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Characterization of short pulse laser-produced plasmas at the Lawrence Livermore National Laboratory Ultra short-Pulse Laser

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ABSTRACT

The K-shell emission from porous aluminum targets is used to infer the density and temperature of plasmas created with 800 nm and 400 nm, 140 fs laser light. The laser beam is focused to a minimum spot size of 5 μm with 800 nm light and 3 μm with 400 nm light, producing a normal incidence peak intensity of 10^{18} Watts/cm^2. A new 800 fs x-ray streak camera is used to study the broadband x-ray emission. The time resolved and time integrated x-ray emission implies substantial differences between the porous target and the flat target temperature. *Work performed under the auspices of U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

1. INTRODUCTION

Ultra-short pulse lasers have shown substantial promise in making high temperature, high density plasmas [1-4]. By focusing sub-picosecond laser light to intensities $>10^{15}$ W/cm^2 on high density matter, hot-dense plasmas can be formed for short periods of time. The nature of these plasmas are highly dependent on the temporal characteristics of the pulse and the surface structure of the interaction material. We present results of the K-shell spectroscopic emission from aluminum targets with two structures; 1) flat, solid density targets and 2) porous, 1% to 5% solid density targets [5]. Additionally, we measure the time resolved, broadband x-ray emission to provide some information on the time history of the cooling in the plasma.

The flat targets are made by vapor plating 1 μm of aluminum on glass substrates. The resulting surface finish is mirror quality, with $\approx \lambda/2$ flatness. The porous aluminum consists of clusters of aluminum particles (≈100 Å chains), with typically greater than 2 μm between particles. The density is ≈1% solid density, with the voids assumed to remain unfilled during laser irradiation.

The laser used in this study is a 120 femtosecond (FWHM) Ti:Sapphire laser capable of producing 60 mJ focused at 800 nm. To minimize the effects of pre-pulse at 800 nm, an IR

140 saturable absorber was added after the last power amplifier. With a minimum spot size of 5 μm, our peak intensity was limited to ≈ 10^{18} W/cm^2.

Experiments were also done at 400 nm to further reduce the effects of prepulse. The doubling was done with a 1.5 mm thick KD*P crystal with a 35 mm clear aperture. Doubling efficiencies as high as 45 % were seen with a negligible effect on the pulse width [6]. Although the energy was lower by a factor of two with the frequency doubled light, the diffraction limited spot size was also smaller by a factor of two, resulting in a net increase in intensity.

The aluminum K-shell data was collected with Von Hamos crystal spectrograph. The spectrograph uses a 7.62 x 1.9 cm potassium acid phthalate (KAP, 2d=26.623 Å), 5 cm cylindrical curved crystal. The detector resolving power is $E/\Delta E \approx 2000$. A x-ray streak camera was used to monitor the time history of the x-ray emission. This streak camera has been altered to produce ≈ 800 fs temporal resolution (calibrated at 400 nm). A series of filters were used to specify specific energy bands. The filter of particular interest is the 12.5 μm Saran filter. This filter is sufficiently thick that it has little transmission below 1 keV but because it has chlorine in it, it has a sharp fall in the transmission above 2.8 keV. This is approximately the energy range that the Von Hamos spectrometer covers. A plot of the folded response of the filters and the photocathode response is displayed in figure 1.

