Laser Machining for Fabrication of Targets used in the FIREX-I project

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Abstract. This paper reports on way to fabricate a gas-tight targets dedicated for the first stage of Fast Ignition Realization Experiment (FIREX-I) at the Institute of Laser Engineering (ILE), Osaka University. It was found that a Ti:sapphire laser machining can be used to fabricate the target. The performance of the laser machining using a fs Ti:sapphire laser was examined on shell materials. The conditions for accurate machining were determined. Michelson interferometer with two different wavelengths which imitates a white light interferometer is an excellent tool for confirming the gas-tightness of the target after assembly.

1. Introduction

The first stage of Fast Ignition Realization Experiments (FIREX-I) is proceeding in the Institute of Laser Engineering (ILE). In the FIREX-I project, unique targets were proposed as shown in Figure 1. Resorcinol-Formaldehyde low density foam and poly-palaxylylene gas barrier are shell material candidates. The CD or CDBr are poly-styrene (PS) based materials are also shell material candidates. Gas-tightness is necessary for these targets since hydrogen fuel or tracer gas are planned to be fed into the shell. Precise machining to make a hole on the shell for inserting the guide cone and the gas feeder are needed. A technique of minute assembling these parts is also needed. A system to confirm the gas-tightness is necessary before starting cryogenic layering.

In a previous work, hole boring on PS shell was carried out by dissolving PS with solvent. Control of the hole diameter was, however, quite difficult and sometimes cracks was a few microns wide would develop. Nd:YAG laser machining has been tested to make a hole on the foam shell. It was useful in the case of a RF foam shell without a gas barrier because the RF foam absorbs the second harmonics of the Nd:YAG laser and it easily decomposes. In the case of a foam shell with a gas barrier and PS shells, the Nd:YAG laser machining with ns is pulses inappropriate because the thermal propagation can not be ignored when the intensity of the ns-pulse laser increases to generate a plasma. Laser machining using a Ti:sapphire fs laser was tried to provide precise laser machining. Multi photon absorption happens and thermal damage does not propagated onto not irradiated areas. Laser power dependence of ablation depth and residual debris around the cutting trace was studied.

It is necessary to control the amount of epoxy resin around the laser guide cone. It is better that the amount of epoxy resin be as little as possible from the point of implosion uniformity, but it is difficult to make a gas-tight target as the amount of epoxy resin decreases. A two wavelength
interference system for checking a gas-tightness after assembly was developed.

2. A fs laser machining

Figure 2 shows the set-up for fs laser machining. A Ti:sapphire laser was used. The wavelength, the pulse width and the repetition rate were 800 nm, 100 fs and 1 kHz, respectively. The laser power was controlled by rotating a 1/2 wave retardation plate. The resolution of the x axis, y axis and z axis of the stage was 100 nm, 100 nm and 1.0 μm respectively. The tests of fs laser machining were done on the RF foam plate to confirm that thermal propagation does not play an important role (Fig.3 (A)). The stage ran at 3.0 μm/sec, the spot diameter was 9.0 μm and the average intensity was $1.6 \times 10^{15}$ W/cm$^2$. Figure 3 (A) shows the cutting width and was mostly same as the diameter of the laser spot. It was found that thermal propagation did not damage any non irradiated area. Laser machining of the foam
plate with a gas barrier was tested for determining the minimum laser intensity to cut the gas barrier. It was possible to machine the foam with the gas barrier. The minimum intensity to make a hole on the 5.3 μm gas barrier was $3.1 \times 10^{14}$ W/cm$^2$. It was also confirmed that there is no damage on the gas barrier when the laser (the intensity was $1.5 \times 10^{14}$ W/cm$^2$) was focused 50μm above the surface. This indicated that the inner surface of the opposite side of the shell should not be damaged. There was little debris around the cutting edge. The dependence of laser intensity and ablation depth was measured on a PS plate. Figure 4 shows the average depth of the track as a function of the intensity. The table shows that the laser intensity needed to cut a 7μm-thick PS shell was $0.8 \times 10^{15}$ W/cm$^2$. Figures 5 show the relationship between laser power and the debris from the fs laser machining on the PS plates. The analysis was done by using Image-J (National Institute of Health, USA) (Fig. 6). In the case of a laser intensity $1.3 \times 10^{15}$ W/cm$^2$ of, the average particle diameter was 0.73 μm, whereas in the case of a laser intensity $1.7 \times 10^{15}$ W/cm$^2$ of, the average particle diameter was 1.4 μm. As the laser intensity decreased, the particle size and the number decreased. Compared with the amount of epoxy resin (about 2.0 pl) for assembling, the total volume of the debris is so small that it can be ignored in the case of $1.3 \times 10^{15}$ W/cm$^2$ in laser intensity. The relationship between the total debris volume and intensity was not linear. As the laser intensity increased by 30%, the volume of debris increased by a factor of three. Judging from these results, it should be better to laser machine the targets with an intensity lower than $1.3 \times 10^{15}$ W/cm$^2$.

