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Experimental Studies of ICF Indirect-Drive Be and High Density C Candidate Ablators*

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Abstract. To validate our modeling of the macroscopic and microscopic hydrodynamic and equation of state response of these candidate ablators to NIC-relevant x-ray drive, a multi-lab experimental program has been verifying the behavior of these new ablators. First, the pressures for onset and termination of melt for both Be and HDC under single or double shock drive has been measured at the Z and Omega facilities. Second, the level and effect of hard x-ray preheat has been quantified in scaled experiments at the Omega facility. Third, a long planar x-ray drive has been developed to check 2D and 3D perturbation growth at the ablation front upon acceleration. The concept has been extended to study growth at and near the ablator-ice interface upon deceleration. In addition, experimental designs for validating the expected low level of perturbation seeding due to possible residual microstructure after melt during first and second shock transit in Be and HDC have been completed. Results so far suggest both Be and HDC can remain ablator choices and have guided pulse shaping designs.

1. Introduction

The indirect-drive Inertial Confinement Fusion (ICF) capsule point design for the National Ignition Campaign (NIC) on NIF uses a Cu-doped Be ablator [1] (see Figure 1a) to decrease sensitivity to hydrodynamic instabilities seeded at surfaces and increase coupling efficiency relative to mid-Z doped CH capsules that have been extensively tested [2] in the past. In addition, a recent alternate ablator candidate, high density carbon (HDC) (see Figure 1b), is predicted to provide a further increase in coupling and yield by virtue of its 2x larger density and hence larger inner diameter and DT fuel capacity for fixed initial outer diameter. However, unlike CH, both Be and HDC are polycrystalline in the solid phase, are predicted to melt at considerably higher temperatures and pressures, and could provide either additional or reduced seeding of instabilities before fully melted depending on the level of material strength remaining.

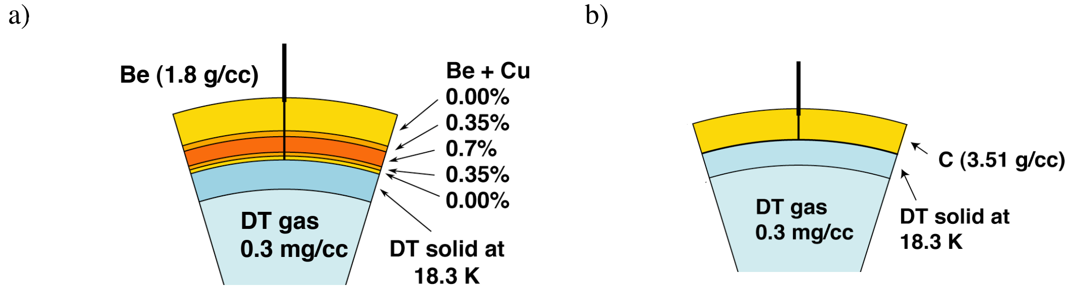

Figure 1. Examples of peak Tr = 300 eV capsule designs for a) Be(Cu) capsule b) High Density Carbon capsule, each with initial 1 mm outer radius

2. Melt Pressures

Since shock propagation through solid polycrystalline Be is predicted to lead to unacceptable distortions of shock front and hence perturbation seeding due to crystal sound speed anisotropies, the first shock pressure for the ignition pulse is designed to fully melt the Be. The single shock pressures for onset and completion of melt in Be has been determined at the Z facility [3] to be 2 and 2.6 Mbar, respectively. Similar measurements suggest HDC fully melts at a single shock pressure of 6 Mbar. However, the shock distortions in nanocrystalline HDC are predicted to be smaller principally due to the smaller grain size (< 50 nm), as long as the HDC is not left in large co-existing domains of melted and solid material. The strategy for HDC is hence to leave it in a low adiabat, solid state after first shock passage (by operating at ≈ 4 Mbar) and fully melt during second shock passage. Experiments to determine this second shock melt pressure were carried out at the Omega facility in a 2-shock direct-drive planar configuration on μcrystalline HDC samples. The experiments inferred the temperature of an overtaking second shock from its optical emissivity (Figure 2) as a function of the strength of the second shock for either a 3 or (4) Mbar first shock. The results show a sudden rise in the second shock temperature at a pressure of about 18 (21) Mbar, indicating the completion of melt. This information has led to a revised HDC drive pulse-shape with a second shock pressure of 23 Mbar.

