Intense high harmonic and attosecond vector beams from relativistic plasmas

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Vector beams are light beams with spatially nonuniform state of polarization. Generation of vector beams has attracted growing interest because they exhibit unique characteristics and novel effects when interacting with matter. For example, they can be tightly focused beyond the diffraction limit and exhibit strong nonvanishing longitudinal electric or magnetic fields. These novel effects can lead to various applications, ranging from high-resolution imaging, to optical trapping, materials processing, and optical communications.

Although various methods can be employed to generate vector beams in the infrared and visible spectral region, it is difficult to extend these linear-optics-based techniques to generate vector beams in the extreme-ultraviolet (XUV) and x-ray regime. Recently, it has been demonstrated that radially and azimuthally polarized XUV vector beams can be generated via high harmonic generation (HHG) from infrared driving vector beams interaction with gas targets. [1] The approach of HHG has the advantage of generating ultrafast vector beams in the attosecond regime and easily controlling the beam properties by modifying the driving beam instead of using inefficient XUV optical components.

To get brighter, ultrafast XUV or x-ray sources, HHG from relativistically intense laser-driven oscillating overdense plasma surfaces has been demonstrated as a promising route. Za ïm et al. reported the first HHG in the relativistic regime driven by vector laser beams. [2] However, only harmonic intensity has been measured. No measurement with respect to the spatial polarization distribution of the high harmonics has been done. Whether high harmonic and attosecond vector beams from relativistic laser plasmas can be generated remains elusive.

In this work, [3] through three-dimensional (3D) particle-in-cell (PIC) simulations, we numerically demonstrate the generation of intense vector beams in the XUV regime via HHG from relativistic plasma mirrors. The electric-field-vector distribution shows that the driving laser pulse can imprint its vector beam pattern onto the higher-frequency radiation coherently during the extreme nonlinear process of HHG based on the mechanism of relativistically oscillating mirrors (ROM). The vector harmonic beams can be generated with a high efficiency and synthesized into attosecond vector beams. High-resolution 2D cylindrical PIC simulation results show the frequency range can be extended to higher photon energies, e.g., up to the soft-x-ray regime. In addition, we show that high-harmonic vector beams with nonzero orbital angular momentum (OAM) can possibly be generated under oblique incidence. The OAM values are directly calculated to be fractional. Such novel light sources with high brightness present new opportunities in various applications such as imaging with high spatial and temporal resolution, ultrafast magnetic spectroscopy, and particle manipulation.

References

[1] C. Hern ández-Garc á *et al*., Optica **4**, 520 (2017)

[2] N. Za ïm *et al*., Phys. Rev. X **10**, 041064 (2020)

[3] Z.-Y. Chen and R. Hu, Phys. Rev. A **103**, 023507 (2021)

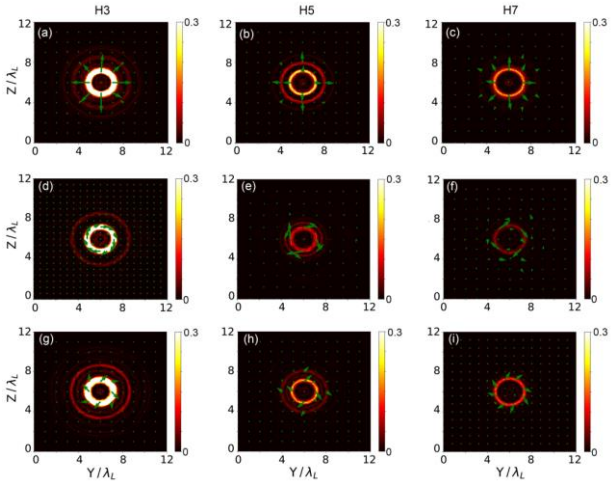

Figure 1. Electric-field (green arrows) and intensity (color scale) distribution of the high harmonics driven by (a)–(c) radially polarized, (d)–(f) azimuthally polarized, and (g)–(i) spirally polarized vector laser beams. The lasers are normally incident onto the plasma surfaces. The first to third columns correspond to the third (H3), fifth (H5), and seventh (H7) harmonics, respectively.