Laser spectroscopy in higher-order interactions of atoms with optical near-fields

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Laser spectroscopy, especially reflection spectroscopy, is one of powerful techniques to investigate atoms and molecules in the proximity of dielectric surfaces [1, 2]. The reflected light is attenuated by vapor atoms absorbing the evanescent light which penetrates into the vapor by sub-wavelength scale from the surface as shown in Fig.1. It is extremely difficult to observe an attenuated total reflection (ATR) spectrum for optically thin medium since the interaction area of atoms with the evanescent field is appreciably smaller than that in free space. Therefore, the vast majority of observed spectra arise from electric dipole transitions using not only the reflection spectroscopy but also other optical near-field regimes. Consequently, optically forbidden transitions such as magnetic dipole and electric quadrupole transitions have been out of target of the spectroscopic study in optical near-fields.

Higher order interactions such as an electric quadrupole and magnetic quadrupole moments can be of interest because such transitions are sensitive to field inhomogeneity. For example, the interaction between a light field and an atomic system with an electric quadrupole transition from the initial state $|i\rangle$ to the final state $|f\rangle$ depends explicitly on the polarization vector $\hat{\mathbf{e}}$ and the wave vector $\mathbf{k}$ of the light, and has the form of $\hat{\mathbf{e}}\cdot\langle f|\mathsf{Q}|i\rangle\cdot\mathbf{k}$, where Q is the quadrupole tensor [3]. It is expected that the electric quadrupole transition strength can be enhanced using change in the wave vector.

We have experimentally studied transition strengths of the electric quadrupole transition of Cs atoms in an evanescent light field using ATR regime [4-6]. Reflection spectra are given from the Fresnel formulas as Ref.[1, 7] and theoretical calculations are good agreement with experiments in electric dipole transitions with fixed transition strengths. We compare experimental signal amplitudes with calculation ones with fixed transition strength in Fig.2, as a function of δ the angle of incidence from the critical angle being 43.38 degrees. The ratios increase with δ for both p and s polarizations and the

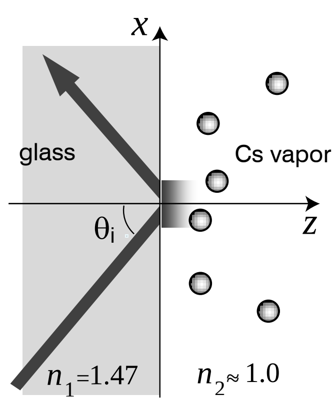

Fig. 1. Scheme of attenuated total reflection and the relevant evanescent field.

calculations with enhanced transition strengths are in good agreement with the experiments. Thus, the transition strengths are roughly proportional to $|k|^2$. The ratio of experiments for *p* polarization is slightly larger than the calculations for large δ. This small discrepancy may be effects of short range interactions from the surface. It is noted that the observed absorption, which is normally averaged over the evanescent field, may be affected by a small amount even though the short-range effects are substantial. Furthermore, it may be available to observe the novel effects close the surface using field enhancement and high sensitive schemes such as dressed photon [8] and laser-cooled atom techniques, respectively.

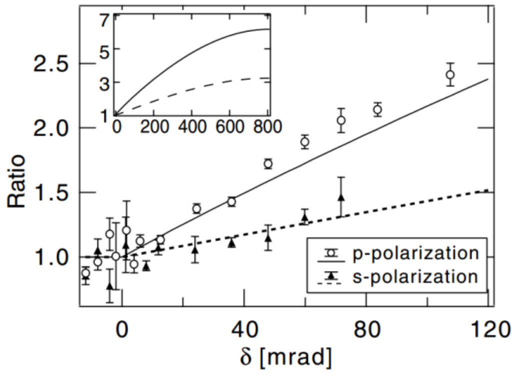

Fig. 2. Ratio of signal amplitudes between experiment and calculation with fixed transition strength, as a function of the angular detuning δ from the critical angle. The solid and dashed lines are calculated ratios with enhanced transition strengths.

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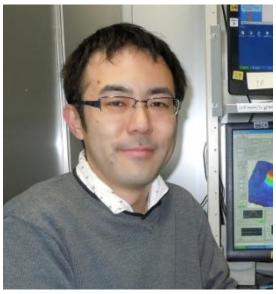

Satoshi Tojo has been working in the field of laser spectroscopy of atoms and molecules since 1997 in Graduate School of Engineering at Kyoto University. He received the Dr. E. degree in engineering science from Kyoto University for his work on reflection spectroscopy of alkali atoms in 2003. He researched ultracold atoms and molecules using laser-cooled Yb cloud as a Postdoc in Graduate School of Science at Kyoto University from 2004, and multi-component Bose-Einstein condensates of Rb atoms as an Assistant Professor at Gakushuin University from 2006. He is just starting up new lab as an Associate Professor at Chuo University from 2012. His present interest is higher order interactions of atoms and molecules with optical near-field.