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Test of an Indirect Drive Fast Ignition Target Concept

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Abstract. We have examined the implosion of an indirectly driven reentrant-cone shell target to clarify the issues attendant on compressing fuel for a Fast Ignition target. The target design is the hydrodynamic equivalent of a NIF cryo-ignition target, but scaled down to be driven by Omega; a sequence of radiographs recorded each implosion. The collapse was also modeled with Lasnex, and simulated radiographs generated for comparison. These radiographs gave implosion velocity and diameter, density, and symmetry at stagnation. The simulations were in good agreement with the experiments with respect to the shell. However, non-thermal gold m-line radiation from the hohlraum wall penetrated the shell wall, vaporized material off the reentrant cone surface, causing some high Z material to mix into the collapsed core. Substantial target redesign will be necessary to avoid this problem.

1. Introduction

The Fast Ignition (FI) Inertial Fusion Energy (IFE) concept is recognized as having the potential to improve the attractiveness of IFE reactors. FI ignites the dense core of separately compressed fuel pellets with a very intense laser pulse [1], achieving much higher gain than is possible with the baseline central hot spot (CHS) approach [2]. The realization of this concept is somewhat complicated because the target core (~200 g/cc) is hidden under a plasma corona that is opaque for densities higher than ~1 g/cc. A FI IFE target therefore must allow the possibility of efficiently converting the photons to a beam of charged particles that deposit their energy in a localized volume of the assembled core. In the initial conception, a laser prepulse was used to clear a path deep into the plasma and allow the ignition pulse to penetrate close to the core [3], where it could create a spray of ~MeV electrons. Experiments have shown efficient conversion to electrons [4], and tunnel digging [5,6] or self-focused propagation [7], but it seems difficult to extend these effects sufficiently to get close to a very dense core. An alternative to ponderomotive tunneling or superpropagation is the use of a reentrant cone to completely exclude the plasma blowoff from one sector of the target [8,9]; this allows the ignition laser a clear, close approach to the assembled core, and a controlled surface at which to create the electrons.

Targets of this form are extremely anisotropic. It is a question whether one could assemble a usable core from such a geometry; or even whether existing hydro models, which accurately describe the implosion of nearly symmetric targets, could accurately predict the implosion of a reentrant cone in shell target. The presence of the reentrant cone could cause turbulence, preventing a useful assembly of fuel, or cause contamination, preventing the assembled fuel from burning, even though such targets have shown great success in heating experiments [8,9].

We set out to examine those questions; the purpose of this paper is to compare the experimental and modeled behavior of an indirect drive, reentrant-cone-in-shell target. The results of our experiment show that the target hydro is well modeled by standard codes, and the fuel is assembled in a reasonably compact form. However, some of the indirect drive spectrum (that from the non-thermal m-line emissions from the gold hohlraum) penetrates the shell and generates vapor from the surface of the gold cone that is mixed in with the assembled fuel. Minimizing that contamination source will require a substantial shine through barrier (for keV X-rays!), or by using direct drive.

2. Experiment

A cross-section of the target design is shown in Fig. 1(b). It was scaled from the NIF ignition target in Fig. 1(a) to be driven in a scale 1 hohlraum[1] on Omega. The shell is 510 µm o.d. with a 57 µm thick plasma polymer wall. The cone is ~ 50 µm thick Au with a hyperboloidal tip (foci separation 40 µm) and a 35° half angle (hyperboloidal shape was chosen for modeling convenience); the intersection of the asymptotes are 12 µm from the center of the shell. The cone was attached to the shell with UV curing glue. This assembly was mounted in a scale 1 hohlraum that had backlighter windows orthogonal to the hohlraum and cone axes (Fig. 2). The gold cone was stepped to minimize interference with the high angle laser beams (the adjacent beams mostly missed the step), and to avoid creating hot spots on the cone surface close to the shell; either effect would have distorted the drive.

