Shock-Timing Experiments in Planar Targets

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VISAR shot 32213

Shock coalescence
Shock breakout

Distance (μm)

Time (ns)

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Summary

We are measuring shock timing to the accuracies required for ICF ignition

• Multiple shock waves condition ICF capsules before implosion; accurate timing of these shocks is critical to target performance.

• The OMEGA laser is used to develop shock-timing techniques for OMEGA experiments and the National Ignition Campaign.

• In experiments with multiple shocks in CH and cryogenic deuterium targets we measure
  – shock velocities to 3% and
  – shock coalescence and breakout times with better than < 50 ps accuracy.

• These events produce unambiguous features in the data that can be resolved with accuracies that exceed the requirements for ignition targets.
Collaborators

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Indirect-drive ignition capsules use four shocks to achieve ignition

- First three shocks ±50 ps
- Fourth shock ±100 ps
Direct-drive capsules use two shocks to achieve ignition.
We use proven diagnostics to observe and time laser-driven shockwaves.

- Planar targets allow a study of shock timing in cryogenic D$_2$.
  - 1-D approximation is good for the initial shocks

- Optical diagnostics such as VISAR and self-emission detect shocks with the high accuracy needed for EOS studies.

- These will be used to provide shock velocity (to $<3\%$) and coalescence data ($<50$ ps) for the first three shocks.

- X-ray radiography will be required to measure the timing and trajectory of the final shock.

- OMEGA experiments have demonstrated these techniques to observe multiple shocks.
Shock velocity and self-emission in laser-driven shock experiments are measured optically.

At ICF pressures, shocks are hot (> 5,000°K), steep, and overdense. They emit and reflect optical wavelengths.

*J. Ortel (LANL)
The velocity interferometer system for any reflector (VISAR) detects Doppler shifts to measure velocity.

Shockwave

Etalon: delay = $\tau \sim 15$ ps

Image plane

Streak camera

$\text{Velocity} \quad U_s$

$\text{Time}$

$\text{Velocity}$

$U_s$

$\text{Time}$

$\text{Space}$

$\text{Time}$

$\Delta \Phi(t) = 2\pi c \left[ \int_0^t \frac{1}{\lambda(t')} \, dt' - \int_0^{t-\tau} \frac{1}{\lambda(t')} \, dt' \right]$

$= \frac{4\pi}{\lambda_0} n \int_{t-\tau}^t U_s(t') \, dt'$
Shock timing is studied using two pulses and CH targets.

Intensity: \( \sim 3 \times 10^{14} \text{ W/cm}^2, \ 90 \text{ ps} \)

Time (ns):

Intensity vs. Time (ns):

Distance (\( \mu \text{m} \)) vs. Time (ns):

Measure coalescence and breakout to \( \lesssim 30 \text{ ps} \)
1-D simulations, including a ray tracing routine, are in good agreement with double-shock experiments in CH.
Simultaneous VISAR and self-emission profiles provide corroborative data.
Simulations of shock coalescence in cryogenic D$_2$ agree well with self-emission measurements.

Coalescence Times in Cryogenic D$_2$

\[ \Delta t = 125 \text{ ps} \pm 75 \text{ ps} \]

- ASBO shot 36457
- SOP shot 36457

- Cryogenic cell
- Liquid D$_2$
- CH ablator
- Shock
- Window

- Coalescence

Distance (\(\mu m\))

Time (ns)

Distance (\(\mu m\))

Time (ns)
Initial indirect-drive shock-timing experiments were performed on OMEGA
We have observed ionization “blanking” of windows in high-intensity experiments.
Ionization by x-rays can limit the diagnosis of shock velocity during the laser pulse.
A strong absorption and phase shifts are measured in x-ray ionized polystyrene and diamond.
Ionization by x-rays creates “free” electrons and in some materials optical transitions in the valence band.

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

Conduction

Valence

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

Conduction

Valence

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

\( > 2.33 \text{ eV} \)

Refractive index

1.59

E\(_\text{VISAR}\)

E\(_\text{Transition}\)

Holes in valence bands

No holes in valence band

Energy (eV)

1 2 3 4

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

*W. Theobald UO1.00006
Final Shock Timing

An x-ray radiograph of an ~4 Mb shock in polystyrene shows a spherical shock driven by an Al pusher.

- Drive pulse: 1 ns at $\sim 2 \times 10^{14}$ W/cm$^2$

[Diagram showing an x-ray radiograph with labels for Sample, Shock, Detector, 40x magnification, Vacuum, CH, Aluminum, Al pusher, Shock front in CH, Unshocked CH.]
An x-ray radiograph of an ~4 Mb shock in polystyrene shows a spherical shock driven by an Al pusher.

- Drive pulse: 1 ns at ~2 x 10^{14} W/cm²

- Shock front in CH
- Unshocked CH
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