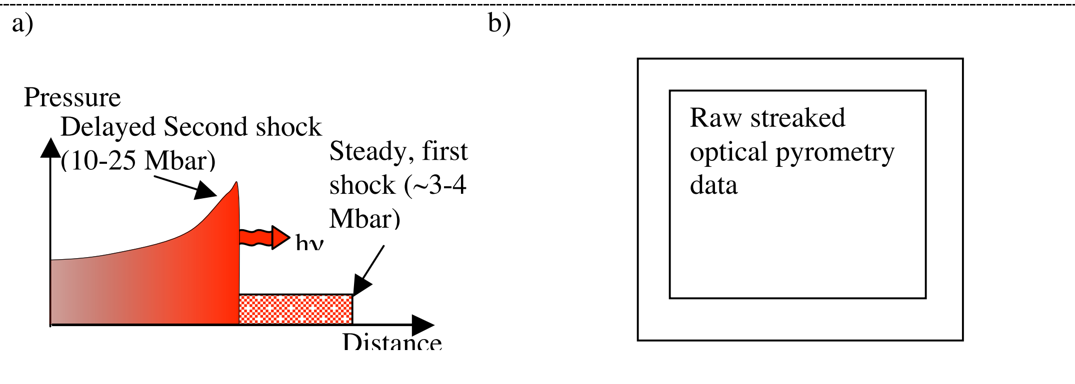

Figure 2. a) Concept of overtaking second shock technique. b) Example of optical streaked shock emissivity data

3. X-Ray Preheat and Shock Heating

Having determined the minimum shock pressure for Be melt, the next question was whether we could predict the hohlraum conditions required to melt Be while not putting it on too high an adiabat. For this purpose, a scaled halfraum experiment was completed at Omega that mimicked the NIF ignition foot conditions in terms of laser power, intensity and fraction of wall covered with laser beams. The observable was the rear-surface expansion of planar Be steps as measured by VISAR fringe shifts (Figures 3a and b). The results showed the expected gradually increasing Be expansion due to > 1 keV x-ray preheat followed by the sudden loss of reflectivity upon shock break-out. Figure 3c shows the calculated rear-surface temperature relative to the expected melt temperature for a variety of Be foil thicknesses. These results validated that for the NIF foot drive pulse, the first 20-25 μm of Be will be melted by x-ray preheat and the remainder by the first shock.

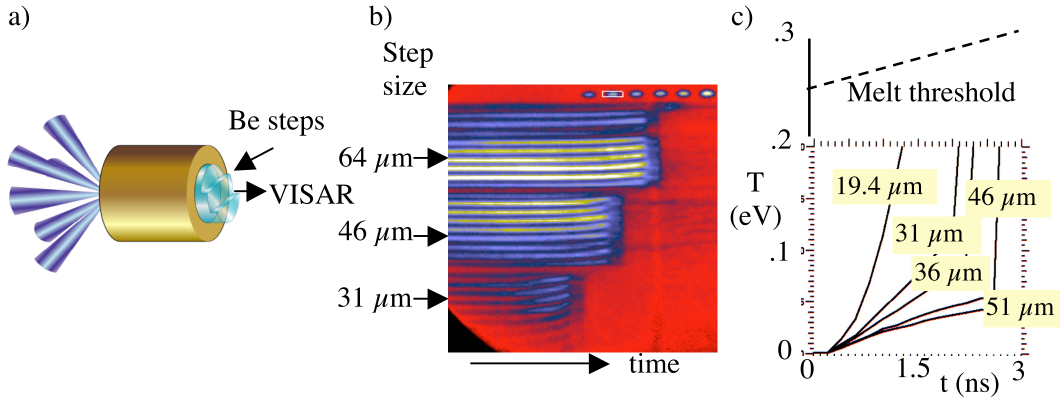

Figure 3. a) Experimental set-up b) Representative VISAR data. c) Calculated rear-surface temperature vs time for various thickness samples.

4. Hydroinstabilities

Simulations predict that residual μstructure and velocity fields in melted Be could still seed some hydrodynamic instabilities upon shock break-out, but at a level below that expected and acceptable from growth of known surface imperfections. To validate these expectations, we have designed Omega experiments to either look directly for the <1 part in 20000 velocity and amplitude perturbation on shock fronts that would still be acceptable (see Figure 5b) or amplify their perturbation seeding using high growth factor (GF ~ exp($\gamma\tau$)) Rayleigh-Taylor instability drives (see Figures 4a and 5a).

