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Control of Be capsule low mode implosions symmetry at the National Ignition Facility

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Abstract. We present results of the beryllium experimental campaign on the implosion symmetry properties of beryllium capsules at the National Ignition Facility (NIF) [1]. These indirect drive experiments measure both the inflight and core self-emission implosion symmetry. The inflight symmetry of the ablator before stagnation is measured using a backlight imaging technique. A copper backlighter was used to measure the transmissions (or backlit absorption) of the copper doped beryllium shells. Images of the x-ray emission from the core around bang time provide a measure of the symmetry near peak compression. Both pieces of information about the 2D symmetry are used to infer the drive and velocity uniformity enabling us to predictably adjust the properties of the incident laser, mainly the time dependent ratio of the inner beam cone power to the outer laser beam powers, to achieve proper symmetry of the implosion. Results from these experiments show inner beam propagation is not degraded compared to similar implosions with CH ablators. Variations in the shape compared with implosions using CH ablators also provides information about the cross beam energy transfer used to adjust the equatorial shape and thus infer information about the differences in plasma conditions near the laser entrance holes. Experimental results of the implosion shape for beryllium capsules will be presented along with comparisons relative to CH ablators.

1. Introduction

Symmetry of implosion systems has been currently identified as one of the main culprits in not achieving ignition at the National Ignition Facility (NIF) using indirectly driven cryogenically layered DT ignition fuels. [2,3,4] Although low order spherical symmetry has been achieved with symcaps, where the layered DT fuel is replaced with an equivalent mass of the shell material [5], the same conditions did not achieve the same goals necessary for ignition with cryogenically layered targets. Differences due to low order symmetry have been explored, but the incapability of accurately calculating the symmetry of the hohraum radiation limits conclusions about the effect. Higher order symmetries, due to instability growth from either objects that carry the capsule, or from the perturbations on the various surfaces in the capsule, offers a slightly better explanation. All the
previous studies have used various CH or Diamond capsules with different levels of doping. Beryllium (Be) ablators have been recognized for quite a while as more efficient ablators, with different instability growth characteristics, requiring different drive characteristics from CH capsules [6,7]. The Be low opacity leads to higher ablation rates, [8] pressure, and velocity. [9] Thus a Be campaign was started to examine the use of Be and find what similar or different issues from those of CH or Diamond occur. Initial studies, in this first Be campaign, have been made with hohlraum conditions as close to those from the high foot campaign [10] to quickly establish differences and discover any issues. In this study, part of the first Be capsule campaign, we concentrate on the study of symmetry of both the imploding non-layered Be capsule shell, as well as the symmetry of the x-ray emission from the imploding fuel. In this paper we concentrate on the results and techniques as used on a 2d-ConA shot techniques [11, 12] that are similar to those used on other shots, and we summarize the results of the symmetry tuning.

2. Experimental Conditions
For this study we used a copper doped Be capsule (Cu:Be) in a 575 Au hohlraum using a 2D-ConA x-ray backlit configuration [11] to measure the symmetry of the in-flight shape of the capsule. The capsule dimensions and doping are shown in Figure 1, while the hohlraum arrangement, target mounting, and backlighter configuration are shown in Figure 2. Basically the capsule is a symcap of the layered capsule, where the DT fuel layer is replaced by an equivalent mass of Be to preserve the hydrodynamic, rocket like, motion of the ablator layer. The capsule also has three copper doped layers, that protects the fuel from the >1.8 keV preheat from the hohlraum and helps controls the ablation front position in the shell. The doped layer, having a different density from the rest of the Beryllium in the capsule, is graded in three densities to reduce the spatial gradient of the density jumps necessary for the copper doping. The surfaces of the Be capsule are polished to NIF specs [13] to reduce the seeding of instabilities. Inherent spatial structures within the Be remain to be controlled in the future. The capsule is held in the center of the hohlraum to an accuracy of 30 µm using a tent, Figure 2, with a thickness of 45 nm enclosing the capsule. Two square windows are placed along the axial line of sight to allow the backlighter radiation, and the x-ray emission form the implosion, to reach a gated x-ray detector [10]. These windows do perturb the capsule implosion, producing an M₂ mode as seen from the polar direction, but are not expected to affect the Legendre mode decomposition in the axial line of sight used in this study. Filtered pinhole x-ray images were acquired using time integrated image plates as well as a gated x-ray camera with a gating time of 80 ps per image [14]. A spatial resolution of 11 microns was achieved using a nominal 10 µm diameter pinholes, and a magnification 6X.

