PAPER • OPEN ACCESS

Attosecond delays in photoionization studied with coherent-controlled FEL

To cite this article: D You *et al* 2020 *J. Phys.: Conf. Ser.* **1412** 112006

Attosecond delays in photoionization studied with coherent-controlled FEL

D You[1], K Ueda[1 *], O Tugs[2], Y Orimo[2], T Sato[2], K L Ishikawa[2], E V Gryzlova[3], E I Staroselskaya[3], A N Grum-Grzhimailo[3], P A Carpeggiani[4], T Csizmadia[5], M Füle[5], N G Harshitha[5], G Sansone[6], P K Maroju[6], M Meyer[7], T Mazza[7], A D'Elia[8], C Callegari[9], M Di Fraia[9], O Plekan[9], L Giannessi[9,10], E M Allaria[9], G De Ninno[9,11], M Trovò[9], L Badano[9], B Diviacco[9], D Gauthier[9], N S Mirian[9], G M Penco[9], P R Rebernik[9], S Spampinati[9], C Spezzani[9], G Gaio[9] and K C Prince[9,12]

[1] Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, Sendai, 980-8577, Japan
[2] The University of Tokyo, Tokyo, 113-8656, Japan
[3] Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, 119991, Russia
[4] Technische Universität Wien, Wien, 1040, Austria
[5] ELI-ALPS, Szeged, 6728, Hungary
[6] The University of Freiburg, Freiburg, 79085, Germany
[7] European XFEL, Schenefeld, 22869, Germany
[8] The University of Trieste, Trieste, 34127, Italy
[9] Elettra Sincrotrone Trieste, Basovizza, 34149, Italy
[10] ENEA Centro Ricerche Frascati, Frascati, 00044, Italy
[11] Laboratory of Quantum Optics, University of Nova Gorica, Nova Gorica, 5001, Slovenia
[12] Molecular Model Discovery Laboratory, Swinburne University of Technology, Hawthorn, 3122, Australia

Synopsis When an electron is ejected from an atom after absorption of a photon, the photoelectron wave packet has an extremely short group delay between the photon absorption and the electron emission. This interval, called the Eisenbud-Wigner-Smith delay, is on the order of a few attoseconds. Here, we present a new method to measure the photoemission delay, using coherent-controlled free-electron laser pulses.

The age of attosecond physics was ushered in by the invention of methods for probing samples on a time scale less than femtoseconds [1], and currently, many such ultrafast phenomena are being investigated. Photoemission is one such process, which has attracted much interest, particularly regarding the photoemission delay between the absorption of a photon and the emission of a photoelectron, which is called the Eisenbud-Wigner-Smith (EWS) delay [2].

Here, we present a new method to measure the EWS delay. In this method, we use short wavelength EUV light, consisting of phase-locked fundamental (ω) and second harmonic (2ω) pulses. It requires extremely accurate phase control (few attoseconds). Such fine control is available from the Italian free-electron laser (FEL), FERMI [3]. We report the measurement of the EWS delay difference between one- and two-photon ionizations using atomic Ne, as a demonstration of the new method. We carried out the measurement at the LDM beam-line, FERMI. The photon energies were set to 14 eV, 16 eV, and 19 eV for ω, which are below the Ne ionization threshold, while the second harmonics 2ω are above the threshold. Phase-locked bichromatic light beams crossed the atomic gas jets of He-Ne mixtures (We used the He for a calibration). A velocity map imaging spectrometer measured ejected electrons. The target processes are the photoionizations of Ne by one or two photon(s): $Ne + 2\omega \rightarrow Ne^+ + e^-$,

$Ne + \omega + \omega \rightarrow Ne^+ + e^-$ (non-resonant).

Because these electrons emitted by the two different pathways interfere with each other, the electron angular distribution is correlated to the difference of the unique phase shifts. The phase shift difference can be extracted by scanning the optical phase difference between ω and 2ω FEL pulses. The EWS delay τ is defined as the derivative of phase shift η with respect to the photoelectron kinetic energy E: $\tau = \hbar \cdot \partial\eta/\partial E$ [2]. We have measured the phase shift differences at several photon energies and found their slope to estimate the delay difference, in order to demonstrate the feasibility of the method.

References

[1] Krausz F *et al* 2009 *Rev. Mod. Phys.* **81** 163
[2] Pazourek R *et al* 2015 *Rev. Mod. Phys.* **87** 765
[3] Prince K C *et al* 2016 *Nat. Photonics* **10** 176

* E-mail: kiyoshi.ueda@tohoku.ac.jp