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Microstructure Filled Hohlraums

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Executive Summary:
We propose replacing the gas fill in a hohlraum with a low average density, variable uniformity 3D printed structure. This creates a bimodal hohlraum which acts like a vacuum hohlraum initially during the picket, but could protect the capsule from glint or direct illumination, and then once expanded, homogenizes to behave like a variable z gas-fill during peak portion of the drive. This is motivated by a two main aims: 1) reduction of the Au bubble velocity to improve inner beam propagation, and 2) the introduction of a low density, high-Z, x-ray converter to improve x-ray production in the hohlraum and uniformity of the radiation field seen by the capsule.

Need and Approach:
Standard ICF hohlraums shot to date have experienced issues with capsule support, capsule radiation uniformity, and coupling of the laser beam geometry to x-ray drive on the capsule. In particular the rapid, untamped expansion of the Au hohlraum wall and ablator into the relatively 'empty' hohlraum limit the time during which the inner beams can successfully deposit energy at the equator of the hohlraum and drive a symmetric implosion. Our proposal aims to utilize a microstructure filling the hohlraum to mitigate this issue and provide a range of other benefits:

1. Microstructure can be of variable density . i.e. high density by outer cone wall region to hold back Au bubble – low to zero density along inner cone beam path
2. Microstructure can support capsule directly – no need for a tent
3. The structure can be designed to limit the direct line of sight for the laser to capsule or Au wall – i.e. laser scatters through structure homogenizing the radiation field that hits the capsule and wall early in time.
4. Structure can be overcoated with thin layers of High or Mix Z to increase x-ray conversion efficiency and reduce hohlraum loss – time-variable shine shield.
5. Potential to prevent glint and shadows impacting capsule.

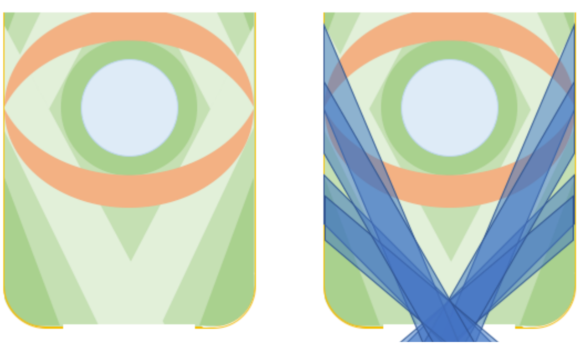

Figure 1: Example concept of variable density microstructure hohlraum fill. Light-to-dark green shades are indicative of low-high low-Z CH foam structures (avg. density: <1mg/cc - 100mg/cc); orange shading a high-Z microstructure converter (density ~ 10mg/cc)

An example of the type of structures that could be used to benefit the hohlraum is shown in Fig. 1. Variable density CH foam microstructures (green) could be printed to maintain low density (light green) along the inner cone beam path, and higher density close to the hohlraum wall and ablator (darker green). Separately a high-Z microstructure converter (orange) could be introduced that would explode and fill the hohlraum to a low (<1mg/cc) average density of high-Z foam that would be more absorbing and opaque smoothing the radiation uniformity seen by the capsule.

Hohlraum Conditions required for typical materials:
Microstructures inside the hohlraum perform two main roles – tamping expansion of the hohlraum wall and possibly the ablator, and maintaining an open beam-path for the propagation of inner beams to the equator. This defines the range of densities required.

For an inner cone beam to propagate unimpeded the average hohlraum electron density needs to be approx. 0.01nc for 3w = $9x10^{19}$cm-3. For a pure carbon plasma, assuming an average charge state of 6, this corresponds to a mass density of 0.3mg/cc. For a Ta plasma a similar calculation yields approx. 1mg/cc. To impede the expansion of the hohlraum wall, simulations indicate that optimal densities of Ta_2O_5 are in the range 20-40mg/cc.

2^{nd} generation octahedral CH microstructures have average densities of order 100-200mg/cc with cell sizes of order 200µm and strut dimensions of order 30µm – see Fig. 2. Future 3^{rd} generation structures (available in 2018) are expected to have strut dimensions of <10µm diameter leading to average mass densities of CH as low as 10mg/cc. These structures are also amenable to coating with materials such as Zn or Ta, after which the CH can be burned out leaving structures with average densities of Ta_2O_5 in the range < 10mg/cc.

