Fast-Ignitor Research at the Laboratory for Laser Energetics

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Summary

LLE is studying the direct-drive fast-ignition concept experimentally and theoretically

• LLE performs direct-drive (DD) cryogenic implosions that may lead to areal densities of ~350 mg/cm².

• LLE (with GA, ILE, LLNL) is beginning to study fuel assembly for fast-ignition (FI) targets:
  – Initial DD cone target implosions (empty)
  – Development of DD cone target with gas fill for diagnostics
  – Design of non-cone, high-areal-density implosions (cryo fuel)

• LLE has proposed to add high-energy petawatt capability for integrated FI experiments: OMEGA EP.
A multi-year science and engineering effort (with GA) was required to produce a reliable and precise cryogenic target experimental capability.
OMEGA can assemble ~ 1 kJ of fast-ignition-relevant cryogenic fuel at high density.

Expect burn-averaged $\rho R_{\text{fuel}}$ to approach 150 mg/cm$^2$ in FY03 and > 300 mg/cm$^2$ in the next 2 to 3 years.
A 1-kJ, 1-MeV electron beam raises the ion temperature in the high-density fuel shell to \(~10\) keV

**Ion-temperature contours**

**Neutron burn rate for D₂ implosion**

- 400 J, 1-MeV beam: $Y = 2.08 \times 10^{13}$
- No fast electrons: $Y = 3.42 \times 10^{12}$
- 1-kJ, 1-MeV beam: $Y = 1.13 \times 10^{13}$

**DRACO simulations**
Integrated cryogenic DD FI experiments would validate/compare both channeling and cone concepts on a single facility.

- Dedicated program
- High throughput
- Proven diagnostics
- Proven cryogenics

Neutronics

Charged-particle spectroscopy

Direct-drive DT cryo capsules and slide cone targets

CryoNTD

Petawatt beam (EP upgrade proposal)

X-ray imaging

CR-39 track data
LLE is beginning to implode direct-drive cone targets on OMEGA

- Cone target implosions have shown encouraging performance.*
- LLE will commence imploding cone targets in the near future:
  - Initially, empty shells with gold cones will be used.
  - Improved target fabrication techniques will allow gas-filled cone targets to be imploded.
  - In the future, cryogenic cone targets will be studied and may be imploded.

Fuel assembly experiments with cone-focused targets have begun on OMEGA

Direct-drive cone targets shot on OMEGA in FY02 (LLNL, GA)

Raw framing camera images: Top shows early in time, bottom near stagnation.

Note that near stagnation, the tip of the Au cone has started to disappear.

Pinhole camera (H8)
A new high-energy petawatt capability at OMEGA next to the existing 60-beam facility will allow integrated FI experiments

- Two short-pulse, 2 ~ 3-PW, 2.6-kJ beams
- Up to four long-pulse (10-ns) UV beams with ~6.5 kJ each
- NIF-like staging
- Integrated experiments with OMEGA or in a dedicated target chamber
- < 2-h shot cycle
By tailoring the DT-ice distribution it should be possible to optimize the fuel assembly for direct-drive FI on the NIF.

Low-k plastic inserts modify isotherm.

“A cone” target

CH/CD

Plastic “thermal breaks” to prevent gold cone from affecting ice isotherm.

A nonspherical copper-layering sphere creates a “thin ice” region at poles where target is warmest.

Modify thermal environment to create low-$\ell$-mode variation.
Integrated direct-drive FI experiments could be carried out on the NIF in indirect-drive configuration.

The penalty from asymmetric illumination may be mitigated by the clever use of phase plate design, beam pointing, pulse shaping, and ice layer/capsule shimming.
An integrated test on OMEGA EP will demonstrate the physics of direct-drive fast ignition.

Driver energy = \frac{1}{\eta_c \eta_{\text{hydro}}} \frac{4\pi (\rho r)^3}{3\rho^2} \epsilon_f

\text{EFI} > 140 \eta_c \frac{100^{1.8}}{\rho} \text{kJ}

Modifications to the NIF for fast ignition by direct drive will be modest.
Summary/Conclusions

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