# §18. Scaling Law for Fast Electron Beam Intensity in Fast Ignition

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The goal of FIREX-I project, in which a cone-guided cryogenic DT target is imploded by the present Gekko XII laser system and its compressed core is heated by the LFEX laser, is to demonstrate that the imploded core could be heated up to the ignition temperature, 5[keV]. To simulate FIREX-I experiments, the heating laser is set to $\lambda_L$=1.06[μm], $\tau_{rise}$=375[fs], $\tau_{flat}$=10[ps], $\tau_{fall}$=375[fs], $I_L=10^{20}$[W/cm$^2$], and the Au-cone tip is introduced as 10[μm], 500n$_{cr}$, real mass and Z=30 plasma with preformed Au plasma, which has a exponential profile of the scale length L$_f$=1, 5 or 10[μm] with density from 0.1n$_{cr}$ up to 500n$_{cr}$. The cone tip plasma is followed by 50[μm] long imploded CD plasma with 500n$_{cr}$, A=7 and Z=3.5. The energy of fast electrons is observed in CD plasma, 10[μm] behind the Au-CD boundary.

Fast electrons are mainly generated by the oscillating component of the ponderomotive force of the laser, and it depends on the large gradient of the laser field at the interaction region. As the temporal pulse length is long enough for Au ions even with real mass, the Au plasma is snowplowed to higher density. The profile steepening also occurs; hence the laser directly interacts with the sharp edge plasma. Time evolutions of fast electron beam intensity and electron density at the laser-plasma interaction front for L$_f$=1, 5 and 10[μm] are shown in Fig. 1. As the laser rises up to a maximum intensity at 1[ps], the fast electron beam intensity also rises up at the same time. The laser keeps its maximum intensity up to 10[ps], however, the intensity of the fast electron bean quickly drops to one third of the maximum value when the electron density increases in the case of L$_f$=1[μm]. The oscillating ponderomotive force on electrons is given by a following equation.1)

$$f_p = -\frac{\partial}{\partial x}\left(\frac{mv_{osc}^2}{2}\frac{4\omega_L^2}{\omega_{pe}^2}e^{-2\omega_{pe}x/c}\left[\frac{1+\cos 2\omega_L t}{2}\right]\right) \propto \left(\frac{v_{osc}^2}{c^2}\right)\omega_L^2\left(\frac{c}{\omega_{pe}}\right) \qquad (1)$$

The magnitude of the force is proportional to c/$\omega_{pe}$, namely (n$_{cr}$/n$_e$)$^{(1/2)}$. As intensity is obtained by multiplying a force by a velocity, the beam intensity of fast electrons that are generated by the ponderomotive force can be estimated by multiplying f$_p$ by the velocity. Because the laser intensity is relativistic, the velocity of fast electrons can be assumed to be a light speed. Thus the fast electron beam intensity would be proportional to f$_p$, hence to the inverse square root of the electron density. Fast electron beam intensity as a function of electron density at the interaction front is shown in Fig. 2 for L$_f$=1, 5 and 10[μm]. The beam intensity well scales as the inverse square root of the electron density independent of the scale length of the preformed plasma.2)

As the core heating is greatly affected by the fast electron energy spectrum, hence the scale length of the preformed plasma, we have performed FI$^3$ integrated simulations to estimate core temperatures.2) Time evolutions of core electron temperatures, which are averaged over the dense region (ρ>10[g/cm$^3$]), are shown in Fig. 3. In the case of the short scale length, the average core temperature quickly rises but shortly saturates because the fast electron beam intensity decreases. With the longer scale length preformed plasma, the beam intensity of fast electrons are maintained and the core heating is sustained for a longer time, the core reaches higher average temperature. The temperature increment for the preformed plasma with L$_f$=10[μm] is three times larger that that with 1[μm].

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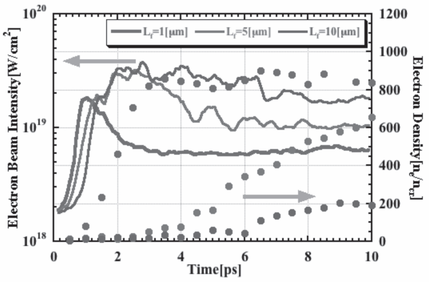

Fig.1. Time evolutions of fast electron beam intensity (solid line) and electron density (circle). Colors of red, light blue and purple indicate L$_f$=1, 5 and 10[μm], respectively.

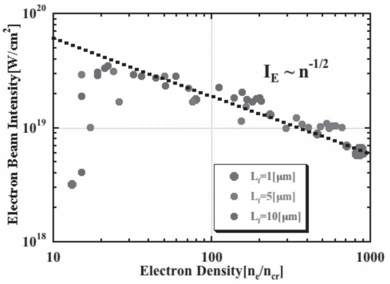

Fig.2. Fast electron beam intensity as a function of electron density.

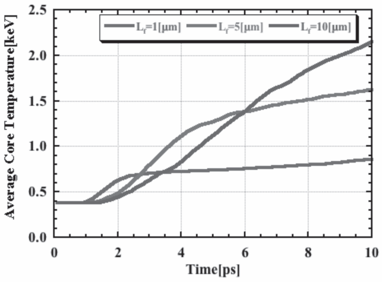

Fig.3. Time evolutions of averaged core (ρ>10[g/cm$^3$]) temperature of electrons.

1) Wilks, S.C. and Kruer, W.L.: IEEE J. Quantum Electronics **33** (1997) 1954.
2) Sakagami, H. et al.: Proc. 34th EPS Conf. on Plasma Physics, (2007) P2.002.