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Wall and Laser Spot Motion in Cylindrical Hohlraums

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I. Introduction

In inertial confinement fusion (ICF), thermonuclear gain is to be obtained by imploding a spherical capsule filled with a deuterium-tritium mixture. One scheme is to indirectly drive the implosion using soft x-rays by placing the capsule at the center of a gold-coated hohlraum which walls are irradiated by high-power laser beams [1]. Hydrodynamics of the hohlraum is a key issue since it directly influences the implosion symmetry of the D-T capsule. Laser interaction with the inner wall creates a hot, low-density plasma that expands towards the hohlraum axis and may cause early degradation of the D-T pellet. This plasma also induces refraction of laser beams, resulting in a change of symmetry of irradiation. Gas-filling [2] or use of a low-Z liner can be used in order to minimize these two effects.

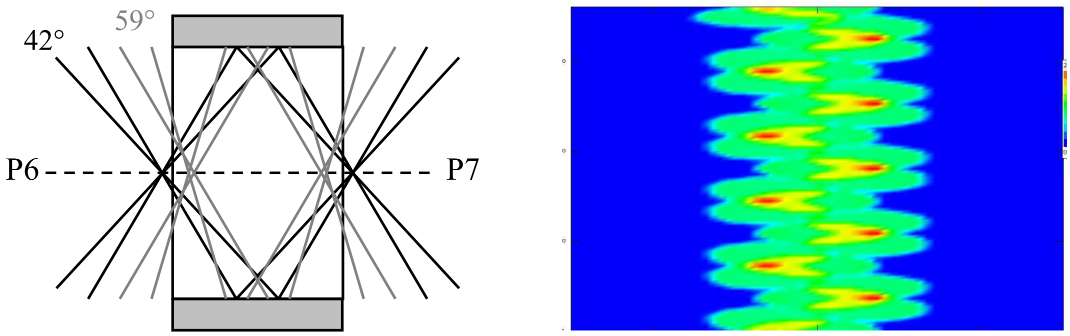
In order to clearly quantify the effect of gas-filling or wall lining on the hydrodynamics of laser-driven hohlraums, we performed a series of shots on the Omega laser facility[3]. We used empty, CH-lined and propane-filled cylindrical hohlraums; those have a somewhat simpler geometry than nominal LMJ or NIF targets in order to have clear line sights and to provide validation elements for 2D simulation codes before going on to more complicated configurations.

II. Experimental setup

The experiments were designed using the 2D radiation hydrodynamics code FCI2, taking into account non LTE treatment of gold wall with the model Radiom [4]. Calculations were post processed to simulate on-axis X-ray images.

Hohlraums dimensions were 1.6mm internal diameter and 1.5mm length. The inner walls were coated with 3µm of gold. The 500 µm thick outer resin walls were machined on one side down to 100µm from the inner Au coating in order to provide a line of sight for the imaging of hard X-rays (≥4.5 keV) generated by hot spots. CH-lined targets had a supplementary 1µm thick CH coating over the inner Au walls. Gas-filled targets had their laser entrance holes (LEHs) covered by a 700nm thick polyimide window and were filled with propane to 1 atm.

The irradiation scheme was designed using commercial 3D view factor software VISRAD [5]. Laser beams from 42° and 59° cones simultaneously irradiated the targets from both sides. The pulse shape was Omega PS26N01A (~1ns pedestal followed by a ~1.5ns main pulse with a 5:1 contrast) and smoothing was performed using E-IDI-300 elliptical phase plates, yielding total on-target energy of about 9.5kJ and negligible backscattering. All beams were defocused in order to provide ~400µm diameter spots. 42° cone beams were all pointed at the hohlraums central inner circumference, whereas 59° beams were slightly pointed outwards (~150µm) in order not to hit the LEHs edges (fig. 1(a)). Initial hotspot pattern results from the superposition of 42° and 59° beams (see fig. 1(b)).



