Searching optimum measurement conditions of the laser-microwave double resonance for the atoms stopped in superfluid helium

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We have developed a laser spectroscopic method named OROCHI (Optical RI-atoms Observation in Condensed Helium as Ion catcher) aiming at nuclear structure studies of unstable nuclei with low production yields and short lifetimes. In OROCHI, highly energetic ion beams are efficiently caught as neutralized atoms in superfluid helium (He II) owing to its high density. In addition, the absorption wavelength of atoms in He II is significantly blue-shifted due to the effect of surrounding He atoms while the emission wavelength is almost the same as that in vacuum. This enables us to detect photons emitted from the atoms with low background by removing the excitation-laser stray light. Consequently, we can measure Zeeman and hyperfine structure (HFS) splittings with a high sensitivity by applying laser-RF and laser-microwave (MW) double resonance methods to the atoms in He II.

So far, we have succeeded in observing the laser MW double resonance (LMDR) signals for 10^4 particles per second (pps) Rb ion beams with an energy of 66 A MeV.[1,2] However, the LMDR signal intensities were insufficient to realize measurements of the HFS splitting for lower intensity ion beams of less than 10^3 pps. In general, it is expected that the higher-power laser and MW irradiations lead to higher resonance peak heights in LMDR spectroscopy. In order to estimate the optimum measurement conditions, it is necessary to experimentally and quantitatively investigate the laser and MW power dependence of LMDR signal intensities. As a pilot study, we measured the laser power dependence of LMDR signal intensities for different MW powers using a glass cell containing Rb vapor with He buffer gas ("Rb cell").

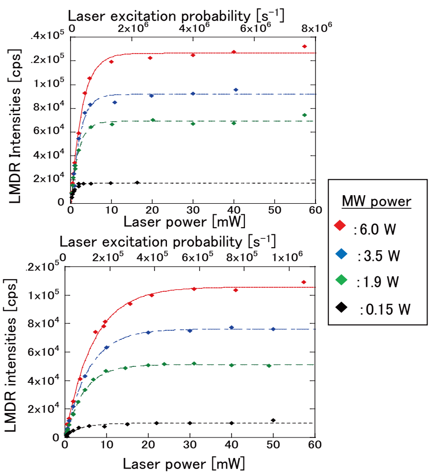

Fig. 1. Laser power dependence of LMDR intensities for different MW powers. The upper and lower figures show the result using Rb cells containing He buffer gas of 1.3×10^4 Pa and 1.0×10^5 Pa, respectively.

We irradiated the Rb atoms in the cell with a circularly polarized laser light (wavelength: 794 nm), and applied a magnetic field to the atoms, parallel to the laser axis, in order to generate and maintain spin polarization. On scanning the MW frequency, we observed a resonant peak at the MW frequency corresponding to the HFS splitting in the ground state of ^{85}Rb. We measured the LMDR signal intensities (defined as resonant peak heights in LMDR − background) for different laser powers when the MW powers were 6.0 W, 3.5 W, 1.9 W, and 0.15 W.

Figure 1 shows the laser power dependence of LMDR intensities for different MW powers with two different Rb cells containing 1.3×10^4 Pa and 1.0×10^5 Pa He buffer gas. The stronger the laser and MW we applied, the higher the LMDR intensities we observed. However, the intensities were saturated at a certain laser power. The higher He buffer gas pressure case required higher laser power for saturation. This means that the laser excitation cross section was decreased because of the effect of pressure broadening. The absorption spectral line width in 1.3×10^4 Pa He gas is of the order of 1 GHz and that in He II is of the order of 1 THz. Therefore, the laser excitation probability is estimated to decrease by the order of 10^3 in He II similar that in to Ref. 3). We can roughly estimate that the saturation of LMDR signal intensities needs 10^3 times more laser power density in He II compared to that in He gas. In the previous online experiment, we performed the experiment with 100 mW laser power (diameter: 2 mm), which corresponds to a laser excitation probability of 1.68×10^3 s^{-1}. Our present result implies that this value was too low to saturate the LMDR signal intensities, and that it was in a linearly increasing region at a low laser power, as depicted in Fig. 1.

The laser power can be increased without increasing the laser stray light by using the newly developed detection system.[4] Now, we can irradiate atoms with up to 1 W laser by using a Ti:Sa laser. By using a laser power of 1 W, the LMDR intensities are expected to be increased by a factor of 10.

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