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Intense high-order harmonics and attosecond pulses carrying angular momentum

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Angular momentum is an intrinsic property of light, with spin angular momentum (SAM) of $\hbar$ per photon carried by circularly polarized (CP) light. It was demonstrated that light beams with helical phase-fronts, described by a transverse phase structure of e^(-ilϕ), where ϕ is the azimuthal angle, carry an orbital angular momentum (OAM) equivalent to $l\hbar$ per photon. In the relativistic regime, the proposed methods to generate intense XUV pulses with OAM mainly utilize vortex laser pulses as the drivers, which suffer from a limitation for the driving intensity. Here we show that the SAM of circularly polarized, high-power laser can be transferred to the harmonics carrying OAM via the relativistic oscillating mirror mechanism.

The principle is shown in Fig. 1(a). An intense left-handed CP Gaussian laser pulse impinges a plane target from the left side. The radiation pressure along the target normal (mediated by the slowly varying V×B force) results in rapid target deformation (so-called denting). This breaks the symmetry of the interaction and results in the laser becoming increasingly obliquely incident away from laser axis and therefore the generation of harmonics in the outer parts of the focal spot, while the suppression of harmonic generation on the axis remains. The laser field component driving the oscillations can be expressed as $E \propto E_0 \sin(\omega_L t - k_L z + \phi)$, where ϕ is the azimuthal angle of the interaction point. It clearly shows that the oscillating phase of the plasma mirror is related with its azimuthal angle. Since the harmonic emission time is directly dependent on the oscillating of the plasma surface, the harmonic phase fronts is then also depended on the azimuthal angle. In other words, OAM is introduced to the harmonics, as shown in Fig. 1(a).

Fig. 1(b) presents the phase structure of the third-order harmonic. As can be seen the isosurface has a helical structure. The intensities distribution of the harmonic shown in Fig. 1(b) is doughnut-like as expected for a laser beam with OAM. The transverse distributions of the harmonic phase indicates that the phases are azimuthally-angle dependent. The (n-1)$\hbar$ dependence of the OAM on harmonic order n can be understood simply in terms of the conservation of angular momentum.

We then consider the possibility of employing a pre-dented target. This opens the possibility of controlling efficiency and denting independent from the intensity. Importantly, it also opens up the possibility of generating a single attosecond pulse with OAM, by shooting a few-cycle and intense laser pulse on a pre-dented target. Fig. 1(c) presents the generation of a pulse with a duration of 450 attoseconds and with an OAM of 5$\hbar$.

References

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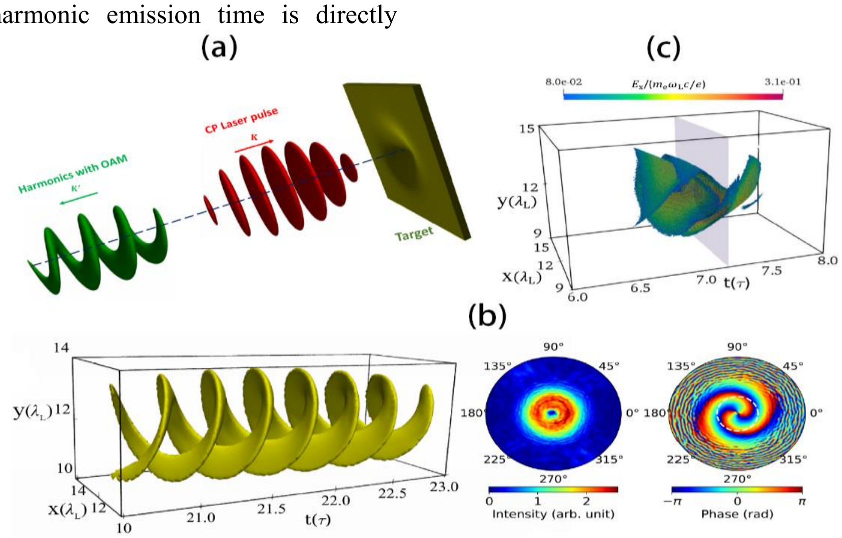

Fig. 1 (a) Principle of OAM harmonic generation. (b) Structure, intensity and phase distribution of the 3rd harmonic. (c) A single attosecond pulse with OAM.