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HYDRODYNAMICS OF DIRECT DRIVE REENTRANT CONE TARGETS FOR FAST IGNITION

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Targets designed for fast ignition must have clear access for the ignitor laser to the compressed core. This is provided in current concepts by embedding a reentrant cone in the shell, the tip of the cone close to the center of the shell. We have designed a gas-tight direct-drive FI prototype target as the first step in developing a FI ignition target, and have studied its implosion dynamics at Omega with back-lit and self-emission framing cameras. A step in the cone surface, and Al on the shell were required to make the assembly gas-tight; these assemblies withstood >10 atm and had a typical pressure half-life of 2–6 h. The implosion of these targets was substantially different from that of previous indirect drive targets; there was much less vaporization of the Au cone, much clearer structure in the collapsing shells. Additionally self-emission images show the heating of the core gas, and its effect on the cone tip. These results will be compared to simulations.

I. INTRODUCTION

The fast ignition concept, in separating the compression and ignition steps, relaxes the energy requirements and symmetry conditions for the compression, but requires delivery of an ignition pulse of 1–10 kJ to the compressed core in ~ 30 ps. That ignition pulse is to be provided by a short-pulse laser using, in the current designs, a re-entrant cone to maintain clear access near the compressed target, and to convert the intense beam (~10^{19} W/cm^2) to relativistic electrons that can deposit their energy in its dense core. Investigations of the implosion hydrodynamics of prototype fast ignition targets have shown that the cone also affects and is affected by this implosion in ways that could affect the required short-pulse ignition energy.

Previous experiments using indirect drive showed that the gold cone was heated early in the collapse, and that the resulting gold vapor expanded into the capsule center and possibly mixed into the collapsing core.[1] This was attributed to the non-thermal, 2–3 keV M-band x-rays generated by the gold hohlraum. Such high energy x-rays are to be expected from any of the potential hohlraum materials, causing concern for realization of an indirect drive fast ignition target.

The current experiments explored the hydrodynamics of direct drive fast ignition targets; direct drive eliminates the troublesome hohlraum x-ray source. We found that the worrisome cone blowoff was substantially reduced, but not eliminated; the remnant was caused by bremsstrahlung emitted near the laser deposition region.

II. EXPERIMENT

The targets used in these experiment were direct drive ~1 mm diameter shells with ~ 24 µm thick CH walls (containing ~ 4 at% O) overcoated with ~0.1 µm thick Al shine-through barrier. They were mounted on a re-entrant cone with half cone angle ~35° by means of a ~100 µm wide step at the outer surface of the shell, where they were glued with UV curing glue (Fig. 1), so they could hold ~ 10 atm gas for proton energy loss measurements of shell ρR.

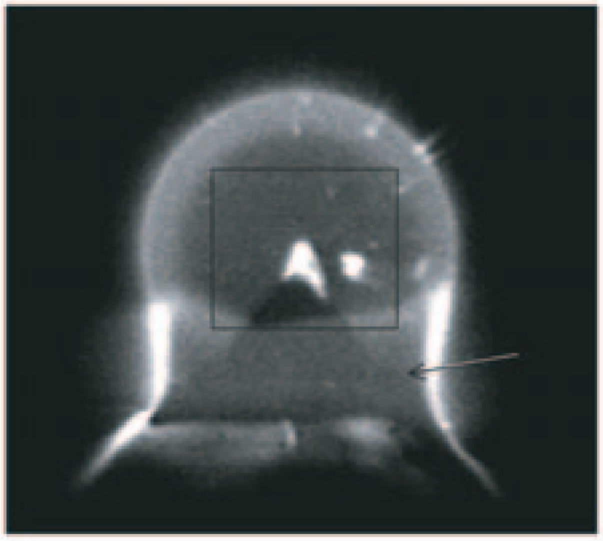

Fig. 1. Time integrated x-ray pinhole camera image of a collapsing shell. The outline shows the original position of the shell. The arrow shows the step in the cone where the shell was bonded. The bright area at the tip of the cone shows the emissions from the hot stagnated shell, and the heated cone. The black square shows the approximate field of view of the backlit images in Figs. 2–5.

