

Temperature Diagnosis of High Power Laser Heated Titanium Targets Using Spatially Resolved $K\alpha$ Imaging Spectroscopy

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1. Introduction

Warm dense matter (WDM), positioned between condensed matter and plasma, is of great interest in astrophysics, inertial confinement fusion, and high-energy-density physics. Short-pulse intense lasers interacting with solid-density foils provide a unique platform to generate WDM. Diagnosing such transient states requires advanced x-ray spectroscopic methods. In this work, we present spatially resolved $K\alpha$ spectroscopy of titanium foils irradiated by femtosecond multi-terawatt laser pulses, enabling direct determination of bulk electron temperature distributions.

2. Experiment

Experiments were performed at the MEC instrument of the Linac Coherent Light Source (LCLS). Ti:sapphire laser pulses (700 mJ, 50 fs, 5×10^{18} W/cm², p-polarized) irradiated 1–10 μ m-thick titanium foils coated with 100 nm Al. $K\alpha$ emissions were recorded using a toroidally bent GaAs(400) crystal spectrograph coupled to an x-ray CCD. The system provided simultaneous one-dimensional spectral resolution ($E/\Delta E \approx 15,000$) and spatial imaging (10 μ m). Abel deconvolution enabled retrieval of radially resolved emission spectra.

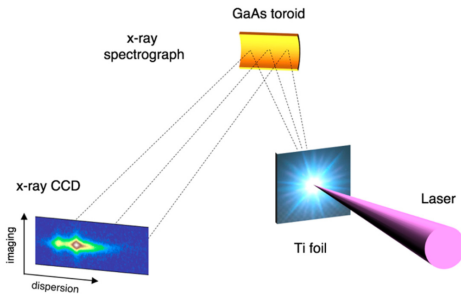


Fig. 1. Schematic of experimental setup (not scaled).

3. Results and Discussion

The $K\alpha$ doublet exhibited strong line-shape modifications depending on bulk electron temperature. Comparison with SCFLY atomic kinetics simulations indicated the presence of multiple temperature

populations ranging from 5–40 eV. Thick targets (5–10 μ m) displayed steep radial gradients, with higher temperatures localized near the laser spot. In contrast, thin foils (1 μ m) showed evidence of hot-electron refluxing, yielding relatively uniform temperatures (~ 20 eV) over diameters up to 150 μ m, nearly ten times larger than the focal spot. These results confirm that target thickness critically influences spatial temperature profiles in WDM generation.

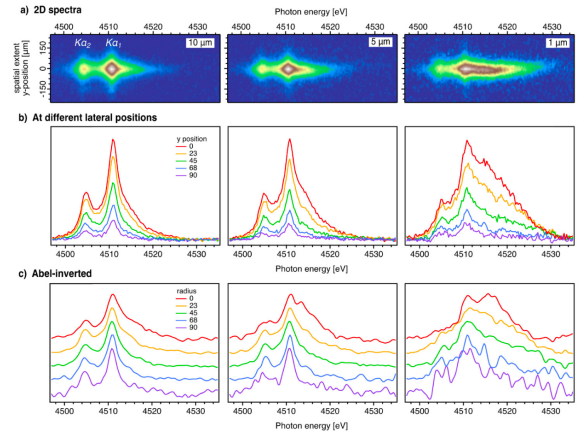


Fig. 2. (a) Averaged $K\alpha$ emission image (top), (b) spectra from different lateral target positions (middle), and (c) Able-inverted experimental spectra of the warm dense titanium foils of 10, 5, and 1 μ m thicknesses (bottom). $K\alpha_1$ emission strengths are normalized to the unity. For clarity, vertical offsets are applied.

4. Conclusions

We demonstrated that $K\alpha$ spectroscopy combined with Abel inversion provides a powerful diagnostic for spatially resolved WDM conditions. The study reveals multi-temperature distributions and highlights the advantage of thin foils in producing extended uniform WDM. These findings contribute to a better understanding of energy transport in relativistic laser–solid interactions and offer benchmarks for theoretical models.

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