35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.**32D**, P-5.121 (2008)

Generation Control for Fast Electron Beam in Fast Ignition

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1. Introduction

The FIREX-I project aims to demonstrate that the imploded core could be heated up to the ignition temperature, 5[keV]. Efficient heating mechanisms and achievement of such high temperature have not been, however, clarified yet, and we have been promoting the Fast Ignition Integrated Interconnecting code (FI^3) project to boldly explore fast ignition frontiers [1-3]. As the pulse duration of the heating laser is designed to be 10[ps] in FIREX-I instead of 750[fs] in previous experiments, it's long enough even for heavy Au preformed plasmas to be pushed and compressed by the ponderomotive force. Thus the profile steepening occurs and the electron density is locally maximized at the laser front. As the heating laser directly interacts with the sharp edge overdense plasma, fast electrons are mainly generated by the longitudinal ponderomotive force, whose magnitude is proportional to the skin depth [4]. It was confirmed by simulations that the fast electron beam intensity well scales as the inverse square root of the electron density [5]. As the electron density goes up, less fast electrons are generated by the weakened force and the beam intensity is also reduced. We have performed FI^3 integrated simulations in such conditions with different scale length (L_f) of preformed plasma and evaluate the core temperature. In the case of short L_f, the average core temperature quickly rises but shortly saturates because the preformed plasma is snowplowed and the electron density increases; consequently fast electron beam intensity decreases according to the scaling law. In the long L_f case, the beam intensity is maintained and the core heating is sustained for a long time, thus the core reaches higher average temperature. So adequate preformed plasma is needed for efficient core heating in FIREX-I experiments. It is emphasized that the characteristic of dependence of core heating on L_f in long pulse lasers is completely different from that in short pulse lasers [3].

The preformed plasma is generated by a pre-pulse of the heating laser, but the pre-pulse characteristic is the property of the laser device itself and is not easily controllable. To control the preformed plasma density, we propose to coat an inner surface of the cone target with low-density materials, such as aerogel. We can prevent the preformed plasma from being snowplowed to extremely high density at the laser front, and expect that the fast electron beam intensity will be kept at the high level during laser irradiation.

2. Low Density Aerogel and Fast Electrons

We set up the heating laser to λ_L=1.06[μm], τ_{rise}=375[fs], τ_{flat}=10[ps], τ_{fall}=375[fs], $I_L=10^{20}$[W/cm^2], and the Au-cone tip to 500n_{cr}, real mass, Z=30, 10[μm] flattop plasma. We put the SiO_2 aerogel plasma (A=20, Z=10, 40[μm] thickness) with different densities (n_{aero}) 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.

Time evolutions of fast electron beam intensity with n_{aero}=2, 10, 20, 50n_{cr} are shown in Fig.1. As the heating laser intensity is 10^{20}[W/cm^2] and the fast electron beam intensity is around 3×10^{19}[W/cm^2] at the maximum level, the instantaneous energy conversion rate from laser to electron can be roughly estimated as 30%. Time averaged fast electron energy spectrum also with n_{aero}=2, 10, 20, 50n_{cr} are shown in Fig.2. If the density of the aerogel plasma is below the relativistic critical density (n_{aero}=2n_{cr}), the heating laser can penetrate into the aerogel plasma and generates high energetic electrons. However it directly interacts with the extreme overdense Au plasma after 2[ps]. So the fast electron beam intensity is quickly reduced and fast electrons with moderate energy cannot be generated so much. When the aerogel density is high enough that electrons in the aerogel plasma are snowplowed at the laser front (n_{aero}=50n_{cr}), the fast electron beam intensity is suppressed at a low level and the

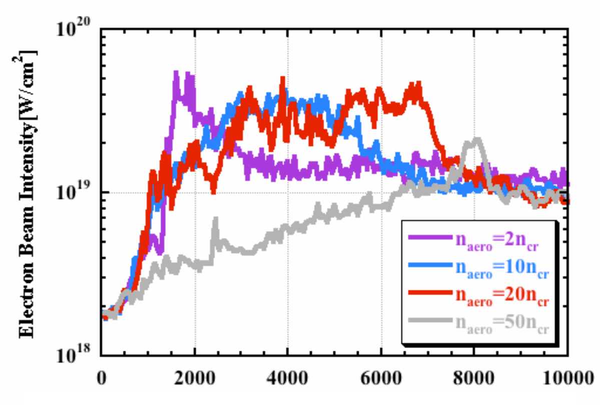

Fig. 1 Time evolutions of fast electron beam intensity. Purple, blue, red and gray indicate the aerogel density of 2, 10, 20 and 50n_{cr}, respectively.

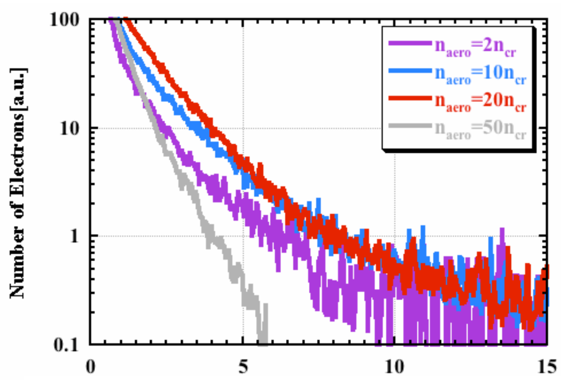

Fig. 2 Time averaged fast electron energy spectrum. Purple, blue, red and gray indicate the aerogel density of 2, 10, 20 and 50n_{cr}, respectively.