The targets were compressed with 35 beams with a total of ~15 kJ UV light using a 1 ns square pulse. The collapsing assembly was backlit with a V or Fe foil and imaged through a 8 μm pinhole with a framing camera whose images span 1.7–2.6 ns after the start of the laser pulse (Figs. 2, 3). The V backlight is low enough energy (~5 keV) to show early details of the shell collapse. The Fe backlight is high enough energy (~6.7 keV) to better show details in the dense shell and in the vapor around the cone. The Fe backlit image sequence also show emission at the cone tip, possibly from hot gas escaping from the collapsing shell; the framing camera filter in that case was 5 mil Be, so was sensitive to x-rays with energy > ~2.5 keV.

This experiment was simulated with Lasnex, although the hydrodynamic model did not include the step in the cone. The simulated radiographs in Figs. 4, 5 were made at times matching the images in Figs. 2, 3 up to peak compression; the material zones become too intertwined to trust the simulation beyond ~ 2.4 ns. For details see the paper by Hatchett, *et al.* in these proceedings.[2]

III. DISCUSSION

The maximum shell compression in the model occurred at ~ 2.2 ns (between (d) and (e) in Figs. 2–5) in good agreement with experiment. The maximum density is difficult to calculate because a source of emission near the tip of the cone offsets the backlighter absorption. This is obvious in Fig. 3, where the 5 mil Be camera filter allowed detection of low energy x-rays. (The source of that emission is not present in the simulations.) The 10 μm V filter used for the V backlight reduces those emissions (~2.5–3 keV) by ~10 times relative to the Be filter; that's still enough to modify perceived brightness by ~10%. We suspect that is the reason that the apparent attenuation at the center of the target in Fig. 2(b,c) is zero.

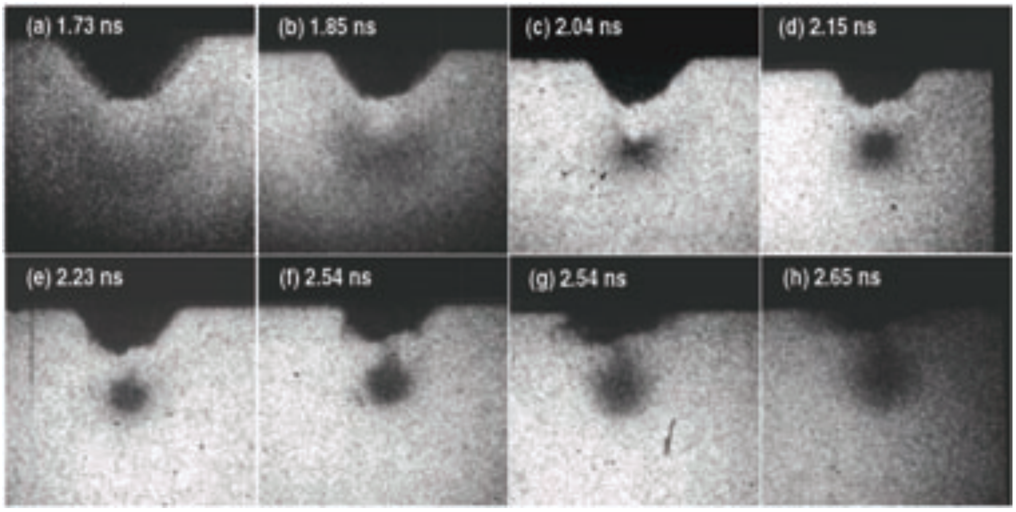

Fig. 2. Framing camera sequence of collapsing shell illuminated by V backlighter. A V filter restricted the camera sensitivity to ~ 5 keV x-rays. Each image is 450 μm across.

