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Extreme-Ultraviolet Vortices of very high Topological Charge

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With widespread applications in optical trapping, super-resolution microscopy, quantum communications & information, and material processing, there is an ever-mounting interest in the generation and characterization of light beams carrying topological singularities [1]. An emblematic situation of this singular-optics is the Laguerre-Gauss laser modes presenting an azimuthal phase dependence: $\varphi(r,\theta)=l\ \theta$ [2]. The integer l also called the topological charge of the singularity, is the number of 2π phase shifts along the azimuthal coordinate of the beam. This phase structure corresponds to a helicoidal wavefront and is often named an optical vortex. These helically phased beams are known to carry Orbital Angular Momentum (OAM). Besides, high-harmonic generation (HHG) in rare gases has proven to be an effective way to extend singular light beams to the extreme-ultraviolet (EUV) spectral range [3, 4]. During HHG with a driver of charge l_1, the momentum conservation results in a linear upscaling of the topological charge with harmonic order [2]: $l_q = ql_1$, where l_q is the topological charge of q^{th} harmonic. In this work, we will present our recent results on the generation, and amplitude, phase, and modal content characterization of EUV vortices until $l = 100$. Furthermore, we will support our experimental findings with simulation results [5].

The EUV vortices of very high topological charge are obtained through HHG in a 15mm long Argon-filled gas-cell. A loose focusing geometry and an extended generation medium allow the production of intense EUV vortices. Besides, instead of relying on diffractive or interferometric techniques, we utilize near-IR and EUV wavefront metrology (HASO4 FIRST and EUV HASO, Imagine Optic) to characterize the intensity, the wavefront of the driving as well as the upconverted EUV-vortex. Moreover, the phase-matched absorption-limited HHG driven by IR-vortex beam yields a sufficiently high signal level permitting wavefront characterization in single to few laser shots. In Fig. 1 (a) and (b), the intensity and wavefront of the IR-vortex of topological charge $l_1 = 3$ are shown. The 25th harmonic of the fundamental driver is spectrally filtered using a narrowband multilayer flat mirror and guided to the EUV Hartmann wavefront sensor, enabling an unambiguous interpretation of the acquired data. The reconstructed intensity and wavefront of the EUV-vortex retrieved from a multi-shot Hartmanngram are depicted in (c) and (d). A continuous and smooth phase rotation with a peak-to-valley variation of ~75 λ confirms the expected upscaling of OAM during HHG. Furthermore, we utilize the experimentally characterized amplitude and phase of the IR-vortex shown in (a, b) to simulate HHG in Argon; the results of advanced simulations are presented in (e-g). An excellent agreement between the simulated and experimental results indicates the high fidelity of our results.

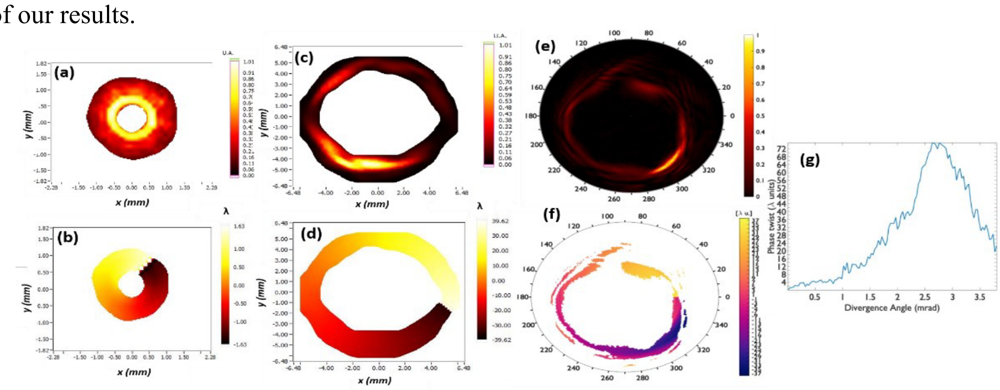

Fig. 1 Characterization of IR-vortex driver and upconverted EUV vortex beam. Intensity (a) and wavefront (b) of IR-vortex $l_1 = 3$. EUV-vortex intensity (c) and wavefront (d) are reconstructed from a multi-shot Hartmanngram. The wavefront bears a peak-to-valley variation of ~75 λ. Exploiting the experimentally characterized amplitude and phase (a, b), 25th harmonic is simulated in Argon: (e) amplitude, (f) phase, and (g) readout of the phase twist as a function of divergence.

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