Wavelength shift of emission from Rb atoms in superfluid helium due to atomic bubble deformation

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Our research group is currently developing a laser spectroscopy technique referred to as OROCHI for studying 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. The shape of the electron orbit of the impurity atom is deformed according to its energy state, which causes the atomic bubble to also change shape. The wavelengths of the atomic transitions for both the absorption and emission in He II are shifted from those in vacuum owing to this deformation cycle.[2] The time dependent wavelength shift between the absorption and emission is referred to as the dynamic Stokes shift.

It is estimated that the bubble deformation requires a few picoseconds;[1] however, the relaxation time in bulk He II has not been measured in the time domain. The emission wavelength is believed to be gradually red shifted during the relaxation process (Fig. 1). This study aimed to determine the relaxation time of Rb atomic bubbles in He II through time-resolved emission measurements at different wavelengths.[3] In the previous phase of this report, we successfully observed laser-induced fluorescence (LIF) from Rb atoms of the D1 line (absorption peak wavelength in He II: 778.0 nm) through picosecond laser excitation and detection with time-correlated single photon counting (TCSPC).[3] Herein, we report the measurement results of the wavelengths being shorter than the emission peak wavelength (the D1 line) of the fully relaxed case. The experimental setup is described in Ref. 4). We used a picosecond mode-locked Ti:sapphire laser (laser power: 100 mW, repetition rate: 90 MHz, pulse time width: 1.6 ps, and center wavelength: 778.2 nm) as the excitation laser. LIF selected through a monochromator was detected using an avalanche photodiode (APD) through a monochromator. The AR-coated windows with a transmission exceeding 99.4% in the wavelength range of 780–830 nm were used in place of a standard quartz cell in a helium cryostat.

Figure 2 shows the photon intensities observed as a function of the delay time. To measure the wavelength shift of fluorescence, we changed the monochromator wavelength from D1 line to the shorter wavelength of 785 nm. Both the LIF signal (Fig. 2(a)) and a laser-scattered light (Fig. 2(b)) were observed. The peaks in Fig. 2(a) corresponded to the time of the excitation

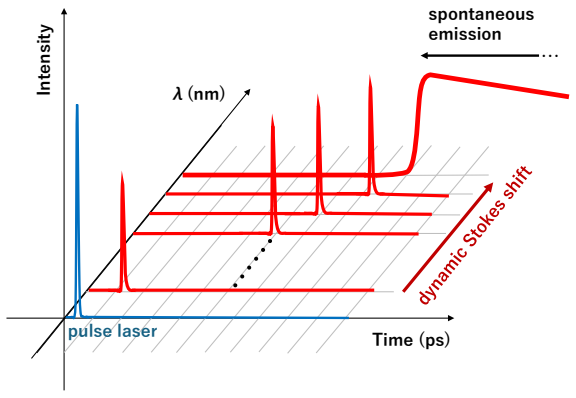

Fig. 1. Conceptional diagram of the dynamic Stokes shift.

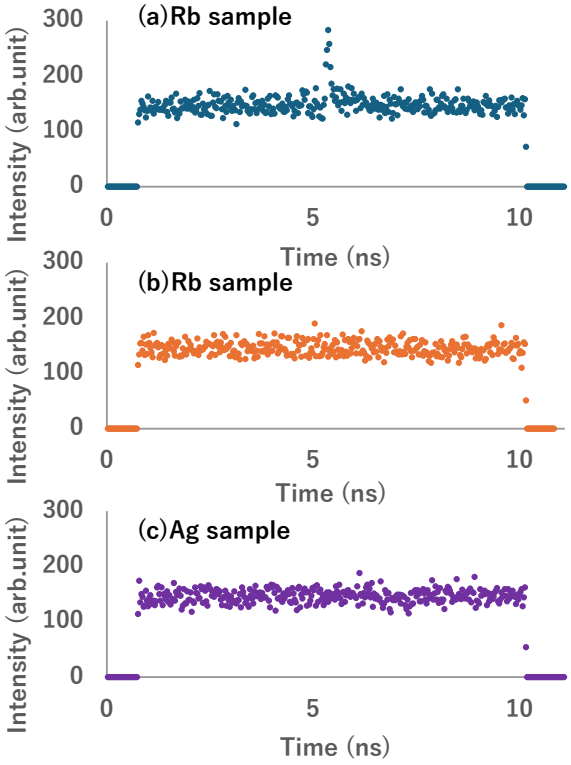

Fig. 2. TCSPC signals for Rb sample (a) with and (b) without ablation, and (c) for Ag sample ablation. Monochromator wavelength for three data points is 785 nm, which is shorter than the emission center wavelength of 793 nm.

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laser incidence. We tentatively assigned these peaks to fluorescence resulting from the Rb dynamic Stokes shift shown in Fig. 1 because the measurement device used in this study had a time resolution of 80 ps. To exclude the possibility that the peaks were caused by micro particles other than Rb atoms, we measured the fluorescence in the case of laser ablation of an Ag sample that did not have the same wavelength with the D1 line of Rb (Fig. 2(c)). Only photons from the laser scattered light were observed with the same intensity as that observed in Fig. 2(a). This means that fluorescence from Rb atoms during the bubble deformation. Notably, the background also contained ambient light other than the laser in the environment and the areas with a value of zero intensity corresponded to the timing when the detection device could not count photons. We will attempt to measure the atomic bubble relaxation times with a higher time resolution setup in the future.

References

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