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Ultrafast multiscale response dynamics of materials under high energy density conditions

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The investigation of equations of state, physical properties, and phase transitions of materials under extreme high-pressure conditions is a fundamental challenge in condensed matter physics and planetary science. Recent advancements in laser-driven compression techniques allow us to replicate these extreme states in laboratory settings, achieving terapascal (TPa) pressures, temperatures exceeding tens of thousands of Kelvin, and time scales from femtoseconds to microseconds. This capability provides a unique platform for exploring material properties under high-pressure and high-strain-rate conditions.

The rapid development of next-generation large-scale laser facilities and advanced X-ray sources, coupled with innovative diagnostic techniques, enhances our understanding of warm dense matter and has significant implications in fields such as astrophysics, inertial confinement fusion, national defense technology, and materials science. The integration of multi-scale (macro-meso-micro) in situ diagnostic techniques with multi-method detection is crucial for constructing a comprehensive understanding of matter under extreme conditions.

This report presents multi-scale diagnostic techniques based on laser-driven platforms and their applications in studying extreme warm dense matter. We have established precise measurement methods for key physical quantities like velocity, temperature, and pressure at the macroscopic scale. Mesoscopically, we achieved in situ characterization of microcrystal sizes and pore structures, while at the microscopic scale, we made strides in real-time detection of lattice structure evolution. By employing various loading methods—including shock loading, quasi-isentropic loading, and static-dynamic combined loading—we have advanced issues such as high-pressure equations of state, superionic water properties, and phase transition mechanisms of high-pressure carbon-based compounds. Furthermore, the report evaluates the feasibility of developing multiple in situ diagnostic techniques on large-scale laser facilities, offering a novel paradigm for analyzing physical processes under dynamic loading.

References:

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