### 3. Confirmation of gas-tightness

After laser machining, a shell, a laser guide cone and a gas feeder were assembled by using a XYZ manipulator. A carbon fibre (the diameter is 1μm) was used as a brush the epoxy resin to minimizing the amount of epoxy. After assembling, it is necessary to confirm the gas-tightness of the target and that the gas feeder is not plugged. Figure 7 shows the set-up to check the gas-tightness of the assembled target. A Michelson interferometer was used. Two beams with different wavelengths from HeNe lasers were interfered forimitating a white light interferometer. One can identify the interference line where there is no phase difference between reference beams and object beams. SF$_6$ gas was used to fill the shell. SF6 has several advantages; molecular weight of SF$_6$ gas is high, so permeation of SF$_6$ gas through the gas barrier is small. SF$_6$ gas has a high refractive index and is not

![Figure 7. A schematic view of the Michelson Interferometer the gas-tightness.](image)

![Figure 6. Results of image analysis. The number and the diameter of debris in a 30 μm×30 μm square are shown by bars. The point and line shows the total volume of debris in 30μm around the hole and then the debris is assumed as an ideal sphere.](image)
corrosive. The target was evacuated and the interference image was taken (Fig. 8 (A)). The red laser was used as a basic interferometer. The phase of the reference beam was adjusted to make the image darkest at the center of the shell. The same procedure was done after filling SF$_6$ gas in the shell (Fig. 8 (B)). The object beam and the reference beam were inclined to each other to make interference fringes. The interval $l$ between the fringes was measured. The distances ($L_1$ and $L_2$) between the center of the shell and certain dark line were measured in the both cases. The yellow laser was used to confirm that the same dark line was selected. The refractive indexes of the gas in the shell was calculated by using the following equation (1)

$$ (n - 1) = \frac{(L_2 - L_1)}{l \cdot d} \lambda , $$

where $d$ is an inner diameter of the shell and $\lambda$ is a wavelength of the red laser. Since there is correlation between the gas pressure and the refractive index, the gas pressure was easily calculated by using Lorentz-Lorenz formula. When the $L_1$ and $L_2$ are different, the gas feeder is not blocked. The correct value of the pressure should be measured when there are no leaks on the target. It was demonstrated that this instrument can be utilized to check the gas-tightness of the target room temperature.

Summary
This paper reports the way to make a gas-tight targets dedicated for the first stage of FIREX-I. The conditions for machining holes accurately on PS shells and foam shells with gas barriers were investigated using a fs laser. The fs laser machining contributes to fabricate the gas-tight targets. The utility of a two laser interference system for checking a gas-tightness was confirmed.

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References
[1] Yamanaka T 1983 Institute of Laser Engineering Internal Report Osaka University 5–6
[2] Tabak M, Hammer J, Glinsky E M, Krueer L W, Wilks C S, Woodworth J, Campbell E M, Perry D M and Mason R J 1994 Phys. Plasmas 1 1626-34
[3] Azechi H and the FIREX project 2006 PlasmaPhys. Control. Fusion 48 B267-75
[4] Norimatsu T et al. 2003 Fusion Science and Technol 43 339-45
[5] Nagai K et al. 2005 Nucl.Fusion 45 1277-83
[6] Yang H, Nagai K, Nakai M and Norimatsu T 2008 Laser Part. Beam 26 449-53
[7] Fujimura T et al. 2007 Fusion Science and Technol. 51 677-81
[8] Obara M, Arai T and Midorikawa K 1998 Laser Application Technology 162-64 (in Japanese)