(a) (b)

Figure 1 : (a) irradiation geometry scheme, (b) resulting initial hotspots in the z-θ plane calculated with VISRAD.

III. Axial imaging

Axial imaging was performed using Omega X-ray framing camera XRFC. A 12-pinhole nose was used so that each horizontal strip gave an image of the expanding plasma in three spectral ranges (~450 eV, ~800eV and above ~1.5keV). Acquisition start times were 1, 1.5, 2 and 2.5ns. For each strip, images in spectral channels are temporally separated one from the next by no more than approximately 70ps (fig. 2).

Empty targets (fig. 2 (a)) exhibit early (~1.5ns) on-axis plasma collision and radial spikes due to the interpenetration of plasma plumes generated on the loci of hot spots. Gas-filled targets (fig. 2(c)) show best retention of wall expansion as expected. The Au/gas interface is modulated by the pattern of laser spots along the target's circumference but no spikes and no on-axis collision occurs. CH-lined targets display characteristics that are similar to the gas-filled target but with a more important closure of the hohlraum. Late-time hard X-ray images (2.5ns) show accumulation of gold that first expands and then recompresses near the CH/vacuum interface (fig 2(b)).

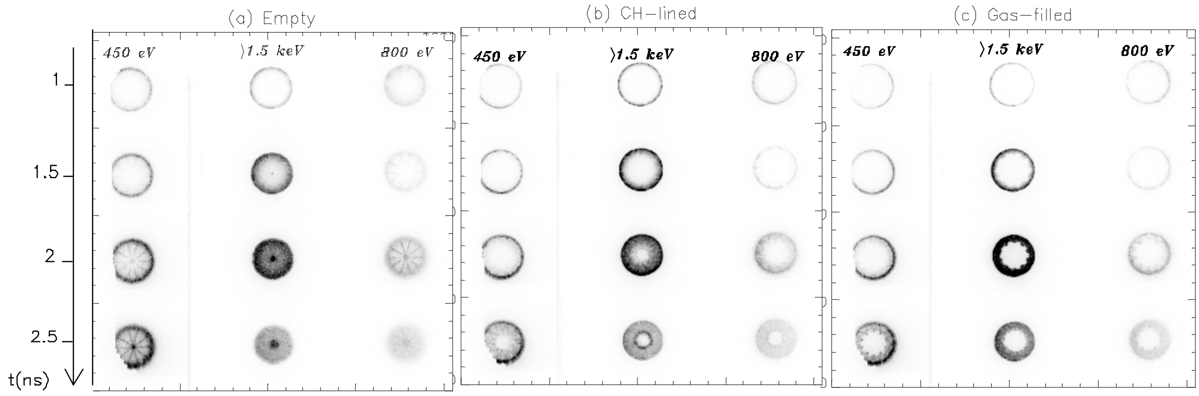


Figure 2 : On-axis imagery of (a) empty, (b) CH-lined and (c) gas-filled hohlraums.

We define a criterion that we call the free radius of the hohlraums, where the intensity falls to half its maximum value. For a better comparison with 2D simulations, profiles were taken where no 3D effects (such as density spikes) are present. Figure 3 shows results obtained for a gas-filled target.

