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Demonstration of symcaps to measure implosion symmetry in the foot of the NIF scale 0.7 hohlraums

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Abstract

Implosions using inertial confinement fusion must be highly symmetric to achieve ignition on the National Ignition Facility. This requires precise control of the drive symmetry from the radiation incident on the ignition capsule. For indirect drive implosions, low mode residual perturbations in the drive are generated by the laser-heated hohlraum geometry. To diagnose the drive symmetry, previous experiments used simulated capsules by which the self-emission X-rays from gas in the center of the capsule during the implosion are used to infer the shape of the drive. However, those experiments used hohlraum radiation temperatures higher than 200 eV (Hauer *et al.*, 1995; Murphy *et al.*, 1998*a*, 1998*b*) with small NOVA scale hohlraums under which conditions the symcaps produced large X-ray signals. At the foot of the NIF ignition pulse, where controlling the symmetry has been shown to be crucial for obtaining a symmetric implosion (Clark *et al.*, 2008), the radiation drive is much smaller, reducing the X-ray emission from the imploded capsule. For the first time, the feasibility of using symcaps to diagnose the radiation drive for low radiation temperatures, <120 eV and large 0.7 linear scales NIF Rev3.1 (Haan *et al.*, 2008) vacuum hohlraums is demonstrated. Here we used experiments at the Omega laser facility to demonstrate and develop the symcap technique for tuning the symmetry of the NIF ignition capsule in the foot of the drive pulse.

Keywords: Drive temperature; Inertial Confinement Fusion; Symcaps

INTRODUCTION

Harvesting energy from nuclear fusion processes would be a major breakthrough in the search for clean energy and is therefore of paramount importance to the scientific community. There are several approaches to this problem, which include the utilization of heavy particle beams (Temporal *et al.*, 2005; Neff *et al.*, 2006; Constantin *et al.*, 2004; Hoffmann *et al.*, 2005), of high explosives (Winterberg, 2008), magnetic fields (Kaw & Burkhard, 2005), and direct and indirect irradiation with lasers (Lindl, 1995; Hora, 2007). In this article, we focus on the inertial confinement fusion (ICF) approach. In order to achieve ICF, a number of problems have to be addressed and solved; these are target design (Cook *et al.*, 2008), ignition (Deutsch *et al.*, 2008; Ghoranneviss *et al.*, 2008), material properties (Elezier *et al.*, 2007), diagnostic issues (Romagnani *et al.*, 2008), simulations (Rodriguez *et al.*, 2008), and symmetry of the implosion (Ramis *et al.*, 2008) just to name the most prominent.

The first attempts to achieve ICF at the National Ignition Facility (NIF) will commence in 2010. These first experiments will use the indirect drive approach where laser beams heat a hohlraum that radiates soft X-rays, which then implode a spherical capsule containing deuterium and tritium fuel. The X-rays emitted by the heated hohlraum walls are absorbed by the capsule, creating shocks, and imploding the capsule that then ignite the compressed fuel. Although using a hohlraum to convert the laser energy into X-ray radiation introduces a loss in energy conversion, it has the advantage of reducing Rayleigh-Taylor instabilities by increasing the ablation velocity of the capsule, and providing a more symmetric implosion. However, “hot” spots on the hohlraum wall, created where the laser beams strike the hohlraum, impose low-mode perturbations in the capsule radiation drive. Small non-uniformities in the drive radiation field can seed instabilities and cause non-spherical, less-efficient implosions. Therefore, it is important to control the symmetry of these low-mode perturbations. This can be done by varying the laser power in the three laser beam cones, by varying the pointing of the laser beam cones on the hohlraum wall, or by varying the hohlraum dimensions.

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In preparation for experiments on the NIF, experiments at the Omega laser demonstrate control of the implosion symmetry At the foot of the NIF laser pulse in 0.7-NIF-scale hohlraums and capsules. These experiments use a symmetry capsule (Symcap) (Hoffmann *et al.*, 2008) to diagnose the hohlraum radiation drive. The symcap is a gas-filled surrogate capsule designed to create X-rays that show the shape of the imploding capsule. The time sensitivity of the experiment is changed by using different capsule wall thicknesses to implode at various desired times. Measurements of the size, shape, and brightness of these X-rays as a function of time can then be used to deduce the time-integrated radiation drive. The experiments described in this article are the first to demonstrate the feasibility of using symcaps to diagnose the symmetry of the drive for the relatively low radiation temperatures (100–120 eV) expected at the foot (first 2 ns) of the NIF laser pulse.

