Advanced Target Design for the FIREX-I Project

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Cryogenically cooled foam shells with deuterium and tritium fuels are expected to be utilized in the fast ignition realization experiment project of ILE, Osaka University, to demonstrate efficient heating of properly compressed fuel plasmas. These targets consist of a foam shell with solid fuel and a conical light guide for additional heating with an ultra-high intensity laser beam, in accordance with previous preliminary experiments [R. Kodama *et al.*, Nature **412**, 798 (2001).] Recent theoretical predictions and elemental experiments have suggested some advanced modifications to enhance the coupling efficiency of fast heating and improve implosion performance. The five major points of these improvements are as follows: 1) use of a low-Z foam layer on the inner surface of the cone; 2) use of a double-layered cone as a light guide; 3) use of a low-Z plastic layer on the outer surface of the cone; 4) adding a Br-doped plastic ablator to the fuel capsule; and 5) evacuation of the target center.

Keywords: fast ignition, FIREX project, inertial fusion, cryogenic foam shell target

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The first step of the fast ignition realization experiment (FIREX-I) project of ILE, at Osaka University, is to demonstrate the efficient heating of properly compressed fuel plasmas. From the results of previous preliminary experiments [1] using polystyrene shells with a gold conical light guide for additional heating, we adopted the target design depicted in Fig. 1 as the most promising target for the FIREX-I project. Figure 2 shows the basic concept of fast ignition found in literature [2, 3]. In this concept, an ultra-intense laser pulse penetrates the high-density region, pushing the critical density surface of the long scale length corona plasma and generates a decent amount of energetic electrons. The electron beam must propagate through the overdense plasma to efficiently heat the small core. The critical surface might be deformed and therefore, making it more difficult for the laser beam to penetrate into the corona. Thus, Kodama *et al.* invented a sim-

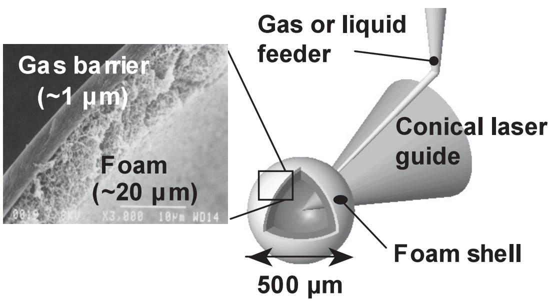

Fig. 1 Basic FIREX-I target design. A foam shell target with a fuel feeder and a conical light guide.

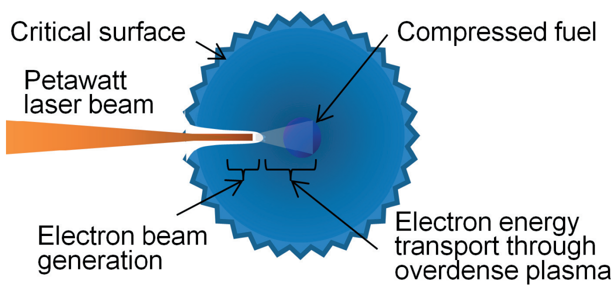

Fig. 2 Fast ignition by a super-thermal electron beam generated by a high-intensity short-pulse laser beam [2, 3].

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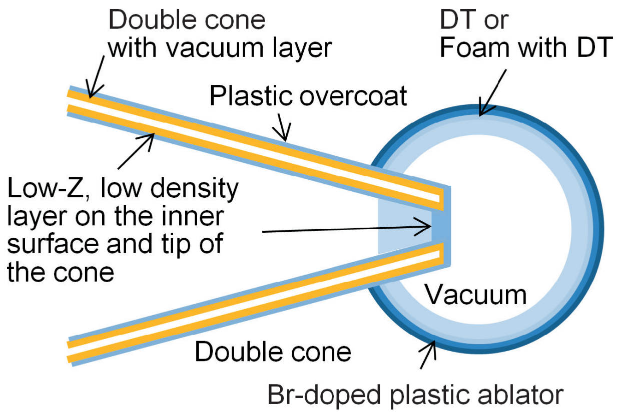

Fig. 3 Conceptual drawing of an advanced target design for the FIREX-I project.

