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Measurement of the In-Flight Pusher Density of an Indirect Drive Capsule Implosion Core Using X-Ray Backlighting

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MEASUREMENT OF THE IN-FLIGHT PUSHER DENSITY OF AN INDIRECT DRIVE CAPSULE IMPLOSION USING X-RAY BACKLIGHTING

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Both the efficiency of an implosion and the growth rate of hydrodynamic instability increase with the aspect ratio of an implosion. In order to study the physics of implosions with high Rayleigh-Taylor growth factors, we use doped ablators which should minimize x-ray preheat and shell decompression, and hence increase in-flight aspect ratio. We use x-ray backlighting techniques to image the indirectly-driven capsules. We record backlit 4.7 keV images of the full capsule throughout the implosion phase with 55 ps and 15 μm resolution. We use these images to measure the in-flight aspect ratios for doped ablators, and we inferred the radial density profile as a function of time by Abel inverting the x-ray transmission profiles.

1 Introduction

In indirectly driven inertial confinement fusion (ICF)[1], a fusion capsule is bathed in soft x-rays created inside a hohlraum. The x-rays ablate the outer surface of the capsule, causing it to implode and compress the fuel. The fuel filled capsules may suffer from preheat due to the x-rays. In order to maintain a low adiabat for the fuel during the implosion, it is necessary to shield the fuel from the x-rays. This is done by introducing dopants that will effectively absorb the x-rays and prevent them from preheating the fuel[2].

The dopant added to the ablator prevents the x-ray drive from preheating the capsule, and as a result, maintains a sharper density gradient and improves both the implosion efficiency and hydrodynamic instability growth[3,4]. To characterize the implosion efficiency and the hydrodynamic instability, we use x-ray backlighting techniques to measure the in-flight areal density of the pusher in an x-ray driven imploding capsule. Previous images of an indirectly driven implosion were used only to provide a measure of the implosion velocity and low-mode distortion[5]. We show large area backlit images that we use to perform radial intensity lineouts and to unfold a radial density profile.

2 X-ray backlit implosions on Nova

We used x-ray backlighting techniques[6] to image an x-ray driven implosion capsule on the Nova laser. The 510 μm diameter plastic capsule consisted of a 3 μm thick polystyrene shell with a 3 μm thick layer of polyvinyl alcohol (PVA), and a 34 μm thick ablator layer coated on the outside. For some experiments the ablator was doped with germanium to shield the fuel from x-ray preheat.

The capsule was placed at the center of a cylindrical gold hohlraum shown in Figure 1. There were two 650 μm diameter diagnostic access holes in the hohlraum, positioned on opposite sides at the midplane of the hohlraum, and covered with 150 μm thick CH foils. A Ti backlighter disk was positioned approximately 3 mm from the center of the hohlraum, collinear with the capsule and diagnostic holes, and with the diagnostic line of sight for backlit imaging.

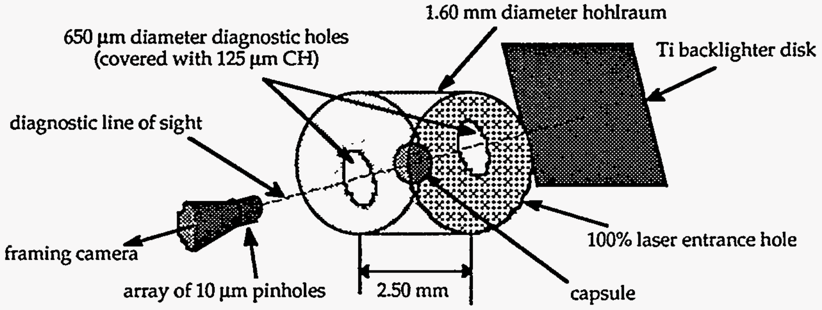
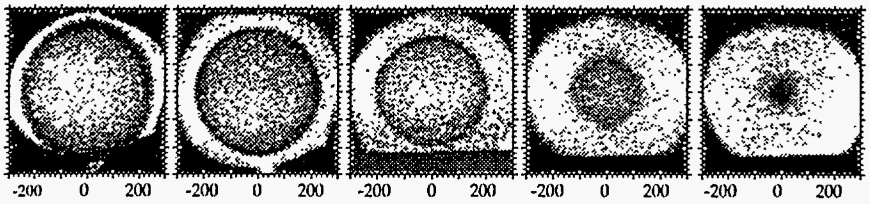


Figure 1: Diagram of the backlighter hohlraum target on Nova.

