9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Terahertz Vortices with Tunable Topological Charges from a Laser-Plasma Channel

Linzheng Wang[1,2], Yanping Chen[1,2], Chen Wang[1,2], Huanyu Song[1,2], Jinyu Hua[1,2], Rong Huang[1,2], Min Chen[1,2], and Zhengming Sheng[1,2,3],
[1] Key Laboratory for Laser and Plasma (MOE), Shanghai Jiao Tong University, [2] Collaborative Innovation Centre of IFSA, Shanghai Jiao Tong University, [3] Tsung-Dao Lee Institute
email (speaker): linzhengwangsjtu@sjtu.edu.cn

The generation and application of vortices in the terahertz (THz) band have attracted increasing interests as it covers characteristic frequencies of many physical processes [1], rotational and vibrational energy levels of many molecules [2], and the communication bands in the near future as well [3]. Heretofore, THz vortices have already been employed to manipulate nonlinearities in graphene [4], Bose-Einstein condensation currents [5], and biological macromolecules [6]. Nowadays, optical vortices can be produced even with fractional topological charge [7], which have attracted enormous attentions in many fields owing to their unusual properties [8]. So far, the generation of fractional THz vortices has merely been reported either theoretically or experimentally

Here we present a way to generate intense terahertz vortex beams with continuously tunable topological charge by injecting a weakly-relativistic ultrashort laser pulse into a parabolic plasma channel. By adjusting the injection conditions of the laser pulse, the trajectory of the laser centroid can be twisted into a cylindrical spiral, along which laser wakefields are also excited. Due to the inhomogeneous transverse density profile of the plasma channel and laser wakefield excitation, intense terahertz radiation carrying orbital angular momentum is produced with field strength reaching sub GV/m, even though the drive laser energy is at a few tens of mJ.

The topological charge of such a radiation is determined by the laser trajectories, which is continuously tunable as demonstrated by theoretical analysis as well as three-dimensional particle-in-cell simulations. Figure 1 shows the simulation results on the manipulation method of THz vortices. Such terahertz vortices with unique properties may find a lot applications in optical manipulation, THz imaging and communications.

References

[1] M. Taghinejad, *et al.*, Science **382**, 299 (2023).
[2] P. A. Banks, *et al.*, Nat. Rev. Chem. **7**, 480 (2023).
[3] R. Jia, *et al.*, Sci. Adv. **9**, eadi8500 (2023).
[4] C. Zhang, *et al.*, Materials **11**, 1054 (2018).
[5] T. Omatsu, *et al.*, Opt. Express **18**, 17967 (2010).
[6] E. Pickwell, *et al.*, J. Phys. D **39**, R301 (2006).
[7] Z. Zhang, *et al.*, Light Sci. Appl. **9**, 179 (2020).
[8] H. Zhang, *et al.*, Nanophotonics **11**, 241–273 (2022).

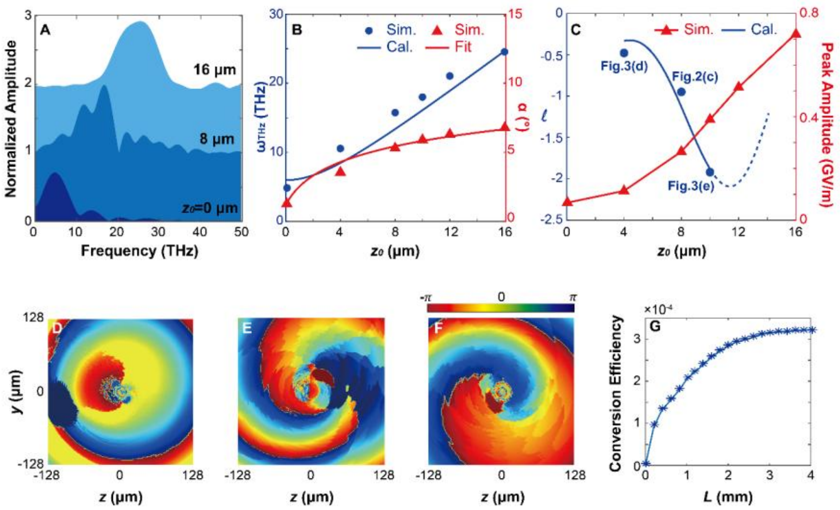

Figure 1 Manipulation of the OAM of the THz radiation. (A) THz radiation spectra under different offset distance z_0. (B) Simulated THz central frequencies and radiation angles under different z_0 while $\theta_y = 88.5°$. (C) Calculated ℓ under different z_0 while $\theta_y = 88.5°$. (D) Phase distribution of the THz radiation under the injection condition of $z_0 = 5\,\lambda_0$ and $\theta_y = 88.5°$. (E) Phase distribution of the THz radiation under the injection condition of $z_0 = 12.5\,\lambda_0$ and $\theta_y = 88.5°$. (F) Phase distribution of the THz radiation under the injection condition of $z_0 = 10\,\lambda_0$ and $\theta_y = 91.5°$. (G) THz conversion efficiency under the injection condition of $z_0 = 10\,\lambda_0$ and $\theta_y = 88.5°$ after different propagation length L.