Effects of Preformed Plasma of CH Foam on Fast Electron Generation

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Abstract. In fast ignition, the intensity of an unavoidable pre-pulse of a heating laser is still high to generate plasmas even if the contrast ratio is high. So, a preformed plasma (pre-plasma) is created before a main pulse of the heating laser irradiates a target. The recent research suggests that coating an inner surface of the cone of the cone-guided target with the low-density foam enhances fast electron generation. But the pre-plasma and the foam structure, which consists of dense CH plasmas and voids, are ignored in that research. In this paper, effects of the pre-plasma and the foam structure on the fast electron generation are investigated with the use of an one-dimensional Particle-In-Cell code. It is found that effects of the pre-plasma on the fast electron generation are small and the foam structure weakens the generation of fast electrons with the moderate energy.

1. Introduction
The cone-guided target, of which an inner surface of the cone is coated with the low-density foam, is proposed for fast ignition experiments in FIREX-I, because it is reported that the low-density foam enhances fast electron generation [1]. In fast ignition, an ultrahigh intense laser is used to heat the core. A pre-pulse of the heating laser is unavoidable and its intensity is still high to generate plasmas even if the contrast ratio is high. Therefore a preformed plasma (pre-plasma) is created before a main pulse of the heating laser irradiates the target. An importance of the pre-plasma on the fast electron generation is suggested in recent researches [2,3]. The pre-plasma is ignored in previous research [1], therefore pre-plasma effects should be investigated. The foam is actually constructed with dense CH plasmas and voids, but the foam structure is also ignored and the foam density is assumed to be uniform in that research. Thus, effects of the foam structure should be also investigated.

We perform simulations for both cases with and without the pre-plasma using an one-dimensional Particle-In-Cell code and investigate the effects of the pre-plasma on the fast electron generation. The foam structure is realized to put dense CH plasma and vacuum gap in turn due to one dimensionality. So, we perform simulations with the different gap lengths and also investigate effects of the foam structure on the fast electron generation.
2. Pre-plasma and Foam Structure

In simulations, the target is constructed from CH foam pre-plasma, CH foam, Au and CD plasmas. The CH foam pre-plasma consists of three parts: each part has an exponential profile with the scale length \( L_{\text{pre}} \) of 56.9 \((0.10 \sim 0.22n_{\text{cr}})\), 18.0 \((0.22 \sim 0.80n_{\text{cr}})\) and 0.869 [\(\mu\)m] \((0.80n_{\text{cr}} \sim n_{\text{foam}})\), where \(n_{\text{foam}}\) is the CH foam density. Supposing full ionization, the ionization degree \(Z\) and the mass number \(A\) of the pre-plasma are assumed to be 3.5 and 6.5 as averaged values of C and H, respectively. The density profile of the pre-plasma is determined by simulations performed with STAR1D, an one-dimensional Lagrangian radiation-hydrodynamic code [4]. STAR1D simulates pre-plasma formation by the pre-pulse which is set to \(I_L = 10^{11}[\text{W/cm}^2]\) and \(t_{\text{flat}} = 1[\text{ns}]\). The ionization degree and the mass number of the CH foam plasma, which has the flat profile with 20[\(\mu\)m] thickness and \(n_{\text{foam}}\), are the same as the CH foam pre-plasma. The profile of the Au (CD) plasma is also flat with \(Z = 8, A = 197, 10[\mu\text{m}]\) thickness and 100\(n_{\text{cr}}\) \((Z = 3.5, A = 7, 35[\mu\text{m}]\) thickness and 100\(n_{\text{cr}}\)). The main pulse of the heating laser is set to \(I_L = 10^{20}[\text{W/cm}^2]\), \(t_{\text{rise/fall}} = 375[\text{fs}]\) and \(t_{\text{flat}} = 1.5[\text{ps}]\). To investigate the difference of the fast electron generation by the foam density, we set \(n_{\text{foam}}\) to 10, 20, 40 and 80\(n_{\text{cr}}\).

2.1. Pre-plasma

To evaluate fast electron characteristics, we observe fast electrons in the CD plasma, 10[\(\mu\text{m}\)] behind the Au-CD boundary. Figure 1 shows time evolutions of fast electron beam intensity (a) with pre-plasma and (b) without pre-plasma. The time when the fast electron beam intensity rises for the first time in the figure 1 (a) is 200[fs] later than that in the figure 1 (b). The time is defined as \(t = 0\) when the heating laser starts to interact with a leading-edge of the pre-plasma, so fast electrons take more time to arrive at the observation point in the case with pre-plasma than that without pre-plasma. As the length of the pre-plasma is about 70[\(\mu\text{m}\)] and fast electrons propagate with almost light speed, the time lag is estimated at 233[fs] and it is a good agreement with the observed delay. In the cases of 40 and 80\(n_{\text{cr}}\), the electron beam intensity with pre-plasma increases more and is maintained with a higher level than that without pre-plasma. But in the cases of 10 and 20\(n_{\text{cr}}\), the electron beam intensities with and without pre-plasma are almost same.

![Figure 1](image)

**Figure 1.** Time evolutions of fast electron beam intensity (a) with pre-plasma and (b) without pre-plasma. Red, green, blue and purple lines indicate \(n_{\text{foam}} = 10, 20, 40\) and 80\(n_{\text{cr}}\), respectively.

