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Optical Probing of Ultrafast Laser-Induced Transitions from Solid to Overdense Plasma

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Capturing the target behavior during a high-intensity laser-solid interaction is crucial to understanding the interplay of fundamental processes such as ionization, collisions, and plasma kinetics. Furthermore, predicting and controlling the pre-plasma evolution produced by the rising edge of the laser is key for enhancing the properties of the accelerated particle beams [1] (electrons and ions), and secondary X-ray sources. In this work, we investigate experimentally and numerically the onset and development of a plasma induced by the interaction of laser pulses starting at intensities $I \sim 10^{15}$ W/cm^2 with Diamond-like Carbon (DLC) foils with thicknesses ≤ 50 nm. On the one hand, a chirped broadband probe pulse (NOPA) [2] ($\Delta\lambda \sim 150$ nm) is propagating longitudinally through the foil and recording the ultrafast transmission dynamics during a single-pulse illumination. On the other hand, the numerical results shed light on the dynamics of the generation and evolution of a plasma with > 100 critical density. To achieve a good agreement between simulation and experiment for target thickness ≤ 20 nm, we developed a novel Two-Step Model. In the first step, a solid-state interaction model is used to describe the interaction up to the melting of the target. In the second step, a 1D Particle in Cell (PIC) code is used to account for the kinetic description of the plasma. For the 5 nm-thick foil, the optical tunneling of the probe through the ultrathin overdense plasma exhibits a sub-picosecond evolution with an expansion up to 16 times the target thickness. This investigation provides a direct insight into the interplay of various ionization processes: multi-photon, tunneling, and collisional. In addition, a detailed description of the spatio - temporal evolution of the plasma properties is obtained such as electron density, temperature, and ion charge state. Finally, this work is a first step towards providing the description of unprecedented detailed pre-plasma conditions for relativistic laser-solid interaction in PIC codes and experiments.

References

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