§11. Heating of Dense Plasma by Laser-produced Hot Electrons by Using Electron Magnetic-Hydro-Dynamics Model

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In fast ignition (FI) of inertial confinement fusion research, it is significantly important to understand how the fast electrons created by ultra intense laser light heat the compressed core plasma. In the previous integrated experiment for FI, we observed a significant reduction on fast electron energy distribution[1)]. Figure 1 shows the fast electron number as a function of electron energy observed at (a) 20° and (b) 40° from the injection axis of intense laser beam. The indications of each spectrum show the injection timing of ultra intense laser beam from the maximum plasma compression timing by GXII 12-beams. The electrons observed at 20° are considered to be passed through the dense core, so that the reduction at 0ps injection timing compered to other timing clearly indicates the plasma heating by the fast electrons. It should be noted that only at 0ps timing, we successfully observed the neutron number enhancement[2)]. On the other hand, we did not observe such reduction on 40° spectra whose electrons may pass only lower density region.

The reduction appears up to 10 or 15 MeV electrons. However by considering stopping range of electrons, such high-energy electrons may penetrate the core plasma being achievable in the current laser condition (up to 50 to 100 g/cm^3) without energy deposition. One possible candidate to explain the anomalous stopping is electron magneto-hydrodynamics model[3)]. However because the analysis in ref. 3 assumes 0°C plasma temperature and immobile ions, it is not clear that the model can really apply for fast ignition condition in which strong self-excited magnetic field and significant temperature gradient are existed.

For this purpose, we carried out electromagnetic particle simulations to understand the particle motion in such extreme conditions. Figure 2 shows the simulation setup. The 100 N_c (N_c: critical density for 1μm laser pulse) plasma is located in the center of the simulation box (10.5μm < x < 13.5μm) with exponential decay density gradient down to 10 N_c in front and rear of the dense plasma (5.5μm < x < 10.5μm and 13.5μm < x < 18.5μm). In front of plasma, we put 10 MeV electron beam with N_c beam density in the area of 2.5μm < x < 5.5μm and -1.0μm < y < 1.0μm with 10N_c constant background plasma. The electron beam has only p_x and perpendicularly incident the dense plasma slab. For the comparison, we conduct a simulation without the dense core region and 10 N_c constant density plasma in whole region.

In the results, with the density gradient, electron beam propagates the plasma without significant beam expansion. It may be due to collimation by internal force via B×∇n drift in addition to the collimation by self-created azimuthal magnetic field. On the other hand, in the case of constant density plasma, the electron beam is clearly expanded especially in backward of the beam where the self-magnetic field becomes weaker. In addition, for the simulation with density gradient, the electron beam keeps its diameter when the beam propagates into density shelf (∇n=0), and becomes to expand from the front part of the beam when the beam comes out the decay density gradient of the plasma due to negative B×∇n drift.

In summary, we successfully observe the effect of B×∇n on the beam diameter of high energy electron beam directly during the propagation. We will continuously investigate the anomalous energy dissipation and resulting heating of the plasma due to the B×∇n drift for the plasma with significant density gradient.

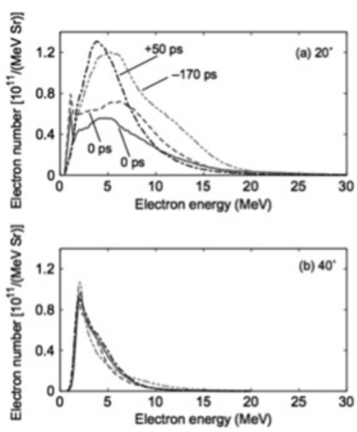

Fig. 1. Fast electron energy spectra observed in different viewing angles, (a) 20° and (b) 40° from ultra intense laser beam injection direction[1)].

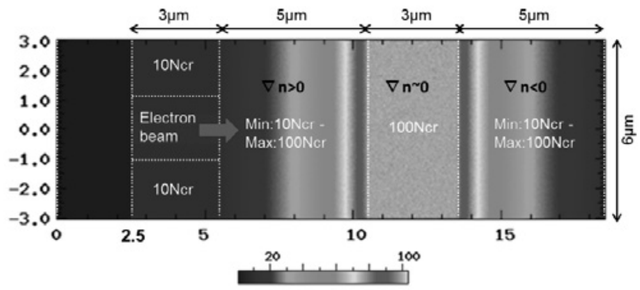

Fig. 2. Simulation setup.

1) T. Yabuuchi, T., et al., New J. Physics **11** (2009) 093031.
2) Kodama, R., et al., Nature **418** (2002) 933.
3) Yadav, S.K., et al., Phys. Plasmas **16** (2009) 040701.