§66. Enhancement of Coupling Efficiency in Fast-ignition Laser Fusion by Controlling Self-generated and External Magnetic Field

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The world largest PW laser LFEX, which currently delivers energy up to 2 kJ in a 1.5 ps pulse, has been constructed beside the GEKKO XII laser at the Institute of Laser Engineering, Osaka University. Direct-drive fast-ignition (FI) laser fusion is intensively studied at this facility under the auspices of the FIREX (Fast Ignition Realization EXperiment) project.

The direct-drive FI is an attractive approach to inertial confinement fusion owing to relaxing the requirements on fuel assembly compared to the central hot spot ignition. Although >10% of heating efficiency is required to make the FI feasible, the experimental campaign conducted in 2013 reveals the heating efficiency was currently very low (0.37 +/- 0.27 %) [1]. The efficiency is defined as the ratio between the increment of internal energy of the fuel core induced by relativistic electron beam (REB) heating and the heating laser energy. The experimental results clarify three scientific challenges for achieving high efficiency with the current GEKKO-XII and LFEX systems: (i) suppression of high energy tail of REB, (ii) guiding and focusing of REB to the fuel core, and (iii) formation of high areal density core. According to the transport calculation, 10% of the efficiency is achievable by the current GEKKO and LFEX laser system after the success of the above scientific challenges. In this talk, we will present important recent progresses of the FI studies with the high-contrast LFEX laser and strong external magnetic field. Perspective of the FI studies will also be discussed based on the results.

In order to control divergence of the REB, we are studying to apply strong external magnetic field (more than 1 kT) to the REB path to the fuel core. Generation of 1 kT magnetic field has been demonstrated by using capacitor-coil targets [2]. Guiding of REB by the external magnetic field in a planar geometry has already been demonstrated at LULI 2000 laser facility. In the more realistic FI scenario, the magnetic field is not parallel to the direction of the REB propagation, but the field is bended due to magnetic field compression associated with the fuel compression. Magnetic mirror is formed between the REB generation region and the fuel core, reflection of the REB by the magnetic mirror could be a problem for guiding and focusing of the REB. Simulation was conducted to study the REB transport in the mirror geometry with varying the mirror ratio from 0 to 20 [3]. The simulation shows a REB with a large divergence angle can be successfully focused by moderately mirror ratio (< 10). REB transport in the magnetic mirror will be investigated experimentally by adjusting coil diameter and shape to vary the mirror ratio.

For the guiding of the REB with the magnetic field, 100 T of the external magnetic field is applied initially to a fuel capsule. Effects of the external magnetic field on the fuel and magnetic field compressions are also investigated experimentally and computationally to optimize magnetic field structure after the compression. Laser produced plasma has a relatively large magnetic Reynolds number, the ratio of the magnetic field's diffusion time to the hydrodynamic time scale. The magnetic field fluxes freeze in a plasma and the field structure changes dynamically associated with the plasma motion. Furthermore, the hall parameter, product of electron gyro-frequency and electron collision time, is larger than unity in 100T. Energy transport in such a magnetized plasma is affected by anisotropic electron thermal conduction induced by the strong magnetic field. 2D-radiation-magnetro-hydrodynamics (RMHD) simulation codes are being developed to design the FI target with the assist of the magnetic field. A preliminary experiment was conducted on GEKKO-XII laser facility for the code verification, here we used a couple of capacitor-coil targets to generate spatially uniform magnetic field with 200 - 300 T of flux density. Intense laser pulse was focused on a 25 μm-thick polystyrene foil to accelerate it in the external magnetic field, and velocity of the accelerated polystyrene foil was found to be 1.5 times faster than that in no external magnetic field. Because anisotropic thermal diffusion reduces thermal energy loss from the ablated plasma to its peripheral cold region, temperature and thermal pressure of the ablated plasma increases, then the polystyrene foil accelerated by the larger pressure gradient. The experimental results were compared with the 2D-RMHD code, a part of the experiment result is consist with the simulation result.

[1] S. Fujioka *et al.*, *"Heating Efficiency Evaluation with Mimicking Plasma Conditions Integrated Fast Ignition Experiment"*, to be published in Phys. Rev. E.
[2] S. Fujioka *et al.*, "*Kilotesla Magnetic Field due to a Capacitor-Coil Target Driven by High Power Laser*", Sci. Rep., 3, p. 1170 (2013).
[3] T. Johzaki *et al.*, "*Control of electron beam using strong magnetic field for efficient core heating in fast ignition*", Nucl. Fusion, 55, 053022 (2015).