§43. Fast Ignition of Super High-Dense Plasmas

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At ILE Osaka University, elemental researches to develop fast plasma heating applicable to fusion reactor technology development have been conducted using the fast ignition of deuterium targets. The researches consist of target fabrication, laser development, integrated implosion experiments, and simulation technology and reactor target design. In FY2014, following progresses were made through collaboration with NIFS and other collaborators.

Target Fabrication and Reactor Technology

In the field of reactor technologies including target fabrication, we engaged in 1) development of cryogenic, fast ignition target, 2) fabrication of partially tritiated-, deuterated-polystyrene shell, 3) development of low density foam target, 4) injection of a real-size fast ignition target and 5) design window of liquid metal mirror for heating laser of a power plant. In 5), the injection, velocity and pointing achieved their final goal but the "tumbling" of the target was too large. We presumed an alternative magnetic field, which was used to release the target from the sabot, induced unacceptable "tumbling". We are now changing the barrel to allow direct observation of the target release.

LFEX with All Four-Beams in High-Power Shots

By completing a full set of large dielectric gratings in the pulse compressor, the LFEX laser were operated with four beams in 2014 (Fig. 1). The total output energy of 2 kJ was obtained in 1~2 ps pulse duration (FWHM). The diagnostic systems after pulse compression were improved. Temporal pulse waveforms of all four beams has been directly measured in real high power shots. Remarkable was the high intensity contrasts of $\sim 10^{-10}$ at 180 ps before the main pulse, which was measured by using a monitor compressor after the optical parametric amplifiers. Adding a plasma mirror improved the contrast for $<10^{-11}$, which was verified by plasma experiments and theoretical analysis. The average filling factor of all beams was slightly below 40%. Diffraction pattern will be suppressed in 2015 to improve it. Then, the encircled energy was obtained between 20% and 50% at 50um in diameter. A deformable mirror will be installed after pulse compressor for one beam as a feasibility study.

Plasma Experiments

The recent experimental results [1] clarify three scientific challenges to achieve high heating efficiency of the fast ignition (FI) scheme with the current GEKKO and LFEX systems: (i) suppression of high energy tail of relativistic electron beam (REB), (ii) guiding and focusing of REB to a fuel core, and (iii) formation of a high areal-density core. For the first challenge, 50% of the total REB energy is carried by a low energy component of the REB, whose slope temperature is close to the ponderomotive scaling value. Higher slope temperature (1.5 MeV) was obtained with the longer pulse duration (4.5 ps) compared to that (0.7 MeV) obtained with the shorter pulse duration (1.5 ps). This is an important experimental validation of the previous simulation [2] for integrated FI design. For the second one, we apply strong external magnetic field to the REB transport region. Guiding of the REB by 0.6 kT field in a planar geometry has already been demonstrated at LULI 2000 laser facility[3]. In the more realistic FI scenario, magnetic mirror is formed between the REB generation point and the fuel core [4]. Computational [5] and experimental studies are conducted to understand REB transport in the magnetic mirror. For the third one, dense core with > 0.2 g/cm^2 of areal density was produced with a 200 μm-diameter solid ball compressed by temporally-tailored converging spherical shock wave. According to the transport calculation, 10% of the efficiency is expected by the current GEKKO and LFEX laser system with the above improvements.

Figure 1 Gratings in the compressor stage.

Theory and Simulation, Target Design

The heating efficiency is not high as had been expected. Controlling the electron beam by external magnetic field is one of the candidates to solve the problem of the large divergence angle of hot electrons. We demonstrated the sufficient beam guiding performance in the collisional dense region by kT-class external magnetic fields for the case with moderate mirror ratio (~10) for the FIREX-class experiments. The boring of mirror field was found through the formation of magnetic pipe structure due to the resistive effects, which indicates a possibility of beam guiding in high mirror field for higher laser intensity. The compression of an external magnetic field by a laser-driven implosion is studied by using two-dimensional resistive magneto-radiation hydrodynamic simulation code for electron-beam guiding in fast ignition. The simulation results show that it is possible to compress the magnetic field to 1 kT; however, the strong magnetic field affects the implosion dynamics because of the suppression of the electron heat flux that crosses strong magnetic field lines. We have studied direct laser irradiation to the inner surface of the shell during the implosion process and ion beam heating of which main advantage is low divergence angle.

[1] S. Fujioka et al., Phys. Rev. E (accepted).
[2] A. J. Kemp et al., Phys. Rev. Lett., Vol. 109, p. 195005 (2012).
[3] J. J. Santos et al., New J. Phys. (submitted).
[4] H. Nagatomo et al., Nucl. Fusion (submitted).
[5] T. Johzaki et al., Nucl. Fusion, Vol. 55, p. 053022 (2015).