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Light-Structuring Plasma Holograms

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Laser-plasma particle accelerators [1,2] and radiation sources benefit from spatiotemporal shaping of intense light. Solid-state optics are limited by their relatively low intensity damage threshold requiring them to be large and placed far from the focal plane. As improvements in laser technology enable higher peak laser powers, these limitations reduce the degree to which light in the nearfield can be manipulated. Plasma-based optics, with an intensity damage threshold several orders higher than their solid-state counterparts, can potentially enable a variety of new intense laser-plasma experiments.

The interference between two pumps—one reference beam and one beam with the desired spatial structure—can imprint a three-dimensional light field into a gas or plasma. When a reference probe propagates through the medium, some fraction diffracts to produce the structured pump beam [3]. Depending on pulse duration and intensity, the imprint mechanism can range from absorptive heating of gases [4] to spatially-varying ionization [5,6] and ponderomotively-driven ion structures [7]. These mechanisms typically have pump energy and intensity requirements that can be far lower than the damage threshold for the probe beam.

In this talk, we explore complex light-structuring holographic gas and plasma optics via particle-in-cell simulations and numerical solutions to the paraxial wave equation as well as recent experiments.

The flexibility of holographic optics enables encoding the phase accumulated by multiple conventional optics into a single refractive index structure. For example, the hologram created by two pump beams at oblique incidence with different focal lengths can simultaneously steer and focus a probe beam.

Plasma-based holograms can also encode more complex spatial variations in beam phase. When the structured pump is a Laguerre-Gaussian beam with orbital angular momentum (OAM), the helical phase is imprinted into the plasma which then imparts it into the diffracted probe beam. Such twisted light beams are particularly useful for generating rotational plasmas that produce large axial magnetic fields [8]. Non-diffractive Bessel-Gaussian beams produced by conventional solid-state axicons and spiral phase plates can also be constructed via plasma-based holograms. In Figure 1, a probe propagating through such a hologram diffracts to multiple orders; the first-order (m=1) diffraction reproduces the transverse intensity and helical phase of the structured pump beam. These extended-focus beams are viable for initializing plasma waveguides to confine intense light over meter-scale propagation lengths [9].

Combined with wide-bandwidth, ultrashort pulses, we also demonstrate how plasma-based holograms enable a myriad of applications requiring wavelength- and time-dependent control of the diffracted probe.

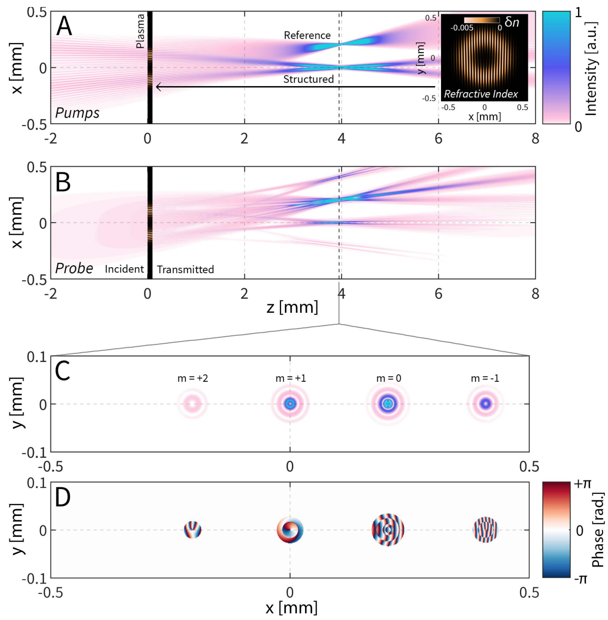

Figure 1. 3D linear propagation simulations for a thin plasma hologram for producing non-diffractive beams with orbital angular momentum. (A) The reference pump is Gaussian at 3-degree oblique incidence while the structured pump is a J_1 Bessel-Gaussian beam at normal incidence. The pump interference pattern is encoded as a refractive index structure in the plasma. (B) The incident probe—identical to the reference pump—is diffracted to multiple orders by the plasma hologram. (C),(D) The different orders of diffraction are different orders of Bessel-Gaussian beams.

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