A Proposed Procedure for Temperature Control of the Cryogenic Target for the FIREX Project

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One of the techniques to produce a uniform solid fuel layer for the Fast Ignition Realization EXperiment (FIREX) target is applying a solid fuel redistribution process. During the redistribution process, temperature control is essential for the FIREX target, because a cone guide, also called a conical laser guide, causes temperature non-uniformity. To minimize its temperature distribution, one possible procedure is temperature control at the cone guide. A radiation plate for indirect temperature control, installed next to the cone guide, is proposed. As the heat input to the radiation plate was varied, the temperature profile of the target was calculated using the ANSYS code. The optimal heat input was evaluated. The feasibility of using a radiation plate is discussed.

Keywords: cryogenic target for FIREX project, fast ignition, layering process, fuel redistribution, temperature control by radiation plate

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The cryogenic target for the Fast Ignition Realization EXperiment (FIREX) project has a unique appearance (Fig. 1). Low density plastic foam covers the inner surface of the shell as a supporting material for the fuel. The cone guide directing an ignition laser to the core plasma is partially inserted into the shell. To supply fuel directly, a fill tube is connected to the shell. Liquid fuel is fed into the shell and soaked up by the foam material by capillary action, where it is solidified. Finally, an ideal cryogenic target would be formed. This fuel layering technique [1], called the foam shell method, is quite convenient compared to others, e.g., beta-layering [2] and infrared (IR) heating [3], because ideally, no hold time is required. Development of the foam shell method, therefore, is one of the important challenges for FIREX.

To confirm the viability of the foam shell method, several cool-down tests have been conducted using a dummy target with an ~800 μm diameter shell and ~60 μm thick foam layer [4]. A problem arises upon fuel layering. Just after the fuel solidifies, defects in the fuel layer or on the inner surface were observed. Therefore, a fuel redistribution process such as IR heating might be required even for the foam shell method. The target for FIREX, however, is not a perfect sphere. During the redistribution, the foam boundary is ignored and the resultant product depends on only the temperature profile in the shell.

To consider the possibility of applying a fuel redistribution process for the FIREX target, its temperature profiles were calculated with various conditions using the ANSYS code. A previous study found that precise temperature control at the cone guide could achieve a uniform temperature contour in the foam layer. [5] However, that arrangement required heat control of sub-nanowatt order. Such a small and precise heat control, e.g., using a heater directly attached to the cone guide, may cause difficulties. Furthermore, the heater might affect the performance of the ignition laser as impurities. Therefore, we propose an indirect temperature control by a radiation plate with a heater. It would be installed next to the cone and is expected to function as an attenuator of the control heater. To discuss its feasibility, target temperature profiles are calculated as the radiation plate temperature is changed. The required heater power is also evaluated.

Figure 2 shows the 2D model of the FIREX target with the radiation plate. A heater for which the heat flux can be varied is attached to the radiation plate to control

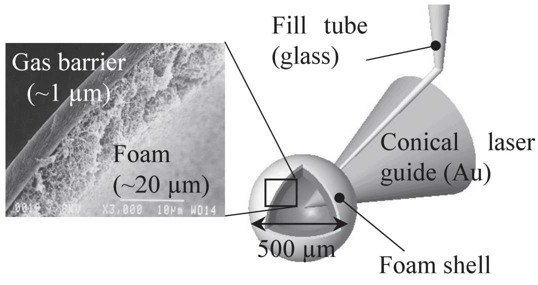

Fig. 1 Typical FIREX target.

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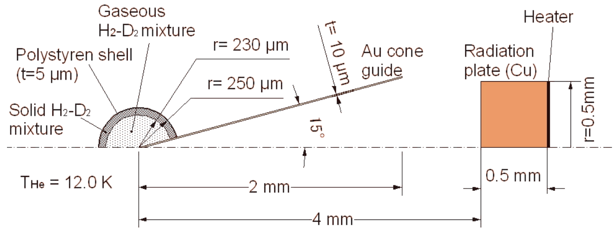

