Improvement of the signal-to-noise ratio of Rb D1 fluorescence in superfluid helium using picosecond time-resolved detection

H. Endo,[*1,*2] K. Ishii,[*3] K. Imamura,[*2] A. Takamine,[*2] Y. Matsuo,[*1,*2] T. Tahara,[*3] and H. Ueno[*2]

Our research group is developing a laser spectroscopy technique (OROCHI) for atoms in superfluid helium (He II). When atoms are injected into He II, the surrounding helium atoms are pushed out by the Pauli repulsion force.[1] The resulting vacuum region is referred to as an atomic-bubble. As the shape of the electron orbit of the impurity atom is deformed according to its energy state, the atomic bubble is also deformed following the shape change of the atomic orbit. The wavelengths of the atomic transitions for both the absorption and emission in He II are shifted from those in vacuum due to this deformation cycle.[2] It is estimated that the bubble deformation requires an order of a few picoseconds;[1] however, till date, the relaxation time has not been measured in the time domain in bulk He II. Because the emission wavelength is expected to change with the degree of the bubble deformation, we aim to determine the relaxation time of Rb atomic bubbles in He II through time-resolved emission measurements at different wavelengths.[3]

We have successfully observed laser-induced fluorescence (LIF) from Rb atoms of the D1 line (absorption center wavelength in He II: 778.0 nm) picosecond laser excitation and detection with time-correlated single photon counting (TCSPC).[3] To measure the fluorescence that is weaker at shorter wavelengths than the center wavelength, the signal-to-noise ratio must be increased. Here, we report the introduction of a metal cell with anti-reflection (AR) coated windows instead of a conventional quartz-cell to reduce the effect of scattered light from the excitation laser.

Figure 1 shows the experimental setup. We used a picosecond mode-locked Ti:sapphire laser (laser power: 100 mW, repetition rate: 80 MHz, pulse width: 1.6 ps, center wavelength: 778.2 nm) as the excitation laser. LIF was detected using an avalanche photodiode (APD) through a monochromator. The transmission of AR-coated windows is greater than 99.4% in the wavelength range of 780 nm to 830 nm. Because a large proportion of the background photons are considered to originate from the scattered light on the surface of the quartz cell, the introduction of the AR-coated windows is expected to reduce the scattered light, in the LIF detection efficiency.

Figure 2 shows the observed photon intensities as a function of delay time. The peaks in Fig. 2 are at the time of the excitation laser incidence, from which the Rb atoms decay along their spontaneous emission lifetime of 27 ns. Figure 2(a) shows the result of the LIF observation using the conventional quartz cell without AR coating. Both the LIF signal (blue) and a relatively large amount of laser-scattered light (orange) were observed. Note that the background also contains ambient light other than the laser in the environment and areas with a value of 0 correspond to the timing when the detection device can not count photons. Figure 2(b) shows that LIF increased when AR-coated windows were used, whereas laser scattered light was almost negligible. We plan to observe weaker emission on the short wavelength side through further improvement of the signal-to-noise ratio by increasing the data acquisition time.

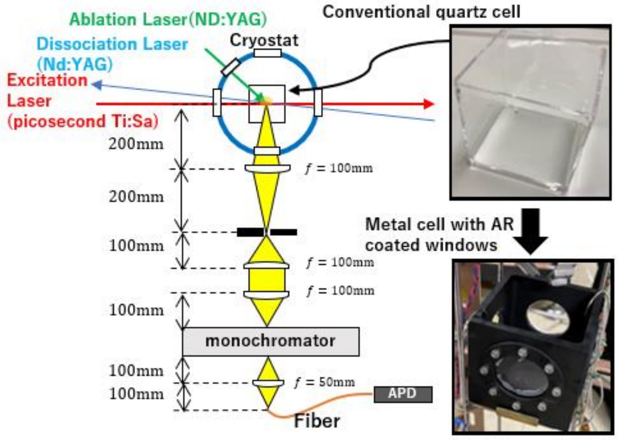

Fig. 1. Experimental setup of LIF detection.

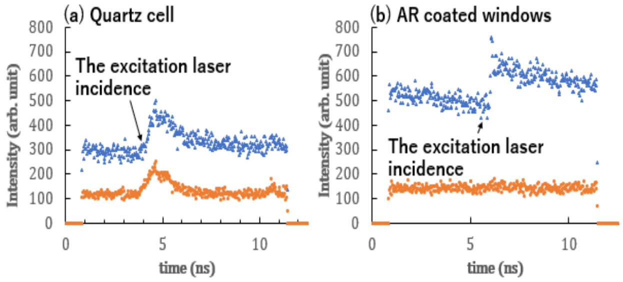

Fig. 2. Intensity detected by TCSPC using (a) a quartz cell, (b) AR coated windows.

References
1) B. Tabbert *et al.*, J. Low Temp. Phys. **109**, 653 (1997).
2) Y. Takahashi *et al.*, Phys. Rev. Lett. **71**, 1035 (1993).
3) Y. Takeuchi *et al.*, RIKEN Accel. Prog. Rep. **54**, 105 (2020).

[*1] Department of Advanced Sciences, Hosei University
[*2] RIKEN Nishina Center
[*3] RIKEN Center for Advanced Photonics