Laser induced rescattering photoelectron spectroscopy of CO_2 molecule

Misaki Okunishi[*], Vandana Sharma[⋆], Yuta Ito[*], Robert R. Lucchese[♯], Toru Morishita[♮], Oleg I. Tolstikhin[†], Lars B. Madsen[‡], Kiyoshi Ueda[*]

[*] *Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, Sendai 980-8577, Japan*
[⋆] *Department of Physics, IIT Hyderabad, India*
[♯] *Department of Chemistry, Texas A & M University, College Station, Texas 77843-3255, USA*
[♮] *Department of Engineering Science, University of Electro-Communications, Chofu, Tokyo 182-8585, Japan*

[†] *National Research Center "Kurchatov Institute", Kurchatov Square 1, Moscow 123182, Russia*

[‡] *Lundbeck Foundation Theoretical Center for Quantum System Research, Department of Physics and Astronomy, Aarhus University, Denmark*

ueda@tagen.tohoku.ac.jp

Abstract: We have measured rescattering photoelectron spectra of CO_2 induced by ultrashort intense laser pulses at 1250 and 1300 nm and extracted field-free differential cross sections of electron scattering from CO_2^+ from the spectra.

OCIS codes: 020.2649, 020.0020

1. Introduction

When atoms and molecules are exposed to strong laser fields, parts of the electrons released by tunnel ionization will be driven back by the oscillating electric field into a recollision with their ion cores. The returning electron then can either recombine with the parent ion to release a high energy photon which is called as high harmonic generation (HHG), or it can elastically rescatter off the ion core. The structure retrieval from HHG has been very broadly studied in last few years [1]. In contrast to HHG, the retrieval of structural information with the rescattered electron is less studied. Rescattering photoelectron spectroscopy (RPS) is similar to photoelectron diffraction measurement in which the molecule under study acts as a source of electron and the scattering target. Recently Morishita et a [2] proposed that the RPS and HHG spectra are factorized into a simple product of two parts: one depends only on the target and the other on the laser pulse. This formula connects the angle-resolved RPS and field-free elastic differential cross sections (DCSs) of an electron scattering from a target ion. Since DCSs by free electrons are the conventional methods for investigating the structure of atoms and molecules, this method offers the possibility of determining their structure using lasers, with the benefit of achieving femtosecond temporal resolutions offered by the short laser pulses. We have recently reported experimental study on RPS of O_2 and CO_2 measured by 800 nm wavelength laser pulses having 100, 35 and 10 fs durations, and extracted differential cross-section (DCS) of electron scattering from target ions [3]. In the present study, we extended the measurements to longer wavelength laser pulses at 1250 and 1300 nm with 100 fs pulse duration for CO_2. We found that the angular DCS extracted from RPS at 800nm in our previous study and the RPS at 1250 and 1300 nm wavelength in the present experiment are quite similar which indicates that the extracted DCS are independent of the wavelength and the pulse duration.

2. Experimental

We have measured angle-resolved RPS spectra of randomly oriented CO_2. The electron spectra are measured using a 264 mm long electron time-of-flight spectrometer, Emitted electrons are detected at arbitrary angles with respect to the laser polarization, which is controlled by a rotating half-wave plate. Infrared laser pulses at 1250 and 1300 nm wavelength are generated by an optical parameteric amplifier from 100 fs titanium-Sapphire laser pulses at 800 nm. CO_2 gas is introduced as an effusive beam into a vaccum chamber, where the laser pulses are focused by a spherical mirror.

