Fluorescence detection of the highly energetic radioactive Rb beams stopped in an optical cryostat at HIMAC

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We are developing a laser spectroscopy technique called Optical RI-atom Observation in Condensed Helium as Ion- catcher (OROCHI) for the study of nuclear spins and moments. In the OROCHI experiment, we catch highly energetic ion beams in superfluid helium (He II) in our cryostat to neutralize them and conduct in-situ laser spectroscopy. We irradiate neutralized atoms with circularly polarized laser light to produce spin polarization and measure atomic Zeeman and hyperfine splitting energies using laser-radio frequency and laser-microwave double resonance method.

In a previous online experiment,[1] our group observed laser-rf double resonance spectra of $^{84-87}$Rb ion beams provided by the RIKEN RIPS at ~60 MeV/nucleon. It is known that the hyperfine structure constants of atoms in superfluid helium are larger than those of free atoms by 1%.[2,3] Therefore, based on our interest in the hyperfine anomalies of atoms in superfluid helium, we plan to measure the hyperfine splitting of the radioactive Rb, Ag, Cs, and Au isotopes, to which this method has not yet been applied.

In FY2019, we measured the beam yields of a higher energy ^{84}Rb beam at the HIMAC SB2 beam line in order to estimate the number of stopped atoms in the laser-induced fluorescence (LIF) observation region (ϕ2 mm $\times$ 5 mm).[4]

Because the result of the FY2019 experiment showed that the diameter of the beam stopping area was over 15 mm, we decided to expand the laser diameter and the observation area to as large as possible (2 mm $\times$10 mm $\times$ 5 mm). We here report the result of an experiment conducted in FY2021 using laser irradiation at HIMAC.

The ^{84}Rb beam produced in proton pickup reactions by a ^{84}Kr beam with 350 MeV/nucleon on a Be target of 12 mm thickness was passed through a 2.1 mm-thick Al degrader and a plastic in the pre-cryochamber, and stopped in He II at the center of the optical cryostat. In the pre-cryostat chamber, the number of beams was counted using a trigger plastic scintillator and two photomultiplier tubes. A laser beam amplified by a taper amplifier (TA) was shaped to the above-mentioned size and introduced to the cryostat. The laser light wavelength was 780 nm with a bandwidth of 2.9 nm (FWHM), which corresponds to the Rb D1 excitation line in He II. The fluorescence from the stopped atoms was collected by a LIF detection system, passed through the optical fiber, the wavelength was selected by a monochromator with a resolution of 8 nm set to 794 nm, and detected using a photomultiplier tube.

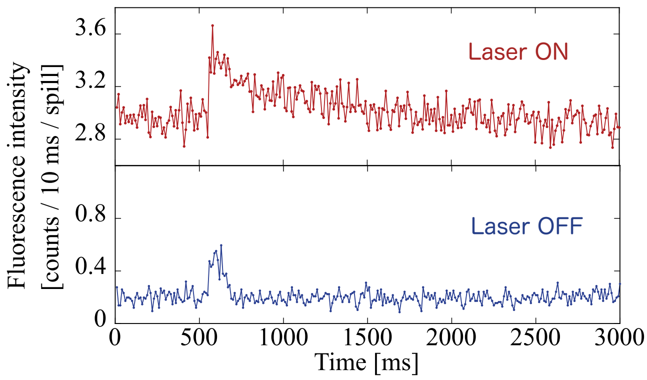

Fig. 1. Detected fluorescence intensity for laser on (upper) and off (lower).

Figure 1 shows the detected photon intensity for when the laser is turned on (upper) and off (lower). The incoming ^{84}Rb beam intensity was 3.7×10^4 particles per spill with a beam purity of 50% (the beam repetition cycle was 3.3 s). An evaluation revealed that 7% of the ^{84}Rb was stopped in the observation region from the previous experimental results[4] and a LISE^{++} calculation. The irradiated laser power was 200 mW. The upper plot clearly shows a long tail for the LIF based on remaining ^{84}Rb atoms compared with the beam-induced fluorescence in the lower plot. This tail stems from Rb atom diffusion caused by liquid helium flow and it shows a similar diffusion time of 1.77 s compared with the value (617 ms) that we measured in our previous experiment at RIPS.[5] The extended LIF decay time can be attributed to the expansion of the observation region being larger than that in the RIPS experiment.

We confirmed LIF detection of ^{84}Rb and conclude that OROCHI can be applied to the high energy beam from HIMAC SB2. Currently, we are in the process of analyzing the data.

References

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