Ultrafast Imaging the Dynamics of Warm Dense Matter

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BACKGROUND

- Using femtosecond laser technology to study the dynamics of warm dense matter (WDM) with atomic-level spatiotemporal resolution promotes understanding of the elementary mechanisms of nature (4). Found in the cores of giant planets (Figure 1), WDM, with temperature ranges of 0.1 eV to 100 eV (1 000 to 100 000 K), bridges the chasm between less-dense plasma and hot, condensed matter (1).

- Gold films were coated onto a substrate and brought to a desired thickness of 30 nm using a high vacuum thermal evaporator.

- Under laboratory conditions, warm dense matter is formed from laser ablation of a nano-foil (5). Formation of WDM is considered a crucial step toward inertial confinement fusion (ICF), a precursor to nuclear fusion.

- In this study, an overall view of the dynamics of warm dense matter from electron shadow images and electron deflectometry is discussed.

EXPERIMENTAL

- Gold films were coated onto a substrate and brought to a desired thickness of 30 nm using a high vacuum thermal evaporator.

- The samples were transferred to a nickel mesh (Figure 2).

- Figure 3a details the schematic for shadow imaging and electron deflectometry. The pump-probe divisions are arranged perpendicularly to the sample as opposed to a near collinear configuration used in diffraction studies (1). Figure 3b shows a more detailed view of this arrangement (2).

- The 545-µJ pump beam carried the bulk of the energy at a wavelength of 800 nm and a 120 fs pulse width.

- Shadow images (Figure 4) were produced with a 40 keV electron beam generated from the frequency-tripled probe laser beam.

RESULTS AND DISCUSSION

- Figure 4 shows real-time measurement of ejected electron dynamics during the early formation of warm dense matter (1-3 ps) in a gold nano-film after a single shot. Increasing the temperature of the lattice through isochoric electron heating is the critical factor in formation of WDM. From the shadow images, the front (left side) of the target spot expands more rapidly than the back (right side) indicating that a bulk of the electrons are ejected from the film surface at the target spot, carrying away much of the absorbed energy. This in turn may block transport of hot electrons within the target, preventing uniform heating of the lattice.

- At 50 ps the deflection curve progresses to a noticeable negative direction after a 25 ps peak because of the accumulation of positive charges on the film surface (Figure 5).

CONCLUSIONS AND APPLICATIONS

- Achieving single state plasma remains problematic in the study of warm dense matter. Further studies on the behavior of electrons after laser ablation of metal foil targets are needed, including manipulation of laser power.

- If the compressed metal surrounds a pellet of hydrogen gas in the form of deuterium or tritium, the temperature of prolonged WDM may be enough to initiate nuclear fusion within the hydrogen sample (3).

- According to researchers at the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL), a 10 mg sample of frozen hydrogen subjected to nuclear fusion via ICF, yields the same amount of energy as one barrel of oil.

REFERENCES


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