Ultra-high energy density conditions produced in free-floating micron-size targets by laser irradiation at 10^{20} W/cm^2

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In relativistic laser-matter interaction, a large fraction of the laser energy is converted to a population of energetic (MeV) electrons. When using “mass-limited” targets (of dimensions smaller than the hot electron range), the hot electrons are confined into the target by electrostatic sheath fields, leading to the generation of matter at ultra-high energy density.

At the PHELIX laser facility, we have subjected micron-sized solid copper spheres to short (~500 fs), energetic (150 J) laser pulses, focused to intensities above 10^{20} W/cm^2, resulting in laser energy per target volume of 10^9 J/mm^3. In order to avoid any nearby material, the spheres were held freely floating by means of a Paul-trap, and active damping was employed to allow overlapping the few-micron laser spot with the target. Broadband K-shell emission x-ray spectra indicate rapid ionization of the entire target to He- and H-like charge states. The x-ray emission source size is found to be comparable with the initial target size, indicating negligible expansion of the target during peak emission. These results are supported by particle-in-cell simulations of the laser-target interaction and subsequent target evolution. Bulk temperatures of several keV are reached while most of the target mass is still at solid density, corresponding to ultra-high pressures exceeding 10 Gbar. Atomic kinetic calculations of K-shell emission spectra at these conditions agree well with the measured spectra.