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 RT 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 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 acceptable accuracy.

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 cooling head (cryo head) is combined together with the target positioner, which has capability of three dimensional translation and rotation around the vertical axis. The cryo head is provided with a 10-K two staged cryogenic cooler. A copper shielding shell connected to the first stage of the cooler with the temperature of 50K serves as a heat insulator against the room temperature. A copper “cryo rod” connected to the 10 K stage of the cooler serves as the cryo-finger, which 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. An electronic pressure gauge serves as an indicator to the gas supply, which can evacuate or let deuterium gas of given pressure into the target cell.

The copper target cell has four windows. Two of them are large ones normal to the laser illumination direction. Another two small ones are to observe the target from the orthogonal direction. All of them are sealed with polyimide films. As shown in Fig. 2, the target cell forms a small room between two parallel polyimide films sealed with double-flanges. 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 (i.e. a sealing flange and an extra flange). As the sealing flange helped to fix the polyimide film and seal the cell, the extra one was employed to stretch the film from outside to enhance its tension. And more important, the distance between two films could be adjusted to change the target thickness with proper spacers.

TARGET CHARACTERIZATION

Though the distance between the front and rear side surface is fixed with the inner spacers, the thickness of liquid deuterium is still uncertain, due to the bulging resulted from the pressure difference.

![Fig. 1. Schematic drawing for the cryogenic target system.](image1)

![Fig. 2. Schematic drawing of the liquid target.](image2)
An interferometric method was used to characterize the cryogenic target before laser shot. The \textit{in situ} target thickness and shape could be obtained with acceptable accuracy. A conventional Mach-Zehnder interference system was 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.

**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, which is coincident with the deuterium surface near the target center. According to Frenel’s law, we have

\[
\sin \theta = n_k \sin \theta_k = n_D \sin \theta_D.
\]

Here, subscripts D and K denote deuterium and Kapton (Polyimide film), respectively. \( \theta \) is the incident angle of the probe beam. \( n \) is the refractive index of each material. The length of a segment in the deuterium of the ray passing through the point \((x_0, y_0)\) is calculated as

\[
P_1P_2 = \frac{d_D}{\cos \theta_D} \left( 1 - \frac{x_0^2 + y_0^2}{r^2} \right) + O\left( \frac{d_D^2}{r^2} \right).
\]

Then the phase map on the target mid-plane is obtained as

\[
\phi(x_0, y_0, \theta) = \frac{2\pi}{\lambda} \left[ 2d_k \left( \sqrt{n_k^2 - \sin^2 \theta} - \cos \theta \right) \right.
\]

\[
+ d_D \left( 1 - \frac{x_0^2 + y_0^2}{r^2} \right) \sqrt{n_D^2 - \sin^2 \theta} - \cos \theta \right]
\]

\[
+ x_0 \cos \theta \tan \delta + \phi_0
\]

where the \( \phi_0 \) is the phase difference between the ray passing the target center and the corresponding reference ray. \( \delta \) is the given inclination of the reference beam to the probe beam, where we assume that the reference beam is inclined to the \( x \) direction to make an image with proper number of fringes. 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 + the fourth term denotes the initial phase difference between the probe beam and the reference beam.

**Mapping between the target mid-plane and the image on CCD**

Assuming that the projection of the target mid-plane onto the CCD is simply described by

\[
x = Mx_c \cos \theta + x_c \quad \text{and} \quad y = My_c + y_c,
\]

the phase map on CCD is given as

\[
\phi(x, y, \theta) = \frac{2\pi}{\lambda} \left[ 2d_k \left( \sqrt{n_k^2 - \sin^2 \theta} - \cos \theta \right) \right.
\]

\[
+ d_D \left( 1 - \frac{x - x_c}{M \cos \theta} \right) \left( \frac{y - y_c}{M} \right) \sqrt{n_D^2 - \sin^2 \theta} - \cos \theta \right]
\]

\[
+ \left[ \frac{x - x_c}{M \tan \delta} \right] + \phi_0
\]

Here, \( M \) is the magnification of the imaging system, \((x_c, y_c)\) are the coordinates of the target center projected on the CCD.

**Procedure to obtain deuterium thickness \((d_D)\) and curvature \((r)\)**

The phase variation along the \( x \)-direction is approximated by a quadratic function on \( x \). The second order coefficient is a function of \( d_D/r^2 \) and \( \theta \). The constat is a function of \( d_D \) and \( \theta \). Therefore, fitting the experimentally obtained phase variation to get the coefficient of each power and compare them for the different value of \( \theta \), one can derive the value of \( d_D \) and \( r \).
Figure 5 shows interference images of the target with a 100 μm thick spacer observed at the incident angle of 21.3° and 30°. Numbers of the interference fringes were counted from the center and fitted with a quadratic curves as in Fig.6, which derived the results of $d_D=119$ μm and $r=2.4$ mm. 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-μm thick polyimide film, liquid deuterium (119 microns at the center and 100 microns at the edge), and another 7-μm thick 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.

**IMPURITIES AND TEMPERATURE VARIATION**

One can see from Fig. 6, the image quality of the interferometer is not good as expected. There are a couple of reasons:

1) The defect of the optical system, especially the glass windows contaminated by the target debris from laser shots. And initial contaminants on the polyimide films. It can be seen from the image before liquefaction (see Fig. 8(a)).

2) Impurities in gas deuterium from inner side. It's obviously seen as bright spots in a bubble of Fig. 8(b).

Due to the large open area on the insulator for diagnostics, monitors and laser entrance, the polyimide films are largely exposed to the radiation of room temperature. Due to the poor thermal conductivity on the plastic foil, the temperature at the film center may be a
bit higher than the copper cell. So when the gas pressure equals the vapor pressure at the temperature of the copper cell, the liquid deuterium is boiling from the target center (see fig. 8(b)). To suppress the boiled bubble, we must have increased the inside pressure gradually until the bubbles disappear.

3) Adherence of residual gas in the target chamber from outer side. (see Fig. 8(c)), which resulted mainly from the vacuum degradation of the target chamber. Though it’s also possible from continuous deposition of residue at even low pressure, such as $10^{-5}$ torr, we haven’t observed obvious image or fringe change in a couple of hours.

Figure 9 shows the cooling curve of the target cell. Though the time duration is as long as 10 hours, it takes less than 30 minutes to cool down from 30K to 14K. Around 30K, the residual pressure equals the vapor pressure of nitrogen, i.e. $2-3 \times 10^{-5}$ torr. Only below this temperature, as the main component of the residue, nitrogen begins to condense on the cold surface. However, because of the low density, it will take a long time to produce significant adherence on the target surfaces. So, if we can prepare to shoot the target within a couple of hours after cooling down, this effect can be neglected.

A typical planar cryogenic target was formed with diameter of 2 mm, which comprised three layers: polyimide film (7 microns), liquid deuterium (119 microns at the center and 100 microns at the edge), and polyimide film (7 microns).

REFERENCES

CONCLUSIONS
A planar cryogenic target system was made to study laser-driven ablative acceleration, Rayleigh-Taylor instability, and shock compression of liquid deuterium. A copper target cell was mounted on lower tip of the cryogenic system, 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 \textit{in situ} target thickness and its bulging shape could be obtained with acceptable accuracy.