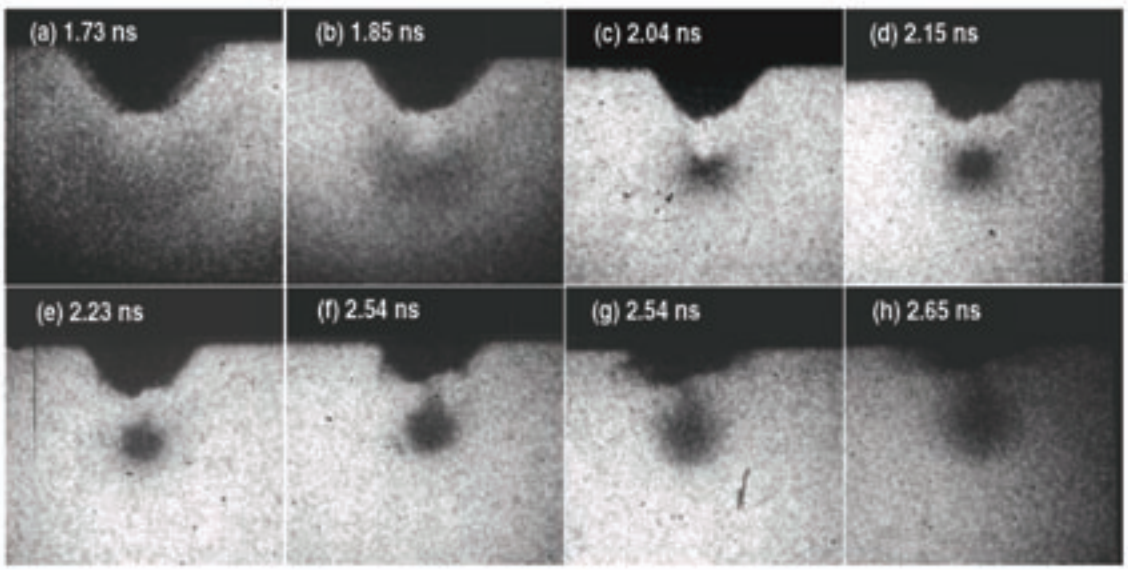

Fig. 3. Framing camera sequence of collapsing shell illuminated by Fe backlighter (6.4 keV). A 5 mil Be filter allowed detection of x-ray E > 2 keV. Each image is 450 μm across.

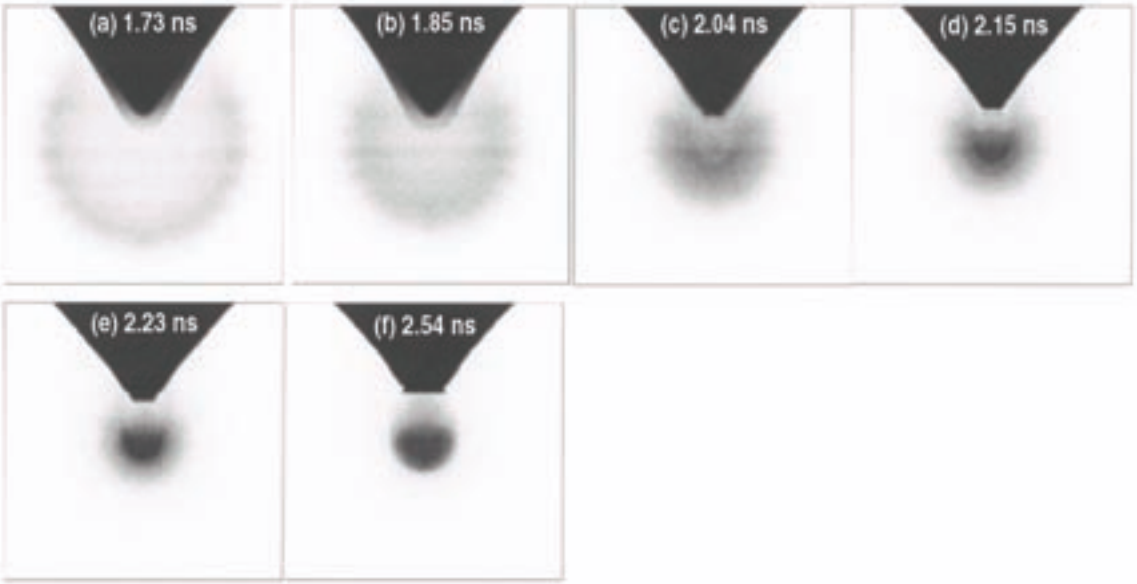

Fig. 4. Simulation of framing camera images of a 6.4 keV backlit collapsing shell. The faint banding is an artifact of limited angular resolution. Each image is 450 μm across.

