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Laser-Plasma Interactions in High-Energy-Density Plasmas

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Laser-Plasma Interactions in High-Energy-Density Plasmas
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High temperature hohlraums (HTH) are designed to reach high radiation temperatures by coupling a maximum amount of laser energy into a small target in a short time. These 400-800 μm diameter gold cylinders rapidly fill with hot plasma during irradiation with multiple beams in 1ns laser pulses. The high-Z plasmas are dense, (electron density, n_e/n_c~0.1-0.4), hot (electron temperature, T_e ~10keV) and are bathed in a high-temperature radiation field (radiation temperature, T_{rad} ~300eV). Here n_c, the critical density, equals $9x10^{21}/cm^3$. The laser beams heating this plasma are intense (~10^{15} – 10^{17} W/cm^2). The coupling of the laser to the plasma is a rich regime for Laser-Plasma Interaction (LPI) physics. The LPI mechanisms in this study include beam deflection and forward scattering. In order to understand the LPI mechanisms, the plasma parameters must be known. An L-band spectrometer is used to measure the electron temperature. A ride-along experiment is to develop the x-radiation emitted by the thin back wall of the half-hohlraum into a thermal radiation source.

Figure 1a shows the experimental setup. About twenty laser beams in three cone angles are incident into a 600 μm diameter, 660 μm long half-hohlraum. The side walls of the hohlraum are gold, usually 20 μm thick. The back wall is thin, ~1 μm gold or 1 μm gold overcoated with 1 μm parylene. The high and intermediate angle beams are focused at the center of the Laser Entrance Hole (LEH), but the low angle beams are focused ~250-400 μm in front of the LEH to avoid hitting the back wall. An LPI probe beams is incident almost normal to the hohlraum axis, and aimed to an interaction region, which is the plasma that is 200 μm in front of the LEH. The transmission and forward scatter of this beam is measured with the temporally and spectrally resolved spectrometers and calorimeters in the Full Aperture Backscatter (FABS) diagnostic. Because of the laser beam configuration on the Omega laser, one can use FABS to measure the forward scattered light from opposing beams. If the beam is deflected, it falls onto the NBI plate. A time-averaged image of this deflection is recorded by the NBI camera. The Lband spectrometer views the plasma in the LEH region. The x-radiation emitted by the thin back wall can be used to heat a physics target. To characterize this source, the heating of a witness place placed ~ 400 μm outside the back wall (Figure 1b) was measured.

Beam deflection is measured with the NBI plate. Figure 2 shows images of the NBI plate as a function of LPI probe beam intensity, for two independent interaction beams. As the intensity increases, the beam deflection increases (the cross marks the center of the beam). The LPI beam is “bent” by the plasma flowing out of the target. Beam deflection occurs when the ponderomotively induced density depressions in the plasma move downstream, and carry the light refracted into them. The images from NBI 25 and NBI 30 corresponds to interaction beams B46 and B61, traversing the plasma at angles 31 and 9 degrees respectively, with respect to the normal to the axis of symmetry of the hohlraum. The beam deflections at $5x10^{15}$ W/cm^2 is approximately 15 and 7.2

degrees respectively. This is the first observation of beam deflection as a function of laser intensity, for different optical paths along the plasma.

Understanding the measured LPI mechanisms depends on knowing the plasma parameters. Radiation-hydrodynamics codes are used to predict the plasma conditions. These must be benchmarked by measurements of n_e and T_e. In highly charged gold, the 3d->2p transitions of individual ionization states are separated by about 40 eV. If these lines can be resolved, the spectrum gives the distribution of the ionization states of gold. This, combined with models that predict the ionization state as a function of electron temperature, would give Te.

The Lband spectrometer is designed to measure the 3d->2p transitions in gold with high resolution. It is a transmission crystal spectrometer mounted to a single-strip framing camera. It captures a single time and space resolved high resolution spectra. Figure 3a shows a measured spectrum. There are a lump of lines, peaking at 10100 eV, with half-width of about 250 eV. Simulated spectra from the non-local thermodynanmic equilibrium (NLTE) code FLYCHK (for $\langle Z \rangle$ as a function of electron temperature) and FLYSPEC (for spectral lines) show similar features: a lump of lines about 200 eV wide. The centroid moves to higher x-ray energy with higher electron temperature. A comparison of the data with simulation shows the measured electron temperature is ~ 7-8 keV.

Measured stimulated Brillouin forward scattering (SBFS) is shown in Figure 4. The SBFS confirms the time at which the plasma reached the interaction region, by the transition from 3w laser light to SBFS. The absence of 3w light after 1ns,may indicate that the nonlinear beam deflection have shifted the beam towards the NBI plate, with the light missing the collecting lens. It is possible that the SBFS is NOT deflected, because of its lower intensity.

