Introduction of silver atoms into superfluid helium using laser ablation method

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The Optical Radioisotope atom Observation in Condensed Helium as Ion-catcher (OROCHI) utilizes superfluid helium (He II) as a stopping material of energetic ion beams of a few tens to hundreds of MeV/nucleon. Injected ion beams are neutralized during the stopping process, and neutralized atoms are confined in a region of 1 to several mm^2 over a second. There He II also serves as a host matrix of laser spectroscopy of stopped atoms[1]. Since He II is optically transparent in wide frequency region from ultraviolet (UV) to radio frequency (RF), it is possible to apply laser-RF and laser-microwave (MW) double resonance methods to atoms in He II to measure Zeeman and hyperfine splitting energies. From these splitting energies, values of nuclear spin and electromagnetic moment can be deduced.

The measured hyperfine splitting (HFS) energies were slightly shifted from those in vacuum for alkali atoms such as Rb and Cs owing to the effect of surrounding helium atoms[2]. However, the observed energy shift $\triangle$ E/E $\lesssim$ 1% was sufficiently small to discuss nuclear structures. Moreover, the preliminary results indicated that this method provides a high-precision measurement of a magnetic dipole hyperfine structure constant to derive a hyperfine anomaly which gives information on the distribution of nuclear charge and magnetization. Recently, we started to apply the method to group 11 atoms such as Au and Ag.[3,4] The observed shift of the HFS energy for Au atoms was even smaller than that for alkali atoms. The investigation of HFS of Ag atoms will lead to more detailed information because Ag has two stable isotopes, which are necessary to determine a hyperfine anomaly whereas Au has only one stable isotope.

In offline experiments, we adopted a two-step laser sputtering technique to introduce atoms into He II (Fig. 1). As the first step, a sample material placed 1 cm above the He II surface is ablated by either a third-harmonic or a second-harmonic pulse of a neodymium-doped yttrium aluminum garnet laser (wavelength: 355 or 532 nm, repetition rate: 10 Hz, pulse width: 8 ns, pulse energy: ∼5 mJ). Clusters out of the sample material immerse into He II. Next, the clusters are dissociated by a femtosecond titanium-doped sapphire laser (wavelength: 800 nm, repetition rate: 500 Hz, pulse width: ∼120 fs, pulse energy: ∼200 μJ). The method was successful in the previous experiments for Rb, Cs and Au atoms. However, a sufficient number of atoms were not introduced into He II in the case of Ag. In this experiment, the ablation plasma produced by the ablation laser irradiation was observed, whereas the plasma produced by the dissociation laser irradiation was not observed. We concluded almost no introduction of Ag atoms in this condition because this dissociation laser was not effective for Ag.

One of the possible reasons for the difficulty in the dissociation by the dissociation laser could be the difference in absorption efficiencies between Ag particles and other species. The Ag sample has a high reflectance ratio in infrared and visible regions. To achieve the measurement of HFS for Ag, we plan to change the dissociation laser to a second-harmonic pulse of the femtosecond laser (wavelength: 400 nm, repetition rate: 500 Hz, pulse width: ∼200 fs, pulse energy: ∼100 μJ) and a XeCl excimer laser pulse (wavelength: 308 nm, repetition rate: 10 Hz, pulse energy: ∼10 mJ) because, generally, UV pulses dissociate particles more efficiently.

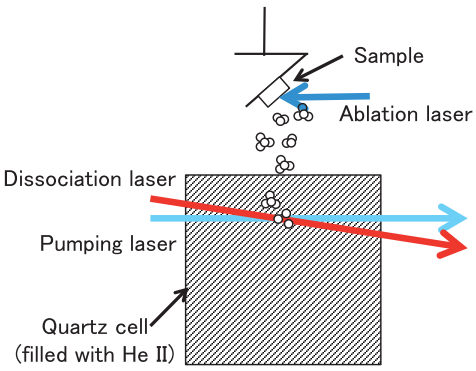

Fig. 1. Schematic of the two-step laser sputtering technique in our experimental setup. For details, see the text.

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