CONF-9606229--12

UCRL-JC-124255
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This paper was prepared for submittal to the
24th European Conference on Laser Interaction with Matter
Madrid, Spain
June 3-7, 1996

May 31, 1996

Lawrence Livermore National Laboratory

FORMING AND SMOOTHING D_2 AND HD LAYERS FOR ICF BY INFRA-RED HEATING

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We describe a technique to form and smooth uniform solid D_2, HD or DT layers for inertial confinement fusion targets. Pumping the infra-red (IR) collision induced vibration-rotation band generates a bulk heating of the solid. Shadowgraphs reveal that this bulk heat quickly redistributes the solid into a relatively uniform layer depending on the IR intensity profile. Measured redistribution time constants are used to determine the conversion efficiency of IR light into bulk heat. Phase shifting interferometry reveals that the surface roughness decreases with increasing IR heating.

1. Introduction

Smooth and uniform 50 μm to 300 μm thick deuterium-tritium (D-T) layers on the interiors of 1-to-3 mm diameter spherical capsules are required for ignitable inertial confinement fusion (ICF) targets for the National Ignition Facility.[1] To form these layers, D-T is frozen inside a capsule, initially forming an anisotropic multicrystalline solid. The tritium decay heat generation in solid D-T, $Q_{DT} = 0.05$ W/cm^3, causes thicker regions of solid D-T to have a higher temperature and thus higher vapor pressure. This results in a redistribution of the solid until the inner D-T surface is isothermal. For an isothermal spherical capsule the D-T layer will be a uniform spherical shell.[2] The time constant for this redistribution (when no ^{3}He is present) is $\tau_0 = l\rho/Q_{DT} =$ 23 minutes, where l is the latent heat (J/mole), and ρ is the density (moles/cm^3). The surface continues to smooth until the thermal energy removed by removing material on bumps in the presence of the D-T bulk heat, is comparable to the surface energy gained in having to form a higher energy viscinal surface.[3] The surface structure of a multicrystalline D-T film is a function of the bulk heating rate of D-T and the distribution of crystallite sizes and orientations which are determined by the initial nucleation and growth.[4]

Because there is no redistribution mechanism for non-tritiated solids and because the bulk heating rate (and thus the redistribution rate and surface roughness) for D-T is fixed, we have developed a technique to generate bulk heating in any hydrogen isotope or mixture. Pumping the infra-red (IR) collision induced vibration-rotation band generates a bulk heating of the solid, Q_{IR}. We have measured redistribution rates, (and thus Q_{IR}) in HD up to ten times higher than the DT value. These values are limited only by the laser used in these experiments and vibrational relaxation time measurements suggest Q_{IR} can be ~1000 Q_{DT}.[5] We can also control the surface roughness for any hydrogen layer by infra-red heating. Phase shifting interferometry measurements show the surface roughness decreases with increasing infra-red heating to values well below the National Ignition Facility specification.

2. Experimental setup

Figure 1 shows a sketch of the experimental setup. The sample cell consists of a 6 mm sapphire cube with a 5 mm O.D. cylindrical hole, a sapphire window at the bottom and an infrasil window at the top of the cell. The hydrogen fill tube is glued into a 381 µm O.D. hole in the side of the sapphire cube. The cell is thermally and mechanically attached to the cold tip of a helium flow cryostat. An F- center laser is used to produce the IR light. Two rotating diffusers remove effects of spatial coherence, leaving a maximum speckle average of 0.1% with a coherence modulation factor 1/e distance of ~ 7µm.[6] The resultant beam has a diverging Gaussian wavefront.

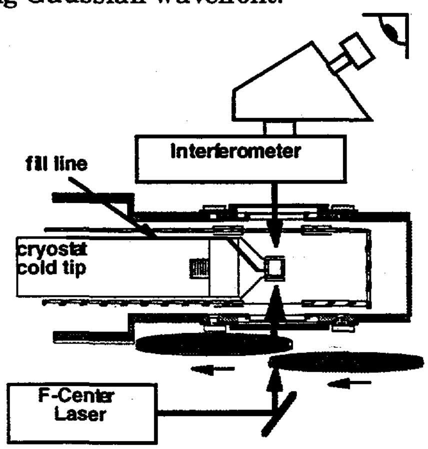

Fig. 1. The surface structure is controlled by a smoothed IR beam and measured by phase shifting interferometry. The IR beam is smoothed by two rotating diffusers.

2. Experimental results

To determine the conversion efficiency of IR light into Q_{IR}, we measured the redistribution time constant. Fig. 2 shows Q_{IR} versus incident flux for HD.[7]

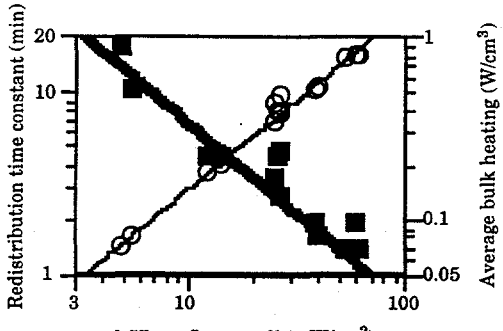

Fig. 2. Measured (dark squares) and calculated (bold line) redistribution time constants and the average heat generation rate (open circles and thin line) versus incident flux for HD.

