Photoelectron Angular Distributions in EUV+IR Two-Color Near-Threshold Ionization of Ne and He

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Abstract: Photoelectron angular distributions (PADs) dependence on the time-delay between EUV-FEL and IR laser pulses is observed for ionization of Ne. PADs for Rydberg excited one- and two-IR photon above-threshold ionization of He are measured.
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1. Introduction

Investigation of nonlinear multiphoton processes in the atomic and molecular systems at the extreme ultraviolet (EUV) energy range has become feasible due to the advent of free electron lasers (FELs) and high-harmonic generation (HHG) sources. Within these processes, the two-color multiphoton ionization of atoms attracts ever increasing attention [1-3]. In this process, first an atom is excited to high Rydberg or continuum states by typical photon energies of EUV-FEL or HHG. Then the photons from infrared (IR) laser ionize the Rydberg atom or add energy to the photoelectron giving rise to so-called above-threshold ionization (ATI). Such experiment is especially attractive for studying near-threshold ionization where the emitted electron has low energy. Thus, the complex dynamics is determined by the interaction with both radiation fields and with the ionic core. During this type of ionization of an atom, the produced continuum wave associated with the ejected electron is the superposition of different partial waves. Such an individual partial wave contains its own orbital angular momentum, intensity and phase. Thus, the photoelectron angular distribution (PAD) produce due to the interference of the continuum partial waves provides important information about the photoionization processes. In this work, we have measured PADs for IR pulse intensity dependent ionization of Rydberg excited He atoms. Also, we have investigated dependence of PADs on the time delay between EUV FEL and IR laser pulses for near-threshold ionization of Ne atoms.

2. Experiment

Experiments were carried out using the Spring-8 Compact SASE Source (SCSS) test accelerator [4] and an IR laser in a pump-probe scheme combined with a velocity map imaging (VMI) spectrometer [5]. Figure 1 shows the schematic of experimental setup. The linearly polarized EUV pulses provided by the SCSS FEL had duration of 30 fs at 30 Hz repetition rate. During the experiments, the average pulse energy of the FEL was 1.4 μJ. At the interaction region, the diameter of the FEL beam was ~15 μm. The EUV photon energies were set to 21.3 and 24.3 eV, respectively, below and above the ionization energy of Ne atom. For He experiments EUV photon energy was set to just below the ionization energy at 24.3 eV. A Ti:Sapphire laser was used to generate 800 nm IR pulses which were electronically synchronized to the EUV pulses. The IR pulses intersected the EUV pulses at an angle of ~ 1^0. Their linear polarization direction nearly coincides with that of the EUV pulses. The temporal jitter between the EUV and IR pulses for a measurement of a short period was ~0,5 ps. The photoelectrons emitted due to simultaneous action of EUV and IR pulses were accelerated through a VMI spectrometer and detected by a microchannel plate detector combined with a phosphor screen.

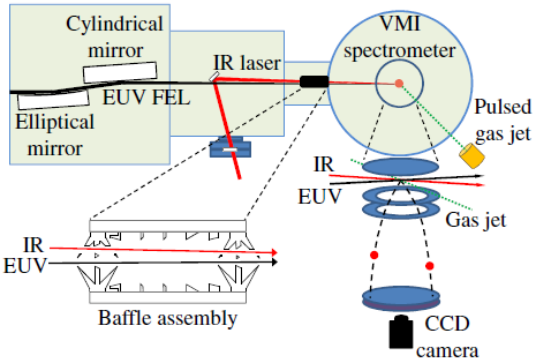

Figure 1. Schematics of the experimental setup

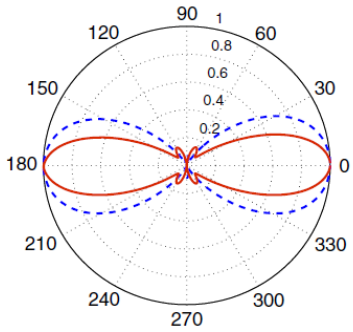

Figure 2. PADs for one IR photon (blue dashed line) and two IR photon (red solid line) ionization of He.

3. Results and discussions

We have measured photoelectron energy distributions of Rydberg excited He atoms at two different two different IR laser intensities corresponding to pulse energies 0.063 and 0.63 mJ. Photoelectron distribution obtained at lower intensity shows only peaks arise due to one IR photon ionization of Rydberg states with n= 4-7. When the IR field increased to higher intensity, a group of additional peaks arises which corresponds to two IR photon ATI of Rydberg excited states of He. Figure 2 shows the comparison of PADs for one IR photon and two IR photon ionization from the n=5 Rydberg state of He. The figure shows that the PAD for two IR photon ionization is narrower than that for one IR photon ionization. The PAD for two IR photon ionization is described by three asymmetry parameters. Associated large third order asymmetry parameter clearly indicates that the PAD for two IR photon ionization contains the contributions from higher *p* and *f* partial waves. For lower IR intensity, we have obtained phase shift difference and amplitude ratio which agree well with the previous measurements [2, 3] confirming the PADs are described by *s* and *d* partial waves.

From the relative intensity of two-photon ATI to the one-photon ionization of the Rydberg excited states of He, we estimated the effective intensity of the IR pulse to be 0.6 x 10^{12} W/cm^2. Using the same laser intensity, we have measured PADs for EUV FEL and IR laser pulse sideband ionization of Ne [6]. The EUV photon energy used in this case was 24.3 eV. Occurrence of sideband photoelectron peaks signifies that the EUV FEL and IR laser pulses were completely overlapped. We have also measured PADs for one IR photon ionization of EUV excited Rydberg states of Ne for EUV and IR pulses completely overlapping and non-overlapping conditions. Solutions of the time-dependent Schrödinger equation indicate that the PADs strongly depend on the time delay between EUV and IR pulses. The experimental results fully confirm the theoretical calculation, illustrating that the measurement of the time-delay dependence of the PAD provide a tool for investigating the fundamental problem of the relative importance between the resonant and nonresonant pathways in the two-color two-photon processes [6]. Observation of such pulse delay dependent photoionization process may give impact on the broad area of atomic and molecular physics as well as surface and condensed-matter physics.

4. References

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