2. DATA and ANALYSIS

The He-like 2p1s-1s^2 was the only resonance transition observed with the flat targets and the method used to determine the plasma parameters require several spectral lines, the density and temperature for the flat target could not be determined. The temperature for the porous targets was determined by finding the best fit between the experimentally measured H-like and He-like spectrum and a synthetically generated H-like and He-like spectrum using the quasi-steady state equilibrium model [7]. These data were collected by integrating the spectra over approximately 700 shots. The shot to shot variation in the laser energy, and hence the intensity, was measured at <7%. A plot of the temperature as a function of laser intensity for 400 nm and 800 nm target illumination is displayed in figure 2. The temperature is noted as having a weak dependence on laser intensity. A comparison to existing theories is suspect because of the apparent higher absorption and lower initial density of the porous material. However, as a footnote intensity dependence of the temperature measured in these plasmas is weaker than the time dependent prediction made in reference 8. Furthermore, the measurements seem to be consistent with the measurements published in reference 9, at lower intensities. The electron density was inferred using Stark broadening of the 1s4p-1s^2 line. By comparing the measured line width to the calculated line width [10], the density was estimated for the laser intensity on target (see figure 3). A qualitative comparison of the relative thermal temperature achieved in the porous aluminum versus that of the flat aluminum indicated that under similar irradiance (4 x 10^{17} W/cm^2), the 1s2p-1s^2 emission was a factor of four greater in the porous aluminum with a factor of ten fewer shots. Furthermore, no emission from states higher than the 1s2p-1s^2 was seen in the flat aluminum. Note, however that estimates of continuum lowering due to higher densities could not account for the lack of emission from the higher states in the flat aluminum.

These results provide indirect evidence that the laser deposition is enhanced in the porous targets, possibly leading to higher temperatures. An alternative explanation of the data is that the flat target achieves a temperature similar to that of the porous target but the energy is conducted away sufficiently fast that the flat target signal is small compared to the porous target signal. The results from the streak camera suggest that a sufficiently high temperature is never achieved (see figure 4). The streaked data shows no emission in the Saran filtered band (approximately viewing the K-shell), no emission in the 25 μm Be filtered band (viewing all x-rays greater than 1 keV), but a 4.47 ps peak (FWHM) in the 12.5 μm Be filtered band (viewing all x-rays greater than ≈ 600 eV). Conversely, the porous target produced emission in all three x-ray bands described above. The Saran filtered band shows a 2.93 ps wide temporal peak, while the 25 μm filtered Be, and the 12.5 μm filtered Be show 3.71 ps and 4.26 ps peaks, respectively. It should be noted that although the flat target and the porous target produced time resolved x-rays with 12.5 μm filtered Be, the porous emission in this band was 10 times as great as that of the flat target. More detailed time resolved experiments are currently underway.

3. CONCLUSIONS

We have done the first measurement of the temperature and density of porous targets using spectroscopic techniques. The measurements indicate temperatures between 240 eV and 310 eV with 800 nm laser light and 280 eV to 370 eV for 400 nm laser light. The electron density was determined by Stark broadening of the $4p1s(^1P_1)$-$1s^2(^1S_0)$ to be $\approx 10^{22}$ cm^{-3}. Work is currently being done to further quantify and model this data.

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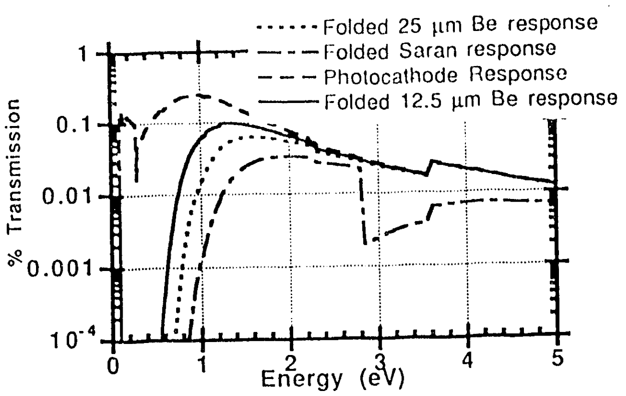

