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sub-10 fs レーザーパルスによる レーザーアシステッド電子散乱の観測

東大院理
○熊倉洸太，石川源基，歸家令果，山内薫

Observation of laser-assisted electron scattering with sub-10 fs laser pulses

○Kota Kumakura, Motoki Ishikawa, Reika Kanya, and Kaoru Yamanouchi
School of Science, The University of Tokyo, Japan

[Abstract] We observed laser-assisted elastic electron scattering (LAES) processes induced by sub-10 fs laser pulses. By the pulse compression using a gas-filled hollow-core fiber and negative dispersion mirrors, near-IR Ti:sapphire laser pulses (λ = 800 nm, Δt = 40 fs) were compressed to few-cycle laser pulses (Δt = 7.4 fs). An electron beam with the kinetic energy of 1 keV collided with Xe atoms under the presence of the few-cycle laser field, and the scattered electrons were analyzed by an angle-resolved time-of-flight type electron analyzer. The LAES signals with a one-photon energy gain appeared in an energy spectrum of the scattered electrons.

[Introduction] In electron-atom elastic collision processes in a laser field, electrons can gain or lose their energy by multiples of the photon energy. This scattering process is called laser-assisted elastic electron scattering (LAES). It was demonstrated recently that the LAES processes induced by femtosecond laser pulses (Δt = 200 fs) can be used for investigating ultrafast responses of electrons within an atom in an intense laser field [1] as well as for determining instantaneous geometrical structures of molecules [2]. Because the temporal resolution of the LAES measurements is determined by the laser pulse duration, LAES measurements with much shorter laser pulses have been awaited for probing ultrafast responses of atoms and molecules. In the present study, we constructed an optical setup for generating sub-10 fs laser pulses, and performed LAES measurements with sub-10 fs laser pulses by an angle-resolved time-of-flight (TOF) type LAES apparatus.

[Experiment] Figure 1 shows the optical setup for the generation of sub-10 fs pulses, in which the pulse compression is achieved using a gas-filled hollow-core fiber [3]. The output of a Ti:sapphire laser system (λ = 800 nm, 5 kHz, Δt = 40 fs) transported through a beam-pointing stabilization module was focused into the hollow-core fiber (1.0 m in length, 330 μm in inner diameter) filled with an Ar gas (0.5 atm), so that the spectral bandwidth was broadened by the self-phase modulation. The group delay dispersion induced by the self-phase modulation was compensated by chirped mirrors and wedged fused silica plates. The compressed pulses were characterized by a two-dimensional spectral interferometer (2DSI).

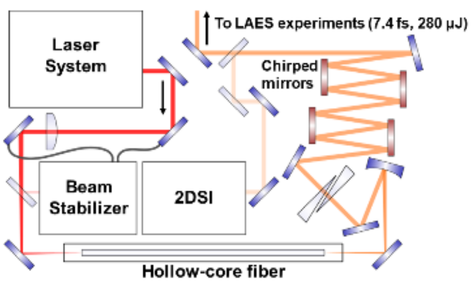

Fig. 1. The schematic of the optical setup generating sub-10 fs laser pulses.

LAES measurements with the sub-10 fs laser pulses were performed by an apparatus equipped with an angle-resolved TOF type electron analyzer, and electron signals of LAES by Xe atoms were recorded as a function of the kinetic energy (E) and the two-dimensional (2D) scattering angles, *i.e.*, the polar angle (θ) and the azimuthal angle (ϕ). The schematic of the LAES apparatus is shown in Fig. 2. The electron beam pulses with the kinetic energy of 1 keV, the linearly polarized sub-10 fs laser pulses, and the Xe gas beam cross each other at right angles. The laser pulses whose polarization direction is parallel to the Xe gas beam axis are focused at the crossing point so that the light field intensity becomes $I = 5.2\times10^{11}$ W/cm^2. The scattered electrons are introduced into the angle-resolved TOF type electron analyzer composed of two electromagnetic lenses and an einzel lens. In the analyzer, the electrons are decelerated first to around 5 eV for lengthening the TOF, and then, accelerated again to be detected by a time-and-position sensitive detector. From the detected position and the TOF of the electrons, E, θ, and ϕ are determined.

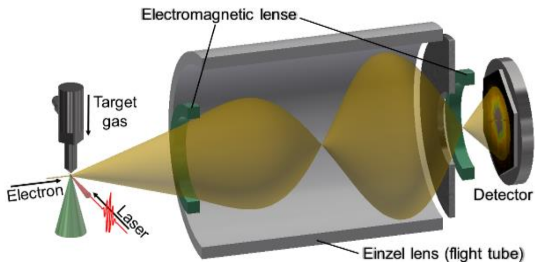

Fig. 2. The schematic of the angular-resolved time-of-flight type LAES apparatus.

[Results and Discussion] Figure 3(a) shows the power spectral density of the compressed pulses measured by the 2DSI. The central wavelength was found to be 740 nm. The spectrum covers the wavelength range between 630 nm and 870 nm. The temporal profile of the recorded laser pulses is shown in Fig. 3(b), and the pulse dutation was determined to be 7.4 fs (FWHM)

Figure 4(a) shows the kinetic energy spectrum of the scattered electrons measured with the laser field (red filled circles) and that measured without laser field (black open squares), both of which were obtained after the accumulation for 13 hours. Figure 4(b) shows the difference spectrum obtained by the subtraction of the spectrum without the laser field from that with the laser field. The signals appearing at the red shaded area in Fig. 4(b), which corresponds to the bandwidth of the laser pulse can be assigned to the LAES signals of one-photon energy gain induced by the 7.4 fs laser pulses.

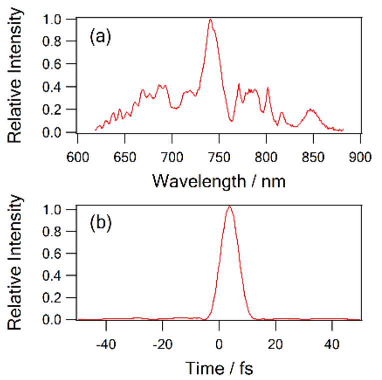

Fig. 3. (a) The power spectral density of few-cycle laser pulses. (b) The temporal intensity profile of few-cycle laser pulses.

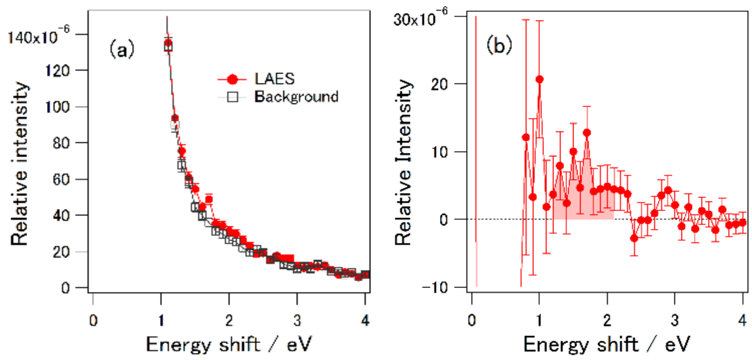

Fig. 4. (a) Energy spectra of LAES by Xe: Electron signals measured with the laser field (red filled circles) and those measured without the laser fields (black open squares). (b) The difference spectrum obtained by the subtraction of the spectrum without the laser field (the open squares in Fig. 4(a)) from that with the laser field (the filled circles in Fig. 4(a)).

[References]

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