Generation of ultrahigh electric fields and megatesla magnetic fields using micro cavities

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Recent progress in ultra-intense laser technology has opened a new frontier for generating extreme electromagnetic fields in the laboratory, far beyond those attainable by conventional means. In this talk, I will present our recent theoretical and numerical studies on the generation of ultrahigh electric fields exceeding 10^{16} V/m and megatesla (MT)-class magnetic fields via laser-driven implosion of micro-scale cavities, such as micro-bubbles, microtubes, and bladed microtubes.

In the microbubble implosion (MBI) scheme, a spherical cavity embedded in a solid target is uniformly filled with MeV-class hot electrons generated by an intense laser pulse. The resulting spherically symmetric electrostatic field drives the bubble-wall ions inward toward the center. Upon collapse, the ions are compressed into an ultrahigh-density nanoscale core, producing a transient electrostatic field as high as $\sim 10^{16}$–10^{17} V/m, which in turn accelerates protons to relativistic energies up to the GeV level.

For magnetic field generation, we have proposed the microtube implosion (MTI) and its advanced variant, the bladed microtube implosion (BMI). Unlike conventional magnetic flux compression or the Biermann battery effect, the underlying mechanism in our scheme is fundamentally different: the Lorentz force in a pre-seeded kilotesla-level magnetic field deflects imploding ions and electrons in opposite azimuthal directions, generating collective Larmor gyromotions. These motions produce ultrahigh spin current densities on the order of peta-amperes per square centimeter around a nanometer-scale Larmor hole at the center, resulting in megatesla-order magnetic fields. In the BMI scheme, the blade-induced geometrical asymmetry spontaneously generates such loop currents without requiring any external seed field, producing gigagauss-level magnetic fields through self-consistent feedback between the current and the field.

These extreme electromagnetic environments open new possibilities not only for compact ion accelerators and high-energy-density physics, but also for laboratory astrophysics, where such conditions mimic those found near compact objects such as neutron stars and magnetars. I will also discuss the underlying scaling laws that connect these microscopic phenomena to macroscopic astrophysical systems, and present recent results on multi-shock implosion dynamics and dual-pulse ion acceleration.

This talk aims to bridge the gap between laser plasma physics, high-field science, and astrophysical applications, and to stimulate further interdisciplinary collaboration in this rapidly evolving field.