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Optimum Density and Thickness of Low-Density Foam Coating on Cone Tip for FIREX-I

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1. Introduction

The heating laser in FIREX-I is designed to have a total energy of 10 kJ but to retain the same intensity in previous experiments because a higher intensity laser generates faster electrons that cannot heat the core efficiently. So the pulse duration is set up to be 10 ps instead of 750 fs. The 10 ps pulse length is long enough even for heavy Au preformed plasma of the cone to be pushed by the ponderomotive force and the laser-plasma interaction is much affected by deformation of the preformed plasma. Thus we have investigated fast ignition for 10 ps heating laser with the use of Fast Ignition Integrated Interconnecting code (FI^3) [1].

Core heating properties are affected by the characteristics of the preformed plasma, which is generated by a pre-pulse of the heating laser. The pre-pulse is, however, the nature of the laser device itself and is not easily controllable. To control the plasma density in the interaction region, we propose to coat an inner surface of the cone tip with low-density foam materials, such as aerogel. The plasma density of the foam can be kept much lower than the solid density even it is fully ionized. Thus we can prevent the foam plasma from being snowplowed to an extremely high density, and expect that the fast electron beam intensity is kept at the high level during laser irradiation. Integrated simulations are performed to estimate core temperatures, and optimize the foam density and thickness [2].

2. Optimum Foam Thickness

To investigate optimum foam thickness with use of the 1D PIC code, we set up the heating laser to λ_L=1.06 μm, τ_{rise}=375 fs, τ_{flat}=10 ps, τ_{fall}=375 fs, $I_L=10^{20}$ Wcm^{-2}, and the Au-cone tip to 500n_{cr}, real mass, Z=30, 10 μm flattop plasma. We place the foam plasma (SiO_2 aerogel, A=20, Z=10, 40 μm thickness) with different densities (n_{foam}) in front of the Au cone tip plasma and the CD plasma (500n_{cr}, A=7, Z=3.5, 50 μm thickness) behind it. The fast electron beam is observed at 10 μm rear of the Au-CD boundary.

As the foam plasma is pushed by the strong ponderomotive force, it is completely plunged into the Au plasma if the foam thickness is not enough. Therefore the heating laser interacts directly with the extremely overdense Au plasma, and it results in reduction of the fast electron beam intensity. To prevent the foam plasma from being swept away during irradiation of the heating laser, we must put the thicker foam plasma. The total fast electron beam energies that are calculated by integrating the beam intensities as a function of the foam density are shown in Fig.1. For the n_{foam}=20 and 30n_{cr} cases, 60 μm thickness seems to be enough to prevent the depletion, but 80 μm thickness is required in the case of n_{foam}=10n_{cr}. The recession velocity of the foam plasma (u) can be estimated by balancing the momentum flux of the mass flow with the laser pressure, given by the following expression [3]:

$$\frac{u}{c} = \sqrt{\frac{n_{cr}}{2n_e}\frac{Zm}{M}\frac{I\lambda^2(Wcm^{-2}\mu m^2)}{1.38\times 10^{18}}} \quad . \qquad (1)$$

The minimum thickness of the foam plasma can be estimated by multiplying the recession velocity by the laser irradiation period, 10 ps, and is given by 94, 66 and 54 μm for n_{foam}=10, 20 and 30n_{cr}, respectively. This estimate is in good agreement with the required foam width evaluated from Fig.1.

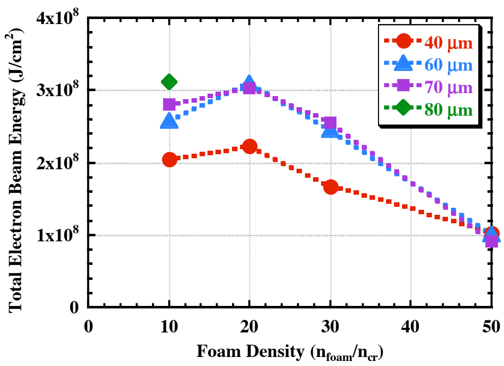

Fig.1. Total electron beam energy.