1.44 MJ of laser energy was converted to an x-ray drive in a hohlraum to implode the Cu:Be capsule. Eight laser beams of the NIF facility were pointed at a copper backlighter target placed outside the hohlraum, while the rest of the 184 beams were directed to the same positions as in a cryo hohlraum. The laser had different wavelengths for each of the cones incident to the hohlraum axis: inner 23.5°
10530.70 Å, 30° 10530.0 Å, outer cones at 45° and 50° 10524.3 Å. The choice of wavelengths was made to allow for cross beam energy transfer [15] in the hohlraum gas (1.6 mg/cc of 4He at 24 K). The laser pulse shape is shown in figure 3, where the inner and outer beams had slightly different pulse shapes and energy per beam to allow for better control of the symmetry and drive in the hohlraum. The laser had 1.32353 Ghz SS modulation. The backlighter beams (BL) turned on from 15.5 to 18 ns to capture the backlight transmission images of the imploding shell before stagnation. Turning off BL before stagnation allowed us to record the X-ray emission around bang time as well.

3. Data
A typical record of the data is shown in figure 4, where the delays at the center of each strip are shown. The data is analysed using two different techniques for different features. At early times, we use the transmission images to extract the position of the Limb (the ring-like light region in the images) as a function of angle and time (Ref 10), and the position of the maximum slope on the outside of the capsule. The angular data is used to extract a Legendre decomposition of the position of the limb as a function of time giving an indication of the symmetry of the imploding shell. At Bang time, we use the x-ray self emission images, shown in the lowest strip in Figure 4, and to extract symmetry properties, [4] also characterized by Legendre Polynomial amplitudes.

A summary of the data for shot N150420-003 is shown in figure 5. Two graphs are shown. The left graph shows the measure size of different parts of the capsule implosion at different times as well as the emitted x-ray flux from the core emission. The radius for the limbs from the shell decreases in time, similar to that from the emission for the edges (17%) of the x-ray emission. The figure also shows the stagnation of the core just before maximum x-ray emission. The graph to the right shows the history of the Legendre $P_2$ amplitudes from the Limb minimum and from the x-ray emission. The $P_2$ shows a slight swing as a function of time, but also shows that the absolute $P_2$ amplitude has the same sign, and is within the statistics, of the Limb amplitudes. Currently, calculations are not able to reproduce these shapes, but are able to reproduce (figure 6) the temporal variation of the Limb radii, provided a multiplier of 0.86X on the laser power was used after subtracting backscatter.

4. Summary
When we compare the results of this measurement to other measurements, figure 7, we note that the equatorial symmetry of the implosion varies monotonically, from prolate to oblate, with the wavelength difference between the inner and outer beams. The figure shows the progression of the tuning of the $P_2$ amplitude for different shots. The points at the right side of the figure are from baseline High-Foot CH shots used to start tuning the Hohraum. The three points at the left are for Be shots. They show the symmetry data from the 2DConA at 6 angstroms, and 1D cona at 5 Angstroms, and the final results of tuning a cryo capsule at 5.5 Angstroms. While the laser pulse shape changed little in between these shots, progress on tuning the symmetry with wavelength difference change is evident. We note that a similar behavior for the Polar M modes was harder to achieve since there are necessary differences in hohlraum symmetry between the 1dConA, 2dconA shots and the cryo implosions due to the use of some laser beams for backlighting.
In a few shots, we were able to demonstrate that we can tune the equatorial symmetry of the Be implosions, that the shell and the core have roughly the same $P_2$ contribution, and that the effects of the tent and fill tube in the implosion images were not observed. We also show that different $\Delta \lambda$s are needed to get to the same $P_2/P_0$ for different materials in the same hohlraum and laser drives.

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References