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Study of Non-LTE Spectra Dependence on Target Mass in Short Pulse Laser Experiments

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Abstract. Backlight sources created from short pulse lasers are useful probes of high energy density plasmas because of their short duration and brightness. Recent work has shown that the production of Kα radiation can be manipulated by the size and geometry of the targets. Empirical relationships suggest that the electron reflux in the target plays an important role in the heating of these targets to create x-ray backlight sources.

Keywords: X-ray backlight, Kα spectroscopy, fast electron transport.
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1. SHORT PULSE X-RAY SOURCES

Bright, high energy photon energy backlight sources are needed for future high-energy density plasma studies. For instance, photon energies of 20-40 keV will be needed to probe plasmas, such as those created from mid- to high-Z implosion experiments at the National Ignition Facility. X-ray sources in laser-produced plasma experiments are often created by using some of the multiple laser beams available to irradiate a secondary target, which itself becomes a plasma. In these sources, the plasma formation is dependent on the laser absorption, and the hydrodynamic evolution can be significant [1]. Unfortunately, backlights formed from "thermal" sources are not efficient enough to produce bright high energy backlights for energies greater than ~13 keV.

An alternative method for creating hot plasmas that can serve as x-ray backlights is to take advantage of the generation of fast particles in short pulse laser-solid interactions [2-7]. In this case, the plasma formation is dependent on the laser field. The electrostatic potential causes hot electrons to stay confined around the target, and the energy is transferred by electron-electron collisions. These kind of plasmas, in which collisional absorption starts to turn off for laser intensities $>10^{15}$ W/cm^2, are often characterized by a hot electron temperature. Recently, embedded silver micro-wire targets have successfully produced high-resolution two-dimensional radiographs using 22 keV photons that achieve a Kα conversion efficiency of $\sim10^{-5}$[8].

2. EXPERIMENTS TO VARY TARGET MASS

In order to better understand fast electron transport, experiments on thin multilayer targets were performed at the LULI 100 TW laser facility. This facility uses a Nd:glass laser to provide up to 100 J before compression. After chirped pulse amplification, this laser can provide up to 30 J in 300 fs, a maximum of $5x10^{19}$ W/cm^2. In short-pulse experiments, higher conversion efficiency of laser energy to Kα emission is observed in smaller targets. Because electron refluxing plays a predominant role in the bulk heating of the target, for constant laser energy, a smaller target is expected to achieve higher temperatures. In these experiments, the laser energy and focal spot were kept constant and the spectra were recorded for targets of varying mass.

The multilayer targets were composed of V/Cu/Al and varied from 300 to 50 μm in diameter. The V layer was 0.2 μm thick and acted as a converter layer for producing electrons. The Cu layer was varied in thickness in order to study the electron heating through 5, 10, and 20 μm thicknesses Cu layers. The Al was 5 μm thick and originally designed to act as a diagnostic layer to monitor the heating of the back surface by the relative intensities of the 1s-2p transitions of Al which were expected to be sensitive to the electron temperature [9-10].

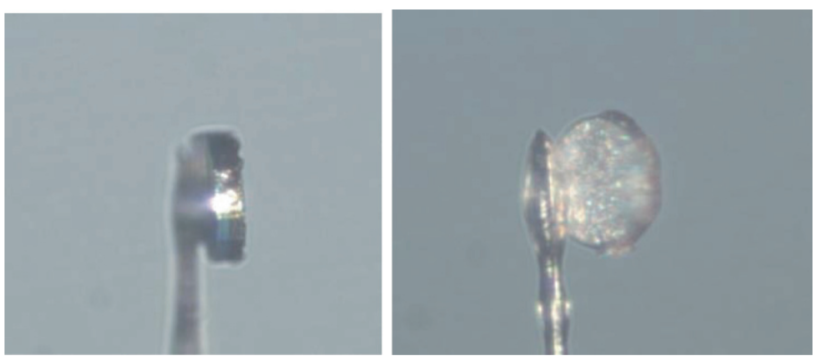

FIGURE 1. The smallest, lowest mass targets were 50 μm diameter disks mounted on a 6 μm dia. carbon fiber.

The targets were isochorically heated by a 20 J, 300 fs laser pulse that delivered $1{\sim}2x10^{19}$ W/cm^2 to form a warm dense plasma. The target surface irradiated by the laser was circular or square. By using targets 50, 200, 300 μm in diameter, and also 100x100 μm and 200x200 μm square, in combination with the different Cu thicknesses, the mass of the target was varied by from 1 to 36 M, where M is defined as the mass of the smallest and lowest mass target, 0.13 μg.

Emission from the rear, unilluminated Al side was recorded simultaneously by three diagnostics. Two time-integrated diagnostics provided 2D imaging and spectra of the Cu. The 2D imager was fielded with a spherical quartz crystal at 1.54 Å to measure the Cu Kα at 8X magnification. The spectrometer used a conical TlAP crystal and covered a range of 7.6-8.4 Å to record both the Al emission in 1st order, and the Cu emission in 5th order. In addition, a sub-ps streak camera was fielded with another TlAP crystal spectrometer to obtain time-resolved spectra of either the Al Kα or Cu Kα emission.

3. EXPERIMENTAL RESULTS

The data from targets of different sizes and/or Cu layer thickness are compared and analyzed to better understand the heating of the target and temperature of the plasma. The Cu Kα imager shows that the emission decreases with target mass quite dramatically when the mass drops below 0.39 μg. The 50 μm diameter targets, which span a range of 1-3 M, are 40% or less than targets having a mass of 8 M.

