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Fabrication of Cryogenic Targets for Fast Ignition Realization Experiment at ILE Osaka

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Abstract. Development of the fabrication technology for the cryogenically cooled fuel targets was initiated as a part of the Fast Ignition Realization Experiment (FIREX) Project at the ILE, Osaka University in the way of bilateral collaboration between Osaka University and National Institute for Fusion Science (NIFS). For the first stage of FIREX, a foam cryogenic target was designed where low density foam shells with a conical light guide will be fueled through a narrow pipe and will be cooled down to the cryogenic temperature. New ultralow density (2~3 mg/cm^3) foam materials have been developed with ~100 nm lamella structure, and is suitable for the cryogenic foam target to ignite in the FIREX project.

1. Introduction

After the success of the heating of deuterated hydrocarbon plasma upto 1 keV temperature [1], enhancement of laser power and fabrication of a cryogenic hydrogen target are required as key technologies for the fast ignition (FI) research. In the paper, we propose a new concept of a fast ignition target with cryogenically cooled fuel and describe the present status and research plan for fabrication technology of the targets for the fast ignition realization experiment (FIREX) at the ILE, Osaka University.

2. Target design

A new cryogenic target for FI research is proposed as shown in Figure 1. The diameter of the fuel shell is ~ 500 μm, which is similar to that for the central ignition target for Gekko XII. To fabricate a uniform, non-spherical solid-deuterium-tritium layer, a low density foam supports liquid or solid fuel (~ 20μm thick) and the shell is covered with a thin (< 1μm) plastic layer .

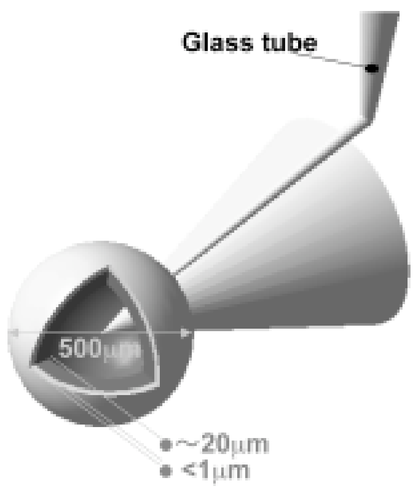

Fig. 1 Schematic view of the cryogenic DT target with a plastic foam shell and a gas feeder

A conical light guide made of gold thin plate is assembled for guiding an ultra-short heating laser beam and the electron beam generated by the laser beam. Mixture of deuterium and tritium gas is fed into the foam shell through a narrow pipe attached on the outer side of the guiding cone and cooled down to fill up the foam layer in a liquid or solid state. In the implosion concept of the target with a conical light guide, asymmetry of the target due to the guiding cone is not expected to degrade the compression.

Although outer and inner surfaces of the target must be sufficiently smooth to avoid harmful non-uniformities with high spatial frequencies spread over the target, a single narrow pipe can be attached on the gold light guide which is not expected to hinder the compression.

To estimate the allowable density of hydrocarbon foam for the gain, a Hydrodynamic code simulation was applied. From the parameters modeling the core plasma generated by GXII and heated by FIREX-1 peta watt laser (Table 1), where the implosion and heating efficiencies were assumed to be 5% and 30 %, respectively, the gain curve was obtained as shown in Fig 2. According to the simulation, the density of hydrocarbon foam is desired to be less than 10 mg/cm^3 to achieve high gain.

Table 1 The parameters for the hydrodynamic simulation

Imploded plasma configurations	
Density, ρ	300 g/cm^3
Temperature, T_0	0.2 keV
Isentrope α	2.0
Radius, R_0	
External heating	
Duration, t_h	10 ps
Spot radius, R_h	20 μm
Optical depth, ρL_h	1.0 g/cm^2
Laser intensity, I_h	7~22 x 10^{19} W/cm^2

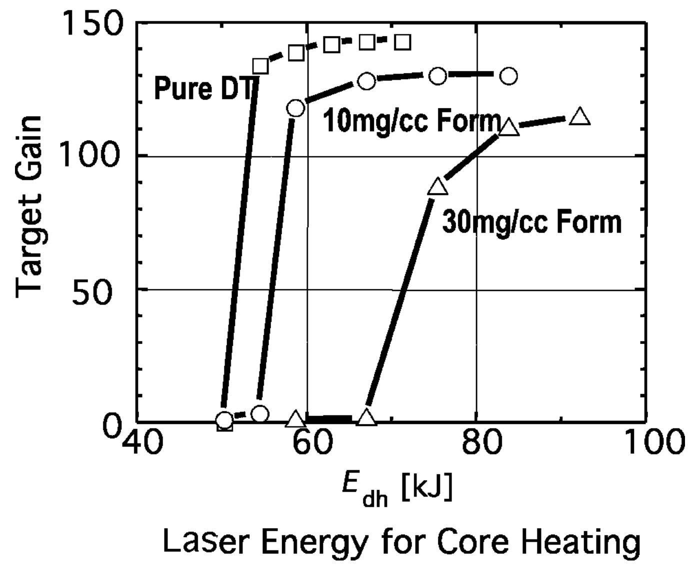

Fig. 2 Target gain for the foam cryogenic target calculated by an Eulerian hydrodynamic code. The imploded plasma and its heating were modeled as shown in Table 1.

