Toward a realistic modeling of the heating and ionization of a solid target irradiated by an ultra-intense laser

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Ultrahigh intensity (UHI) lasers interacting with solid targets are widely employed to generate bright X-ray sources and investigate isochoric heating of buried samples in the warm/hot dense matter regime. Such heating arises from the relativistically hot electron population created at the target surface, whose subsequent transport into the target core induces ultrafast ionization and heating processes. Accurate modeling of these phenomena using particle-in-cell (PIC) codes poses significant computational challenges, often necessitating approximations such as preionized targets or reduced target densities. The purpose of this work is to present realistic, fully self-consistent PIC simulations of the interaction of a 30 fs, 2.2×10^{18} W cm^{-2} laser pulse with a 2 µm thick Al target, using the CALDER code.

Our first effort was to quantify and mitigate numerical heating, a common artifact in PIC simulations involving solid-density plasmas and collisional algorithms. We then sought to elucidate the primary mechanisms behind the physical heating of the target core: (i) collisions between the laser-driven relativistic electrons and the much colder bulk electrons; (ii) resistive dissipation of the return current carried by the collisional bulk electrons, which is induced to neutralize the hot-electron current. This latter Joule-type heating is highly sensitive to the treatment of elastic electron-ion collisions. We show that incorporating the screening effect of bound electrons leads to an enhanced ion-electron collision rate, and thus to stronger heating. Additionally, we study the influence of electron-impact ionization coupled with ionization potential depression, and find that while the ionization level is increased, the overall heating is reduced.

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