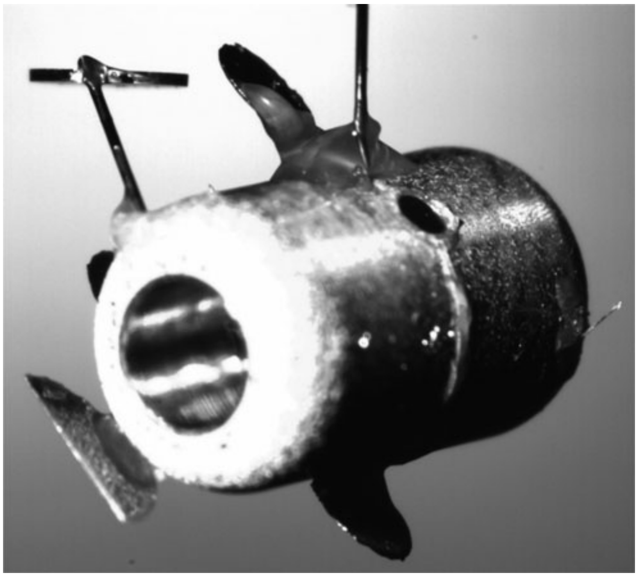

Fig. 1. Photograph of one of the targets. One can see the LEH, the stalk to mount the hohlraum in the experimental chamber, the window with the beryllium plug and shields to block unwanted X-rays from diagnostics.

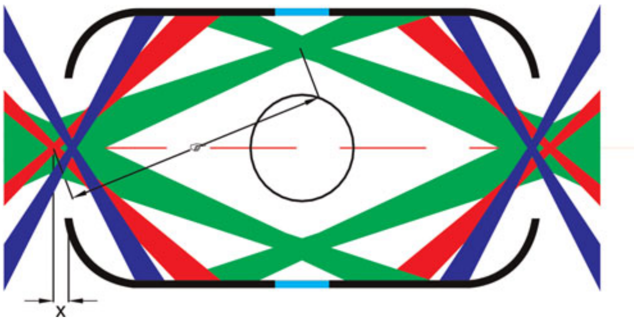

Fig. 2. (Color online) Sketch of the pointing of the three different cones from each side of the hohlraum. Blue, Cone 3 (59° with respect to hohlraum axis); red, cone 2 (42°); green, cone 1 (21°). *F* is the distance of defocusing, *x* is the distance where the beam intersects the axis with respect to the laser entrance hole.

EXPERIMENTAL SETUP

The experiments used vacuum-filled gold hohlraums surrounding capsules filled with deuterium (D_2) gas. The gold hohlraums were cylindrical and had dimensions of 6.8 mm in length, 3.56 mm in diameter, a laser entrance hole (LEH) diameter of 1.90 mm, and 0.1 mm thick walls. These dimensions were selected to produce a 110 eV radiation drive at Omega using 15 kJ of laser energy. Furthermore, they are a scale 0.7 NIF Rev3.1 point design hohlraum, but without the gas fill and without the gas windows. The hohlraum axis is aligned along the Omega P6-P7 axis. Two 750 μm diameter X-ray diagnostic holes were drilled on the side of the hohlraum and filled with beryllium or aluminum plugs. These holes allowed viewing of the capsule implosion with X-ray framing cameras at directions perpendicular to the hohlraum axis. The plastic polystyrene (CH) capsule was placed in the center of the hohlraums, using a stalk to maintain exact centering and had a 1.387 ± 0.003 mm inside diameter, and a shell thickness of 19.6 ± 0.2 μm. The capsule was filled with 1 atm of D_2 gas at 300 K. The capsules were centered within 35 μm of the hohlraum center. Figure 1 shows a photograph of one of the targets. In this figure, one can see the LEH, the stalk to mount the hohlraum in the experimental chamber, the window with the beryllium plug, and shields to block unwanted X-rays from diagnostics.

Three cones of laser beams enter the hohlraum from each end at angles of 21°, 42°, and 59° with respect to the hohlraum axis (Fig. 2). The 42° cone consists of 10 beams while the 21° and 59° cones consist of five beams each. The cones are pointed in a configuration that creates two rings in the hohlraum, with the beams distributed uniformly in azimuth. This is done by pointing the 21° beams to the same axial point on the hohlraum wall as the 44° beams from the opposite side of the hohlraum. The laser is fired with a 2 ns square pulse with ~375 J in each beam. The 21° cone had an elliptic phase plate (EIDI-300) that was designed to have a circular cross-section at the LEH. The other cones did not use phase plates. The pointing and defocusing of the laser beams for each of the three cones as well as the irradiant power on the walls of the hohlraum is given in Table 1.

