Three-Dimensional Characterization of Ice Layers for Cryogenic Targets at LLE

X view

Equator

Camera views

Great circles

Keyhole projection

Y view

Polar cap

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Summary

Optimization of layering geometry will be required to eliminate ice layer nonuniformities

- 3-D target characterization is standard operating procedure for OMEGA cryogenic targets.
- The D$_2$ ice index of refraction has been identified as $\sim$1.15.
- Relayering was observed upon rotation of target inside the layering sphere.
  - time constants ($\sim$ 15 to 25 min near triple point)
- Target rotation and relayering studies show ice layer roughness dominated by external nonuniformities in the layering and heating geometry.
Collaborators

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Reflection and refraction due to the ice layer produces characteristic rings in shadowgraphs.

Ring positions are determined by ice thickness, surface tilt, and index of refraction.
Shadowgraphs are unwrapped around the target center to measure the Fourier modes of the rings and target surface.

Unwrapped image intensity along radial lines was analyzed to determine $R(\theta)$, ring/surface radius versus polar angle.
Shadowgraphs are unwrapped around the target center to determine Fourier modes of the rings and target surface.

Bright ring power spectrum (rms = 1.3 µm)

\[ R(\theta) \text{ analyzed to get Fourier power spectrum, } P_n \]
Accurate 3-D reconstructions for implosion simulations require multiple views.

3-D Ice Layer Characterization

DRACO 2-D density near peak burn, shot 35713, $\alpha \sim 4, 17.5$ kJ

15 $\mu$m offset, 4.1 $\mu$m ice rms

Detection probability of an isolated feature (%)

Mode number

(Courtesy of R. Stephens)
Low-order Legendre modes are determined by a least-squares fit to spherical harmonics $Y_{\ell m}$

\[ P_\ell = \sum_{m=-\ell}^{\ell} A_{\ell m}^2 \]

- Great circle positions are mapped onto a sphere.
- The maximum $\ell$-mode is limited to $\ell \leq 8$ to 10 by the polar caps and spacing of the great circles.
Higher-order Legendre modes are determined by a mapping from the average Fourier components*.

\[ \langle P_n \rangle \] 2-D Fourier components averaged over many great circles.

Higher-order Legendre modes are determined by a mapping from the average Fourier components *

\[ \langle P_n \rangle \] smoothed to improve behavior of mapping.

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\[ \langle P_n \rangle \text{ smoothed to improve behavior of mapping.} \]

\[ \langle P_n \rangle \]

\[ \text{Smoothed } \langle P_n \rangle \]

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*S. Pollaine and S. Hatchett, Nucl. Fusion 44, 117 (2004).*
Higher-order Legendre modes are determined by a mapping from the average Fourier components*.

\[ P_\ell = \sum_{n=\ell}^{\infty} a_{\ell n} \langle P_n \rangle \]

- Average Fourier components \( \langle P_n \rangle \) mapped* to Legendre modes \( P_\ell \).
- Assumes isotropic distribution of perturbations.

Higher-order Legendre modes are determined by a mapping from the average Fourier components.*

Same procedure is applied to get outer surface of power spectrum.

Multiple views allow some bright ring structures to be uniquely related to target surface features.

$\theta_{MCTC} = 115^\circ$
Multiple views allow some bright ring structures to be uniquely related to target surface features.

$\theta_{\text{MCTC}} = 130^\circ$
Features Can Be Studied Using Multiple Views

Multiple views allow some bright ring structures to be uniquely related to target surface features.

These ring structures are due to surface features and should not be included in ice roughness analysis.

$\theta_{MCTC} = 145^\circ$
Multiple views allow some ice nonuniformities to be uniquely identified.

Convex feature on inner ice surface closest to camera.
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We have observed consistently different ring structures at the same viewing angle before and after a 40-min set of target rotations → relayering during rotation of the target.
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Relayering occurs with a 14 to 24 min time constant after a 180° rotation.

The standard deviation of difference between bright ring versus reference ring (taken at 70 min) shows a smooth relaxation to “steady state.”
Reliable 3-D characterization is maintained by fast “fan” rotation to the imaging angle then back to home

- Quick rotations followed by annealing rests ($\Delta t \geq 20$ min)
- The change is sufficiently small to allow determination of the low-mode number $Y_{\ell m}$ components.
The similarity between relaxed bright rings at all rotations indicates the primary influence is external to the target.

- Images taken after a 25 min rest at many rotation angles.
- Ice layer relaxes to a similar orientation with respect to the external layering-sphere geometry.
- Target shell thickness and uniformity are not a primary influence on layer uniformity.
Three-dimensional characterization is now standard procedure for LLE cryogenic targets

- Automated shadowgraphic analysis and 3-D characterization
  - bright ring identified to ~0.1 pixel (0.12 µm)
- 3-D characterization yields more detailed information on ice layer roughness and asymmetries
There are several possible sources of nonuniformity external to the target

- **Layering sphere geometry**
  - breaks in spherical geometry due to windows and keyhole
  - imperfect thermal contact between components

- **Heating laser illumination**
  - hot spots may occur at point of first bounce
  - sphere reflectivity not uniform due to damage from use on OMEGA

- **Reduction of layering sphere nonuniformities will be needed to optimize ice layer quality**
Uniformity of illumination of the inside of the layering sphere is not easily achieved

Half of the layering sphere

Typical commercial gold diffusers

$$\cos^9 \theta \times \cos(\theta - \theta_0)$$ distribution
Uniformity of illumination of the inside of the layering sphere is not easily achieved.
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“Blind spot” due to x-ray ablation from previous target shot.
Additional Shadowgraphic Analyses

The D₂ ice index of refraction can be determined by simultaneously analyzing multiple rings.

- Different rings depend differently on the ice layer thickness and index of refraction, \( \eta_{D₂} \).
- The bright ring typically fits only to the ice thickness, assuming a fixed \( \eta_{D₂} \).

Previous estimate: \( \eta_{D₂} = 1.13 \) doesn’t produce a good match to all the rings.
Simultaneous fitting of multiple rings yields $\eta_{D_2} \approx 1.15$

- Fitting both ice thickness and $\eta_{D_2}$ allows all rings to be matched.
- This results in a several percent change in estimated ice thickness.

$\eta_{D_2} = 1.15$ at $\lambda = 644$ nm produces a good match to all the rings.
Summary/Conclusions

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