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Structuring XUV Vector-Vortex Beams via High Harmonic Generation

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The nonlinear optical process of high harmonic generation (HHG) provides an appealing opportunity to up-convert the properties of visible or infrared (IR) beams into the extreme ultraviolet regime (XUV), or even into the x-ray regime. This is particularly relevant in the context of the emerging field of structured light[1], since a precise control of light properties is substantially more demanding in the high-frequency spectral range. Remarkably, it has recently been shown that the coherent nature of the HHG process allows to up-convert vortex driving beams—carrying orbital angular momentum (OAM)—and vector beams—which present spatially tailored polarization encoded in their spin angular momentum (SAM)[2-4]— from the IR into the XUV.

In this work, we demonstrate experimentally and theoretically a novel short-wavelength XUV structured beam, a Vector-Vortex beam (VVB), which integrates the characteristics of vortex and vector beams into a unique configuration of phase and polarization singularities[5]. Such structured XUV beam, which is spatially tailored in its phase and polarization, results from driving HHG with an IR VVB. However, the up-conversion process is far from trivial. The HHG build-up is governed by the conservation of the Pancharatnam topological charge of the qth-harmonic, $\ell_{P,q}$, which considers the intertwined OAM and SAM properties in its definition[6], and scales linearly with the harmonic order q ($\ell_{P,q} = q\,\ell_{P,1}$, being $\ell_{P,1}$ the topological charge of the driving beam). As a result, the complex propagation dynamics of the IR VVB driver is not mapped into the XUV VVB, which exhibits a smooth propagation. Figure 1 shows the IR VVB at its generation plane (a) and at the gas target (b), which reflects its complex propagation dynamics. In contrast, the 25th harmonic VVB presents a clean structure both at the gas target (c) and at the far-field (d). This behaviour can be understood in terms of the conservation of the Pancharatnam charge, and taking into account the drastic HHG efficiency decrease for high driving ellipticities[7].

The 25th harmonic VVB characterization in Fig. 1(c,d) points out the spatial dependence on both polarization and phase. On the one hand, the inhomogeneous polarization structure of the harmonic VVB can be identified in the vertical polarization projection depicted in (c,d). Apart from the polarization dependence on the azimuthal coordinate, we distinguish a rotation of the polarization plane along the propagation axis both in the IR and XUV as an effect of the Gouy phase[8]. On the other hand, we show the wavefront characterization of the 25th harmonic VVB in Fig. 1(d), where we identify a topological charge $\ell_{P,25} = 50$, in agreement with the theoretical scaling of the topological Pancharatnam charge for a driver with charge $\ell_{P,1} = 2$.