Advances in High Gain Target Design

Laser IFE Meeting
Pleasanton, CA
November 13 & 14, 2001

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Advances in high gain target design

1 Review the 1999 direct-drive target design for fusion energy

2 Challenges and Problems
   – Partial solutions

3 Questions and Uncertainties
   – Partial answers
1999 high gain target design*

First laser fusion target design with both energy gain > 100 and possibly sufficient control of plasma and fluid instabilities.

$E_L \sim 1.3$ MJ and Gain $\sim 127$

(using KrF laser and zooming)

- **Overcoat**: Solid CH overlaid with 300 Å of Au
- **Ablator**: 10 mg/cc CH foam filled with DT
- **Fuel**: DT
- **DT gas**

Foam density may be too low to be fabricated

- Foam density can be raised from 10 mg/cc to ~100 mg/cc with minor penalty in target performance.

- Pore size and uniformity of foam is critical (need very uniform density for scale lengths >10 microns). Still need 2D implosion studies for quantitative specifications.
Au overcoat not permeable to DT

- Changed to Pd overcoat with minor change in target performance.
- Pd thickness can be increased to 1000 Å (even higher for higher-laser-energy targets)

![Recent target designs graph]

- Gain vs. Pd thickness for 1.48 MJ KrF laser and 4.0 MJ KrF laser
Excessive viscous & IR heating during target injection into the chamber

- **Viscous heating**
  - Must lower gas density in reactor chamber, compared to Sombrero concept.

- **IR heating**
  - Lower chamber wall temperature, or
  - Maintain high IR reflectivity of metal overcoating (cocktail mixture of Pd + ... ?)
Can N and O be added to the CH foam?

• Preliminary survey (limited class of target designs) indicates that N and O must be limited to less than a few percent.
Scaling of target performance with laser energy?

1D target design modeling

Recently modified laser pulse shape
Target performance using solid-state laser light?

Lower target coupling efficiency requires more laser energy, higher laser efficiency, and lower laser capital cost (than KrF). Zooming is important; it raises absorption from ~65% to ~90%.
SSD optical smoothing has a worrisome residual in the intermediate modes.

\[ t_{av} = 500 \text{ ps}, \quad \Delta \nu = 1 \text{ THz} \]

SSD angular divergence: \( \Delta \theta_x = 100 \text{ XDL}, \quad \Delta \theta_y = 50 \text{ XDL} + 50 \text{ XDL} \) from DPP.
Status of 2D & 3D integrated implosion calculations?

- Simplified modeling, with 2D piggybacking on 1D code, predicted sufficient control of fluid instabilities.

- Until recently, no ICF code could simultaneously, calculate 2D implosions with nonlinear multi-mode coupling, in the higher modes.

- New NRL FAST code can reach these goals simultaneously, but is still in preliminary evaluation phase.
Realistic comparison of design codes with experiment?

- Excellent comparison in many experiments through years between FAST1D, FAST2D, and FAST3D and Nike low-isentrope CH planar acceleration targets.

- Recent Nike experiments with Pd coated-CH again demonstrate that metal coatings provide a significant reduction in laser imprinting. Metal coating probably necessary for robust direct-drive target performance.

- However NRL FAST2D code still incorrectly predicts that a thin metal coating enhances the laser nonuniformities, in contradiction to Nike experiments. Possible reasons for discrepancy still under investigation.
Acceleration of CH/Pd foils using Nike
Summary

• The IFE target design so far:
  – Robust to the changes needed for fabrication.
  – Near or below threshold for laser-plasma instabilities.
  – Metal overcoat required to control laser-imprinting, and probably required to prevent IR preheating.
  – Major advances in FAST 2D implosion modeling capabilities, but still challenging:
    • modeling the early-time behavior of metal overcoat
    • simultaneous modeling of large spectrum of modes
    • Magnitude of inner surface DT roughness

• Overall, we may have a successful IFE target for a fusion reactor, but it is not yet provable to a reasonable skeptic.