Spectral measurements of asymmetrically-irradiated capsule backlighters[a)]

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Capsule backlighters provide a quasi-continuum x-ray spectrum over a wide range of photon energies. [Hansen et al, 2008] Ideally one irradiates the capsule backlighter symmetrically, however, in complex experimental geometries, this is not always possible. In recent experiments we irradiated capsule backlighters asymmetrically and measured the x-ray spectrum from multiple directions. We will present time-integrated spectra over the photon energy range of 2-13 keV and time-resolved spectra over the photon energy range of 2-3 keV. We will compare the spectra from different lines of sight to determine if the laser asymmetry results in an angular dependence in the x-ray emission

I. INTRODUCTION

In x-ray absorption spectroscopy experiments, one creates a source of x-rays which interacts with a sample material. One can determine the density and temperature of the sample based on the photons that are absorbed by the sample. Ideally these x-ray sources have a smooth, featureless spectrum over the spectral region where one expects the absorption features to occur. In many previous laser-based opacity experiments, this was achieved by irradiating one or more high-Z materials with lasers and using L-shell or M-shell line transitions to produce unresolved transition arrays (UTAs) to produce as smooth of as spectrum as possible.[?, ?] However, the actual smoothness of the spectrum depends on how close together the transitions are. One must characterize the x-ray source well in order to determine if a spectral feature in the data is due to absorption from the sample or due to a feature in the source. For example, variations in the laser parameters could result in changes in the plasma conditions and therefore the source spectrum generated.

Yaakobi et al[?] and Hansen et al[?] demonstrated that laser-irradiated gas-filled capsules provide a short duration (less than 200 ps) and provide a smooth, continuum spectrum.for photon energies of 4-6 keV using gas filled-capsules. Yaakobi used H-filled capsules, which results in the primary emission coming from bremsstrahlung emission. Hansen used higher-Z gases such as Kr to create a laser-driven dynamic hohlraum, which is a radiative, spherical collapsing shock that traps radiation in its enclosed volume. They found the dynamic hohlraums to produce a smoother spectrum and higher signal levels.

However, in complicated high-energy-density (HED) experiments, one can often be limited on the geometry and may not be able to symmetrically illuminate a capsule backlighter. We present spectral measurements at multiple angular positions from asymmetrically laser-irradiated capsules. In Section II we discuss the experimental setup and in Section III we present the results.

II. EXPERIMENTAL CONFIGURATION

The experiment was performed on the OMEGA-60 laser.[?] 20 beams with a nominal energy of 450 J/beam, a 800 micron diameter focus and a 1 ns laser pulse irradiated a capsule with the irradiation pattern shown in Figure 1. The laser power is peaked around $\theta = 115$ degrees, ϕ=145 degrees. The Glow Discharge Polymer (GDP) capsules had an outer of diameter of 857 +/- 3 microns and a wall thickness of 8.9 +/- 2 microns. The capsules either were evacuated or contained 1 atm of air. It was important not only to measure the implosion form multiple directions to observe the symmetry, but also to observe the x-ray spectrum from multiple directions in order to determine if there was an angular dependence to the x-ray spectrum due to the asymmetric laser drive. Diagnostics included soft x-ray cameras, which observed the laser-ablated plasma and self-emission of the capsule, the Henway x-ray spectrometer and a streaked x-ray spectrometer.

In order to determine the energy dispersion for each of the spectrometers we irradiated planar foil targets to generate He-alpha emission. These targets were composed of Ni and Polyvinylidene chloride $C_2H_2Cl_2$ semi-circles on a single target. We used the Cl and Ni emission lines to determine the energy dispersion of each spectrometer.

III. RESULTS

A. Streak Camera

We measured the x-ray spectrum from the capsule over the photon energy range of 2.1 - 3.1 keV with a streak camera located at θ=116.57 degrees and ϕ= 162 degrees, which provides a time-resolved measurement of the spectrum over a 4 ns window. In general, there are two sources of emission observed with the streak camera, the

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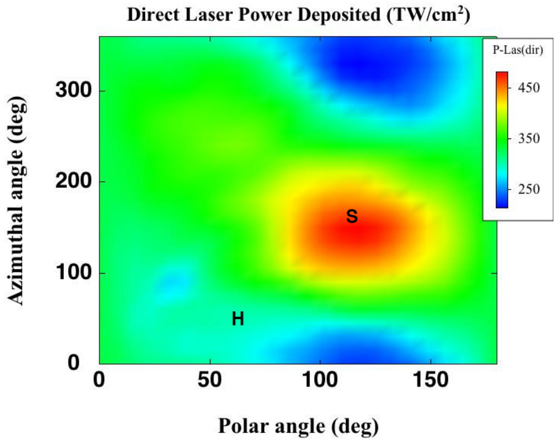

FIG. 1. The laser power deposition profile on the capsules as calculated by the Visrad view factor code. The emission is peaked around θ = 115 degrees, ϕ=145 deg reeswith an amplitude that is a factor of 2 higher than the minimum. The 'H' and 'S' designate where the Henway and Streaked spectrometers are probing.

