Rapid Heating of Solid-Density Matter During High-Intensity-Laser Interactions: Small mass targets are of interest in high-intensity laser–solid interactions because of their unique fast-electron-transport properties.\(^1\)\(^2\) Electron refracting by the Debye sheath fields that are set up at the target surfaces provides a unique environment for studying the rapid heating of solid-density matter and determining the laser-to-electron energy conversion efficiency. Previous measurements of the absolute \(K_\alpha\) yield from copper foils as a function of the laser intensity demonstrate excellent agreement with electron-refracting models and laser-to-electron energy conversion efficiencies of \(\sim 20\%\).

Ionization of the M-shell during volumetric heating within such small mass copper targets can cause a deviation in the ratio of the number of emitted \(K_\beta\) and \(K_\alpha\) photons below the cold material limit. For sufficiently high energy densities, it is possible to impact both the \(K_\alpha\) and \(K_\beta\) emission probabilities. This is a direct consequence of bulk target heating because of fast-electron energy loss. Such a deviation could provide a useful benchmarking parameter on the energy content of the fast electrons and a consistency check on the laser–electron-conversion efficiency. To study this effect, copper foil targets ranging in size between 500 \(\mu\)m and \(20 \times 20 \times 2 \mu\)m were irradiated by LLE’s Multiterawatt (MTW) laser system with 1-ps-duration pulses at intensities of \(2 \times 10^{19} \text{ W/cm}^2\). The nonthermal plasma K-shell line emission was measured approximately normal to the target surface with an x-ray CCD operating in the single-photom-counting mode.\(^3\)

Figure 1 shows example copper K-shell spectra from a 500 \(\times\) 500 \(\times\) 20-\(\mu\)m target (a) and a 20 \(\times\) 20 \(\times\) 3-\(\mu\)m target (b). M-shell depletion due to target heating in the 20 \(\times\) 20 \(\times\) 3-\(\mu\)m target and its impact on the emission of \(K_\beta\) photons is clearly observable. Figure 2 shows the ratio of the number of emitted \(K_\beta\) and \(K_\alpha\) photons (\(NK_\beta/NK_\alpha\)—normalized to the cold material limit) as a function of the target volume. Three distinct regions are accessible experimentally: from the cold material limit in Region I, to the onset of M-shell depletion in Region II, to the highest energy-density environment observed in Region III, where both the \(K_\alpha\) and \(K_\beta\) emission are significantly affected. The absolute \(K_\alpha\) yield is compared to a semi-analytic model of \(K_\alpha\) production to infer the laser–electron conversion efficiency, \(\eta_{L\rightarrow e}\). A value of 20% to 30% is in good agreement with previous measurements to within the experimental errors and indicates the achievement of an electron temperature of \(\sim 200 \text{ eV}\) at a solid density. Three-dimensional numerical calculations are currently underway using the implicit-hybrid particle-in-cell code \(LSP\), coupled with a collisional-radiative code and a K-shell emission postprocessor, to infer the energy content of the fast electrons that will enable a direct comparison against the predictions of the absolute \(K_\alpha\) yield semi-analytic model.

**OMEGA Operations Summary:** During July 2007, 103 OMEGA target shots were conducted (with an overall shot effectiveness of 99%) for experiments led by LLE (68), LLNL (29), and NLUF (6). The NIC IDI program accounted for 23 of these shots; 50 target shots were provided to the NIC DDI campaign, and the remaining 30 shots were for various non-NIC programs. The ASBO off-axis telescope was qualified for use on the P6/P7 axis during this month.

---


Contact: John M. Soures (585) 275-3866; fax: (585) 256-2586; e-mail: jsou@lle.rochester.edu  
http://www.lle.rochester.edu