The use of the back wall as a radiation source is demonstrated by using it to heat a witness plate. The arrangement for the HTH half-hohlraum with the witness plate is shown in Figure 5. Figure 5a shows a schematic of the target. The witness plate is mounted ~400 μm from the back wall, at an 11^{o} tilt to the back wall so that the imaging diagnostic views the witness plate edge-on. The witness plate is a thin chromium foil sandwiched in plastic (1 μm on each side). Figure 5b shows the heated witness plate at two different times. These were taken on two different shots, so the distance of witness plate from back wall is a little different. However, the witness plate is clearly expanding as it is heated. Figure 5c shows the measured width of the witness plate as a function of time from several shots on several different days. The line is the predicted expansion from a rad-hydro simulation, assuming the witness plate is heated solely by radiation from the back wall. The data is consisitent with the simulation, which predicts the radiation temperature in the plate to be ~165 eV.

Other measurements of the plasma parameters in the LPI region have been performed. These are (a) the M-shell spectra of gold; (b) raman backscatter and (b) 2w and 4w Thomson scattering. These data are still being analyzed.

Figure captions:

Figure 1: Experimental set-up: (a) Hot hohlraum showing LPI region, drive, and interaction beams. (b) Hot hohlraum showing location of witness plate and view of Lband spectrometer.

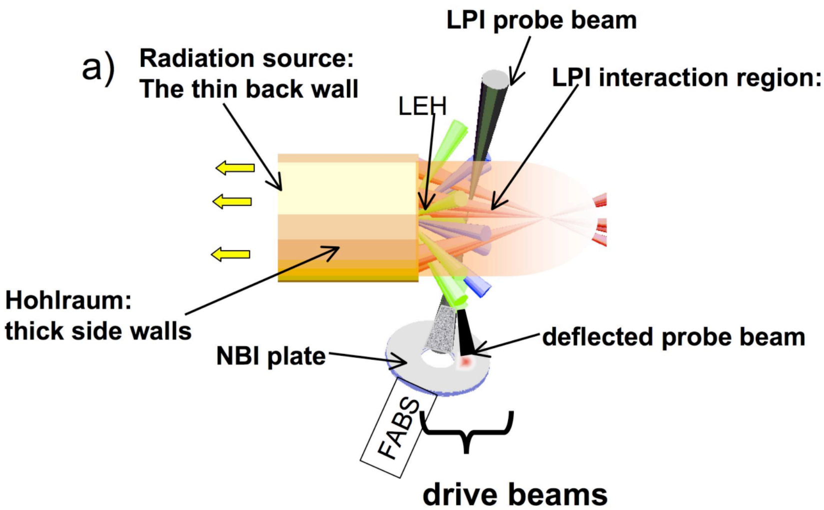
Figure 2: Images of NBI plates show beam deflection as function of LPI probe beam intensity.

Figure 3: 3d-> 3p transitions in highly-charge gold.

Figure 4: Streak camera image showing forward SBS.

Figure 5: Fig 5: New radiation source: thin back wall of HTH half-hohlraum is used to heat a witness plate. (a) The sketch of target shows witness plate mounted ~300μm from back wall at 11^{o} angle so it is viewed edge-on by OMEGA diagnostic. (b) The data shows witness plate glowing after it has been heated by back wall (also glowing). (c) measured expansion.

FIGURE 1a


a)
Radiation source:
The thin back wall
LPI probe beam
LPI interaction region:
LEH
Hohlraum:
thick side walls
NBI plate
deflected probe beam
FABS
drive beams