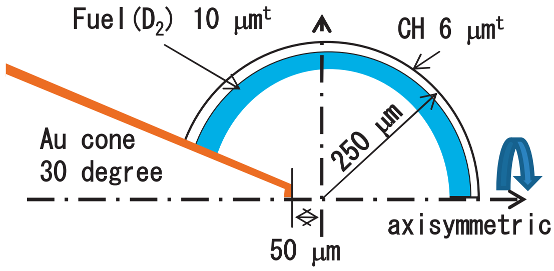

Fig. 4 Target structure for computer simulation [5].

pler fast ignition approach, using a cone guide for the heating laser beam. Although the fabrication technique for this target design is under development, some advanced modifications for the design are proposed to enhance the fast heating coupling efficiency and improve implosion performance.

Since the approval of FIREX-I, experimental and theoretical physics studies at ILE have been devoted to investigate the heating mechanism and increasing the coupling efficiency from laser to electrons, and finally, to the core thermal energy. In particular, the computer simulation study, "Fast Ignition Integrated Interconnecting code (FI3)" project [4] has been promoted to combine three different codes in different regions of interest and evaluate the overall performance of fast ignition schemes. Recent investigation of the project suggested some advanced modifications to our target design for the FIREX-I project. Figure 3 schematically illustrates the five important points of the advanced modifications, which are described in detail in this article.

The initial target point design was the one depicted in Fig. 4 [5]. Since the main driving laser is GEKKO-XII in the first stage of the FIREX project, the fuel capsules must be similar in size to those in the previous experiment in which high-density compression of more than 600 times was achieved. The typical diameter and areal density of the shells are 500 μm and 7-8 × 10^{-4} g/cm^2. The cone geometry was optimized using a PIC code developed by Nakamura [6]. During simulation, 30 degrees of open angle was shown to be optimum, and a beam with a spot 3 to 4 times larger than the tip was proposed to be effective.

Two changes are expected to increase coupling efficiency:

1) A low-Z foam layer on the inner surface of the cone. There is an optimum plasma density of the inner surface of the conical light guide for good coupling. If the density is too low, the hot electron temperature becomes too high to be efficiently absorbed by the core plasma. If the density is too high, the temperature becomes too low (due to shallow skin depth) to penetrate deep into a high-density core. The optimum plasma density can be realized with a low-density foam layer on the inner surface of the cone. Our previous experiment demonstrated increased coupling by using a low-density gold foam [7]. A low-Z plastic foam is therefore desired for efficient electron transport.

2) Double cone. A conical light guide with additional outer wall is preferable. Electrons generated in the inner surface of the double cone will be returned by the sheath potential generated between the two cones. Our two dimensional PIC simulation indeed indicates the improvement of the electron confinement by a factor of 1.7 [6].

The implosion performance is to be improved in three ways:

1) A low-Z plastic layer on the outer surface of the cone may suppress the expansion of the Au cone that flows into the interior of the compressed core. The 2-D hydro simulation PINOCO predicts that the target areal density increases by a factor of 2 if we employ this scheme.

2) A Br-doped plastic ablator may significantly mitigate the Rayleigh–Taylor instability [8], making implosion more stable.

3) Evacuation of the target center. If there is a substantial amount of fuel gas in the target, it generates a gas jet that may potentially destroy the cone tip and thus hinder the efficient coupling of the heating laser with the plasma. This undesired effect was indicated in previous Japan-US collaboration experiments [9]. Therefore, the interior of the fuel shell must be evacuated or kept sufficiently cold.

Some important modifications to the target design for FIREX-I project are proposed to enhance the coupling efficiency of fast heating and improve implosion performance.

[1] R. Kodama *et al.*, Nature **412**, 798 (2001).
[2] M. Tabak *et al.*, Phys. Plasmas **1**, 1626 (1994).
[3] S. Atzeni, *The Physics of Inertial Fusion* (Oxford sci. pub. 2004).
[4] H. Sakagami *et al.*, Laser Part. Beams **24**, 191 (2006).
[5] H. Nagatomo *et al.*, Phys. Plasmas **14**, 056303 (2007).
[6] T. Nakamura *et al.*, Phys. Plasmas **14**, 103105 (2007).
[7] A.L. Lei *et al.*, Phys. Rev. Lett. **96**, 255006 (2006).
[8] S. Fujioka *et al.*, Phys. Rev. Lett. **92**, 195001 (2004).
[9] R. Stephens *et al.*, Phys. Plasmas **12**, 056312 (2005).