§31. Fast Ignition of Liquid Deuterium Targets

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At ILE Osaka University, elemental researches to develop a neutron source for fusion technology have been conducted basing on the fast ignition of liquid deuterium targets. The researches consist of laser development, target fabrication, simulation technology and integrated implosion experiments using developed elemental researches. In 2009, following progresses were made through collaboration with Kyushu University, Hiroshima University, .Gifu University, NIFS and other collaborators..

LFEX Laser Construction

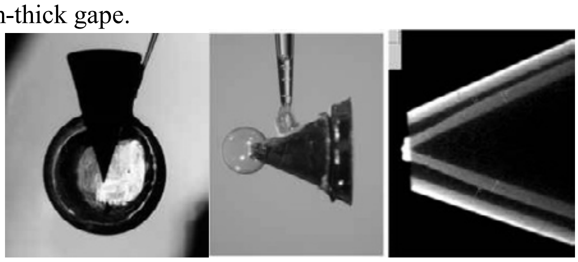
One arm among four of the LFEX laser system was operated in pulse-compressed mode, and was utilized in the integrated Fast Ignition experiment. A 2.2-ns amplified chirped pulse was compressed with large grating system down to 1.3 ps. The compressed beam was focused onto targets with an off-axis parabola mirror. Focal spot size of 30-60 μm was achieved. Maximum output energy was 1 kJ and the size of focusing spot was 30 x 60 μm, which was the double of the diffraction limit..

Target Fabrication

To make a spherical solid fuel layer inside a non-symmetric target with a cone guide, two approaches are investigated. One is conventional foam technology which is a reliable pathway toward the fusion power plant including a scenario for mass production. The critical path of this technique is fabrication of low density foam layer to support the fuel layer. In 2010, the foam density of 100 mg/cc was achieved.

The other is dynamic layering technique that needs precise temperature control around the melting point. Figure 1 (a) shows a 200-μm-thick solid hydrogen layer inside a 2-mm-diameter polystyrene shell. This research was conducted at NIFS. In the foam method, repeatability for fabrication of low density foam shell was improved.

Another progress in target field is fabrication of a double cone target that has a vacuum insulation layer to help focusing of electrons accelerated with the heating laser[1]. Figure 1 (b) and (c) shows the double cone target with a 10-μm-thick gape.



(a) (b) (c)

Fig. 1 200 μm thick solid hydrogen layer inside a 2 mm PS shell with a guide cone.(a), double cone target (b) and x-ray image of the double cone.

Theory and Simulation

Particle-in-cell simulations aimed at improving the coupling efficiency of input laser energy deposited to a compressed core by using a double cone are described. It is found that the number of high-energy electrons escaping from the sides of the cone is greatly reduced by the vacuum gap inside the wing of the double cone. Two main mechanisms to confine high-energy electrons are found. These mechanisms are the sheath electric field at the rear of the inner cone wing and the quasistatic magnetic field inside the vacuum gap. The generation mechanism for the quasistatic magnetic fields is discussed in detail. It is found that the quasistatic fields continue to confine the high-energy electrons for longer than a few picoseconds. The double cones provide confinement and focusing of about 15% of the input energy for deposition in the compressed core.

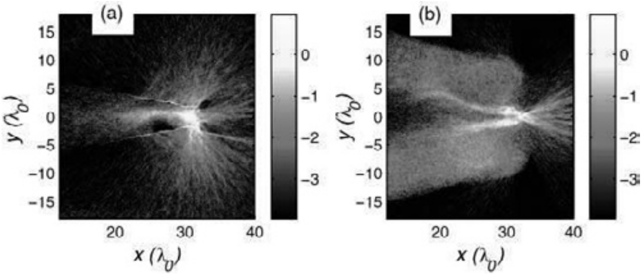


Fig. 2 The natural logarithm of the electron energy density for single cone (a) and double cone (b)

Plasma Experiment

Integrated experiment of Fast Ignition was performed by using Gekko-XII laser (0.53 μm, 9 beams, up to 3 kJ in total / 1.5-ns pulse) for implosion of the target (deuterated polystyrene shell, 500 μm in diameter, 7 μm in thickness) and LFEX laser (1.05 μm, 0.6 kJ/1.3 ps or 1 kJ/5 ps) for fast heating of the imploded core plasma. Enhancement of the neutron yield due to LFEX heating by a factor of up to 30 was observed. We will increase the heating laser energy up to 10 kJ in four beams to achieve heating up to 5 keV. The integrated experiments were performed in a hard x-ray harsh environment due to LFEX irradiation. Hard x-ray shielding for neutron detectors as well as hard x-ray elimination by using total x-ray reflection mirror for x-ray imaging diagnostics were achieved. Fundamental experiments to examine advanced targets such as double cone were also performed.

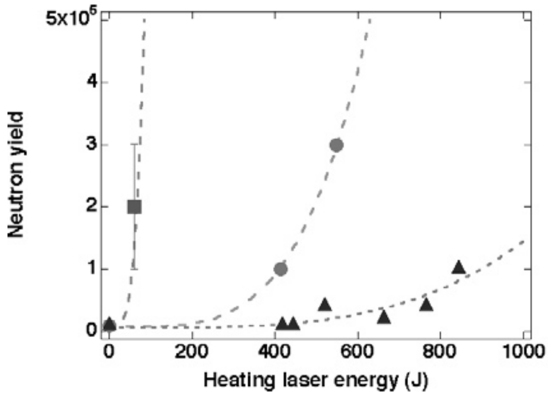


Fig. 3 Enhanced neutron yield by heating laser injection.

[1] H. Nagatomo, et al., Nucl. Fusion **49** 075028, 2009.