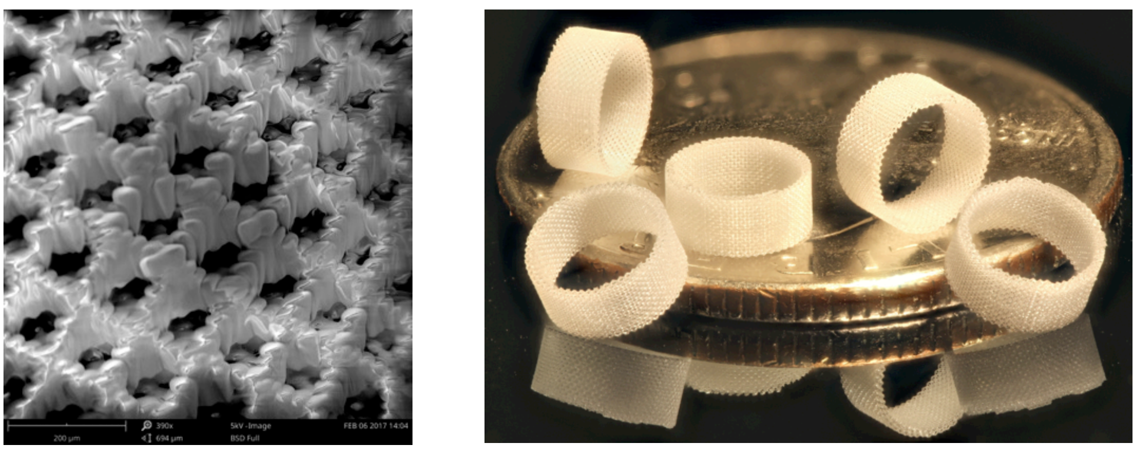

Figure 2: Example of 2nd generation microstructure: 200µm unit cells with 28µm features

While these average densities are ideal for impeding expansion of the hohlraum wall and possibly the ablator, significantly lower (~10x) densities are required for beam propagation. To achieve this will either printing structures with larger void regions that will fill with plasma once heated. Estimations of the homogenization time depend on the cell size structure, but using a typical expansion velocity of about 100µm/ns, for the microstructures described a uniform plasma could be expected within approx. 1-3ns.

Benefit and Cost:

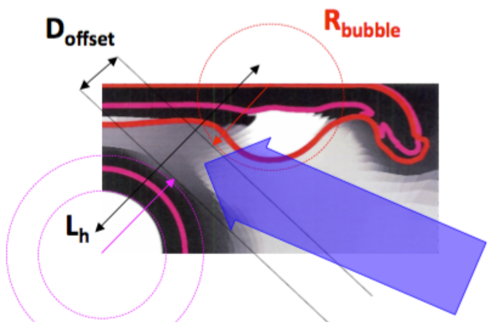

Figure 3: Illustration of ballistic model to estimate inner beam propagation for a given hohlraum and capsule design (C. Thomas).

Capsule coupling improvements can be estimated by considering a simple ballistic wall and ablator motion. Using this description we can estimate the increased coupling factor that could be realized by maintaining an open beam path for the inner cone beams to reach the equator:

$$L_h - R_0 M - (V_{bubble} - V_{capsule})tM = D_{offset} > 0$$

As shown in Fig. 3, L_h is the distance separating the capsule and wall bubble, R_0 is the capsule radius at t=0, V is the expanding velocity of the bubble and/or exhaust velocity of the capsule, and M is a multiplier on the capsule scale. In this formalism the energy coupled to the capsule scales as M^3.

Recent foam ring experiments (N170123-002-999) indicate that a 20mg/cc Ta2O5 foam liner holds back the wall by 50-100µm - equivalent to about 1ns - compared to a Au equivalent. Applying this in the above expression indicates the potential to increase the coupled energy in a bigfoot design by almost 30% (see appendix). Alternatively, if the bubble expansion can be mitigated completely, then the same calculation indicates that the energy coupling increases by 2-2.5x.

Time/Investment required:
2^{nd} generation microstructures are currently being manufactured and tested, and could be fielded in a hohlraum design within 3-6 months of being requested. To ensure that the average hohlraum fill density remains low the 2^{nd} generation structures would likely be limited to testing high-Z wall liner or converter schemes. 3^{rd} generation structures are really the enabling technology for printing structures that entirely fill the hohlraum and provide both a variable density, bimodal hohlraum fill, and also support the capsule and mitigate wall expansion. With the current level of investment it is expected that 3^{rd} generation structures might be available to test in early FY18. It is important to note that these concepts can be tested in existing hohlraum designs requiring relatively little new target development.

To proceed requires 0.5 FTE designer effort to develop the microstructure converter and fill concepts into a simulated design and 1.0 FTE in development of the ALD of 2^{nd} generation microstructures. Some of the 3^{rd} generation microstructure development is already funded, so we estimate that to be available in mid FY18 would require an addition 1.0 FTE effort in 3D printing development.

Appendix:
Recasting the equation above leads to the following expression for the capsule scale multiplier. M < 1 implies that the bubble and capsule have interacted and the inner beam can no longer

propagate after time t_0, M=1 indicates that a design is optimized such that the inner beams begin to be impeded at the end of the drive, while M > 1 indicates that the inner beam is still propagating after t_0, and that more energy can be coupled to the capsule, or a longer pulse could be designed to lower the adiabat of the implosion.

$$M = \frac{L_h}{R_0 + \left(V_{bubble} + V_{capsule}\right)t_0}$$

Using the bigfoot design as an example:

$$M = \frac{900 + 2750}{900 + (300 + 120).\,6.5} = 1.01$$

If the bubble trajectory is modified through the introduction of a foam liner, delaying the evolution of the wall by 1ns, then

$$M = \frac{900 + 2750}{900 + 300\,.\,5.5 + 120\,.\,6.5} = 1.10, \quad M^3 = 1.33$$