Observation of Rb D1 fluorescence in superfluid helium using picosecond time-resolved detection

Y. Takeuchi,[*1,*2] H. Kuramochi,[*3] K. Ishii,[*4] K. Imamura,[*2] A. Takamine,[*2] M. Doi,[*1,*2] T. Yamamoto,[*1,*2] Y. Matsuo,[*1,*2] Y. Zempo,[*5] T. Tahara,[*4] and H. Ueno[*2]

Our research group is developing a laser spectroscopy technique (OROCHI) for atoms in superfluid helium (He II). When atoms are introduced into He II, the surrounding helium atoms are pushed out by the exchange (Pauli) repulsion force.[1)] The resulting vacuum region is called an atomic bubble. Because the shape of the electron orbit of an impurity atom is deformed according to its energy state, the atomic bubble is also deformed following the shape change of the atomic orbit. According to the Franck-Condon principle, the time required for the atomic transition is 10^{-15} s, which is much shorter than the time required for the bubble deformation therefore, it is considered that the bubble is deformed after the transition. The wavelengths of atomic transitions for both absorption and emission in He II are shifted from those in vacuum owing to this deformation cycle.[2)] The emission wavelength is considered to change in correspondence with the degree of bubble deformation.

It is estimated that the time required for the bubble deformation is of the order of a few picoseconds, but so far, the relaxation time has not been measured in the time domain in bulk He II. In this study, we aim to determine the relaxation time through time-resolved emission measurements at different wavelengths.

The OROCHI group is conducting a research project in collaboration with the Molecular spectroscopy laboratory to observe the relaxation time of Rb atomic bubbles in He II.[3)] Recently, we evaluated the performance of the time-correlated single photon counting (TCSPC) detection system that will be used for photo-detection in the relaxation time measurement. Observations were performed using an avalanche photodiode (APD) and time amplitude converter (TAC) as detectors. So far, our research group has used PMT for laser-induced fluorescence (LIF) photon counting of Rb atoms. This measurement will be the first LIF observation by the TCSPC system.

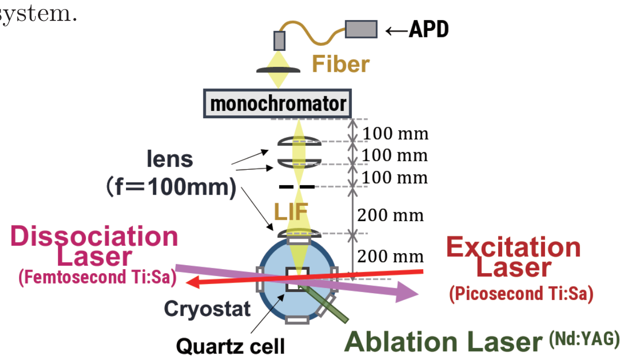

Fig. 1. Experimental setup of LIF detection.

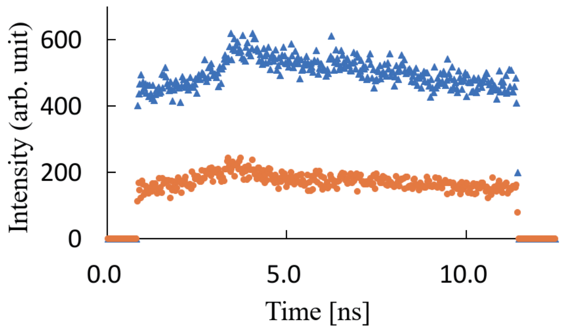

Fig. 2. Observed photon intensity as a function of delay time.

We first confirmed the fluorescence detection of the D1 line of the Rb atom (absorption center wavelength in He II: 778.0 nm). We used a picosecond mode-locked Ti:sapphire laser (laser power: 130 mW, repetition rate: 80 MHz, pulse width: 1.6 ps, center wavelength: 778.2 nm) as an excitation laser, and we observed LIF using the APD and acquired data using a TCSPC module (SPCM, Becker & Hickl GmbH) (Fig. 1). The Rb atoms were supplied by performing laser ablation on the RbCl sample installed above the observation area and laser dissociation to RbCl clusters in He II. The monochromator wavelength was set at 793 nm, which is the center of the emission line.

Figure 2 shows the result of the observation. The data plotted here are the observed photon intensities as a function of delay time. In this figure, the blue triangle is the total detected light when all lasers are turned on, and the orange dot is the scattered light when only the excitation laser is turned on. The fact that the peaks appear at the same position of the horizontal axis indicates that the excitation laser is scattered inside the cryostat and is slightly detected, although the monochromator wavelength is 15 nm longer than that of the excitation laser. The background also contains ambient light from sources other than the laser in the environment. The blue curve has a longer tail. This tail indicates the decay due to the lifetime of the Rb D1 emission. While the excitation pulse interval was 12.5 ns, the fluorescence lifetime was 27 ns therefore, atoms are excited by the next laser pulse before the emission vanishes and LIF photons are piled up. Therefore, the result agreed with the expectation that the spectrum would have the appearance of a sawtooth wave with repeated cycles of decay and rise due to excitation on top of the piled-up signal.

With the current data, the background scattered light is not small, and the setup should be adjusted so that more fluorescence light can be obtained. We are planning to make such improvements and move to the observation of weaker emission on the short-wavelength side.

*1 Department of Advanced Sciences, Hosei University
*2 RIKEN Nishina Center
*3 Institute for Molecular Science
*4 Molecular Spectroscopy Laboratory, RIKEN
*5 Department of Computer and Information Science, Hosei University

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