The hohlraums were vacuum hohlraums, in contrast with the gas-filled hohlraums to be used at NIF. The short laser

Table 1. *Pointing, focusing and irradiation of the laser beams of the three cones for shot #45797*

Cone #	Pointing (μm)	Focusing (μm)	Energy (J)	Irradiation (W/cm^2)
1	350	3500	376	0.75×10^{14}
2	500	0	370	1.5×10^{14}
3	0	0	373	1.6×10^{14}

pulse eliminated the effect of wall on capsule uniformity and obviated the need for a gas fill. This simplified the experiment, minimized the effects of laser-plasma instabilities, and eliminated the presence of the LEH windows that can affect laser beam propagation. We used up to 16 fast filtered X-ray diodes (the DANTE spectrometer) to measure the time-resolved brightness temperature between 0 and 5000 eV (Kornblum *et al.*, 1986, Seifter & Kyrala, 2008) emitted through the LEH at 37° with respect to the axis.

EXPERIMENTAL RESULTS

The measured peak radiation drive at the end of the laser pulse is ~118 eV (see Fig. 3), consistent with the scaling of the drive with laser energy and hohlraum dimensions, and matches the point design NIF foot. Processed images of the X-ray measurements, made by the X-ray framing camera at different times are shown in Figure 4. The images show the X-ray emission at different times during the implosion (the intensity for each image is normalized to its peak). The signal levels are clearly strong enough to diagnose the implosion symmetry under NIF foot radiation drive conditions. The time dependence of the shape of the core can be determined, for each image, along with the peak emission time for the implosion (6.03 ns). These quantities will be compared with simulations to benchmark their predictive accuracy.

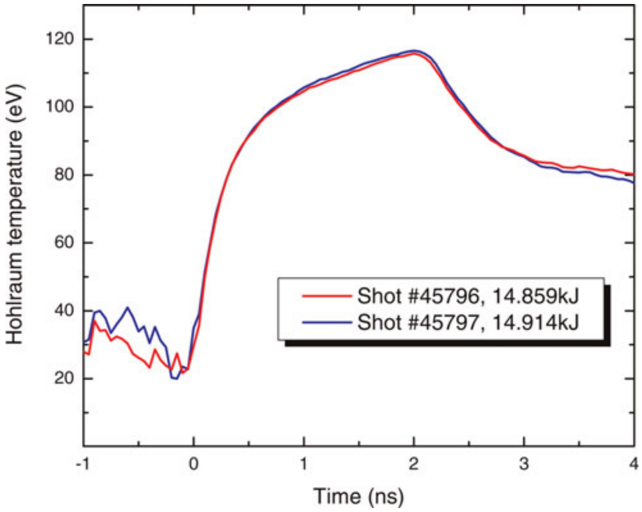

Fig. 3. (Color online) Hohlraum brightness temperature as measured by DANTE shows reproducibility of the laser drive as the desired peak temperature of 118 eV was achieved.