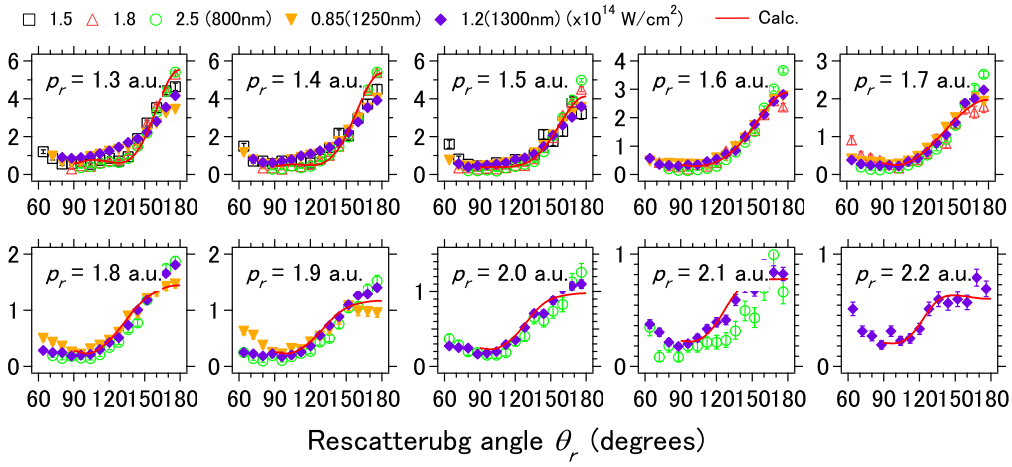

Fig. 1. Experimentally extracted DCSs of electron scattering from CO_2^+ ion from RPS at different laser parameters, and theoretical calculation of the DCSs

3. Results and discussions

The extraction procedure of the DCSs from the RPSs for molecules are shown elsewhere [3]. The key point is the factorization of the rescattering electron yield into a product of the electron scattering DCS and a "wave packet" representing the momentum distribution of the returning electron ($S(\mathbf{p})$) as

$$S(\mathbf{p}) = \bar{W}(p_r)\bar{\sigma}(p_r, \theta_r), \tag{1}$$

where $\bar{\sigma}(p_r, \theta_r)$ is the DCS convoluted over the alignment angles of the molecule with respect to the laser polarization direction, and p_r and θ_r represent the momentum of rescattered electron at the time of recollision. After the recollision, the backward-rescattered electron receives additional drift momentum ($\mathbf{A_r}$) from the electric field, and then is ejected as a high-energy plateau photoelectron . Here the ratio of the absolute value of the recollision momentum (p_r) to that of the drift momentum (A_r) is approximated as 1.26 (= p_r/A_r) assuming a monochromatic field. Since the "wave packet" does not depend on the scattering angle (= $\bar{W}(p_r)$), angluar DCSs can be extracted from the RPS spectra as a function of p_r.

Fig. 1 shows experimentally extracted DCSs from the RPS measured by 800 nm, 1250 nm, and 1300 nm laser pulses, and theoretical calculation of the field-free DCSs of electron scattering from CO_2^+ ion. In the calculation, we use the angle-dependent ionization rate calculated from the weak-field asymptotic theory [4, 5]. We found that the experimental DCSs extracted from several RPS with different laser wavelength and pulse duration agree well in the momentum range of 1.3 a.u. $\sim$ 2.0 a.u. Furthermore, the DCS extracted from RPS and the theoretical calculation also show good agreement as a function of the electron momentum. This indicates the validiy of the present extraction procedure of the DCSs from RPS based on the factorization formula.

acknowlegement

We would like to thank Hiromichi Niikura, Kozo Shimada for invaluable contributions to the present study.

References

1. S. Patchkovskii et al., Phys. Rev. Lett. **97**, 123003 (2006), and ref. therein.
2. T. Morishita ,A.-T. Le, Z. Chen, and C.D. Lin, Phys. Rev. Lett., **100**, 013903 (2008).
3. M. Okunishi, H. Niikura, R. R. Lucchese, T. Morishita, and K. Ueda, Phys. Rev. Lett. **106**, 063001 (2011).
4. O. I. Tolstikhin, T. Morishita, and L. B. Madsen, Phys. Rev. A **84**, 053423 (2011).
5. L. B. Madsen, O. I. Tolstikhin, and T. Morishita, Phys. Rev. A **85**, 053404 (2012).