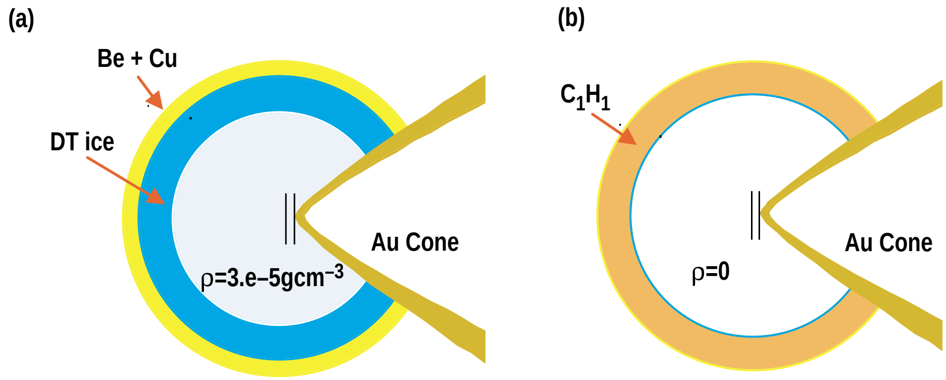

Fig. 1. (a) A cryogenic ignition target (designed to be indirectly driven in NIF using 1.8 MJ) consisting of a 2 mm o.d. Be shell surrounding a DT ice layer, into which a hyperboloidal cone is inserted. (b) Cross-section of target scaled down to a CH shell 510 µm o.d., 57 µm wall, which can be driven in a scale 1 hohlraum on Omega with 14 kJ in "pulse shape 26."[2] The focii of the hyperboloidal cone are separated by 40 µm, and the intersection of asymptotes set back ~15 µm from the shell center.

We used Fe (6.7 keV) to backlight the target for an X-ray framing camera that took images through a 10 µm pinhole at ~70 ps intervals. The fixed structure in the images was eliminated by reference to a flat-field image (e.g. camera was illuminated with an open aperture instead of a pinhole). One pixel wide streaks in the image, from pixel defects, were replaced with the adjacent row of pixels. Then the images were smoothed using a 5 µm boxcar average.

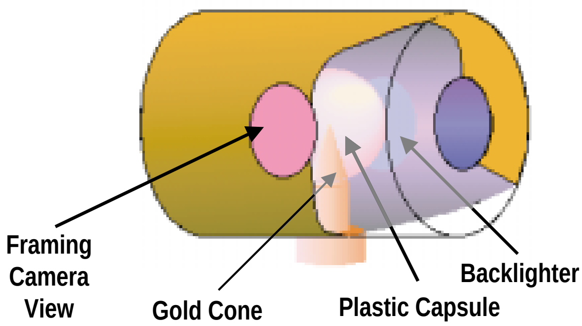

Fig. 2. Schematic of re-entrant cone-in-shell target mounted in an Omega scale 1 hohlraum.[1] The 7 µm thick Cu backlighter foil is mounted on the hohlraum wall behind the shell; the X–ray framing camera looks at the target from the other side through a 50 µm thick CH window with 0.5 µm thick Ta coating on the inside.

This sequence of pictures clearly shows the evolution of the shell and cone [Fig. 3(a)]. An equivalent set of pictures was generated from the simulation [Fig. 3(b)]. For both sets of images, profiles were taken from a 15 µm wide, 300 µm long strip perpendicular to the cone axis (35° from vertical) (Fig. 4 inset). Backlighter brightness along that path was estimated by fitting a parabola to the intensity seen at each end of the strip. Experimental dark counts and light leakage were estimated from counts between illuminated sections.

Using the brightness and background, we calculate absorption strength versus position across the apparent center of each image (Fig. 4), and the full width half absorption size of the assembled target as a function of time (Fig. 5).

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[1]These hohlraums are 2.5 mm long, 1.6 mm i.d., and have 1.2 mm diameter laser entrance hole.
[2]A shaped pulse 2.5 ns long with a contrast ratio of 5 and used for low adiabat implosions.

