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Sub-femtosecond electron sheets from a Laguerre-Gaussian laser interaction with micro-droplets

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Abstract—An all-optical scheme for generation and acceleration of relativistic electron sheets is proposed. When an intense Laguerre-Gaussian (LG) laser pulse sweeps micro-droplets, annular sub-femtosecond electron bunches with one laser wavelength spacing are dragged out by the radial component of laser electric fields, and then efficiently accelerated by the longitudinal electric fields. Once fleeing from the droplet, these bunches are squeezed into dense sheets and trapped by the potential well of the transverse ponderomotive force, which can stably propagate for several hundred femtoseconds and are potential for applications in short x/γ-ray radiation sources.

Keywords— high power laser, sub-femtosecond electron sheets, Laguerre-Gaussian laser, novel radiation source

I. INTRODUCTION

The development of laser facilities paves the way for the investigation of ultraintense laser-plasmas interaction, which is of utmost important for the design of “tabletop” particle accelerators. The relativistic ultrashort electron bunches may be applied in injection into accelerators, ultrafast electron diffraction imaging, and compact radiation sources. In the obvious schemes [1], relativistic electron bunches are generated from linearly/circularly-polarized Gaussian laser-illuminated droplets. However, electron bunches are pushed aside by the outward ponderomotive force of Gaussian pulses and quickly disperse after getting away from the target. The phenomenon seriously hinders their applications. To solve this problem, we propose a new scheme to trap relativistic sub-femtosecond electron sheets by using a Laguerre-Gaussian pulse [2].

II. SCHEME AND SIMULATIONS

We perform a series of simulations by using the 3D PIC code VLPL (Virtual Laser Plasma Lab) [3], which allows direct fully electromagnetic simulations of relativistic laser-plasma interactions starting from the most fundamental plasma models. The size of the simulation box is $x \times y \times z = 16\lambda_0 \times 12\lambda_0 \times 12\lambda_0$ and the spatial resolutions in all directions are $0.02\lambda_0$. Here $\lambda_0 = 1 \mu\text{m}$ is the laser wavelength. According to Courant stability condition, we set the time resolution as $\Delta t = 0.01T_0$ in all simulations below with $T_0 = 3.3$ fs the laser cycle. Here we make use of a pre-ionized, cold liquid-helium droplet with a diameter $D = 2\lambda_0$ and an electron density $10n_c$, where $n_c = 1.12 \times 10^{21} \text{ cm}^{-3}$ is the critical density for a $\lambda_0 = 1 \mu\text{m}$ laser. The target could be easily produced in large numbers in experiments. A LG laser pulse with mode (1, 0) is

employed and it is focused at $x = 3\lambda_0$ and propagates along the x -axis. The dimensional laser intensity $a_0 = 10$, which is already available in several laboratories in the world. The pulse has a cosine-squared profile in time with a duration of $10T_0$ and a focal spot radius of $3 \mu\text{m}$.

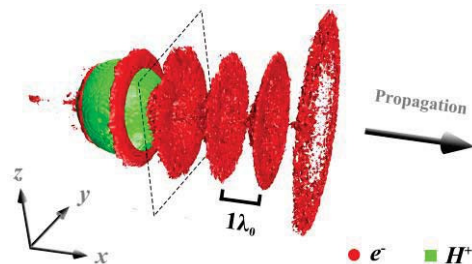


Fig. 1. Electron and ion density isocontour surfaces when a LG laser impinges a droplet target.

III. RESULTS AND CONCLUSIONS

As is shown in Fig. 1, when the LG laser impinges the helium droplet, annular electron bunches are expelled from the target every laser cycle and propagate along the x -axis, unlike a sawtooth or spiral structure from a normal Gaussian pulse. The distinction in our case can be attributed to the structure of the laser electric field. The simulation results also show that the electron acceleration is dominated by the longitudinal electric fields of the LG laser. Once fleeing from the target, these bunches are squeezed into dense electron sheets and could stably propagate for several hundred femtoseconds. We can qualitatively interpret the electron dynamics by using the ponderomotive potential model. The LG laser with a hollow intensity distribution forms a potential well, where electrons are subject to inner ponderomotive force and tightly trapped. The sub-femtosecond electron bunch is potential for applications such as generating ultrashort x/γ-ray radiation sources or ultrafast electron diffraction imaging.

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