Fig. 2 2D model of the FIREX target with a radiation plate cooled by ambient helium gas. Average heat transfer coefficients on the shell, the cone, and the radiation plate surfaces are 83.4, 6.26, and 7.85 W/m^{2}K, respectively. The radiation coefficients of 0.5 for copper and 0.02 for gold were applied.

its temperature. The model represents the ideal fuel layered target. No foam layer was considered because solid fuel redistribution ignores the foam boundary. To discuss the practical FIREX target, a hydrogen and deuterium fuel mixture (20% hydrogen) was employed. The hydrogen has the function of supplying the volumetric heat from the ortho-para conversion. It was assumed to be 251 W/m^3, which was calculated by Gaspak (ver.3.30, Cryodata Inc.) Consequently, the heat generation from the fuel results in 50.2 W/m^3. The average heat transfer coefficients of the shell, the cone and the plate surfaces were applied. Radiation from the environment to the target was ignored to simulate an ideal cooling environment. The temperature profile of the target was calculated as the changing heat flux from the heater.

Figures 3 (a) and (b) show calculations with and without temperature control by the radiation plate. It was reconfirmed that the cone guide reached the lowest temperature without the control. However, the temperature difference in the fuel layer is less than 4 μK. On the other hand, the heater heat flux of 70 W/m^2 can minimize the temperature difference within 1 μK, corresponding to 5.5×10^{-5} W of heater power. At this point, the radiation plate temperature is 16.5 K.

The applicability of the radiation plate for experiments is now considered. Small heaters with ~100 ohm resistance can be envisioned to be attached to the plate. The heater requires ~0.7 mA of electric current to generate 5.5×10^{-5} W, which is controllable using commercial power supplies. Additionally, if direct control by the heater attached at the cone is employed, an electric current of ~1 μA must be controlled. The radiation plate works as the attenuator of the control heater and can provide practical temperature control.

Radiation from the environment to the target was ignored in the calculations. These radiations will have to be considered while performing experiments. The target is surrounded by a thermal shield in a small chamber and is cooled by ambient helium gas. To observe solid fuel

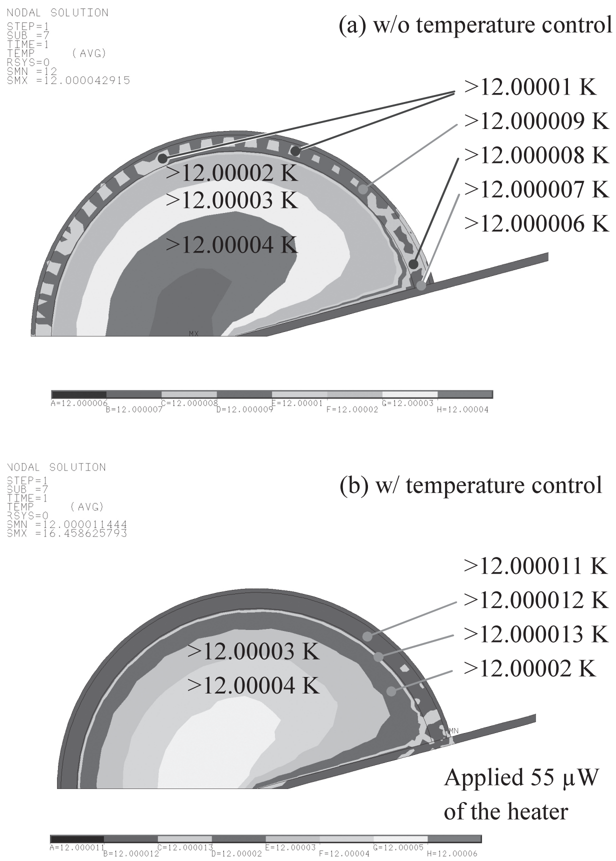

Fig. 3 (a) and (b) Temperature distribution in the target.

redistribution, some viewing windows are installed on the shield and chamber. These windows are a significant source of radiation to the target. In actual use, the windows need to be opened only when the target is inspected. Applying a well-designed opening and closing mechanism of the windows could make the radiation negligibly small.

The temperature control by the radiation plate is discussed for the FIREX target. According to the calculations using the ANSYS code, the radiation plate works as an attenuator of the control heater and can provide a practical temperature control.

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