Fabrication and Characterization of Planar Cryogenic Targets for GEKKO-XII

T X Huang, M Nakai, K Shigemori, H Shiraga, T Sakaiya, T Watari, K Ohtani, T Shiota, K Takeda, O Maegawa, H Azechi, M Nagata, T Norimatsu, K Nagai, K Mima, Y Izawa, T Mito, and K Iwamoto

1Institute of Laser Engineering, Osaka University, Suita, Osaka 565-0871, Japan
2National Institute of Fusion Science, 322-6 Oroshi-cho, Toki, Gifu 509-5291 Japan.
mitsuo@ile.osaka-u.ac.jp

Abstract. A planar cryogenic target system was built to simulate the ablator+fuel shell physics in ICF experimental studies. In the center of the target cell, a sandwich target of liquid deuterium was formed, which has open geometry for conventional side-on and face-on backlighting diagnostics. A set of double-flanges comprised a sealing flange and an extra flange, with which the target thickness could be changed using proper spacers. Furthermore, an interferometric method was used to characterize the cryogenic target before laser shot. The in situ target thickness and bulging shape could be obtained with acceptable accuracy. A typical planar cryogenic target was formed with diameter of 2 mm, which comprised three parts: a 7-μm thick polyimide film, a layer of liquid deuterium with the thickness of 119 μm at the center and 100 μm at the edge, and another 7-μm thick polyimide film.

1. Introduction

In the inertial confinement fusion, cryogenic targets help to maximize compression of fuel (DT or D2) and hence high gain. Due to its simplicity and convenience for diagnostics, a planar cryogenic target is employed to simulate the multi-layered structure in the fuel capsule, with which one can investigate the preheating of the fuel, the hydrodynamic instability growth, ablative acceleration, shock compression and so on [1, 2].

A cryogenic target system has been developed to be applicable to the HIPER laser and PW laser at ILE, which can be used to perform above experimental studies. The target cell is mounted on the tip of a cryostat, with which one can make a sandwich-like planar cryogenic target. A typical target is formed with liquid deuterium sealed with polyimide films. An interferometric method was also used to characterize the cryogenic target before laser shot. The in situ target thickness and shape could be obtained with an acceptable accuracy.

2. Target system

As shown in Fig. 1, the entire target system comprised three parts: low temperature bath, target supporter, and gas supply. We employ a liquid helium compressor as a low temperature bath. The cryogenic cooler is combined together with the target positioner, which has capability of three dimensional translation and rotation round the vertical axis. The cryogenic cooler provides two stage cryostats, which have temperatures of 10 K and 50 K, respectively. A copper shielding shell connected to the 50 K cryostat serves as an insulator against the room temperature. A copper cooling rod
Connected to the 10 K cooling head supports the target cell on its lower tip. With help of extra heaters, the temperature of the target cell can vary from 14 K to 25 K, without stopping the compressor. The target cell has four windows (Fig. 2). Those are two large windows normal to the laser illumination direction and two small side holes to observe the target from the orthogonal direction. All of them are sealed with polyimide films. As shown in Fig. 2, the copper target cell forms a small room between two parallel polyimide films sealed with double-flanges on the two large windows. After the system is cooled down to low temperature, deuterium gas was let in through a metal tube, and condensed into liquid in the cell. In the center of the target cell, a deuterium target sandwiched with polyimide films was provided.

A set of double-flanges comprises two flanges. One of the flanges fixes the polyimide film and seal the cell, another one is employed to stretch the film from outside to enhance its tension. The distance between two films could be adjusted to change the target thickness with a proper spacer.

3. Target characterization

Although the distance between the inner surfaces of the two large windows is fixed with the inner spacer, the thickness of liquid deuterium is still uncertain, due to the bulging resulted from the pressure difference. An interferometric method is used to characterize the cryogenic target before laser shots. The in situ target thickness and shape could be obtained with acceptable accuracy. A conventional Mach-Zehnder interference system is employed, where we use a microscope on the probe beam to transfer the phase image through the deuterium target, as is shown in Fig. 3. It is impossible to deduce the full structure of the object from a single interference image but is necessary to apply a some tomographic observation. We simply evaluated the effect of bulging under the hydrostatic pressure of the deuterium by assuming the target surfaces as parts of spheres and observing the target from different directions.

