Optical Measurements of Preheated Polystyrene and Aluminum Layers

W. Theobald
University of Rochester
Laboratory for Laser Energetics

47th Annual Meeting of the American Physical Society
Division of Plasma Physics
Denver, CO
24–28 October 2005
Collaborators

University of Rochester
Laboratory for Laser Energetics

J. Eggert, P. M. Celliers
Lawrence Livermore National Laboratory
Preheating leads to a strong absorption and frequency shift of an optical-probe laser

• X-ray preheating can compromise shock-timing (VISAR) measurements at high laser intensities.

• Preheat experiments using 100-ps laser pulses and planar CH targets revealed a preheat precursor of up to \(~4\) eV at \(5 \times 10^{14}\) W/cm\(^2\).

• The expansion of an aluminum layer because of preheat is inferred from a Doppler blue-shifted probe-laser wavelength.

• Preheated polystyrene leads to a strong absorption and a temporally increasing refractive index.
X-ray preheating can compromise the optical shock-timing diagnostics.


†T. R. Boehly C12.005
Strong absorption and wavelength shifts are measured in preheated polystyrene and aluminum
Preheating of up to ~ 4 eV is measured prior to the shock front at the target back side.
The expansion of the aluminum layer due to preheat is inferred from a Doppler blue-shifted probe-laser wavelength.

- Expansion toward the probe laser \([v(t) < 0]\) results in a blue shift \(\Rightarrow + \Delta f\).

- Ionization \((dn/dt < 0)\) also leads to a blue shift \(\Rightarrow + \Delta f\).

**Probe beam frequency**

\[ \omega(t) = \omega_0 - 2k_0 \frac{\partial}{\partial t} (nL) \]

**Moving mirror (if n = const.)**

\[ \Delta f(t) = -\frac{2n}{\lambda_0} \int_{t-\tau}^{t} v(t') dt' \]
An increasing refractive index with time is measured for preheated polystyrene.

An additional experiment confirms no measurable thermal expansion of polystyrene ($dL/dt = 0$).
Ionization by x-rays creates “free” electrons and in some materials optical transitions in the valence band:

\[ n \approx \sqrt{n_r^2 - \frac{\omega_p^2}{\omega_0^2 + \nu^2}} \]

\[ n \approx 1 + \frac{2P}{\pi} \int_0^\infty \frac{\omega' \alpha(\omega')}{\omega'^2 - \omega^2} d\omega' \]

Ionization: \( \omega_p \uparrow \)
\( \frac{dn}{dt} < 0 \rightarrow \text{blue shift} \)

Conduction

Valence

> 2.33 eV

Holes in valence bands

E\text{VISAR}

E\text{Transition}

Refractive index 1.59

Energy (eV)

1 2 3 4

\( \frac{dn}{dt} > 0 \)

†T. R. Boehly C12.005
Summary/Conclusions

Preheating leads to a strong absorption and frequency shift of an optical-probe laser

- X-ray preheating can compromise shock-timing (VISAR) measurements at high laser intensities.

- Preheat experiments using 100-ps laser pulses and planar CH targets revealed a preheat precursor of up to ~4 eV at $5 \times 10^{14}$ W/cm$^2$.

- The expansion of an aluminum layer because of preheat is inferred from a Doppler blue-shifted probe-laser wavelength.

- Preheated polystyrene leads to a strong absorption and a temporally increasing refractive index.
A novel experiment studies preheating in polystyrene by preventing mirror heating.

Mirror

VISAR

30-μm Au

CH

Ω

VISAR-1, shot 38786
The wavelength and amplitude variation during the VISAR etalon delay time is taken into account.

\[ \Delta \Phi(t) = c \left[ \int_0^t k(t') dt' - \int_0^{t-\tau} k(t') dt' \right] = 2\pi c \int_{t-\tau}^t \frac{1}{\lambda(t')} dt' \]
A temporally increasing optical path length is inferred for polystyrene from a red-shifted probe wavelength. The corresponding fringe shift is in negative direction.

Probe beam wavelength
\[ \lambda(t) = \lambda_0\left[1 - \frac{2}{c} \frac{\partial}{\partial t} (\eta L)\right]^{-1} \]

Red shift
\[ \lambda(t) > \lambda_0 \]

The corresponding fringe shift is in negative direction
\[ \Delta f(t) = c \left[ \int_{t-\tau}^{t} \frac{1}{\lambda(t')} dt' - \frac{\tau}{\lambda_0} \right] = -\frac{2}{\lambda_0} \left[ \eta(t) L(t) - \eta(t-\tau) L(t-\tau) \right] \]
X-ray radiation might open optical transitions in the valence band

*VEH density of valence states for a stereo-regular polystyrene chain with a \((\text{TG})_3\) conformation

The increase in the refractive index is proportional to the oscillator density.