7th Asia-Pacific Conference on Plasma Physics, 12-17 Nov, 2023 at Port Messe Nagoya

Efficient generation of axial magnetic field by multiple laser beams with twisted pointing directions

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Strong laser-driven magnetic fields are crucial for high-energy-density and laboratory astrophysics research, but generation of axial multi-kT fields remains a challenge. The difficulty comes from the inability of a conventional linearly polarized laser beam to induce the required azimuthal current or, equivalently, angular momentum (AM). We show that several laser beams can overcome this difficulty.

The approach, illustrated in Figure 1 for four beams, is motivated by the development of PW-class laser systems like SG-II UP that will have multiple kilojoule-class picosecond laser beams. Even though each laser beam alone carries no intrinsic OAM, we show that they can be assembled to efficiently generate OAM in the plasma that they irradiate. Multi-kJ PW-class laser systems like LFEX, NIF ARC, and Petal offer the highest energy that can be delivered on a ps time scale. These lasers are all composed of multiple LP beamlets. The multi-beamlet configuration is not just an essential feature of the laser system design, but also the key to advanced laser-plasma interaction regimes. The number of multi-beamlet facilities will increase, as SG-II UP is due to be upgraded to have multiple kJ-class ps laser beams.

Our three-dimensional kinetic simulations demonstrate that a twist in their pointing direction enables them to carry orbital AM and transfer it to the plasma, thus generating a hot electron population carrying AM needed to sustain the magnetic field. The resulting multi-kT field occupies a volume that is tens of thousands of cubic microns and it persists on a ps time scale. The twist in the pointing direction of the pulses is the key to driving an azimuthal plasma current that sustains the magnetic field. The twist angle is a convenient control knob for adjusting the direction and magnitude of the axial magnetic field.

The mechanism can be realized for a wide range of laser intensities and pulse durations. Our scheme is well-suited for implementation using multi-kJ PW-class lasers, because, by design, they have multiple beamlets and because the scheme requires only linear-polarization.

References

[1] Yin Shi *et al,* Phys. Rev. Lett. **130**, 155101(2023)

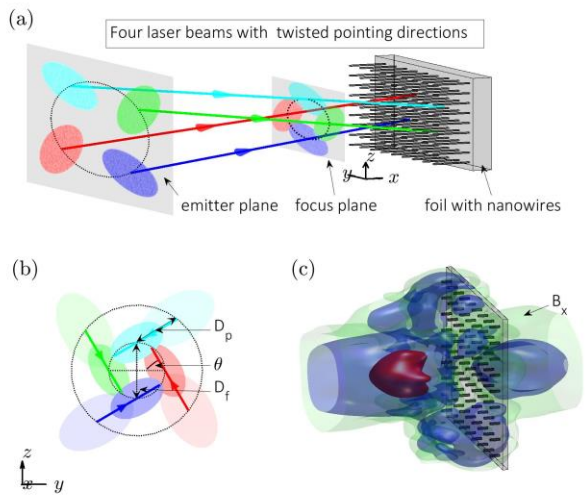

Figure 1. (a) Setup for axial magnetic field generation using four linearly-polarized Gaussian laser beams with twisted pointing directions, shown with solid lines, and a structured target. The size of each beam is shown with a color-coded ellipse in the emitter plane left side of the simulation box and in the focus plane. (b) Projections of the two planes on to the (y, z)-plane. The parameters setting up the beam orientation are defined in the text. (c) Surface plots of the axial magnetic field B_x after the lasers have left the simulation box (t = 20 fs). The green, blue, and red surfaces represent B_x/B_0 = -0.1, -0.2, and -0.8, where B_0 = 13.4~kT.