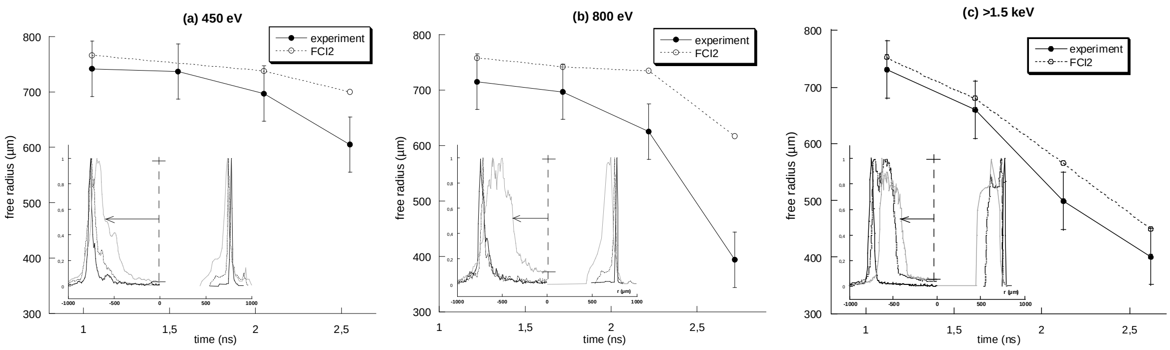


Figure 3 : Time resolved measurements of free radius for a gas-filled hohlraum in all three spectral ranges. Insets at the left bottom of each plot show experimental (left) and simulated (right) profiles at 1ns, 2ns and 2.5ns. Arrows oriented to the left in the insets illustrate the definition of the free radius at 2.5ns.

Best agreement is found at 450 eV, which is characteristic of thermal emission layers of the plasma in the vicinity of the critical density, and above 1.5 keV which corresponds to the emission of the hot, non-equilibrium corona expanding toward the center of the hohlraum. The 800 eV channel, where both LTE and non-LTE phenomena contribute, is harder to interpret. The same features were found for empty and CH-lined hohlraums.

IV. Streaked perpendicular imaging

Streaked hard X-ray (≥4.5 keV) imaging was performed using Omega SSCA X-ray streak camera with a line of sight that is perpendicular to the hohlraum axis within ~2°. Two 10 µm diameter Pt fibers were glued onto the outer thinned wall and the spacing between them was measured in order to define a spatial reference. Empty targets clearly exhibit the fastest laser spot displacements (fig.4 (a)), while CH-lined targets appear to better retain laser spot motion (fig. 4 (b)) and gas-filling best inhibits motion (fig. 4 (c)).

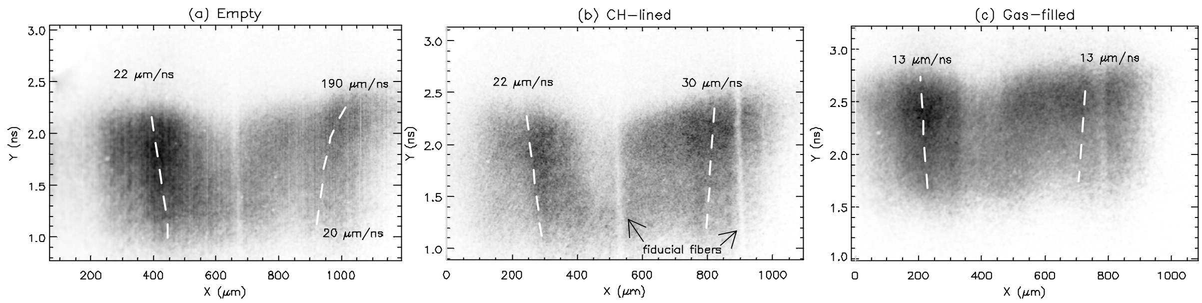


Figure 4 : Streaked perpendicular imaging of laser spots as seen through the thinned wall of the different kinds of hohlraums that were shot. White dashes illustrate trajectories of hot spots with their average speeds.

Horizontal profiles of streaked images are not symmetric because of the complex arrangement of hot spots that was exposed in Sec. I. To quantify the performances of the different types of targets, we examine the motion of local centroids of X-ray emissions on the left and right side of each image.

V. Conclusion

This experiment gave a lot of valuable results which are necessary to validate the description of the irradiation symmetry by the hydro code FCI2. As expected, gas-filling provides much better performances concerning the reduction of wall and laser spot motion and hence a better control of symmetry. However, low-Z ablator inner lining of hohlraums also provides interesting results and probably deserves optimization, given the fact that these targets are much easier to handle than in the case of gas-filling.

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