3.1. Calculation of the phase map on the target mid-plane

The target surfaces can be approximated as parts of spherical ones around the center as shown in Fig. 4. We place the origin of Cartesian coordinates on the target center, where \( x_0, y_0 \) are the coordinates
on the target mid-plane. $R$ is a curvature radius of the deuterium surface near the target center and $r$ is a virtual radius on the target mid-plane cut by the spherical surface. The length of a segment in the deuterium of the ray, passes though the point $(x_0, y_0)$ and intercepted by the spherical surface is calculated as $P_2P_1 = \frac{d_D}{\cos \theta_D} (1 - \frac{x_0^2 + y_0^2}{r^2}) + O(\frac{d_D^3}{r^3})$.

Here, $\theta_D$ is an incident angle of probe beam to the target normal and $d_D$ is a thickness of deuterium. Then the phase map on the target as a function of the coordinates on the mid-plane and the incident angle of the probe rays is obtained as

$$\phi(x_0, y_0, \theta) = \frac{2\pi}{\lambda} \left[ 2d_K (n_K - \sin^2 \theta - \cos \theta) + d_D (1 - \frac{x_0^2 + y_0^2}{r^2})(\sqrt{n_D^2 - \sin^2 \theta} - \cos \theta) + x_0 \cos \theta \tan \delta \right] + \phi_0.$$  \hspace{1cm} (1)

Here $n_D, n_K$ are refraction indices of deuterium and Kapton, $\delta$ is the angle shift between the probe and reference beams, and $\phi_0$ is the phase difference between the ray past the target center and the corresponding reference ray. The first term on the right side is contribution from the two polyimide films, the second term is contribution from the deuterium layer, and the third and the fourth term denote intrinsic phase differences between the probe beam and the reference beam. Thus we can derive the thickness $d_D$ and the virtual radius on the target mid-plane $r$ by measuring the phase differences at the different points and the angles.

3.2. Experimental results

Figure 5 shows interference images of the target with a 100 $\mu$m thick spacer observed at the incident angle of 21.3° and 30° degree. Numbers of the interference fringes were counted from the center and fitted with binomial curves as in Fig. 6, which derived the results of $d_D = 119$ $\mu$m, $r = 2.4$ $\mu$m. Figure 7 shows the deduced horizontal cross section of the target.

A typical planar cryogenic target was then formed with diameter of 2 mm, which comprised three parts: a 7-$\mu$m polyimide film, liquid deuterium with the thickness of 119 $\mu$m at the center and 100 $\mu$m at the edge, and another 7-$\mu$m polyimide film. The deuterium thickness at the edge was the same.
thickness as that of the inner aluminum spacer, which convinced us the accuracy of the interference method is better than 1 μm.

4. Conclusion

A planar cryogenic target system was made to study laser-driven ablative acceleration, Rayleigh-Tailor instability, and shock compression of liquid deuterium. A copper target cell was mounted on lower tip of the cryostat, which formed a small room between two parallel polyimide films sealed with double-flanges. After the target cell is cooled down to 20 K, deuterium gas was let in and condensed into liquid. Then, a sandwich target was obtained.

One of the double-flanges is employed to seal the cell with polyimide films, and the extra one is used to adjust the positions of the film surface, so that the target thickness can be fixed with proper inner spacers between two films. Furthermore, an interferometric method was used to characterize the cryogenic target before laser shot. The in situ target thickness and its bulging shape could be obtained with acceptable accuracy.

As a test, a typical planar cryogenic target was formed with diameter of 2 mm, which comprised three layers: a 7-μm thick polyimide film, a layer of liquid deuterium with the thickness of 119 μm at the center and 100 μm at the edge, and another 7-μm polyimide film.

References
[1] J. D. Sethian, et al., Phys. Plasmas 6, 2089(1999).
[2] A. N. Mostovych, et al., Phys. Rev. Lett. 85, 3870(2000).