§57. Areal Density Measurements of Imploded Cone-in-shell Targets with High-energy K-alpha X-ray Backlighters

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Fast Ignition (FI)[1,2] Laser fusion is one of the advanced inertial confinement fusion (ICF) concepts that independently achieve the formation of a high density core and a rapid heating of the fuel for ignition using high-power lasers. The separation of the compression and ignition phases gives several advantages such as relaxed constraint on implosion symmetry that is severely distorted by hydrodynamic instability, and less required compression laser energy, leading to a potentially higher fusion gain than the conventional hot-spot ignition. In cone-guided FI, a deuterated plastic (CD) shell with a re-entrant cone is compressed by nanosecond long pulse lasers to create a high density core. The compressed core is rapidly heated with an ultraintense, picoseconds ignition laser near the peak compression to the ignition temperature. The presence of the cone maintains the clear pass for the ignition laser during the implosion, but it breaks the symmetry of the implosion. Two-dimensional radiation hydrodynamics simulation is, therefore, required to accurately predict the core formation. Consequently, benchmarking the 2-D simulation capability is crucial for designing a successful high gain FI target.

The goal of this project is to obtain a 2-D monochromatic image of an imploded cone-in-shell target using a 4.5 keV x-ray radiography developed in previous year, similar to 8.0 keV radiography developed by Theobald *et al.*[3] The experiment was performed utilizing a spherical crystal imager and high-energy, short-pulse laser, LFEX at Institute of Laser Engineering, Osaka University. Figure 1 shows a schematic of the radiography experiment and two types of targets: 200 μm diameter CD sphere with a cone and 350 μm diameter, 17 μm thick CD shell with a Au cone. 9 GXII beams with 2 kJ of the total beam energy in 1.3 ns Gaussian pulse were used to drive the target. 4.5 keV x-ray photons were produced by irradiating ~500 J, 1.6 ps LFEX laser on a Ti foil near the peak compression. The backlighter x-ray, reflected off with the spherically bent crystal, was recorded with an imaging plate (IP) detector.

Figure 2 shows the radiographic image of a driven CD sphere (s37622) and the transmission profile of the core. From the analysis of the image, we estimate that the core size is ~ 100 μm in diameter and the stand-off distance between the core and cone tip is ~ 50 μm. The experimental transmission shown in Fig. 2(b) was obtained by subtracting the high-energy bremsstrahlung background in Fig.2 (a) and normalized by the initial x-ray intensity. The implosion of the cone-sphere target is simulated with 1-D rad-hydro code Helios with a post-processor Spect3D to calculate synthetic transmission profile at 4.51 keV. The comparison of the experimental and simulated transmission agrees well as shown in Fig. 2(b). This suggests that the implosion of the CD sphere with a cone is 1-D like even though the cone-in-sphere target was driven by 9 beams. The 1-D hydro simulation predicts the plasma condition of the core to be 40 mg/cm^2, ~ 8 g/cm^3 (8 times compression of solid CD) and 10-100 eV electron temperature at the time of the radiograph image taken.

Several radiography shots for imploded shell and cone-in-shell targets were taken during the same campaign. The timing of the backlighter beam was within 300 ps from the peak x-ray of the implosion. However, no core image was observed. An investigation after the campaign reveals that laser shine-through could significantly affect the compression of the core. The low intensity rise of a Gaussian pulse can penetrate through a CD shell until the laser start ablating the shell at the intensity > ~10^{10} W/cm^2. The penetration of the laser beam into the shell was not predicted by hydrodynamics code. A thin Al coating on a shell or fast rise of laser pulse can prevent the shine through effect. These improvements will be included in future campaigns.

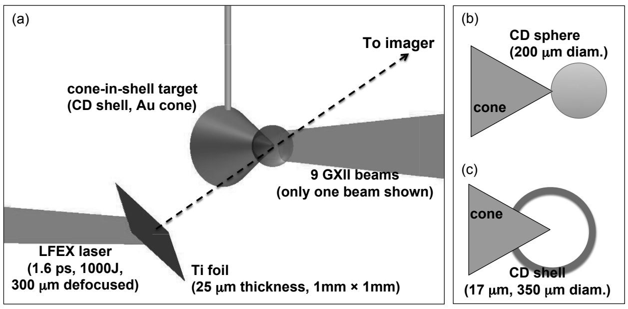

Fig. 1. (a) Experimental layout, schematics of (b) a CD sphere with a cone and (c) CD shell with a cone

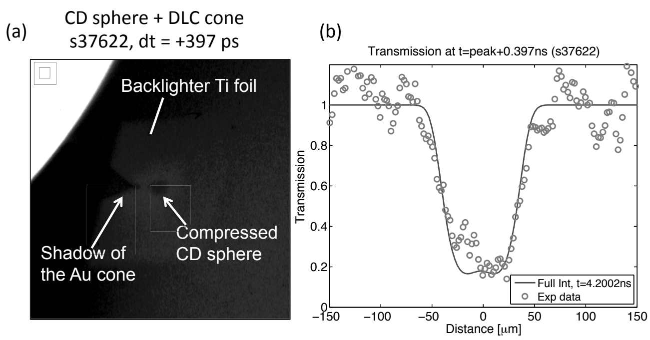

Fig. 2. (a) A monochromatic x-ray images of driven CD shell and (b) transmission profile of the driven sphere target.

1) Tabak M. *et al*., Phys. Plasmas **1**, 1626 (1994)
2) Kodama R. *et al*., Nature **412**, 798 (2001)
3) Theobald W. et al., Nature communications, **5**, 5785 (2014)