We used 8 beams of Nova at 0.35 μm to create the x-ray drive in the hohlraum. These beams delivered about 25 kJ in a 2.2 ns pulse with a peak power of about 18 TW. We used two beams at 0.53 μm for the backlighter. These were configured with random phase plates, and focused with a ~700 μm focal spot on the Ti backlighter foil at about 5x10^{14} W/cm2 to generate a large area x-ray backlighter. The laser pulse shape on these two beams was 2 ns square, which gave us a constant intensity of Ti K-shell x-rays. By filtering with 12 μm Ti, the spectrum is nearly monochromatic, principally in 4.7 keV emission from the 1s2p-1s^{2} line of Ti.

We recorded radiograph images of the fusion capsule at various times during the implosion over a range of 3 ns using a gated x-ray framing camera[7,8]. The x-ray camera was configured with 10 μm pinholes at 8X magnification, and it had a gate width of 55 ps.

Figure 2 shows a series of backlit images of implosions using a Ge doped ablator. These images are shown corrected for the diagnostic flat-field and for the spatial emission intensity profile of the x-ray backlighter, which we characterized by imaging the backlighter foil from the back side.



a) t=0 ns b) t=1.0 ns c) t=1.5 ns d) t=2.0 ns e) t=2.5 ns

Figure 2: Series of x-ray backlit images of a Ge-doped implosion capsule on Nova. The scales are in microns at the target.

3 In-flight pusher density profile

The images shown in Figure 2 were obtained on two Nova target shots. For each shot, the capsule had an initial outer radius of 255 μm. We performed a radial lineout of each image, averaging in the azimuthal direction. For images where we had a view of unattenuated backlighter around the full azimuth, we averaged around the full 360°. For others where the capsule was partially eclipsed by the diagnostic holes, we were limited to a smaller section of the azimuth.

We performed an Abel inversion of the radial lineouts by assuming that the capsule is spherically symmetric, and that the images are monochromatic. If we then divide the Abel inverted lineouts by the cold opacity for Ge-doped polystyrene, these lineouts represent the density profile of the capsule pusher. They provide a measurement of the radius and the aspect ratio as a function of time.

We plot the radial density profile calculated by Abel inversion for several times in Figure 3. Note that we have smoothed the inverted lineouts at small radius. The azimuthal average smooths the radial lineout at large radius, but we are dominated by the noise statistics and speckle of the backlighter profile at small radius.

We measured the radius of the half maximum density on the outer edge of the Abel-inverted lineouts. This is shown in Figure 4, plotted with the aspect ratio which we calculate as the average radius to the full width at half maximum of the radial density profile for each time. The hohlraum drive temperature is also shown in the graph for timing.

4 Summary

We have used x-ray backlighting techniques to record images of an indirectly driven ICF capsule on Nova. These large area images of the full capsule provide quantitative information about the in-flight pusher density profile as a function of time. This technique may be used to characterize the in-flight aspect ratio of capsules, providing information about the efficiency and hydrodynamic instability of an implosion.

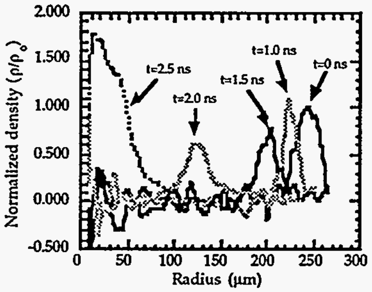


Figure 3: Radial density profiles calculated by Abel inverting radial lineouts of the x-ray transmission through the capsule.

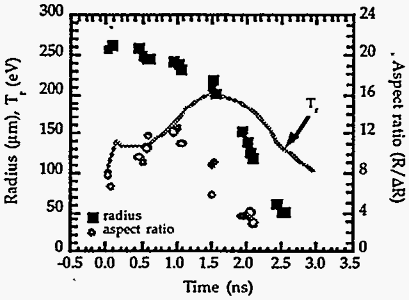


Figure 4: Radius and aspect ratio of the capsule as a function of time. The x-ray drive is overlaid for timing.

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