Therefore the key technologies to be developed are: 1. fabrication technology of the uniform low density foam capsules with fine structures, 2. uniform cryogenic fueling technology and the characterization and 3.material development for ultralow (~10 mg/cm^3) density foam capsule. In order to accelerate the second task, a bilateral collaboration between Osaka University and National Institute for Fusion Science (NIFS) has been initiated.

3. Present status of the developments

3.1. Target fabrication

As a test of the gas feeder, cone guided plastic capsule was fabricated with a glass pipe (30 μm/ 10 μm of outer/inner diameter) as shown in Fig. 3, and it was successfully demonstrated that the narrow glass pipe fed the polystyrene shell with liquid 2-propanol at room temperature.

Therefore, the next step is to confirm the validity of the feeder under the cryogenic condition. Although our institute has been demonstrated foam cryogenic target using opaque acrylic foam material [2], transparent foam capsule should be used in order to test the fueling by optical monitoring. In the present stage, a resorcinol/formalin (RF) foam [3] is chosen as a test material for the cryogenic fueling, because RF is transparent at the density of 50 ~ 200 mg/cm^3.

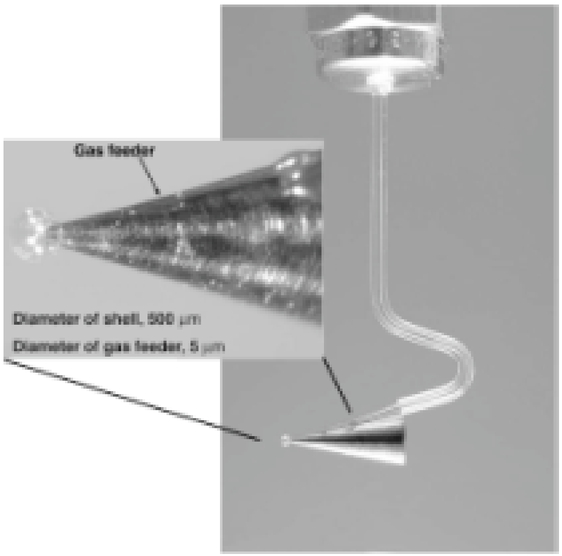

Fig. 3 A fabricated cone guided target equipped with fuel gas feeder.

3.2 Cryogenic fueling

A cryostat to study fueling with a narrow pipe has just equipped and the first experiment is going to be carried out. Development of fabrication technology of low-density foam shell is continued and supplied for the experiment. An optical imaging interferometer is designed in ILE and equipped. As an outcome of the collaboration, an implosion experiment using the deuterium filled foam shell with a conical light guide is scheduled in fiscal year 2005.

In the cryogenic target implosions, preheating of the fuel by an electron transport is one of the most serious problems to be solved. The equation of state of the deuterium with foam tissue is another important subject to be understood experimentally. A new cryogenic cooling system was equipped at the GEKKO-XII HIPER experiment chamber for basic hydrodynamic experiments in a planar geometry. A slab of the RF foam 0.3-mm wide, 1.5-mm high, and 0.1-

mm thick, attached on a 4-μm thick polyimide film was located at the center of the HIPER chamber and fueled with liquid deuterium in situ just before it was irradiated by the HIPER laser beams successfully.

The quality of the target was not characterized well. However it was confirmed that liquid fueling keeps the target transparent and interference flings using a He-Ne laser beam were visible.

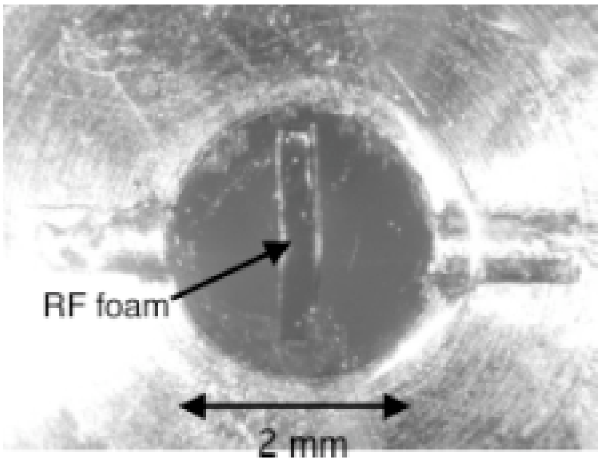

Fig. 4 An RF foam target supported by polyimide film and settled on a window of cryogenic chamber for fueling liquid deuterium

3.3 Low density foam materials

As we reviewed in the last meeting [4], we demonstrated fabrication of cone guided target using acrylic foam shell with the density of about 50 mg/cm^3. Both acrylic and RF foam do not provide lower density foam than 40 mg/cm^3. To date, any foam capsules have not exhibited below 40 mg/cm^3. We have investigated such ultra-low density (<10 mg/cm^3) foams using poly(4-methyl-1-pentene) (PMP).