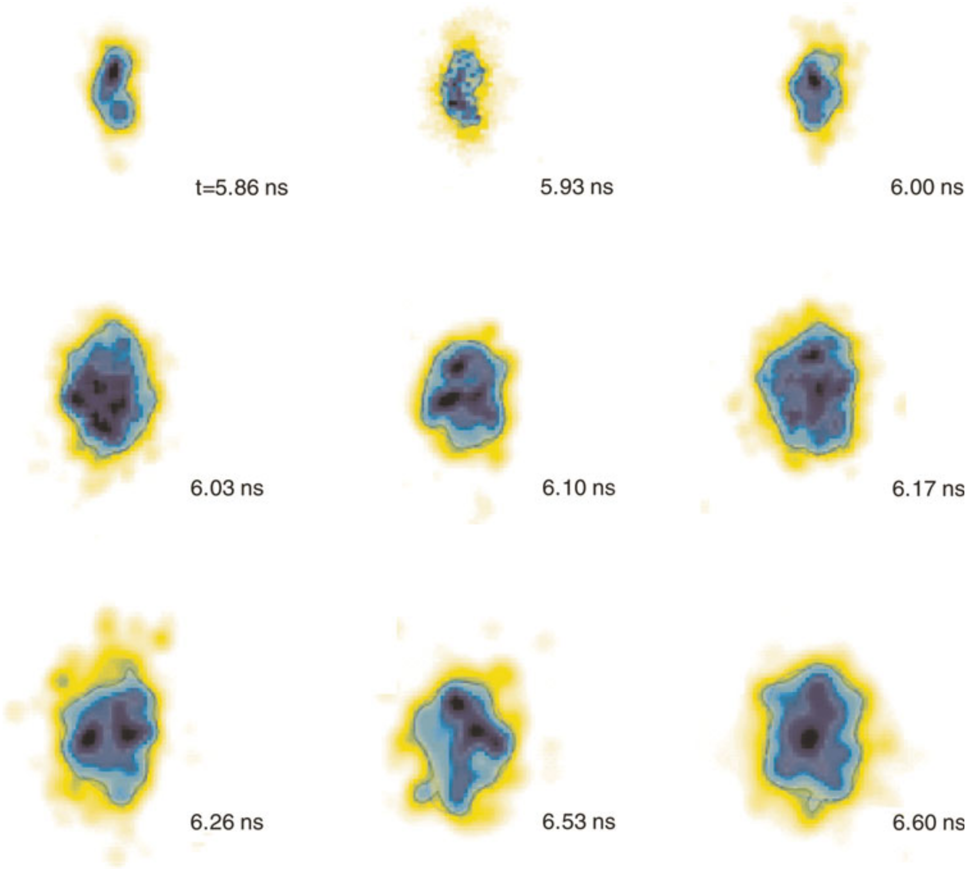

Fig. 4. (Color online) Processed images of the capsule X-ray self emission of shot #45797, where the intensity for each image is normalized to its peak. The implosion occurs at $t = 6.03$ ns (peak X-ray emission time), the hohlraum axis is horizontal. The brightest emission is shown by the darkest colors.

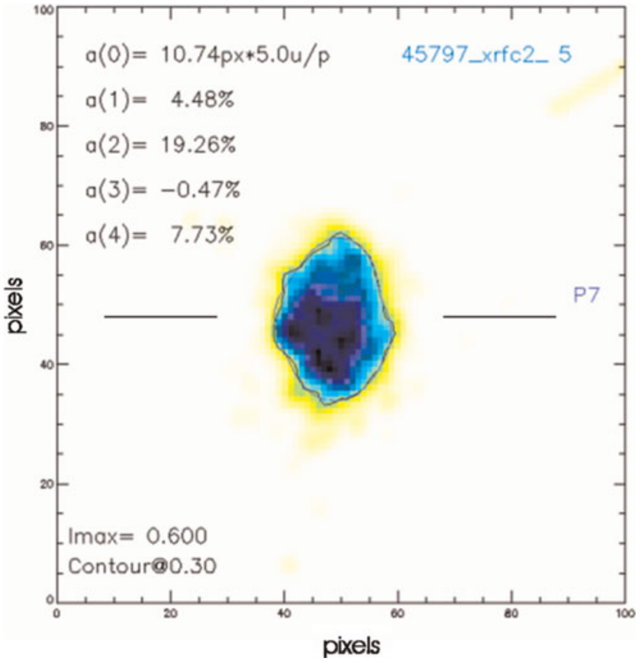

Fig. 5. (Color online) Detailed image of the capsule implosion of shot #45797 at peak emission time, integrated over 35 ps (FWHM). The hohlraum axis is horizontal. The parameters a(0) to a(4) are the fractional amplitudes of the Legendry-fit parameters normalized to the fitted zero order amplitude (a(0); measured to be 53.7 μm) at the 30% brightness contour.

To quantify each of the image shapes, a Legendry polynomial is fit to a brightness contour of the X-ray emission. The fitting algorithm uses singular value decomposition (SVD) to determine the best Legendry fit. Figure 5 shows a sample fit to the 30% brightness contour of the implosion image at 6.03 ns (peak emission time). In this case, the implosion has a positive 20% P2 asymmetry meaning the radiation drive is larger near the ends of the hohlraum than at the center or equator. The analysis also shows a small P4 asymmetry of 8% as well.

CONCLUSIONS

The present work demonstrates the ability to use specially designed symcaps to diagnose the low radiation temperature drive symmetry at the foot of the NIF laser pulse. This is the first time this technique has been applied to large hohlraums with relatively low radiation drive. Under these conditions, the core X-ray emission is of sufficient brightness to measure the size, and shape of the core in addition to the X-ray peak emission time. Future experiments will use this technique and similar symcaps made of Be at the Omega laser to verify the ability to tune experimentally the symmetry of the implosion and validate the predictive capability of simulations.

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