Introducing silver atoms into superfluid helium for precision laser spectroscopy

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In the Optical Radioisotope atom Observation in Condensed Helium as Ion-catcher (OROCHI), the short-lived and low-yield radioisotope (RI) atoms generated as high-energetic ion beams at accelerator facilities are stopped in a very narrow region in superfluid helium (He II) owing to the high density of He II. Laser-RF and laser-microwave (MW) double resonance spectroscopy for the atoms enable the determination of the nuclear spin and electromagnetic moment, respectively, through the measurements of Zeeman splitting and hyperfine splitting (HFS). Even without the high energy ion beams, by using the laser ablation technique, we can supply stable isotope atoms into He II. We have successfully measured HFSs of alkali atoms, ^{85,87}Rb and ^{133}Cs in He II.[1,2] Consequently, we found that the HFSs differ from the ones in vacuum by a little less than 1% and the achieved precision was sufficient even for the study of hyperfine anomalies. Currently, we are attempting to apply this method to group 11 atoms to verify whether a similar difference appears in atoms other than alkali metal elements. The HFS of the stable isotope ^{197}Au atom in He II was measured using this technique.[3] To discuss the differential hyperfine anomalies between isotopes, it is necessary to measure the HFSs of at least two isotopes. Silver is a good candidate with two stable isotopes, ^{107}Ag and ^{109}Ag, whose natural abundance ratio is almost 1:1. Previously, however, we faced difficulties in the preparation of Ag atoms in He II.[4] In this report, we describe how we solved this problem.

In offline experiments, atoms are introduced into He II by laser ablation and laser dissociation. As the first step, a metal sample placed above He II surface is ablated by a second-harmonic pulse of a Nd:YAG laser in the same manner as Ref. 4). Only Ag clusters, among the particles generated by the ablation, can be immersed into He II because the energy barrier for a thermalized atom is too high to penetrate the surface of liquid helium. Next, the clusters are required to be dissociated by a dissociation laser to produce atoms for the application of our spectroscopic technique. If dissociation occurs, highly excited atoms are generated and the plasma emission from those atoms should be observed. When we used a femtosecond Ti:Sa laser for Ag atoms, however, even plasma emission was not observed, as reported in Ref. 4).

It has been reported that Ag clusters in superfluid helium droplets have an absorption at the around 330–360 nm instead of 800 nm.[5] Considering this characteristic of Ag clusters, we used the third-harmonic pulse of Nd:YAG laser (wavelength: 355 nm, repetition rate: 20 Hz, pulse width: 5 ns, pulse energy: 8 mJ) for the dissociation. Consequently, plasma emission was observed. From this result, it was revealed that laser wavelength selection is crucial for the dissociation of Ag clusters, which was not the case for Rb, Cs, and Au clusters.

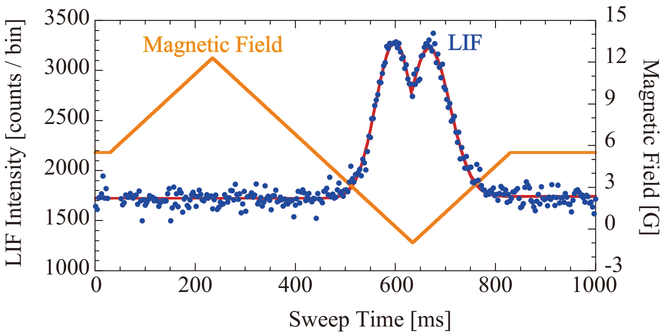

Fig. 1. Variation of LIF intensity with sweeping a magnetic field.

Next, we generated spin polarization by an optical pumping method. The Ag atoms in He II were optically pumped and polarized by irradiation with a circularly polarized pumping laser, which was the fourth-harmonic pulse of a neodymium-doped yttrium vanadium oxide (Nd:YVO_4) laser (wavelength: 335.5 nm, repetition rate: 20 kHz, pulse width: ~25 ns, pulse energy ~1.5 μJ). When optical pumping is achieved, the intensity of laser-induced fluorescence (LIF) due to the pumping laser is decreased because we optically pumped the atoms into a dark state. Spin polarization was confirmed by the observation of the variation in LIF intensity while sweeping a magnetic field (0–12 G). Figure 1 shows the decrease in LIF intensity when a sufficient magnetic field was applied. We preliminarily confirmed from this spectrum that we achieved a spin polarization of 50%. This result also leads to the conclusion that we successfully introduced Ag atoms into He II and observed LIF. The HFS measurement for Ag atoms in He II is in progress.

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