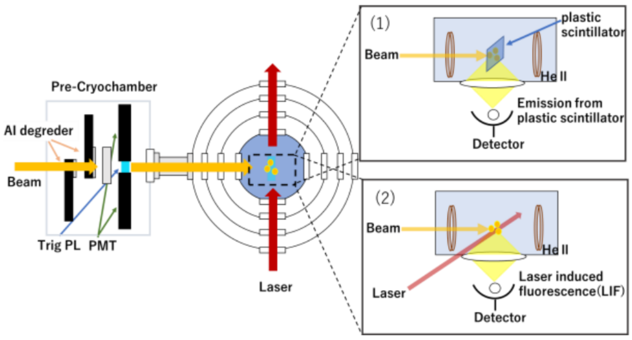

Fig. 1. Schematics of RI beam introduction to helium at HIMAC SB2 beamline.

*1 RIKEN Nishina Center
*2 Department of Advanced Sciences, Hosei University
*3 National Institute for Materials Science (NIMS)
*4 Center for Nuclear Study, University of Tokyo
*5 Institute for Quantum Medical Science, National Institutes for Quantum and Radiological Science and Technology (QST-iQMS)

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