3. Optimum Foam Density

To avoid the heating laser anomalous penetration into the foam plasma, the density of the foam should be higher than the relativistic critical density. On the other hand, the density of the foam should be low enough to prevent electrons in the foam plasma from being snowplowed to extremely high density at the laser front. Electron density profiles around the interaction region for n_{foam}=20 and 50n_{cr} with 40 μm thickness at t=1 ps are shown in Fig.2 (a). In the case of n_{foam}=50n_{cr}, the foam plasma is snowplowed to more than 3 times higher density than the initial density (>150n_{cr}) at the boundary, and the fast electron beam intensity can be substantially suppressed to a low level. The foam plasma is, however, compressed less than one-and-a-half times the initial density (<30n_{cr}) and no depletion of the beam intensity is expected for the n_{foam}=20n_{cr} case. Electron temperature profiles that are calculated by averaging all electrons are shown in Fig.2 (b). In the case of n_{foam}=50n_{cr}, the recession velocity given by Eq.1 is 6 times higher than the sound velocity, $(Zm/M)^{1/2}v_{te}$. In such supersonic conditions, the plasma can be successfully compressed and the shock wave front,

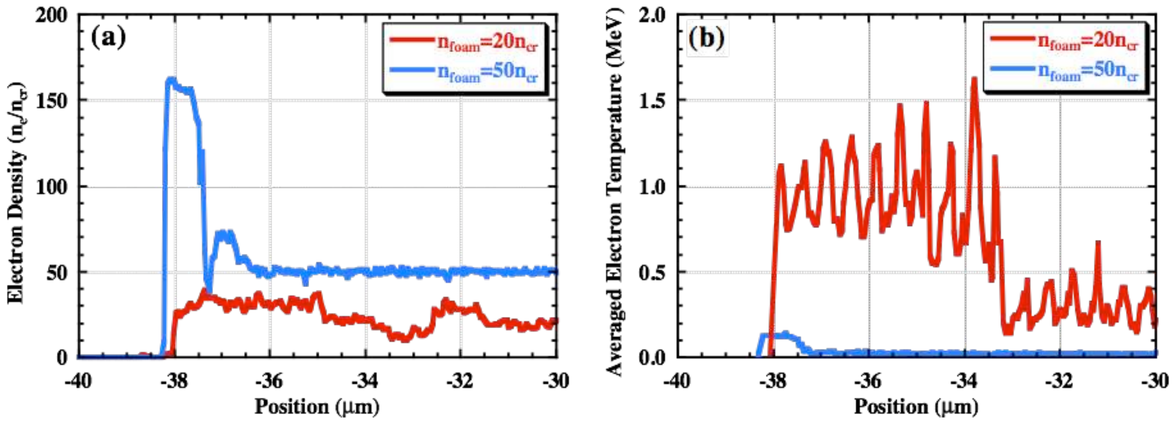

Fig.2. (a) Electron density and (b) averaged electron temperature profiles at t=1 ps.

which is clearly seen at -37.5 μm in Fig.2 (a), is formed in the electron density profile. The shock wave travels with the speed of the order of the recession velocity, but the compressed plasma that is located behind the shock front runs away with the sound velocity. The averaged electron temperature of the foam plasma quickly rises up to 1 MeV for the n_{foam}=20n_{cr} case. In such high temperature plasma, the sound velocity is almost the same as the recession velocity and the compression cannot be maintained. So the plasma is not piled up as in the n_{foam}=50n_{cr} case and the shock wave front is not seen. If the foam density is below the threshold density, fast electrons, which are generated by the heating laser, excite the stream instabilities. As a result, the plasma is heated up and the sound velocity increases, preventing from piling up the plasma. So fast electrons are continuously generated and above process is preserved. When the foam is denser than the threshold value, less fast electrons cannot excite the instability and heat the plasma to such temperature that disturbs pilling up. Then the plasma density increases and the chance to heat up the plasma is missed ever. For current simulation conditions in this paper, the threshold foam density for this transition, namely the critical foam density to be snowplowed is found to be 50n_{cr}.

Electron density and averaged electron temperature profiles with n_{foam}=10 and 20n_{cr}, 40 μm thickness for I_L=10^{19} Wcm^{-2} at t=1.5 ps are shown in Fig.3 (a) and (b), respectively. Other parameters are same as previous. As the laser intensity is lower than that in the previous case, the foam plasma is not heated to high temperature enough to disturb pilling up in the n_{foam}=20 case, but is sufficiently heated in the n_{foam}=10 case. Same profiles with n_{foam}=50n_{cr}, 40 μm thickness for I_L=10^{20} and 10^{21} Wcm^{-2} at t=1 and 2 ps are shown in Fig.4 (a) and (b). If I_L is 10^{20} Wcm^{-2}, a low temperature is maintained and the foam plasma is still compressed. Because much more fast electrons are generated in the case of I_L=10^{21} Wcm^{-2}, the instability is eventually excited and the plasma is heated up to such a temperature that the compression is defeated. Thus the threshold density increases with increasing of the laser intensity.

