§21. Integrated Simulations for Fast Ignition with Cone-Guided Targets

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It was reported that the fuel core was heated up to ~ 0.8 keV in the fast ignition experiments with cone-guided targets at Osaka University, but efficient heating mechanisms and achievement of such high temperature have not been clarified yet. To estimate the scheme performance of the fast ignition, we must consider 1) overall fluid dynamics of the implosion, 2) laser-plasma interaction and fast electron generation, and 3) energy deposition of fast electrons within the core. It is, however, impossible to simulate all phenomena with a single simulation code due to divergence of both space and time scales, and we must simulate each phenomenon with individual codes and integrate them. To attack this challenging problem, we have been promoting the Fast Ignition Integrated Interconnecting code (FI) project.[1,2) Under this project, the radiation-hydro code (PINOCO), the collective Particle-in-Cell code (FISCOF1), and the relativistic Fokker-Planck code (FIBMET) collaborate with each other by data transfer via the computer networks.

In the cone-guided target, there is a density gap between the cone tip and the imploded plasma, and fast electrons must across this boundary to reach the core. We model this density gap in FISCOF1 as follows: the preformed plasma is assumed to have exponential profile of the scale length 5 μm with density from $0.1n_c$ up to $100n_c$, where n_c is the critical density. Behind the preformed plasma, the cone tip is assumed as the plasma of 10 μm width and $100n_c$, following the 50 μm long imploded plasma with n_c, $2n_c$ or $10n_c$. Fast electrons are expected to lose their energy when they across the density gap. Simulations are performed with Gaussian laser pulse of $\lambda_L = 1.06$ μm, $\tau_{FWHM} = 150$ fs, $I_L = 10^{20}$ W/cm^2 and immobile ions, and the energy of fast electrons is observed at 10 μm rear of the density gap. The temporal profiles of the electron bean intensity are shown in Fig. 1 (a) and the time-averaged electron energy distributions are shown in Fig. 1 (b) for the density gap of $10n_c$(gray solid), $2n_c$(black solid) and n_c(black dash). Electron phase spaces at 350 fs are shown in Fig. 2 for the density gap of (a) $10n_c$, (b) $2n_c$ and (c) n_c. The density gap is placed at the center of figures. In case of $10n_c$, the fast electron current is completely canceled by bulk electrons because the density of bulk electrons is much higher than that of fast electrons, and no micro-instability occurs. Thus fast electrons propagate through the imploded plasma without losing their energy, and they are too hot to heat the core. In case of $2n_c$, all of bulk electrons in the imploded plasma must flow with 70% of the light speed, and this stream of bulk electrons excites a strong two-stream instability, in which bulk electrons are heated up. An electrostatic field is built up at the gap, and a relatively low energy part of fast electrons is confined inside the cone tip. On the other hand, the return currents are accelerated at the gap and injected into the cone tip. Therefore the cone tip is filled up with sloshing fast electrons, and some fractions of them are continuously released from there even after the laser pulse is dropped off, and expected to heat the core. The electron beam intensity does not drop off even after the laser pulse vanishes (see Fig.1(a)), and sub-MeV electrons that are very efficient for core heating are clearly observed much more (see Fig.1(b)). In case of n_c, the fast electron current is not neutralized any more even all of bulk electrons run with the light speed because the density of bulk electrons is only n_c, and a very strong electrostatic field is built up at the gap. Thus bulk electrons are also heated up by the two-stream instability, but sub-MeV electrons are reflected by this strong potential and confined inside the cone tip. The return currents are accelerated at the gap into the cone tip by this very strong electrostatic field and are sloshing inside the cone tip. Thus electrons with more than MeV energy are launched into the imploded plasma after laser irradiation.

If the density of the imploded plasma is large, the fast electron current can be easily neutralized without driving the instability. When it is small, the strong electrostatic potential is build up and disturb the propagation of sub-MeV electrons. Thus there would exist an optimal density of the imploded plasma for the core heating.

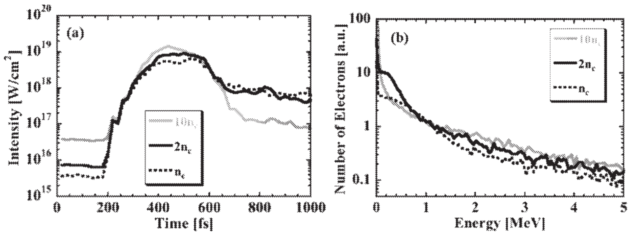

Fig.1. The temporal profiles of (a) the electron bean intensity and (b) the time-averaged electron energy distribution.

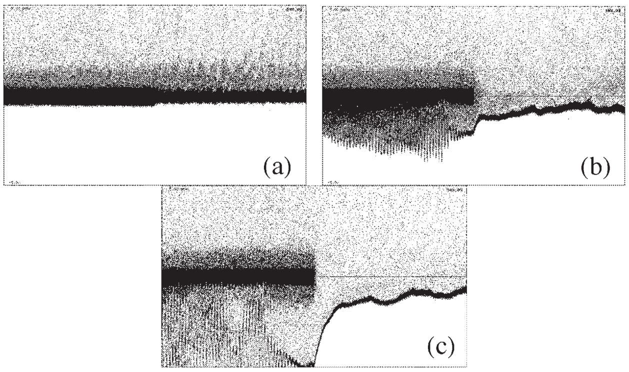

Fig.2. Electron phase spaces with the density gap of (a) $10n_c$, (b) $2n_c$ and (c) n_c.

References

1) Sakagami, H., and Mima, K. : Laser and Particle Beams **22** (2004) 41.
2) Sakagami, H., Johzaki, T., Nagatomo, H., and Mima, K. : Laser and Particle Beams **24** (2006) 191.