Ultra-intense vortex laser generation from a seed laser illuminated axial line-focused spiral zone plate

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Since Allen et al. [1] found the vortex beams carrying orbital angular momentum (OAM) along their propagation axis in 1992, the vortex laser has been widely applied in many domains spread over the microhertz to megaelectronvolt–gigaelectronvolt frequency ranges, such as microscopic particle control, microscopy imaging, and optical communication. Unlike the normal Gaussian laser having nearly flat wave front, the vortex lasers have a helical wave front and hollow transverse intensity distribution. With these unusual properties, the vortex laser has been a unique tool to gain insight into the dynamics of particles. Over the past decade, vortex laser has also drawn wide attention in the research area of laser-plasma interaction. Unfortunately, such a relativistic vortex laser is still a challenging work for the current laser technology, principally due to the limit of the damage threshold of optical modulators. Although a couple of feasible schemes have been reported recently, like light fan[2], Raman amplification[3], plasma holograms[4,5], spiral-shaped foil[6], spiral phase plasma[7], and azimuthal plasma phase slab[8], the highest intensity of vortex laser pulse achieved experimentally is still lower than 10^{20} W/cm^2 [9,10]. New schemes for the generation of ultra-intense vortex laser with intensity above 10^{21} W/cm^2 are in high demand.

Spiral zone plate (SZP) is a kind of diffraction optical elements to generate optical vortexes. The SZP is modified from Fresnel zone plate, which can perform radial Hilbert filtering operation and the focusing operation in one step. However, the optical vortexes diverge rapidly after passing through the focal point owin g to the SZP structure. In order to overcome this limitation, Zheng et al [11] signed a novel diffraction optical element called axial line-focused spiral zone plates (ALFSZP), to create optical vortexes with a long focal length along the propagation axis in tradition optics. Compared to the SZP, the change of ALFSZP relies on the adjustment of the number of wave zones N and the width variation between adjacent wave zones δd of the SZPs.

In this paper, we present a plasma-based scheme to generate ultra-intense vortex laser pulse by employing an ALFSZP. Figure 1 illustrates schematically our scheme and the key features of the produced vortex laser beams. Three-dimensional particle-in-cell (3D-PIC) simulations show that a vortex laser with the focused intensity above 10^{21} W/cm^2 can be achieved. Such an ultra-intense vortex laser may trigger many potential applications in various domains, enabling future experimental tests of vortex-laser-plasma interaction in the ultra relativistic regime.

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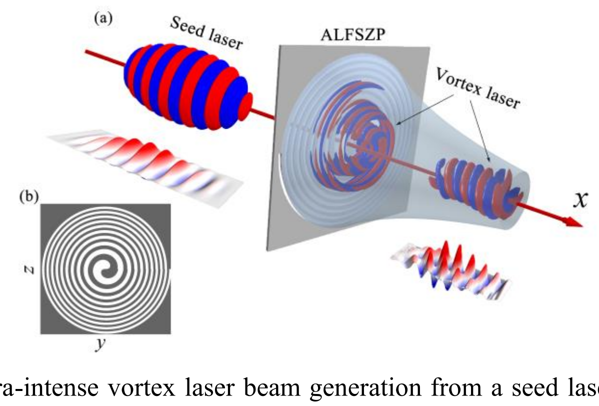

Figure 1. (a) Schematic of ultra-intense vortex laser beam generation from a seed laser-illuminated axial line-focused spiral zone plate (ALFSZP). A Gaussian laser pulse is incident from the left and irradiates the ALFSZP. This finally results in the generation of an ultra-intense vortex laser pulse. Here, the projections are the electric fields of incident seed laser and vortex laser, respectively. (b) The transverse profile of an ALFSZP with the topological charge l=1.