Heat Transport Measurements in Foil Targets Irradiated with Picosecond Timescale Laser Pulses

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Background

- High temperature and high density opacity experiments have been performed on the HELEN CPA laser using short pulse driven electron transport to heat buried layers in plastic foils but the details of the heating mechanism are not understood.

- A number of measurements using X-ray spectroscopy and electron spectrometers have been carried out to try to better understand the heating mechanisms and to benchmark electron transport codes under development at AWE.

- The time delay of heating at different depths in plastic foils has been investigated using X-ray spectroscopy and an ultra-fast streak camera.

- The effect of target resistivity and refluxing of electrons has been investigated.
Time resolved and time-integrated diagnostics were fielded.

X-ray spectrometer and ultra fast streak camera

1.5µm CH

2µm CH

X-ray pinhole camera

1.5µm CH

2µm CH

(Electron Spectrometer)

1.5µm CH

2µm CH

X-ray pinhole camera

Two crystal, time-integrating spectrometer

0.1µm mid Z/ low Z mixture.

Alignment and focussing aid

Plastic washer hole diameter 0.8mm OD 2mm

Sample foil mounted on a plastic washer.

50µm diameter microdot.

Target mounting
Electron heating of the target not effective in the presence of pre-pulse.

(a) Spectra with green light

(b) Spectra with infrared light

Electron heating of the target not effective in the presence of pre-pulse.
Pre-pulse mitigation was important for effective heating

$2\omega$ conversion and plasma mirrors were used to mitigate pre-pulse

- Plasma mirrors were used in 1.06$\mu$m wavelength experiments.
Plasma mirror and $2\omega$ results compared.

IR + plasma mirror produces similar plasma conditions to using green light in experiments with aluminium buried layers.

IR+plasma mirror

Green light

Broad 1-3 line emission indicates densities ~ 1-2g/cc.

Ly$_b$/He$_b$ ratio indicates high Te ~500eV.
Heat penetration was measured using aluminium layers buried in parylene N plastic foils.

Penetration with 0.5ps pulses

Penetration with 2ps pulses
Time delay in the emission of the two layers expected for
• (a) Thermal heat conduction
• (b) Coronal radiative heating enhancing the thermal conduction
• Alternative/ additional heating mechanisms
• (c) Return currents
• (d) electron refluxing

Predicted heat front position v time assuming thermal diffusion of electrons into the target

Thermal conduction predicts a rapid fall off of temperature with depth
Electron transport experiments with multilayer targets

Temperatures inferred from analysis of the Silicon emission are in reasonable agreement with those inferred from aluminium spectra.
Electron transport models are being developed and will be incorporated into an AWE radiation-hydrodynamics code.

The target heating depends on return currents and the target conductivity $\sigma$.

\[
j_c = -j_h = \sigma E
\]

- Thor II electron transport model includes return current heating.
The effect of conductivity change was studied using chlorinated plastic layer targets.

Target 2µm PyN/1µm PyD/ 2µm PyN
PyD – parylene D 50% by weight chlorine
41J, 0.5ps $2 \times 10^{19} \text{W/cm}^2$. 

![Graph showing energy levels with peaks at He$\alpha$, Ly$\alpha$, He$\beta$, and Ly$\beta$.]
Chlorine 1s3p data indicate higher temperatures than Al, Si.

2µm PyN /1µm PyD/ 2µm PyN
41J 0.5ps ~2x10^{19} W/cm^2

6µm PyN /1µm PyD/ 2µm PyN
20J 0.5ps ~1x10^{19} W/cm^2

Data is normalised – not an absolute flux comparison.
Low and high spectral resolution data agree.

- Although resolution is low ($E/dE \sim 300$), the temperature inferred from the CsAP crystal spectrum agrees with that from the PET crystal.
HELEN experiments have demonstrated the technique of long pulse shock compression and short pulse heating.

Predicted density and temperature histories for shock compression and short pulse heating.

- Shock velocity ~$3 \times 10^6$ cm/s
- Ablation rate ~$6 \times 10^5$ cm/s
- Ablation pressure ~$12$ Mb

Experimental setup schematic:
- CPA 2w 0.5ps
- SP 30J 0.5ps
- LP 300J 1ns
- XRSS 1
- XRSS 2
- West beam

Density (g/cc) vs. Time (nanoseconds)

Temperature (keV) vs. Time (nanoseconds)
Shocked aluminium experiment streak data – Line broadening used to diagnose shock compression of an aluminium layer.

Fits to peak compression indicate density 3g/cc and peak temperature 600 ±50eV.
Comparison of LTE and non-LTE opacity code predictions to the shocked germanium data.

The shocked germanium samples are nearer LTE but gradients are an issue.

Gradients from radiation-hydrodynamics
450-650eV, 4g/cc
Experiments to measure the electron distribution

Electron distribution inferred from fluorescence

Thermal emission

Kα fluorescence

2PN/ 0.15Al/ 8PN / 15Sc/1PN

Electron spectrometer measurements

Emergent electron spectra for targets with different density scale-lengths

Film data

Scandium Kα

Aluminium emission

Electron spectrometer

frequency

UNCLASSIFIED
FLYCHK calculations including background hot electrons show these generally have little effect on the spectrum.

\[ f_{\text{hot}} = \frac{n_{\text{hot}}}{n_e} \]

- \( T_{\text{hot}} \sim 200\text{keV} \) based on Beg scaling.
- HELEN K\(_{\alpha}\) measurements show conversion efficiency \(10^{-4}\) and imply \( f_{\text{hot}} \) closer to 1% than 5%.
- Possible effect on Ti spectrum. Ly\(_{\alpha}/\text{He}_\beta\) ratio not a good temperature diagnostic.
- Al Ly\(_{\beta}/\text{He}_\beta\) ratio not affected.
Summary/conclusions

- Electron transport experiments using buried layer targets have shown that target heating using ultra-short pulse lasers is not due to thermal conduction.

- Near instantaneous heating through up to 15µm of plastic is consistent with the Thor2 model of hot electron collisional heating and Ohmic heating via a thermal return current, with Ohmic heating the dominant mechanism.

- Initial experiments changing the target conductivity show an increased heating for insulator rather than metal buried layers.

- Experimental measurements have begun to better characterise the electron distribution in the target.
Future work

- Experiments proposed for the TITAN laser will, if approved, continue this work in the next year. In the longer term studies will continue on ORION.

- It is proposed to better characterise the electron distribution using electron spectrometers and $K_\alpha$ fluorescence and possibly $He_\alpha$ emission.

- It is proposed to investigate further the role of conductivity and to sample deeper buried layers using absorption spectroscopy.