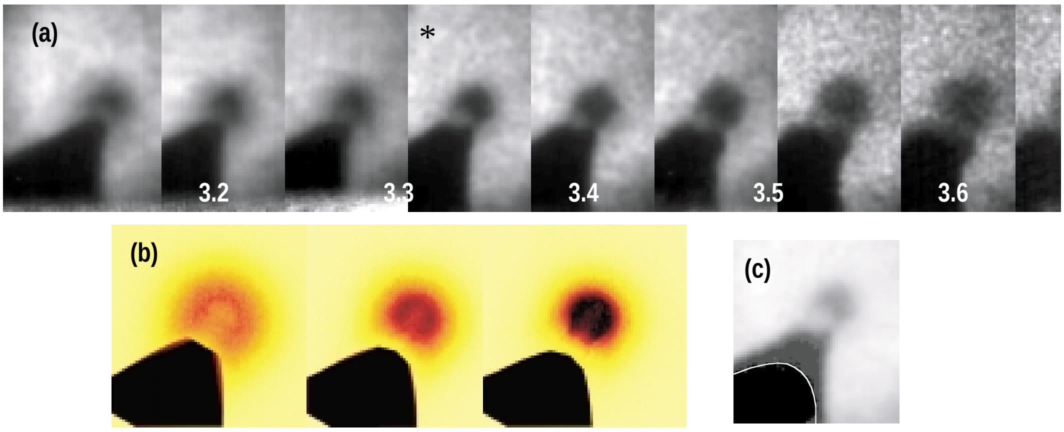

*Fig. 3. 8 keV x-radiograph sequence of shell collapse. (a) Experimental results, (b) simulation collapse sequence – model and experiment. The center of each picture is set at approximately the time (ns) after the start of the pulse at which it occurred. (c) Shows the experimental image at stagnation (the *ed image) using a log grey scale and with a white divider between the black and grey, so one can see that the experimental cone shadow (black) is very similar to the model, but has been extended by nearly opaque (dark grey) blowoff from the cone.*

3. Discussion

The collapsing shell's stagnation time (3.35 ns), fwhm size (90 µm), and maximum absorption fraction (0.86), agrees with that from the model (3.4 ns, 90 µm, and 0.9, respectively), and gross structure of the collapsing shell (horseshoe crab-like) looks very much as predicted. But there are significant differences: the experimental profiles lack a hollow center that ought to be observable (compare the 3.1 ns profiles in Fig. 4) and an increase in maximum density or decrease in fwhm size as the shell collapses. More noticeably, the shadow of the cone extends much closer to the shell than predicted. We believe these effects are connected. Closer examination of the cone shadow [Fig. 3(c)] shows that only a portion similar to the original cone shape is completely opaque (delineated by the white line in Fig. 3(c). The rest shows some backlighter transmission – about 10% near the end of the shadow; that corresponds, for Au vapor, to ~0.6 g/cc. The simulation shown in

