Generation of Angularly-Dispersed, Circularly Polarized High Harmonics via Non-Collinear Mixing of Intense, Ultrafast Laser Fields

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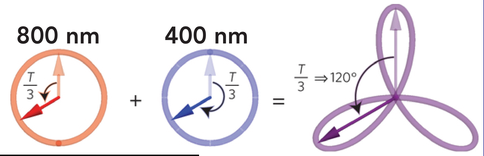
Abstract

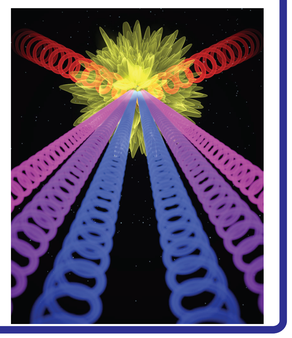
• **Motivation** - The recent realization of bright, circularly polarized (CP) extreme ultraviolet (EUV) light via high harmonic generation (HHG) has opened a new realm of experimental physics previously unaccessible to table-top scale systems.[1] However, the resulting CP harmonics are collinear with the intense driving beams, which require the use of expensive filters and optics to remove the fundamental fields.

• Experiment - We generate, for the first time, angularly isolated EUV beams of circularly polarized high harmonics via non-collinear mixing of circularly polarized driving laser fields.

• Results -

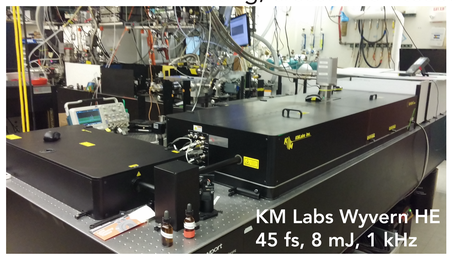
1. Demonstrated the first generation of angularly separated, CP HHG beams, NCG-HHG.
2. Measured the magnetic circular dichroism (MCD) of a 20 nm Fe film.

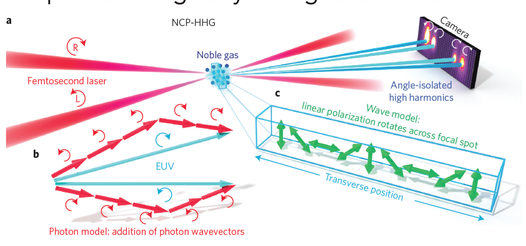




NCG-HHG Experiment

• Counter-rotating, crossed femtosecond pulses = Angularly diverged CP-HHG!





• Wyvern HE produces 45 fs pulses centered at 795 nm.

• A Mach-Zender interferometer creates and recombines the two pulses in a noble gas jet (Ne, Ar, or Xe) in a noncollinear geometry.

• Driving laser polarizations were controlled via half and quarter achromatic waveplates in each arm.

• Second and third harmonic generated in 200 μm thick beta barium borate (BBO) crystals.

• Pulse energies were ~ 200 - 400 μJ in each beam.

• The two noncollinear beams were crossed with a half-angle separation of 20 - 50 mrad.

References

[1]**Hickstein, D.D. et al. Non-collinear generation of angularly isolated circularly polarized high harmonics. *Nature Photonics.* 2015. Advanced Online Publiction (AOP).**

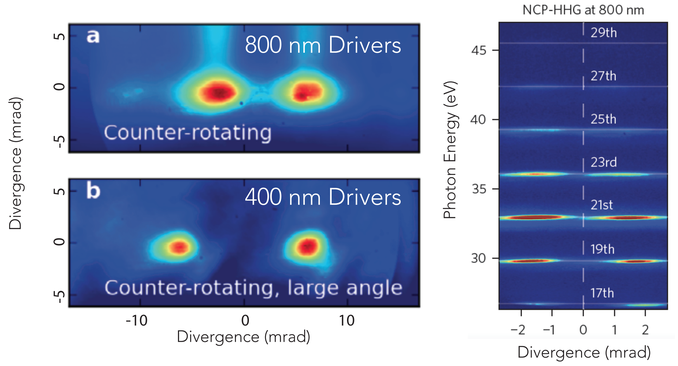
[2]Hernández-García, C. et al. High-order harmonic propogation in gases within the discrete dipole approximation. *Phys. Rev. A* **82**, 033432 (2010).

[3]Boeglin, C. et al. Distinguishing the ultrafast dynamics of spin and orbital moments in solids. *Nature* **465**, 458-461 (2010).