The influence and control of the hydrogen layer profile with IR illumination is amazing. Figure 3 shows an optical path depth interferograms of an HD layer illuminated with IR without any beam smoothing and after the beam is smoothed with two rotating diffusers. This figure shows that we can either modulate the hydrogen layer profile for advanced target designs or smooth the layer profile for high yield NIF targets. The bullsey pattern results from the Gaussian curvature in the smoothed IR beam.

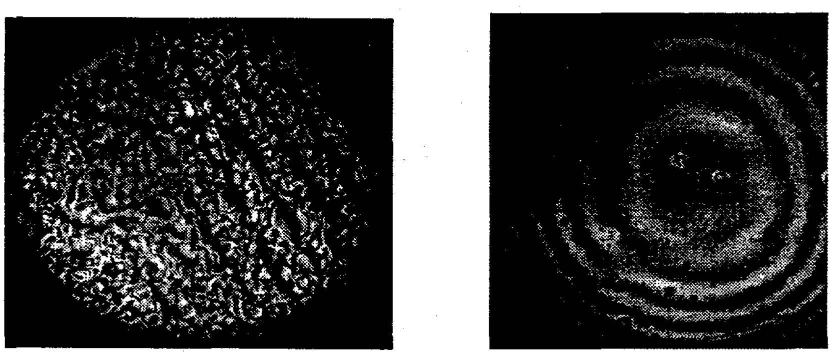

Fig. 3. Optical path depth interferograms of HD layers formed by ~ 50 mW of non-smoothed (left) and smoothed (right) 2.57 μm radiation.

The Gaussian curvature in the layer results directly from the Gaussian IR wavefront. Figure 4a shows the surface roughness rms versus Q_{IR} after removing the layer curvature. The lengthscale for these rms measurements is 3mm. The surface roughness decreases with increasing Q_{IR} to values well below the NIF specification. The solid line in Fig. 4a shows a best fit to surfaces smoothed by a surface heat flux. The ability to smooth an interface with either bulk heat or surface heat flux is proportional to the increase in surface temperature with increasing layer thickness, $\delta T/\delta h$, which for bulk heat is $\delta T/\delta h\sim$

Qh/κ, and for surface heat is δT/δh ~ F/κ, where κ is the thermal conductivity of the solid and F is the surface heat flux. We plot the surface heat flux data in Fig. 4a by setting $F = Q_{IR}$ h.[3] Hydrogen surfaces are smoothed both by surface heat and bulk heat.

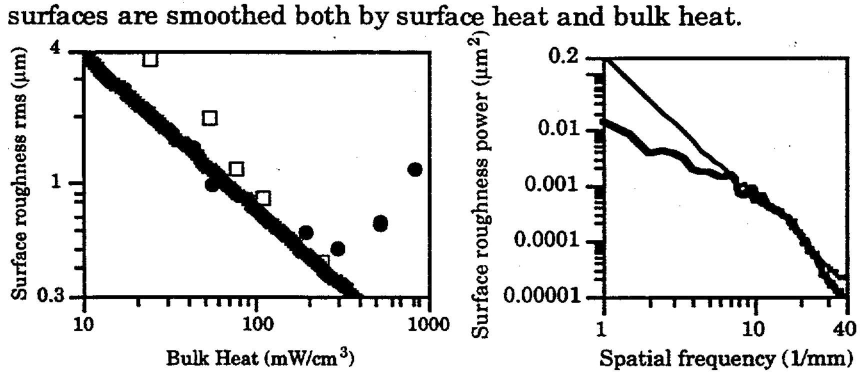

Fig. 4 (a) Surface roughness rms versus bulk heat for HD, 60 µm thick at 16 K,(open squares) and 100 µm thick at 16.4 K (dark circles). The bold line shows the surface roughness rms from surface heat flux experiments. (b) Surface roughness power spectra for 60 µm HD with 100 (thin) and 235 (thick) mW/cm^3

Finally in Figure 4b we show surface roughness power spectra for two smoothed HD layers. Bulk heating smoothes the low frequency components most effectively. Modeling shows that the efficiency of smoothing surface roughness, ~δT/δh, decreases with spatial wavelength as $\frac{\partial T}{\partial h} \approx \frac{Q_{IR} h}{\kappa\sqrt{1+(2\pi h/\lambda)^2}}$.

2. Conclusion

We have developed a technique to redistribute and smooth hydrogen (D_2, HD, D-T etc.) layers for ICF by pumping the rotation-vibration absorption bands of the solid. With this technique we can form modulated layer profiles for advanced target designs or smoothed layer profiles for high yield ignition targets for NIF.

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[7]In these experiments the HD was IR illuminated from the top.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

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