Figure 2 shows time-integrated energy spectra of fast electrons (a) with pre-plasma and (b) without pre-plasma. In the cases of 10 and 20\(n_{\text{cr}}\), the energy spectrum with pre-plasma is very similar to that without pre-plasma in whole range of electron energy. However, in the cases of 40 and 80\(n_{\text{cr}}\), fast electrons with pre-plasma increases more than those without pre-plasma of a low-energy (1~5 [MeV]) component. Even though fast electrons of a high-energy (>5 [MeV]) component are not generated at all without pre-plasma, those are generated in the case with pre-plasma.
Figure 2. Time-integrated energy spectra of fast electrons (a) with pre-plasma and (b) without pre-plasma. Red, green, blue and purple lines indicate $n_{\text{foam}} = 10, 20, 40$ and $80n_{\text{cr}}$, respectively.

Figure 3 shows electron density profiles with and without pre-plasma in the case of (a) $n_{\text{foam}}=20n_{\text{cr}}$ and (b) $n_{\text{foam}}=40n_{\text{cr}}$. We compare results at difference time, because fast electrons with pre-plasma reach the observation point 200[fs] later than those without pre-plasma as stated above. In the case of $20n_{\text{cr}}$ without pre-plasma, the low-density plasma is generated in front of the CH foam plasma and expected to interact with the heating laser just same as the pre-plasma. As a result, the spectrum without pre-plasma is same as that with pre-plasma. In the case of $40n_{\text{cr}}$ without pre-plasma, no low-density plasma is found in front of the CH foam plasma. Consequently, fast electrons of the high-energy component are not generated. On the other hand, the electron density at the laser front in the steepened density profile without pre-plasma is found to be $\sim 100n_{\text{cr}}$ and it is higher than that ($\sim 80n_{\text{cr}}$) with pre-plasma. As a result, in the case of $40n_{\text{cr}}$ without pre-plasma, the laser directly interacts with the higher density plasma and fast electrons of the low-energy component are generated less than those with pre-plasma [1].

Figure 3. Electron density profiles with and without pre-plasma for (a) $n_{\text{foam}}=20n_{\text{cr}}$ and (b) $n_{\text{foam}}=40n_{\text{cr}}$. Red and green lines indicate the cases with pre-plasma and without pre-plasma, respectively.

2.2. Foam Structure
The foam is actually constructed with a solid CH and voids. After laser irradiation, the solid CH becomes plasmas, which are quickly diffused into voids. Thus the density of the foam is defined as an averaged density and the foam density is assumed to be uniform in previous research [1]. However, the foam structure should affect the fast electron generation if the size of voids is enough large not to fill them with plasmas instantaneously. So, we investigate effects of the foam structure on fast electron generation. In one-dimensional simulations, the foam structure can be imitated by dense CH plasmas.
and vacuum gaps in turn. Fast electrons with energy of ~1 [MeV] can heat the core most efficiently [2], and they are generated most in previous simulations when the foam density is 20n_{cr}. So we choose the foam with n_{foam}=20n_{cr} for foam structure investigations, and set the density of the dense CH plasma to 100n_{cr} and the length of it four times longer than that of the vacuum gap. Simulations are performed with the different gap lengths, namely 2, 4 and 8[μm], and other parameters are same as that of previous simulations.

Figure 4 shows time evolutions of electron beam intensity and time-integrated energy spectra of fast electrons. If the width of the vacuum gap is wider, the rising of electron beam intensity occurs at later time. Looking at spectra, as the width of the gap is wider, less electrons of the low-energy component are generated and more electrons of the high-energy component are generated. It takes longer time to fill the vacuum gap by plasma diffusion when the length of the gap is longer, and then an electrostatic sheath field is maintained for longer time. While the electrostatic sheath field is preserved, fast electrons of the low-energy component are reflected by this field and cannot pass through the vacuum gap. These reflected electrons of the low-energy component are propagated to opposite direction of laser irradiation, accelerated by the reflected laser. Then they are reflected again by the electrostatic sheath field in front of the pre-plasma edge. As a result, if the width of the gap is wider, the electrostatic sheath field is maintained for longer time and more fast electrons of the high-energy component are generated.

![Figure 4](image)

Figure 4. (a) Time evolutions of fast electron beam intensity. (b) Time-integrated energy spectra of fast electrons. In two figures, red, green, blue and purple lines indicate that no gap, the gap size of 2, 4 and 8[μm], respectively.

3. Summary
We have investigated effects of the pre-plasma on the fast electron generation for low-density foam coated targets in fast ignition. Fast electron generation in the case of n_{foam}=20n_{cr} with pre-plasma is same as that without pre-plasma. However, in the case of n_{foam}=40n_{cr} with pre-plasma, fast electrons are generated more than those in the case without pre-plasma. Even such difference, we can conclude that effects of the pre-plasma are not significant for the fast electron generation. We have also investigated effects of the foam structure and found that the number of fast electrons of the low-energy component decreases, but these of the high-energy component increases when the length of the vacuum gap is 8 [μm]. Even so, we can also conclude that the foam structure does not significantly affect on the fast electron generation.

References
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