Spectra including the Al-Kα, Al He-α, and Cu-Kα emission from the unirradiated Al side of the target show significant qualitative changes as a function of total mass. In general, a stronger continuum appears for the lower mass targets. But more evident, shown in Fig. 2 below, is the shift of the line emission to shorter wavelength as the plasma becomes more ionized for lower mass targets. When the target mass is decreased, the cold Kα of Al decreases, while the He-α from the ionized Al increases. The Kα disappears for targets <300 μm in diameter. This shift is expected, however, the more surprising result is that the cold Kα of Cu almost entirely disappears for the 50 μm diameter targets.

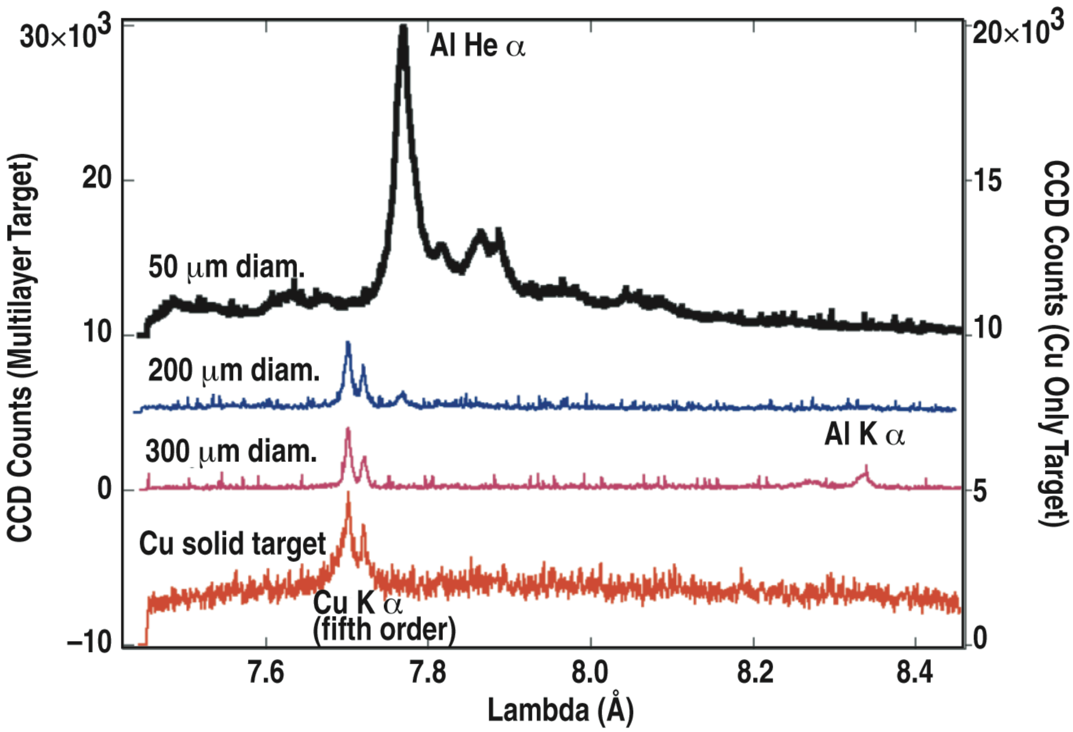

FIGURE 2. Spectra from a multilayer targets 50, 200, and 300 μm in diameter. All targets were composed of 0.2 μm V, 5 μm Cu, and 5 μm Al, and the laser irradiated the V side. The solid Cu target is shown to provide a reference spectra for the cold Cu Kα.

Calculations for the Cu spectra show that the thermal electron temperature effectively determines the charge state distribution for isochorically-heated targets. The effect of the hot electrons is to pump up the excited state populations so that the emission can be observed. The Kα lines for the L-shell ions at these densities and temperatures quickly become optically thick for plasmas even with the thinnest 5 μm thick Cu targets. Analysis of the Cu-Kα line at 8.064 keV shows that an electron temperature of 240 eV is most consistent with the measured spectra.

In these dense targets, the Al He-α line is expected to be opacity broadened. However, on the streak camera, this emission line does not appear to be reabsorbed. Instead, it appears optically thin, and has a relatively long duration of 5-15 ps. Preliminary modeling shows that the plasma expansion may be significant enough that the spectra of the 1s-2p transitions is not an effective electron temperature monitor of the dense plasma conditions in the Cu [11-12].

4. CONCLUSIONS

In conclusion, the spectra from low mass targets show trends that are consistent with the creation of a hot plasma. As the Cu is heated, the ionization balance changes and the cold Kα shifts and broadens. This has also been recently observed in experiments with chlorinated targets [13]. Furthermore, for the lowest mass targets in these experiments, the Kα nearly disappears.

Unfortunately, the 2-ps temporal resolution of the streak camera was not sufficient to record the Al spectra emitted during the time-of-interest when the plasma was hot and dense. Based on modeling, we now believe the hydrodynamic expansion compromised the use of the Al layer as a diagnostic of the electron temperature because it caused decompression of the Al plasma in the picosecond timeframe of the observation. Since the hot Al plasma takes a long time to cool due to low recombination rates, the lower density "expanding" plasma dominates the measured spectra. Future experiments are planned to continue refining this spectroscopic diagnostic.

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