Inertial confinement fusion characterization with phase-contrast x-ray imaging

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Spherical deuterium-tritium (D-T) fuel layers are compressed to high density in inertial confinement fusion experiments, such as those planned at the National Ignition Facility (NIF). Current specifications require less than 1 μm RMS roughness for the 1 mm radius, 100 μm thick fuel layers. Careful preparation and characterization of the fuel layer is required for correct interpretation of ignition experiment results. A spherical shell of either low-Z plastic or beryllium encapsulates the D-T. Beryllium is preferable because hydrodynamic instabilities are significantly reduced compared to plastics during implosion. Visible light and ultrasonic characterization methods have not been able to characterize a D-T layer inside of a beryllium capsule. X-ray absorption imaging is not suitable because the opacity of beryllium is 10^4 times higher than that of D-T. Phase-contrast enhanced imaging has been demonstrated for low-Z materials where absorption imaging does not provide contrast and should enable characterization of the D-T fuel layers.

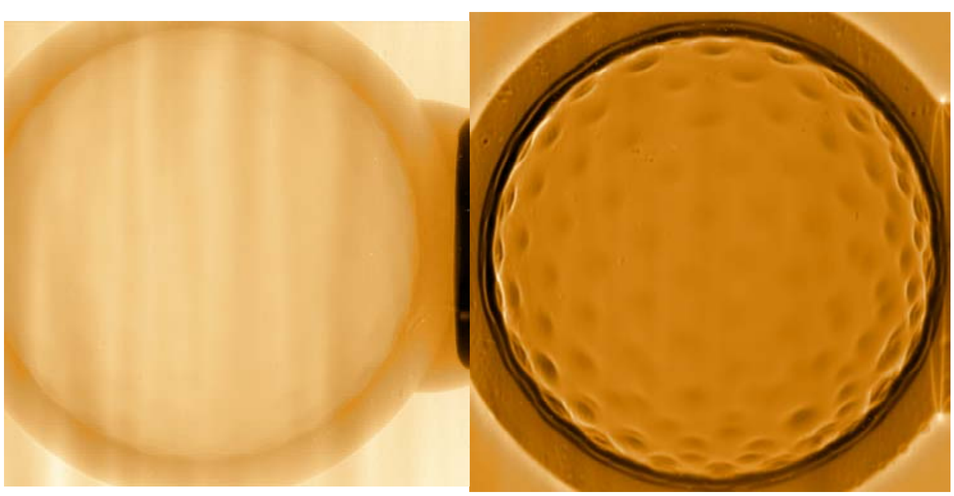

Figure 1: 2 mm diameter, 150 μm thick polyimide shell on 17 μm thick CH shell imaged using 10 keV x-rays at the APS. The left image is taken with object-detector distance of 2 mm and the right image at 1150 mm. The rough inner surface is much more visible in the right image due to the phase-contrast. The dimpled surface demonstrates that phase-contrast enhanced imaging is applicable for characterizing surface roughness.

We first demonstrated the applicability of phase-contrast enhanced imaging using a low density foam shell at the Advanced Photon Source (APS). The average refractive index of the foam is comparable to that of solid D-T. We also imaged a plastic shell with a rough inner surface to verify that phase-contrast enhanced imaging can successfully characterize a rough surface. One such image is shown in Figure 1. The two images show the difference between absorption imaging (left) and phase-contrast enhanced imaging (right). The surface features are easily visible in the phase-contrast images.

We want to determine the roughness of the surfaces in a NIF capsule. We found that the inner surface can be located using an edge detection algorithm. A raytrace of a rough shell was performed using a known surface roughness. The analysis of the raytraced image was compared to the input surface and found to be in excellent agreement, as shown in Figure 2. Thus we are confident that D-T surface can be accurately characterized using phase-contrast enhanced imaging.

There are other areas where phase-contrast x-ray imaging can be useful for NIF ignition and high-energy density physics (HEDP). Imaging of shock waves propagating through materials, density measurements, and material mixing during compression are examples where phase-contrast enhanced imaging would be suitable. Continued development of phase contrast imaging and image inversion algorithms will benefit our characterization.

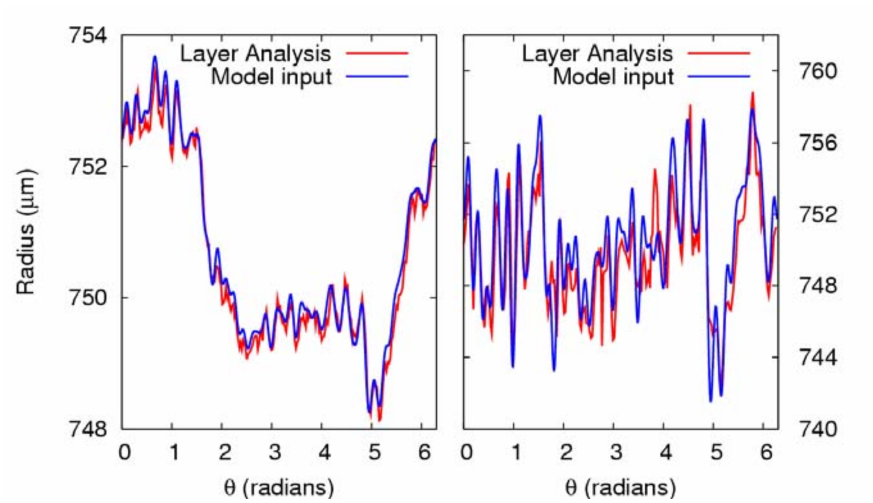

Figure 2: Comparison of rough surface as input to a raytrace model and as detected in image analysis for (left) 1.4 µm RMS and (right) 3.4 µm RMS roughness. The surface detected from the raytraced image agrees very well with the model surface.