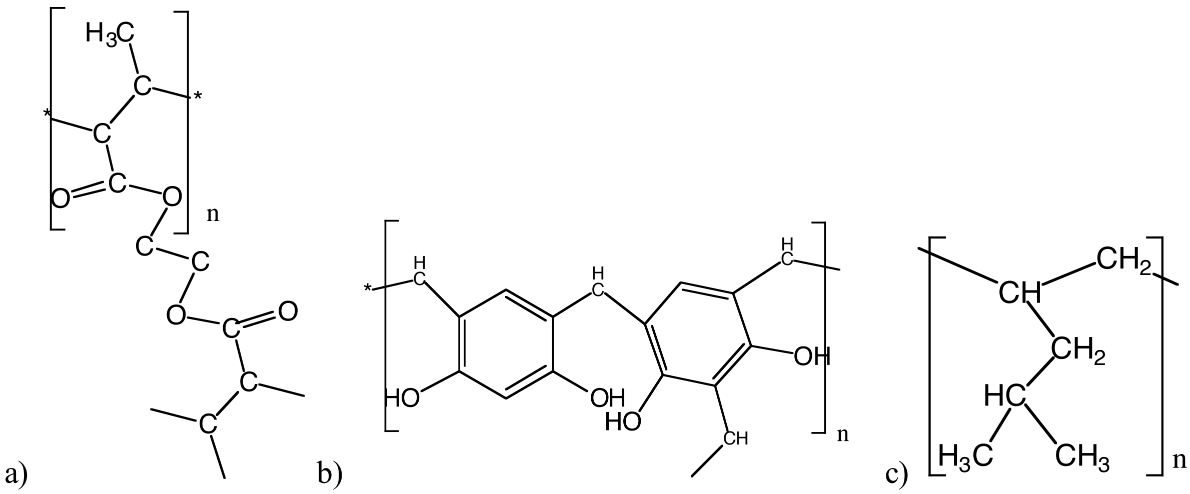

Fig. 5 Chemical structures of foam material, a) a possible structure of poly(ethyleneglycol dimethylacrylic acid) (pEGDM) as an example of acrylic polymer , b) a possible structure of resolcinol/formalin(RF) polymer, and c) poly(4-methyl pentene)(PMP).

The foam was fabricated from alcoholic gel of PMP via supercritical fluid extraction technique. Furthermore, it was emerged that various ultra-low-density (2~3 mg/cm^3) PMP foams with micrometer- and nanometer-structures using various coagulant alcohol, especially hexanol or butanol derivatives [5, 6]. Figures 6 show the SEM images of PMP foams obtained from butanol gel.