Figure

1b

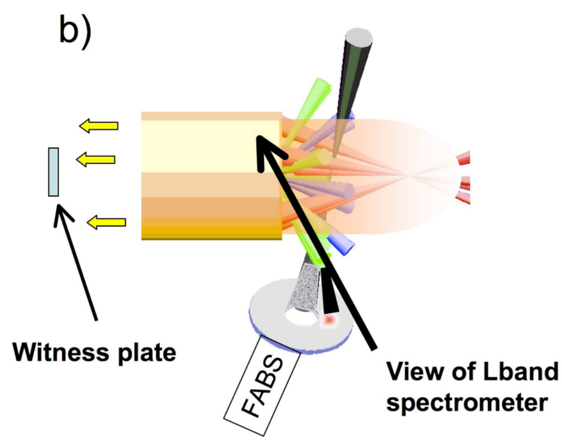


Figure 2

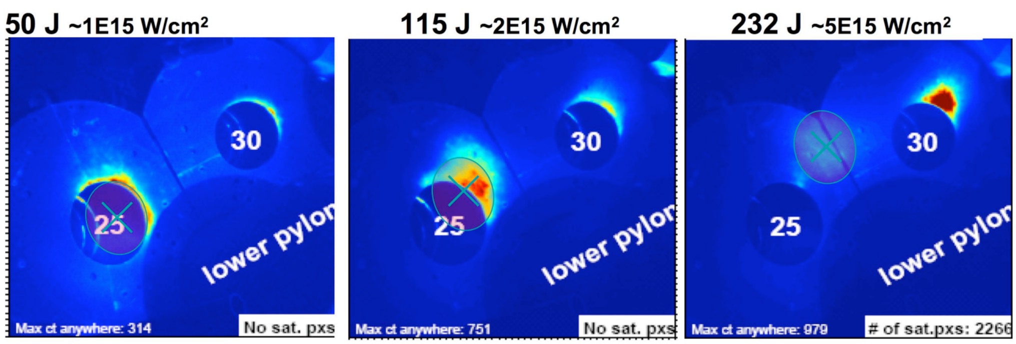
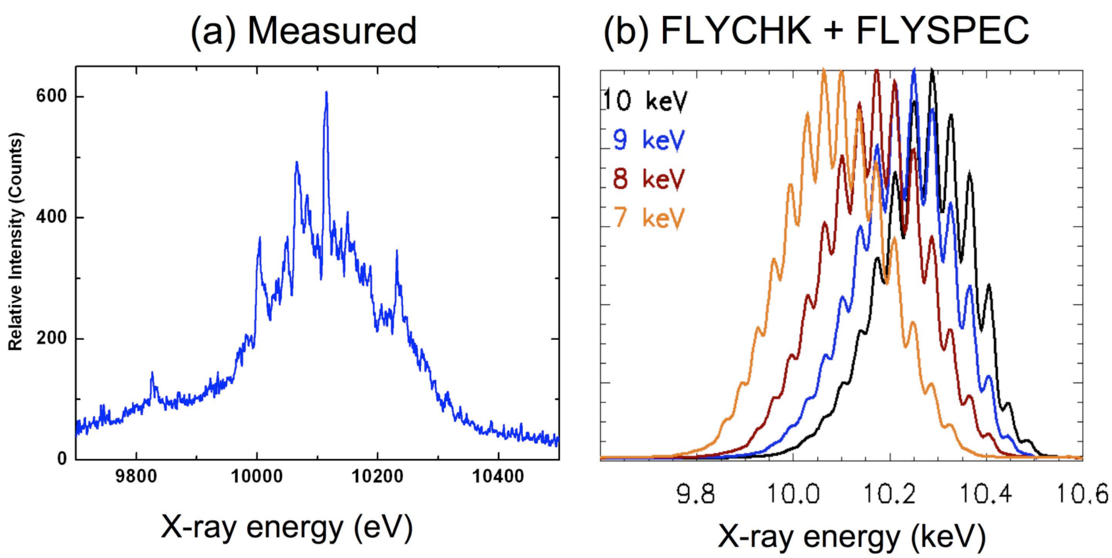


Figure 2: LPI: beam deflection as function of LPI probe beam intensity.

Figure 3


(a) Measured
Relative Intensity (Counts)
600
400
200
0
9800
10000
10200
10400
X-ray energy (eV)
(b) FLYCHK + FLYSPEC
10 keV
9 keV
8 keV
7 keV
9.8
10.0
10.2
10.4
10.6
X-ray energy (keV)

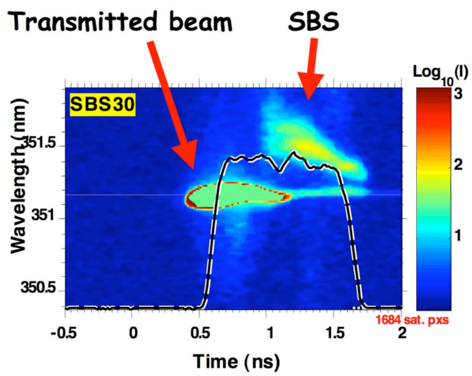

Transmitted beam
SBS
SBS30
Log10(I)
3
2
1
Wavelength (nm)
351.5
351
350.5
1684 sat. pxs
-0.5
0
0.5
1
1.5
2
Time (ns)

Figure 4

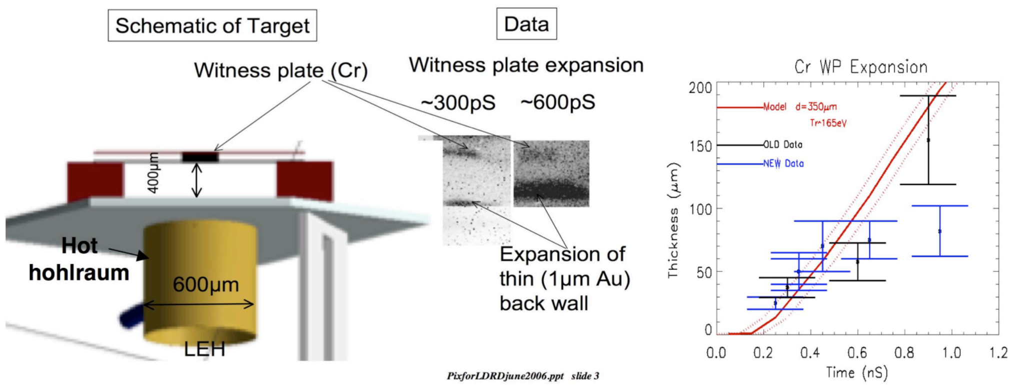

Schematic of Target
Witness plate (Cr)
400µm
Hot
hohlraum
600µm
LEH
Data
Witness plate expansion
~300pS
~600pS
Expansion of
thin (1µm Au)
back wall
PixforLDRDjune2006.ppt slide 3
Cr WP Expansion
Model d=350µm
Tr=165eV
OLD Data
NEW Data
Thickness (µm)
Time (nS)

Figure 5