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Generation of Coherent Extreme-Ultraviolet Vector-Vortex beams

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Optical vortex and vector beams are two paradigmatic examples of structured light. While the first ones carry orbital angular momentum (OAM), and thus their wavefront spirals along the propagation direction, the second ones present spatially inhomogeneous distributions of polarization. Harnessing structured light is opening new perspectives in communications, quantum information, processing, high-resolution imaging, or particle trapping. Among them, the generation of coherent structured beams in the extreme-ultraviolet (EUV)/soft x-ray regime is of high interest due to their unique ability to interact with matter at the nanometer and sub-femtosecond scales. During the last years, high-order harmonic generation (HHG) has opened a new paradigm to up-convert infrared vortex [1, 2] and vector beams [3] into the EUV, circumventing the use of inefficient optical converters. Previous results proved that a synchronous control over the polarization and the OAM is possible through HHG [4,5].

In this work, we introduce and characterize a novel structured EUV beam —a vector-vortex beam— which possesses the combined phase and polarization properties of vortex and vector beams. Our simulations and experimental results, where the intensity and wavefront of such beams are characterized, demonstrate that vector-vortex EUV beams can be generated through HHG [6]. Unlike the up-conversion of vortex or vector beams in HHG [1-3], the up-conversion of a vector-vortex beam is far from trivial, since the properties of such a complex beam change along propagation. Indeed, we have found that up-conversion of a radial or azimuthal vector-vortex beam through HHG is more efficient for higher OAM values. The conservation of spin and orbital angular momentum results in the generation of high-frequency vector-vortex beams with azimuthal or radial polarization and high OAM. An intrinsic property of these beams is the polarization rotation along propagation, from radial to azimuthal modes or vice versa, which is a consequence of the Gouy phase and introduces a phase shift similarly to the circular birefringence present in chiral media. In addition, our simulations show that the vector-vortex high-harmonic beams can be synthesized into azimuthally polarized attosecond light-springs (see Fig. 1).

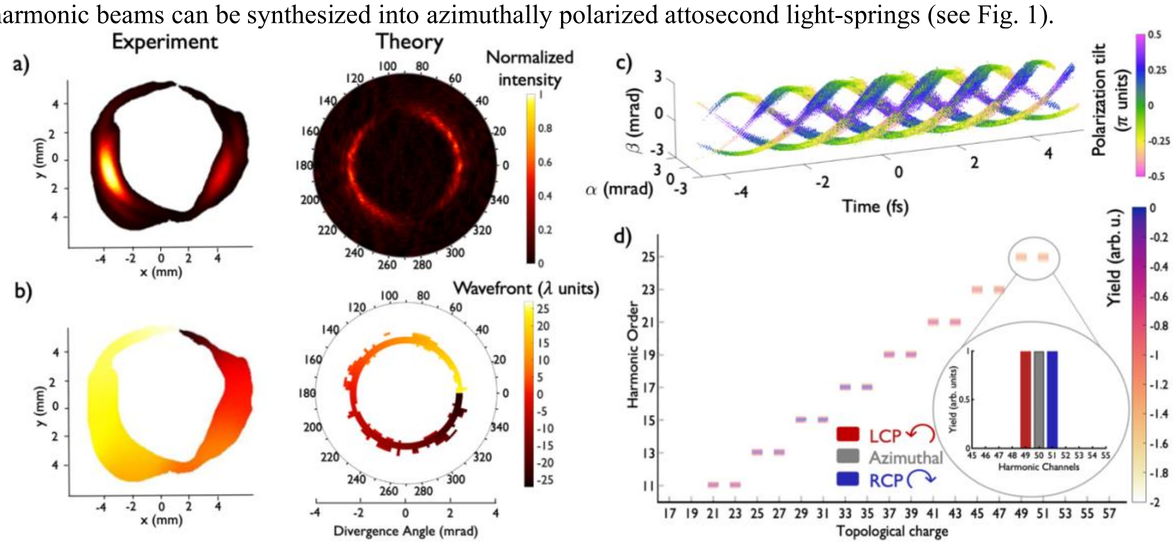

Fig. 1 Characterization of an EUV vector-vortex driven by an IR vector beam with topological charge $\ell = 2$. For the 25th harmonic, we compare the numerical results with the experimental characterization of the s-polarization (a) and wavefront (b). Additionally, we show the spatiotemporal structure and polarization tilt of the attosecond pulses (c) and the OAM analysis for several harmonic orders (d), with a zoom on the 25th harmonic in the inset.

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