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Investigation of Hot Electron Generation Mechanism from High-Power Laser and Solid Interactions using Coherent Transition Radiation Diagnostics

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1. Introduction

High-power laser-driven electron acceleration has attracted significant interest in high-energy-density physics, ultrafast science, and compact radiation sources. In particular, pre-plasma formation induced by amplified spontaneous emission (ASE) and pre-pulses from high-power lasers plays a critical role in modifying the underlying laser absorption mechanisms. In this work, we present a new laser absorption mechanism emerging in steep-like pre-plasma conditions, revealed through coherent transition radiation (CTR) measurements and validated by particle-in-cell (PIC) simulations.

2. Experiment

Experiments were performed at the CoReLS of the Institute for Basic Science (IBS). Ti:sapphire laser pulses(2 J, 30 fs, 5×10^{19} W/cm², p-polarized) irradiated 8, 15 and 20 µm-thick aluminum foils with 30˚ incident angle. Fundamental and second harmonic frequency CTR were recorded using an optical imaging setup. The double plasma mirror was used to reduce the ASE and pre-plasma in the pico-second region, resulting in a contrast of 10^{10}. Therefore, pre-plasma is not formed on the target surface and interacts with the main pulse.

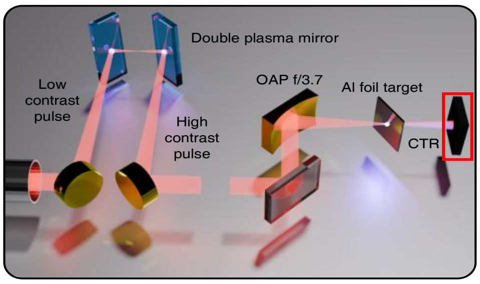

Fig. 1. Schematic of experimental setup (not scaled).

3. Results and Discussion

CTR imaging and PIC simulations revealed that electron dynamics and laser absorption strongly depend on the pre-plasma scale length. For smooth target surfaces, hot electrons exhibited narrow angular distributions synchronized with the laser cycle, while steep-like pre-plasma conditions produced broader, multi-directional emission and enhanced electron injection into the target. Measurements of CTR spot separation for various target thicknesses (8–20 µm) showed excellent agreement with simulation predictions, providing direct experimental evidence of a previously unreported laser absorption mechanism. These findings highlight the critical role of pre-plasma in governing hot-electron dynamics and offer new insights for optimizing relativistic laser-driven electron acceleration and high-energy-density plasma generation

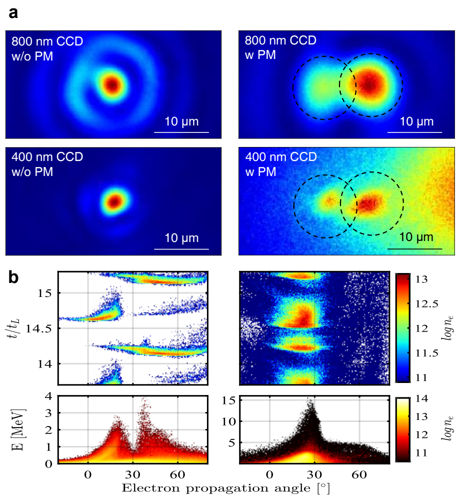

Fig. 2. (a) CTR images at 800 nm and 400 nm with and without a plasma mirror (PM). (b) 2D PIC simulation results showing electron propagation angles and energy spectra for smooth and steep-like pre-plasma surfaces.

4. Conclusions

We demonstrated that CTR measurements combined with PIC simulations provide a powerful diagnostic for hot-electron dynamics in relativistic laser–solid interactions. The study reveals a new laser absorption mechanism under steep-like pre-plasma conditions and highlights the critical role of pre-plasma in controlling electron injection and angular distributions. These findings improve our understanding of energy coupling in high-intensity laser interactions and provide valuable benchmarks for theoretical and computational models.

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