Supersonic Propagation of a K-Shell Ionization Front in Metal Targets

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OMEGA EP
Line-of-sight block
Ultrafast x-ray streak camera
Spherical crystal imager

Target

Laser: 1200 J, 10 ps
Target: 500 × 500 × 20 μm Cu

Target edge

d_{80}

Time (ps)

Signal (analog-to-digital units)

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Summary

Hot-electron–driven ionization fronts were measured in high-intensity, laser-irradiated metal targets

- A monochromatic, streaked x-ray crystal imager has been developed for the OMEGA EP laser to study collisional ionization-front dynamics in solid-density metals.

- Spatial, spectral, and temporal resolution is obtained by coupling a spherically bent crystal imager with a 2-ps-resolution x-ray streak camera.

- Implicit-hybrid particle-in-cell (PIC) and collisional-radiative code calculations are used to model the hot-electron transport, target heating, and front dynamics.

The predicted front and target-heating dynamics are consistent with experimental observations.
Collaborators

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Little time- and space-resolved data exists on ultrafast energy transport inside solid matter

- Warm-dense-matter (WDM) systems start as a solid and end as a plasma
- WDM is found in stellar interiors, cores of large planets, and inertial confinement fusion (ICF) implosions\(^1,2\)
- Significant uncertainties exist in WDM equation of state\(^3\) and opacity\(^4\)

Measurements are required for model development.

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Spatial, spectral, and temporal resolution is obtained by coupling a spherical crystal imager with an ultrafast x-ray streak camera.

OMEGA EP
10 ps, >10^{18} W/cm^2

Cu foil

Target
Spherical crystal imager

Line-of-sight block

Ultrafast x-ray streak camera

S. A. Pikuz et al., Rev. Sci. Instrum. 68, 740 (1997);
J. A. Koch et al., Rev. Sci. Instrum. 74, 2130 (2003);
Y. Agiltskiy et al., Phys. Rev. Lett. 87, 265001 (2001);
Streaked Kα imaging shows a collisional ionization front and ultrafast energy transport into the target

The initial hot-electron beam diameter is comparable to the laser focal-spot size.
The $K_\alpha$ front dynamics are modeled in two parts

- Hot-electron transport, target heating, and $K_\alpha$ emission are calculated using the hybrid particle-in-cell code $LSP^*$
- The $K_\alpha$ signal in the aperture energy bandwidth of the crystal imaging system is corrected for
  - temperature-dependent $K_\alpha$-yield suppression and spectral shifts
  - opacity effects along the diagnostic line of sight (LOS)
  - geometric effects

Cold $K_\alpha$ emission profiles calculated by $LSP$ are corrected based on the local temperature at the time of emission.

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$Laser: 1200 \, J, 10 \, ps$

$eV$

$T_e$

$cm^{-3}$

$\times 10^{20}$

$K_\alpha$-yield suppression, spectral shifts, and opacity modify the signal in the aperture energy bandwidth

These data are used to post-process the cold $K_\alpha$-emission profiles predicted by LSP.

The predicted ionization front and heating dynamics show reasonable agreement with the data.

Target heating suppresses $K_\alpha$ emission from the central regions of the target.
Summary/Conclusions

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