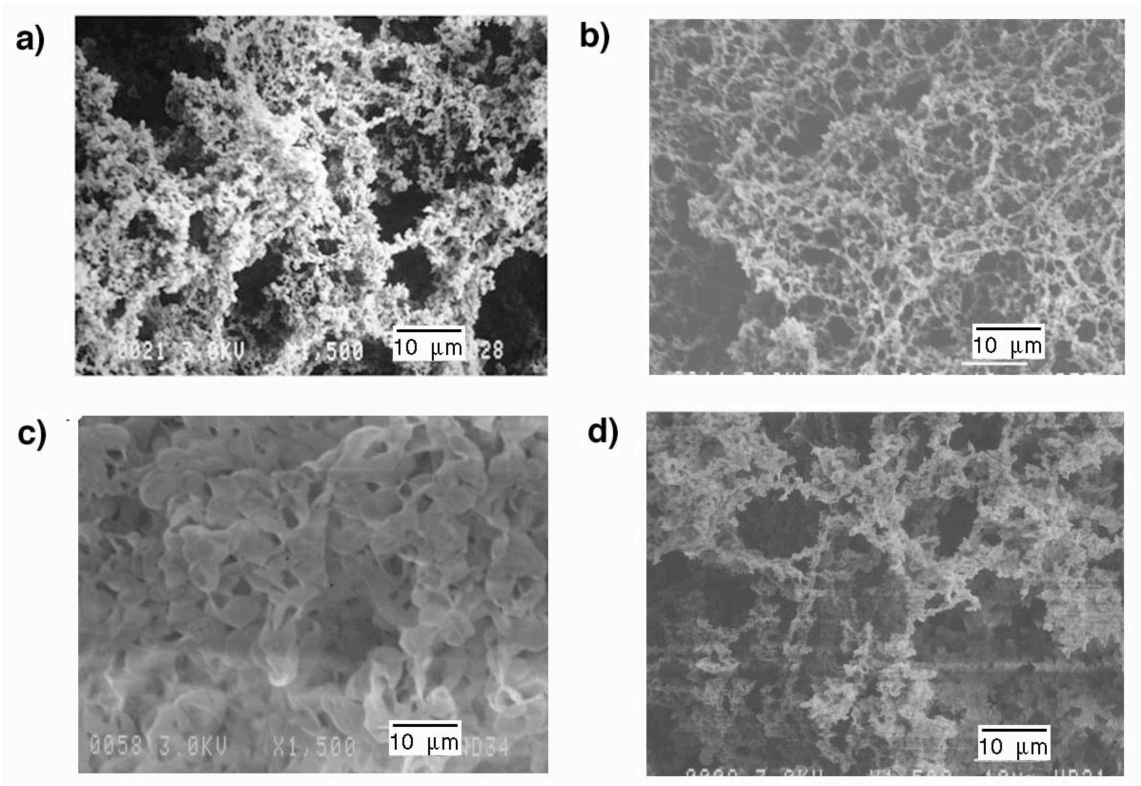

Fig. 6. SEM image of poly(4-methyl-1-pentene) foams prepared from a), 1-butanol, b) 2-butanol, c), 2-methyl-1-propanol, d), 2-methyl-2-propanol.

Fine structure is required for the foam target because its roughness gives perturbation during implosion process. All the foams exhibited lamella structure. The mechanism of lamella formation was explained by the gelation process rates of fast nuclear formation (r_n) and lamella growth (r_l) (Fig. 7). The results indicated that the ratio of r_n/r_l should be large to obtain fine foam structure, and 2- butanol gave the finest structure among those obtained from butanol derivatives. The linear isomers of 1-butanol and 2-butanol has low affinity for the side chain of PMP, and bulky 2-methyl-2-propanol also has much lower affinity to the side chain. These three isomers gave very fine lamellar structure to be less than 1μm. On the contrary, a 2-methyl-1-propanol gel gave larger lamella around 4 μm size. These tendency can be explained that rapid lamella growth (large r_l) takes place due to the affinity of alkyl chain of alcohol and the side chains of PMP. The average size of the lamella is smaller than that for hexanol isomers, which can be explained by the high r_n value and actually, the gelation processes for butanol were more rapid than those of hexanol gels.

We have found that the foam obtained from 2-butanol gel has the finest structure size to approach sub-micrometer size. The present ultralow density with fine lamella polymer foam are promising for the ignition target of FIREX project at ILE.

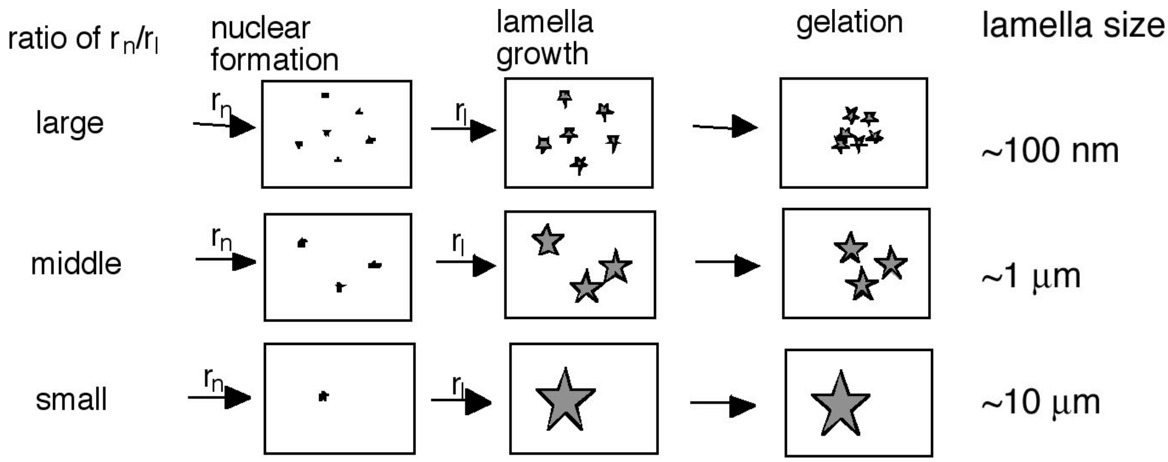

Fig. 7. Schematic view of coagulation process in terms of nuclear formation and lamellar structure growth. The lamella size would be determined by the ratio of (r_n/r_l) and be correlated with affinity between the alkyl chain of alcohol and the side chain of poly(4-methyl-1-pentene).

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