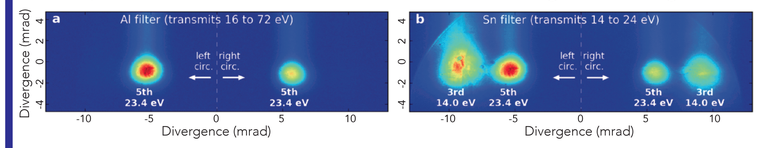
NCG-HHG Experiment and Numerical Modeling

Experiment

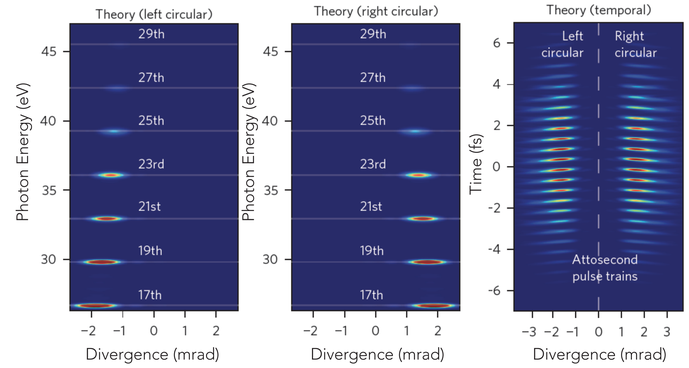
• Noncollinear mixing with counter-rotating driving fields

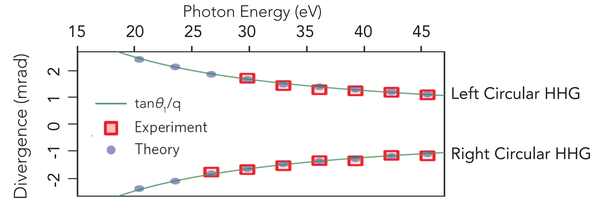


• Separation of individual harmonic orders using 267 nm light!

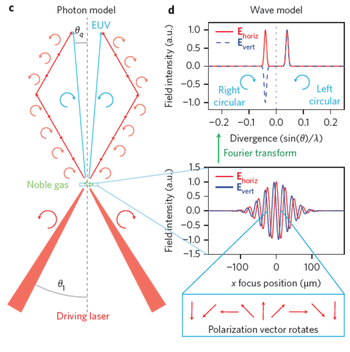


Advanced Numerical Theory[2]





NCG-HHG in the Photon and Wave Models



• **Photon Model**

- Conservation of spin angular momentum results in two angularly-isolated, CP HHG beams of opposite helicities.

$$n_q = n_+ - n_- \overset{!}{=} odd \qquad n_L = n_R \pm 1$$

- Simple vector addition rules and geometric constraints show that the individual HHG orders diverge as the photon energy increases.

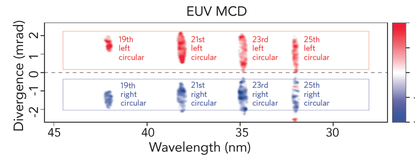
$$\tan\theta_q = \pm \tan\theta_i / q$$

• **Wave Model**

- Interference of the driving fields generates a linear "rotating polarization grating" along the transverse dimension of the focus, which produces circular polarization in the far-field.

$$n_q = n_+ - n_- \overset{!}{=} odd \qquad n_L = n_R \pm 1$$

EUV MCD Measuremnts of Fe Film

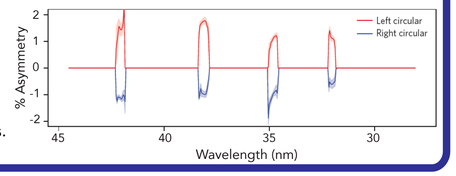


• Fe exhibits differential absorption of CP EUV light as a function of the Fe magnetic moment.[3]

• The MCD asymmetry,

$$(A_{MCD} = [(I_+ - I_-) / (I_+ + I_-)])$$

reveals the high degree of circular polarization of the generated harmonics.



Conclusions and Outlook

• The NCG-HHG method allows for the generation of angularly-isolated CP harmonics of opposite helicities.

• The EUV beams are spatially separated from the intense driving fields, allowing MCD measurements to be performed on fragile samples.

• NCG-HHG naturally separates the harmonics, thus eliminating lossy optics in the EUV.

• **Numerical simulations show that NCG-HHG is the only method capable of producing an isolated, CP attosecond pulse!**