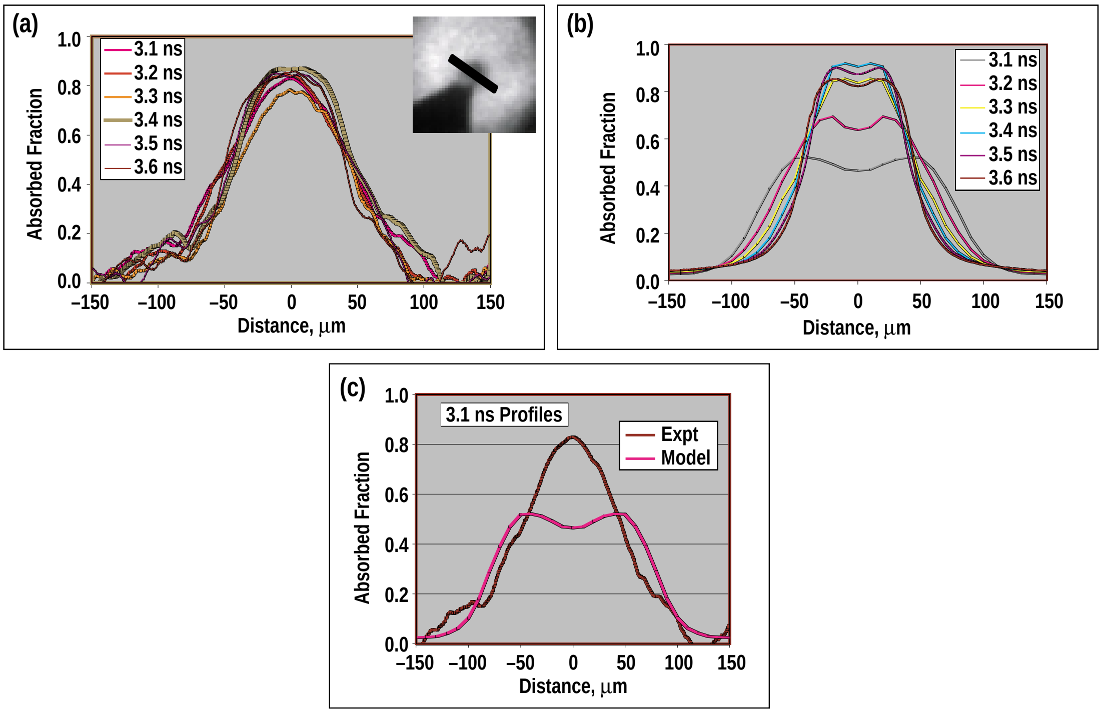

Fig. 4. Absorbed fraction across the center of the collapsing shells (the path is shown in the inset) from (a) experimental and (b) simulated images. (c) Compares the experimental and simulated profiles at 3.1 ns.

Fig. 3(b) used a thermal spectrum for the x-ray drive, neglecting the non-thermal Au m-lines (~2.3 keV) that can penetrate the shell and directly heat the cone tip. A simulation including that spectrum shows a Au blowoff that extends out to the compressed shell (Fig. 6), as seen in the experiment. The simulation cannot handle mixing of the CH and Au, but the vapor cloud is dense enough that the boundary is RT stable, so mixing is expected to be minimal. We can see that vapor shadow has tendrils extending all the way to the shell, so some Au vapor could have mixed into the central cavity of the collapsing shell. It would only take ~ 0.6 g/cc of Au in the central cavity to give the profiles the experimentally observed sharp peak, and anomalously narrow, unchanging width (Fig. 5).

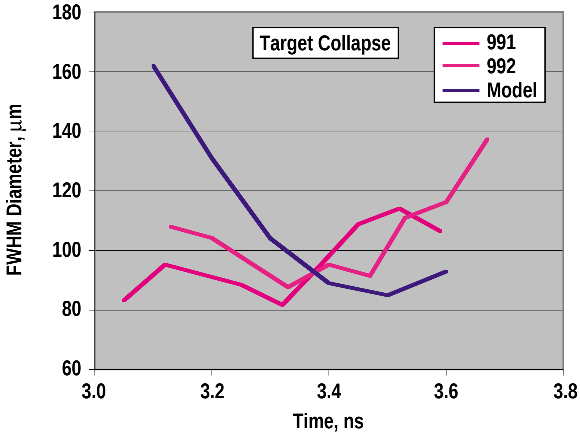

Fig. 5. Full width at half absorption of profiles as a function of time.

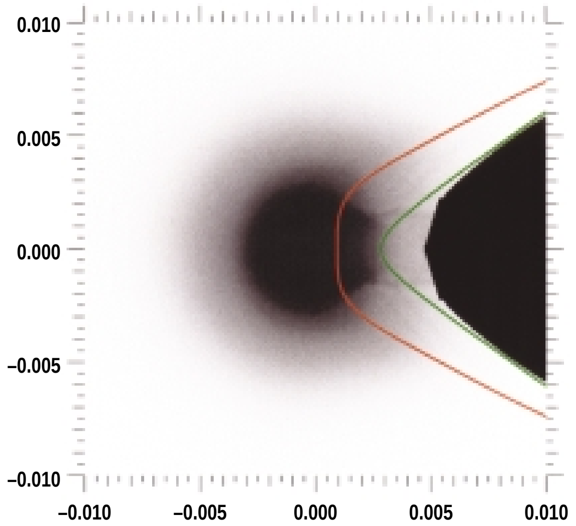

Fig. 6. Simulated 6.4 keV x-radiograph at stagnation with lines showing the original cone profile and extent of gold vapor expansion.

4. Conclusion

The presence of the reentrant cone causes gross changes in the collapse that are accurately described by Lasnex modeling; this suggests that the hydro-equivalent, NIF-scale, cryo-ignition target would implode to a useful ρR. However, non-thermal emissions from the gold hohlraum vaporized gold off the outside of the reentrant cone, and this vapor apparently mixed into the low density core of the assembled fuel at a concentration that would hopelessly poison any fusion burn there, both through radiation loss and increased heat capacity. That would not be a problem, if there is no mixing of the core with the dense shell, since a FI target burns only the dense shell. Minimizing such mixing would put unexpectedly stringent requirements on the smoothness of the target surfaces. Alternatively, the target could be designed to prevent (by using direct-drive geometry) [8,9] or block (by building in a shine-through barrier) the non-thermal radiation.

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