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Bright atto-second X/γ-rays emission in near-critical-density plasmas driven by Laguerre-Gaussian lasers

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In recent years, although high energy radiation sources have been demonstrated numerically and experimentally, it is still very difficult to generate attosecond photon pulses with desirable angular momentum. Here, we propose a novel scheme to produce attosecond γ-rays with tunable angular momentum in near-critical density (NCD) plasmas, which has been well demonstrated by three- dimensional (3D) particle-in-cell simulations.

As shown in Fig. 1(a), when a left-hand circularly polarized (CP) Laguerre-Gaussian (LG) laser pulse (gold-white-black and white-cyan iso-surface represent the distribution of E_y and laser intensity $I = E_x^2 + E_y^2 + E_z^2$, respectively.) interacts with the NCD plasmas, a fairly large number of electrons are excited to form a string of isolated attosecond electron bunches (red iso-surface), and substantial electrons are compressed on the laser axis, which can be attributed to the unique structure of the CP LG laser fields in the radial and azimuthal directions[1,2]. Figure 1(b) and 1(c) present the spatial distributions of E_y and I in the y-z plane, respectively. One sees that the LG laser pulse interaction with the NCD plasma is greatly different from the case of a normal CP Gaussian laser-NCD plasma interaction.

Here, the LG laser electric field shows spatially periodic rotating structures (see Fig.1(b)), which plays a significance role in the formation of isolated electron atto-bunches. The underlying physics has been well explored in our previous work [3,4]. In each laser period, the plus and minus radial electric fields produce inward and outward radial forces on the electrons, which in turn help to accumulate the electrons from the edge of the nonpositive radial electric field, and lead to an annular electron bunch. At the same time, these electrons are accelerated by the longitudinal electric fields in the forward direction and rotate anti-clockwise under the force of the clockwise azimuthal electric field. As shown in Fig.1(d), electrons are revolving around laser axis counter-clockwise. Eventually, the electrons gradually form multi-GeV isolated annular bunch trains with a spatial period of ~1.0 μm. In addition, these electrons are compressed on the laser axis with some pushed to the front of the laser pulse, which have much smaller energy than that in the ring-shaped electron bunches.

The energetic electrons oscillate in the LG laser electric fields and emit a string of sub-GeV attosecond γ-ray pulses [5]. At the laser intensity of $5.52 \times 10^{22}\ \mathrm{W/cm^2}$, the yield of the single γ-photon pulse with energies above 1 MeV is as high as $\sim 10^{13}$ and the energetic γ-photons have an extremely narrow divergence of $\pi/32$. Additionally, the generated γ-ray sources have the orbital angular momentum of $\sim 10^{-15}\ \mathrm{kg \cdot m^2/s}$. The corresponding brightness of the photons is as high as $\sim 7\times 10^{24}\ \mathrm{photons/s/mm^2/mrad^2/0.1\%BW}$,which may have diverse applications in various domains [6].

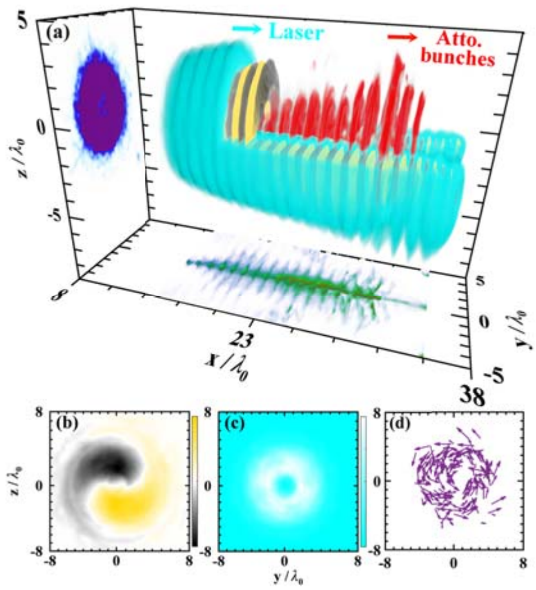

Fig. 1. (a) 3D iso-surface of attosecond electron bunches generated from the CP LG laser irradiating NCD plasmas at t=132 fs. The x-y plane and y-z plane illustrate the distributions of electron density at z=0.0 μm and energy density at x=32.0 μm, respectively. The spatial distribution of the electric field E_y (b), incident laser intensity I (c) and electron velocity (d) in the y-z plane.

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