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Energetic Au ions and high yield X-ray/gamma-ray generation from near-critical-density targets irradiated by multi-peta-watt lasers

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Ultra-short laser-driven ion acceleration would be a compact and cost-efficient alternative to provide ion beams with unique properties (i.e. high density and ultra-short duration) that conventional accelerators can not offer, which is extremely attractive to applications to nuclear astrophysics, cancer therapy, and high-energy-density physics. In the past two decades, the acceleration of protons, low-Z ions, and mid-Z ions has been extensively explored. However, only a few experimental results of super heavy ions (SHIs) were reported because SHIs are hard to be ionized to very high charge states and efficiently accelerated.

Recently, multi-PW laser facilities, for example, GIST (4.2 PW) and ELI (10 PW), have been constructed or under construction. These facilities, capable of generating ultra-short laser pulses with focused peak intensity exceeding 10^{22} W/cm^2[1], have opened the avenues to new areas for investigating laser-driven SHI acceleration. Our recent experiments in GIST demonstrate the generation of deeply-ionized Au ions with unprecedented energy of 1.2 GeV and charge state up to 61+ by femtosecond laser pulses at the intensity of 10^{22} W/cm^2. The combination of ultra-high intensity laser and near-critical-density (NCD) double-layer targets can overcome the difficulties of ionization and acceleration of SHIs. Besides, we realized a novel self-calibrated detection based on single-ion events, to obtain the absolute charge state distribution of Au ions, which can be used as a tool to understand the details of ionization and acceleration. Particle-in-cell simulations reveal that the laser intensity plays a crucial role in the generation of highly energetic Au ions. The employed double-layer targets, which have been successfully used for the acceleration of 58 MeV/u carbon ions[2], results in the 1.5 times enhancement of the Au energy as compared to 150-nm single-layer Au foils. The measured charge state distribution and the simulations confirm such an enhancement is due to the prolonged acceleration time in the double-layer targets.

High-energy photons have enormous applications in fundamental research and industry. Some applications such as ultrafast radiography require ultra-short (femtoseconds), brilliant gamma-rays with a small source size (micrometers), which have been successfully achieved over the past two decades by irradiating intense laser pulses on low-density targets such as gas jets and discharged capillaries. Further improving the densities of targets to near-critical density (1e21 /cm^3) can achieve a highly efficient laser absorption and a strong self-induced magnetic field, resulting in a compact gamma-ray source with higher yield and photon energy.

Recently, we realized the experimental generation of high-yield X-ray/gamma-ray photons from petawatt laser irradiating NCD foils. Utilizing free-standing carbon nanotube foam as thickness-controlled and homogeneous plasmas with an electron density of 1.7e21 /cm^3, we successfully measured the hard X-ray emission when a high-density electron bunch is violently driven by its self-induced magnetic field. By appending a diamond-like carbon foil behind the carbon nanotube foam as the plasma mirror to reflect the driving laser, In order to furthermore improve the photon energy, the generation of high-yield gamma-rays was generated through nonlinear Thomson backscattering. The obtained experimental results well agree with the results in our previous simulation study[3].

References

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