Polarization Control of Isolated Attosecond Pulses

Pei-Chi Huang^{1,2}, Jen-Ting Huang¹, Po-Yao Huang¹, Chih-Hsuan Lu^{1,2}, A. H. Kung^{1,2}, Shang-Da Yang¹, Ming-Chang Chen¹

¹Institute of Photonics Technologies, National Tsing Hua University, Hsinchu 300, Taiwan ²Institute of Atomic and Molecular Sciences, Academica Sinica, Taipei 100, Taiwan i9xas9966514@gmail.com

Abstract: By adjusting the ellipticity of counter-rotating polarized few-cycle pulses for non-collinear high order harmonic generation, we obtain full control of polarization states of isolated attosecond pulses for the first time.

Ultrafast Extreme ultraviolet (EUV) beams carrying spin angular momentum are currently thoroughly studied for their applications for investigating the structural, electronic, and the magnetic properties of materials, discriminating between enantiomers as well as working out how chiral molecules interact. Such light sources are already been produced by few free-electron laser facilities [1]. Although it's powerful, the pulse duration of FEL is typically tens of femtoseconds and the large-scale facilities with high costs results in a limited number of beamlines.

High harmonic generation (HHG) driven by femtosecond lasers makes it possible to capture the fastest dynamics of molecules and materials in attosecond (10^{-18} s) scale. In 2016, we experimentally demonstrated the generation of isolated circularly polarized attosecond pulses by non-collinear HHG driven by two few-cycle circularly polarized counter-rotating pulses (~3.6 fs, 1.4 optical cycles, generated by the MPContinua [2]). This produces a pair of HHG supercontinua beams, one with left-circular and one with right-circular polarization, and spanning photon energies from 25 to 40 eV with a Fourier limit pulse duration of 190 as [3].



Fig. 1 (a) Schematic of the experimental setup. The inset shows the electric field distribution on the focal plane - local E-field vectors rotating crossing the transverse direction \hat{x} .

In this work, we further propose and experimentally demonstrate full polarization control of isolated attosecond pulses ϵ_{atto} , by adjusting the ellipticity of two counter-rotating driving pulses, ϵ_{fund} . Importantly, the polarization state of the attosecond pulses was fully analyzed with an EUV polarimeter, which unambiguously determines the ellipticity and helicity of attosecond pulses. Fig. 2A shows the polarization states of the isolated circularly, ellipticaly and linearly polarized attosecond pulses that have been produced.

To control the ellipticity of attosecond pulses, two elliptically polarized few-cycle fundamental beams with the same ellipticity ϵ_{fund} but opposite helicity are prepared and focused into a gas jet in a non-collinear geometry (Fig. 2). At the focal plane, z=0, the combination of electric field E_{focus} becomes

$$2[\epsilon_{fund}\cos(kx\sin\theta)\hat{x} - \sin(kx\sin\theta)\hat{y}]e^{-(t/\tau)^2 - i\omega t}$$

E-field vectors, rotating crossing the transverse direction \hat{x} with a period of $2\pi/(k\sin\theta)$, were created. The local E-field of each position oscillates linearly as a HHG local emitter and superposes two elliptically polarized EUV beams in the far field. As a result, the ellipticity ϵ_{atto} of the attosecond pulses can be controlled with the fundamental ellipticity ϵ_{fund} as presented in Fig. 2. Moreover, this non-collinear scheme also supports generation of isolated attosecond pulses, when driven by few-cycle pulses. This has been theoretically and experimentally demonstrated [3,4].



Fig. 2 (a) The polarization states, Stokes parameters, of isolated attosecond pulses have been generated, characterized, and marked on the Poincaré surface (blue circle and purple square represent positive and negative helicity, respectively), while one HHG pulse driven by single linearly polarized fundamental was also measured (gray triangle and inset VI). (b) Blue and purple (yellow) lines representing attosecond (fundamental) pulse intensity varied with the axis of a polarization analyzer, together with one table giving ellipticity relations between them.

REFERENCES

- E. Allaria et al., Phys. Rev. X 4, 041040 (2014); M. Suzuki et al., 1. Journal of Synchrotron Radiation 21, 466 (2014); A. A. Lutman et al., Nature Photon 10, 468 (2016); C. Spezzani et al., Phys. Rev. Lett. 107, 084801 (2011).
- C.-H. Lu et al., Optica 1, 400 (2014) 2.
- P.-C. Huang et al., in CLEO2016, p. JTh4A.7 3.
- 4 C. Hernandez-Garcia et al., Phys. Rev. A 93, 043855 (2016)