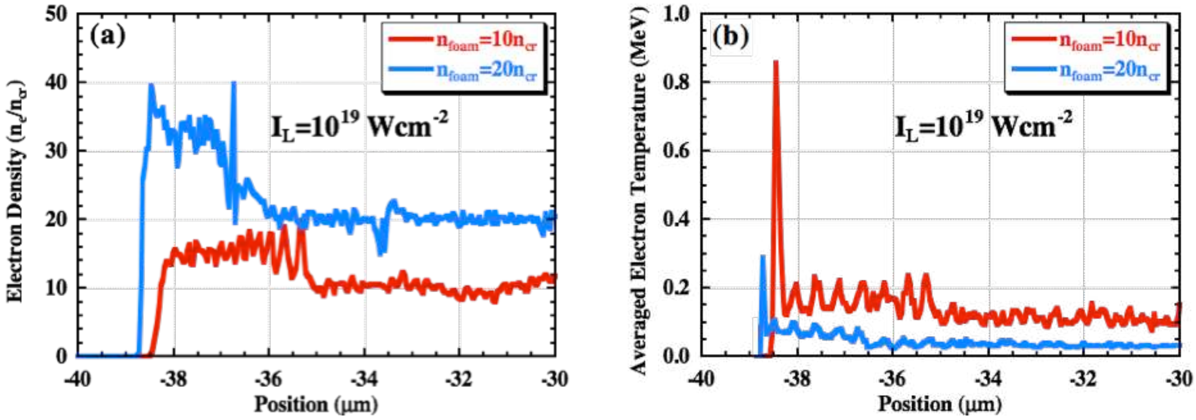

Fig.3. (a) Electron density and (b) averaged electron temperature profiles at t=1.5 ps for $I_L=10^{19}$ Wcm^{-2}.

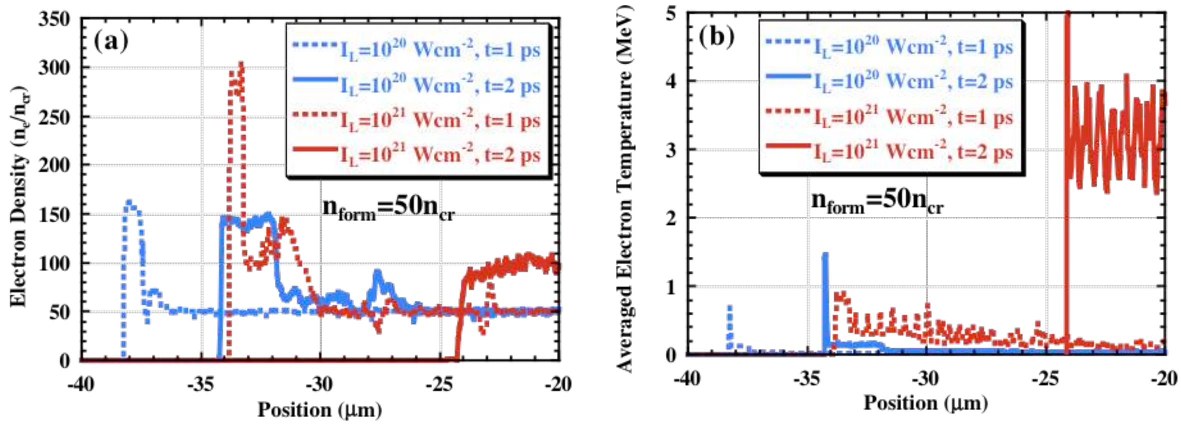

Fig.4. (a) Electron density and (b) averaged electron temperature profiles at t=1, 2 ps for $I_L=10^{20}$, 10^{21} Wcm^{-2}.

4. Summary

We conclude that we can appropriately control the fast electron generation for core heating with the low-density foam coating on cone targets. As the core heating is greatly affected by not only the beam intensity but also the energy spectrum of fast electrons, hence the foam density, we have performed FI^3 integrated simulations to estimate core temperatures. Under current parameters, the averaged core electron temperature can reach 2.6 keV with 20n_{cr}, 60 µm thickness foam [2]. Of course, 10 ps laser-plasma interactions excite many multi-dimensional effects and we should perform 2D PIC simulations. But we just started to look at what happens as a preliminary simulation research with use of the 1D PIC code for FIREX-I.

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