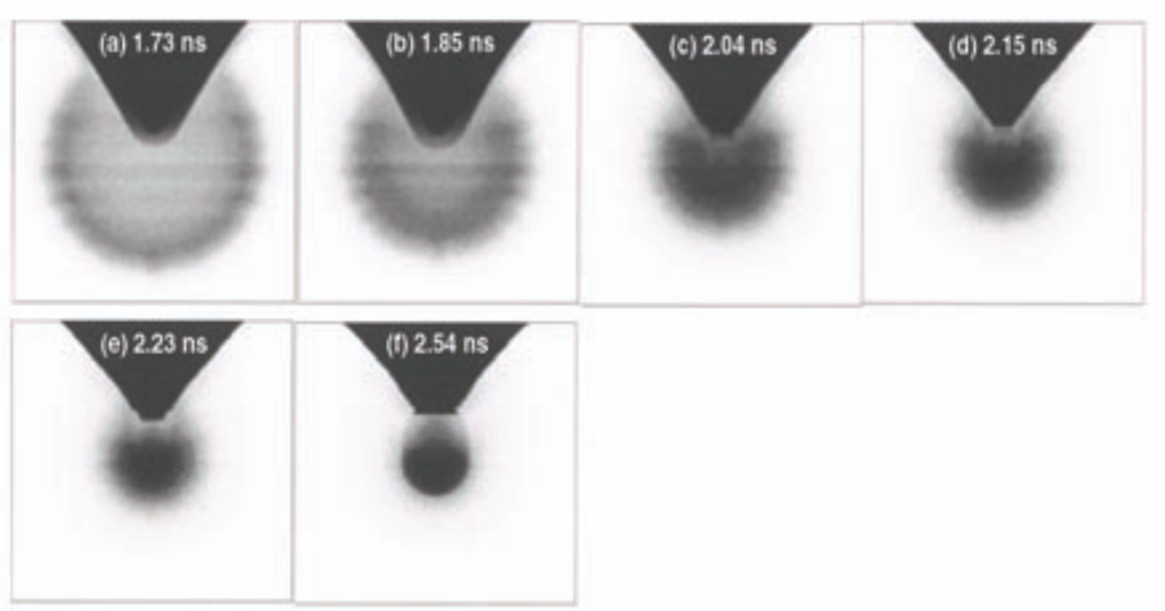

Fig. 5. Simulation of framing camera images of a 5 keV backlit collapsing shell. The faint banding is an artifact of limited angular resolution. Each image is 450 μm across.

One can see vapor (~30 μm thick) around the cones in the first image of each sequence. That must be gold (~70 mg/cc); it would require ρ>1 g/cc to produce the observed absorption with C. This was anticipated in the simulation, and generated by x-rays (estimated in the simulation at ~9 kJ/cm^2) from bremsstrahlung produced near the laser deposition region. The vapor is visible because the calculated pressure near the cone surface at that early time is ~300 kbar so it easily expands against the capsule fill. According to the simulation, as the shell passes down the cone the back pressure rises sharply and the vapor collapses back onto the cone [Fig. 4(b)]. Experimentally the vapor near the tip of the cone collapses about as predicted [Fig. 3(b)]. It collapses much slower at the base; we think this is an effect of the step on the cone; capsule material under the step is not ablated so there is a sort of hydrodynamic shadow. The vapor is also notably absent at the tip. In previous indirect drive experiments we suggested the possibility of Au at the tip mixing into the gas core. In that case there was much more vapor (we estimate ~ 4 times the power was absorbed in the cone) and one could see tendrils of absorption that suggested turbulent mixing (Fig. 6). There is nothing in the images to suggest such mixing in the present case; the interface looks sharp and smooth everywhere until about maximum compression (image d in the sequences) when gas exhausting from the collapsing shell blows the tip apart.

Fig. 6. Backlit image from indirect drive experiment. Because the Au density is much higher in this case, the intensity is rendered with a logarithmic scale to show both the extent of the vapor and the tendrils extending toward the collapsed shell.

IV. CONCLUSION

A re-entrant cone fast ignition target is quite susceptible to contamination of the fuel by vapor from a preheated cone. The direct drive configuration used in these experiments reduces the problem by ~ 4 tmes compared to the previous indirect drive configuration and there is no visible indication of turbulent mixing of the Au with CH. The experiment and simulation agreed well.

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