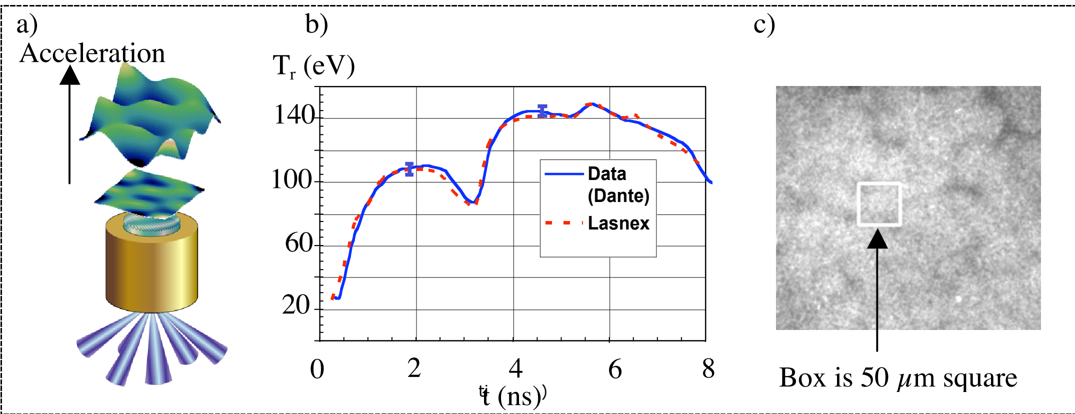

Figure 4. a) Experimental set-up for ablation front Rayleigh-Taylor growth measurement. b) Measured vs calculated x-ray drive Tr c) 4.3 keV radiograph of growth of NIC-surface roughness on Be(Cu) foil at 8.2 ns

To achieve this, a τ = 8-10 ns long drive has been developed [4] (see Figure 4b), which for a given achievable radiographic accuracy $\Delta GF/GF = \tau\Delta\gamma$, leads to an improved growth rate accuracy $\Delta\gamma \sim 1/\tau$.

growth from BeCu planar foils with a level of surface roughness equal to the NIF ignition design surface roughness tolerance (see Figure 4c). The results when compared to simulations ignoring possible growth from Be microstructure and hence only considering growth from surface perturbations suggest that at least for ablation front instability growth, µstructure is not important. Ongoing Omega experiments shown schematically in Figure 5 are testing for seeding and growth at the ablator-ice interface. We expect the use of a 2 pulse 2D VISAR system (Figure 5b) to provide shock velocity perturbation measurements down to 1 part in 10^5 on relevant spatial scales (few microns), for both planar and sections of real capsule shells.

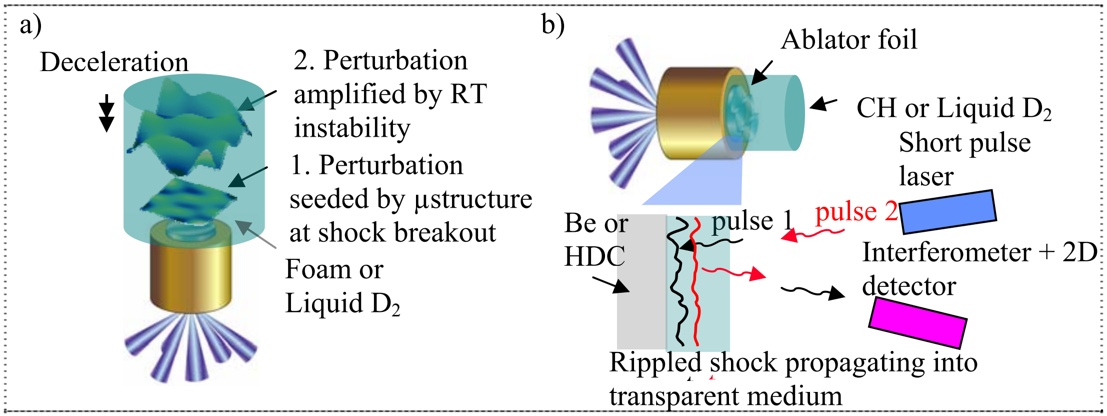

Figure 5. a) Experimental set-up for deceleration RT experiment b) Experimental set-up for rippled shock detection

5. Summary

We have experimentally validated many of the residual physics parameters for polycrystalline ablators. Experiments measured or confirmed shock pressures for onset and termination of melt, the level of hohlraum X-ray preheating and shock heating and the expected ablation front Rayleigh-Taylor growth. Results so far suggest both Be and HDC can remain ablator choices and have guided pulse shaping designs. Other hydroinstability and material strength experiments have been designed and/or are in progress to further test models and physics.

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