Fig. 1. Response of filters used with x-ray streak camera

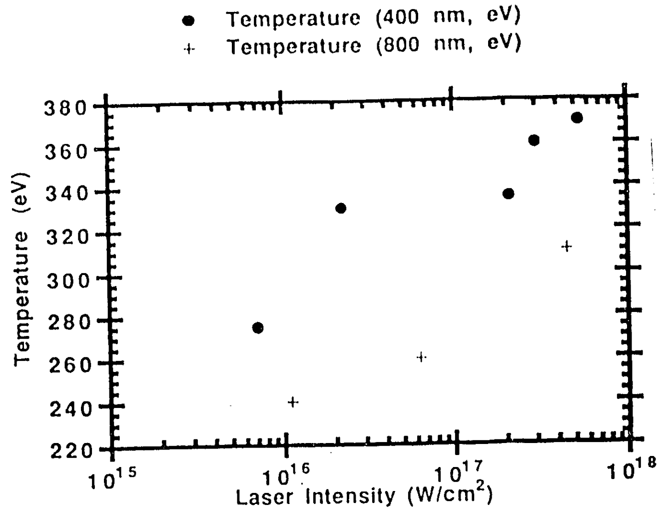

Fig. 2. Laser intensity vs. temperature

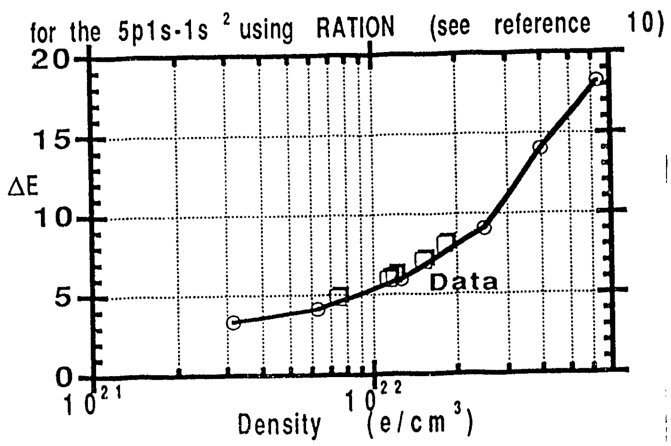

Fig. 3. Plot of line width vs. electron density

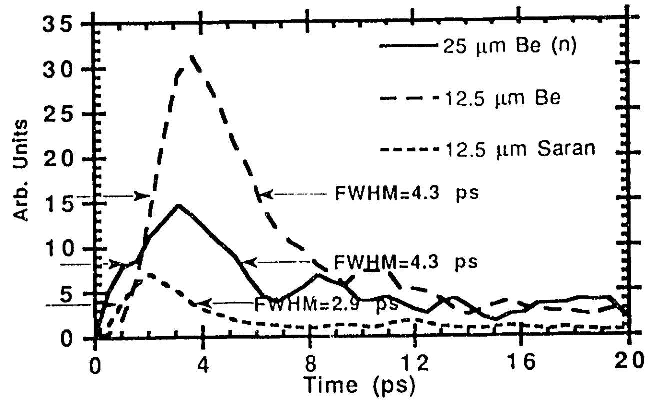

Fig. 4a. Streaked broadband Porous target x-ray emission

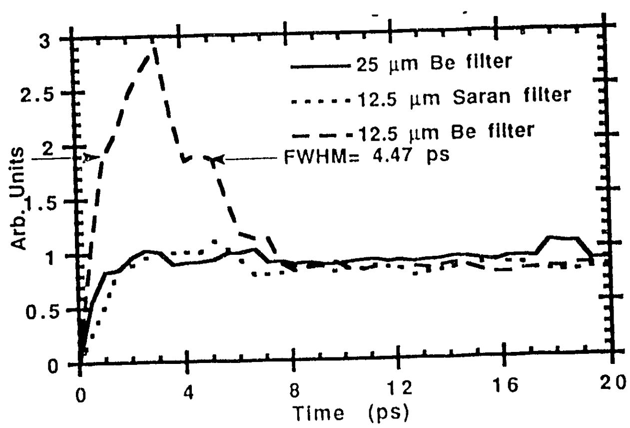

Fig. 4b. Streaked broadband flat target x-ray emission

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