fast electron slope temperature is also low from the beginning. But the fast electron beam intensity is sustained at the nearly peak level until 5[ps] with n_{aero}=10n_{cr} and 7[ps] with n_{aero}=20n_{cr} because the electron density at the interaction region does not increase so much. In there cases, much fast electrons whose energy is efficient for core heating are generated. As the core heating is greatly affected by not only the beam intensity but also the energy spectrum of fast electrons, hence the aerogel density, we have performed FI^3 integrated simulations to estimate core temperatures. Time evolutions of core electron temperatures, which are averaged over the dense region (ρ>10 [g/cm^3]), are shown in Fig. 3 for different aerogel densities. In the case of n_{aero}=2n_{cr}, the core temperature quickly increases until 3[ps], then the pace becomes slow down due to reduction of the fast electron beam intensity. The core temperature gradually increases from first to last in the case of n_{aero}=50n_{cr}. On the other hand, temperature increments are maintained until 6[ps] with n_{aero}=10n_{cr} and 7.5[ps] with n_{aero}=20n_{cr}, and the core temperature reaches 1.4[keV] and 1.8[keV], respectively. Checking ion density profiles, it was found that the aerogel plasma is pushed by the ponderomotive force and plunged into the Au cone tip plasma at that time in both cases. The heating laser, thereafter, interacts with the overdense Au plasma and it causes reduction of the fast electron beam intensity, hence slow down of temperature increment. To prevent the aerogel plasma from being swept away during irradiation of the heating laser, we put the thick aerogel plasma (60[μm] thickness). Time evolutions of fast electron beam intensity with n_{aero}=10, and 20n_{cr} are shown in Fig.4 as solid lines. The drop off time is successfully extended with the thick

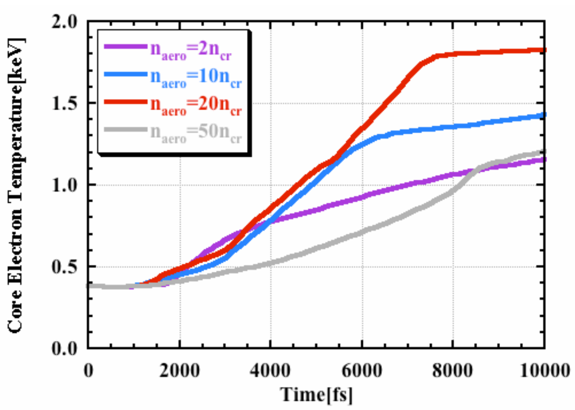

Fig. 3 Time Evolution of average core electron temperature for ρ>10[g/cm^3]. Purple, blue, red and gray indicate the aerogel density of 2, 10, 20 and 50n_{cr}, respectively.

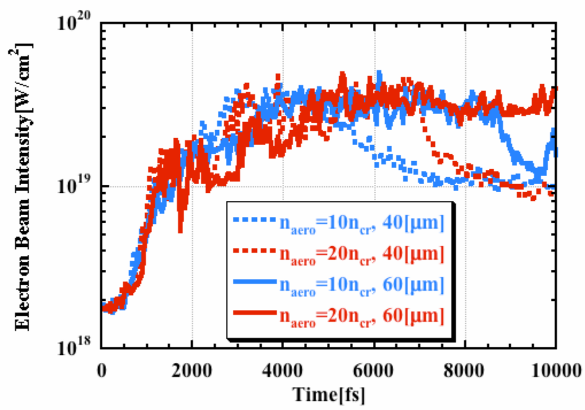

Fig. 4 Time evolutions of fast electron beam intensity with 40[μm] (dash) and 60[μm] (solid) thicknesses. Blue and red indicate the aerogel density of 10 and 20n_{cr}, respectively.

aerogel plasma. Even 60[μm] thickness, the aerogel plasma is completely plunged at t=8[ps] in the case of $n_{aero}=10n_{cr}$, but it's enough for the case of $n_{aero}=20n_{cr}$.

3. Optimum Aerogel Density and Thickness

To avoid the heating laser anomalously penetrating into the aerogel plasma, the density of the aerogel should be higher than that of relativistic critical density, namely $8.6n_{cr}$ for $I_L=10^{20}$[W/cm^2]. The density of the aerogel should be low enough to prevent electrons in the aerogel plasma from being snowplowed to extremely high density at the laser front. The aerogel plasma should also be so thick to stay there until the heating laser is turned off, and lower density requires thicker coat. But the thick aerogel plasma leads to less efficient heating due to a long travel distance of fast electrons to the core. Thus the optimum aerogel density and thickness for core heating may exist. Maximum core electron temperatures as a function of the aerogel density for different thicknesses are shown in Fig. 5. Under these parameters, the core electron temperature can reach 2.1[keV] with $20n_{cr}$, 60[μm] long aerogel.

We can conclude that we can appropriately control the fast electron generation for core heating with the low-density aerogel coated cone targets.

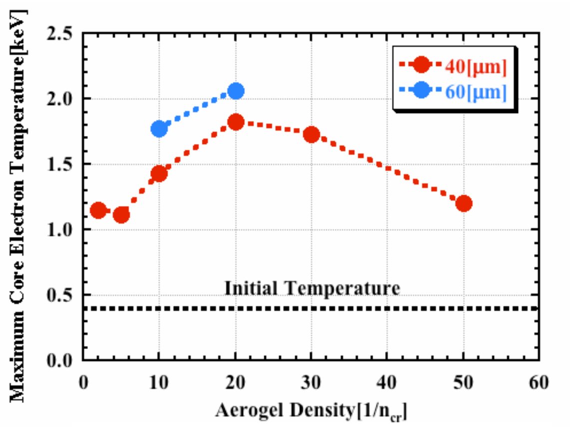

Fig. 5 Maximum core electron temperatures as a function of the aerogel density. Red and blue indicate the aerogel width of 40 and 60[μm], respectively.

Acknowledgments

This work was supported by MEXT, the grant-in Aid for Creative Scientific Research (15GS0214).

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