§59. Proof-of-principle of Heating Efficiency Enhancemen in Fast-ignition Laser Fusion by using Extenral Strong Magnetic Field

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i) Introduction Here we report recent experimental results relevant to the fast ignition (FI) inertial confinement fusion assisted with external kilo-tesla magnetic field. We have experimentally observed generation of 0.6 kT of magnetic field by using laser-driven capacitor-coil scheme [4, 1], short diffusion time ($\ll 1$ ns) of laser-generated magnetic field into a target material, reduction of the REB beam diameter by the factor of two and additional acceleration of a fusion plasma hyrdodynamics in the strong magnetic field.

One of the critical problems facing the FI scheme is large divergence angle of the laser accelerated relativistic electron beam (REB) [2]. The application of a strong external magnetic field in the REB path to the fuel core is being investigated for controlling transport of the REB [3]. Larmor radius of a 1 MeV electron, which heats efficiently the fuel core, is 6 m in a 1-kT magnetic field. The radius is smaller than the typical radius of the REB at the generation point, thus a 1-kT magnetic field is enough for the REB guiding. Kilo-tesla magnetic field affects not only REB transport but also hydrodynamics of a fusion plasma by anisotropic thermal heat transport.

ii) Guiding of relativistic electron beam by external magnetic field A 1-kT magnetic field has been generated by using capacitor-coil targets [4]. Laser produced magnetic field is pulsive, therefore diffusion time of the magnetic field in a target material ($\tau_{\mathrm{diffusion}} = \mu_0 L^2/\eta$) is essential for the application of the magnetic field to the fusion target, here μ_0, L and η are the permeability, resistivity, and diffusion length. Uncertainness of the diffusion time estimation is caused by calculation difficulty of the resistivity of an insulator below 1 eV of temperature (an intermediary between insulator and conductive plasma). Two capacitor-coil targets were aligned in Helmholtz geometry to generate a relatively spatially uniform magnetic field. A 250 μm-thick plastic foil was placed between the two coils to study magnetic field diffusion. A laser-produced proton beam was used to image magnetic field strength in the plastic foil. Measured proton pattern shows an evidence of fast diffusion of magnetic field in the plastic sample [1]. The plastic remains insulator for the pulsive kilo-tesla magnetic field. This is a benefit for the fast ignition.

iii) Hydrodynamics under strong magnetic field The magneto-hydrodynamics (MHD) of a laser fusion plasma in the strong external magnetic field is a new field of high-energy-density plasma physics. The important parameter is Hall parameter $\xi = \omega_{\mathrm{ce}}\tau_{\mathrm{ce}}$, here ce and ce are electron gyrofrequency and electro collision time, respectively. When the Hall parameter is non-zero, thermal transport is modulated by gyromotion of thermal electrons in a magnetized plasma. $\beta > 100$ and $\chi \sim 1$ - 3 in a typical laser fusion plasma for kilo-tesla magnetic field, therefore magnetic pressure has relatively small impacts on the hydrodynamics while the anisotropic thermal heat transport alters the hydrodynamics.

Figure 1 shows trajectory of laser-driven polystyrene foils driven by a 10^13 W/cm^2 laser pulse in the 300 T external magnetic field. The points represents trajectories of the rear surface of the foils, and the lines are computed by the two-dimensional PINOCO-MHD code [6]. The flying velocity with the magnetic field is 50% faster than that without magnetic field. The comparison between the experimental and computational results indicates that the external magnetic field changes plasma hydrodynamics by the anisotropic thermal conduction.

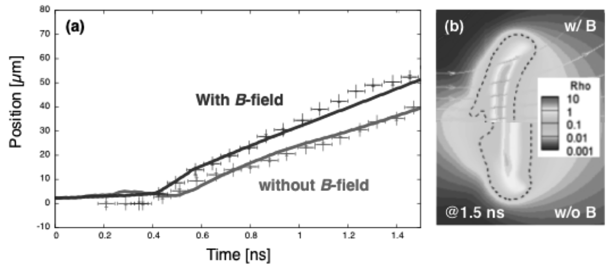

Fig. 1: Trajectory of laser-driven polystyrene foils with and without external magnetic field. Dots and lines are experimental and simulation results. (b) Two-dimensional density profile at 1.5 ns calculated with two-dimensional PINOCO-MHD code. In this experimental condition, the dimensionless parameters are $\beta > 100$ and $\chi \sim 1\ \ 3$ in the corona plasma.

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