History BL Capsules.eps

Time History BL Capsules-eps-converted-to.pdf

FIG. 2. A time history of the x-ray emission of the capsule backlighters. Data from both air-filled and vacuum capsules are shown. The time axis is relative to the start of the emission of x-rays.

emission of the laser-generated plasma and the emission from the bright core. Figure 2 shows the time history of the x-ray emission with t=0 corresponding to the start of the x-ray emission, not the start of the laser pulse. The x-ray emission has a duration of ∼1.3 ns with the peak of the emission occurs roughly 1 ns from the start of the emission. The emission from the bright core has a duration of roughly 300 ps and is roughly twice as bright as the capsule self-emission. The time history of the emission is essentially identical regardless of the fill of the capsules. This result is consistent with the x-rays being generated by bremsstrahlung emission from electrons interacting with the shell material. An X-ray framing camera measured the self emission of the capsule and the data indicates the bright core forms at 1.4 +/- 0.1 ns. This is consistent with the streak camera and with simple 1D radiation hydrodynamic simulations that were performed.

B. Henway Data

The Henway diagnostic is a four channel x-ray spectrometer, which provides spectrally and temporally integrated spectra from 1.5 to 13 keV. The data was recorded on Biomax film. The Henway diagnostic is located at θ=63.44 and ϕ= 54. Figure 3 shows the x-ray spectra from a capsule backlighter from one of the Henway channels used. With the exception of the Si emission lines due to the lasers irradiating the target stalk, one notices that the spectrum is featureless.

Spectrum.png

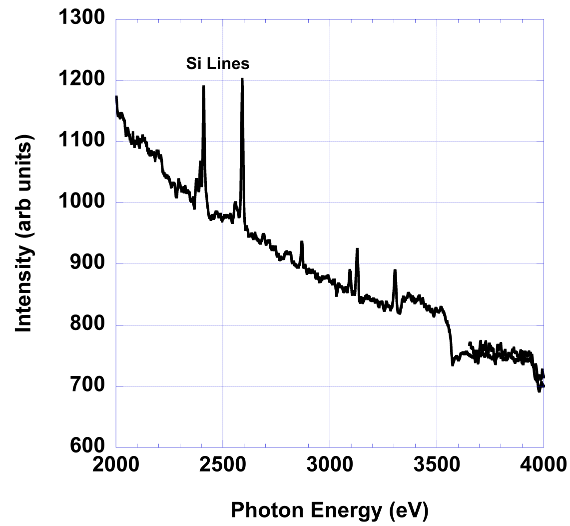

FIG. 3. The measured x-ray spectrum from 2-4 keV from the Henway spectrometer. The spectrum is flat with the exception of Si lines from the stalk.

C. Comparison

We now compare the spectra from the two different spectrometers to examine the angular dependence of the x-ray spectra. To make this comparison, we have summed the data from the streak camera over its entire 4 ns window and compare it to the time-integrated Henway data. Figure 2 shows that the emission goes to zero before the end of the 4 ns, which means we are captur-

Capsule Slope3.eps

Henway Capsule Slope3-eps-converted-to.pdf

Camera Slope 3.eps

Streak Camera Slope 3-eps-converted-to.pdf

FIG. 4. Comparison of the Henway and Streak Camera data from 2-4 keV. The dashed green line represents the slope of the Henway data. There is excellent agreement when it is compared to the slope of the streak camera data.

ing all of the x-ray emission. In Figure 4, we plot the Henway spectrum from 2.2 - 3 keV from all of the different shots. This demonstrates the reproducibility of the capsule backlighter spectrum. With the exception of the previously discussed Si lines, the spectrum decreases in intensity as the photon energy increases. We perform a fit to the slope of the line, indicated by the dashed green line. Figure 4 shows the integrated streak camera signal from 2.2 - 3 keV. One also observes the Si lines from the target stalk in this data. While one can notice a different ratio between the amplitudes of the Si peaks between the different diagnostics, this only indicates that the Si plasma parameters may be different along each line of sight and is not an indicator of the plasma conditions of the capsule. Recall that the Si emission is due to the laser-ablation of the Si stalk, while the emission from the capsule is from bremsstrahlung emission. In 4, we have plotted the slope of the Henway spectrum, multiplied only by a constant to fit the amplitude of the data. One can see that the slope of the streaked data is also described well by the line with a minor deviation around 3000 eV. More investigation must be done to determine if this is an effect of being near the edge of the spectrometer or due to the physics. The laser energy variation between the different shots was $\sim 5\%$, which is not large enough to produce appreciable differences in the plasma parameters as seen in the Henway spectra, where the slope is identical regardless of the laser energy. Recall that the radiated bremsstrahlung power depends on the electron density and temperature. If the plasma conditions, i.e. the density and temperature, varied at different angular positions, one would expect to see a difference in the slope of the line. The fact that the slopes appear very similar suggests qualitatively that there is not a significant angular dependence to the spectrum. This appears consistent with the soft x-ray framing camera data that shows asymmetric self-emission in the oft channels, but at the time of the bright core, the emission of x-rays with energies greater than 1 keV appears fairly symmetric. Qualitatively, the data suggests that for this level of asymmetry, the spectrum does not have an angular dependence.

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