Effects of Multi Laser Beams for Fast Electron Generation

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1. Introduction

The FIREX-I (Fast Ignition Realization EXperiment project, Phase-I) project aims to demonstrate that the imploded core could be heated up to 5 keV, and integrated experiments for FIREX-I, in which heating is combined with implosion, have been carried out at Osaka University. 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 [1-6]. The heating laser LFEX (Laser for Fast ignition EXperiment) was designed to consist of four beams for FIREX-I, but one or two beams were actually available and lack of the heating energy was serious problem in previous experiments. In next integrated experiments, four beams will be operational to maximize the heating energy. Four beams can be combined with two different ways. One way is a train of four pulses and the other is an overlap in time. The pulse train method has no interference between beams, but maximum energy that we can get is limited by a damage threshold of laser media against one beam even we want as much energy as possible. If we use the time overlap method, we can get four times higher maximum energy than that by the pulse train method with the same damage threshold. Combining four beams with the time overlap method, however, would introduce a beam-interference pattern, which could affect laser plasma interactions and fast electron generations, hence the energy coupling from the heating laser to the core. Therefore we must decide which beam combining method is better, namely lower laser energy without the interference or higher laser energy with the interference. Thus we have been investigating interference effects of multi laser beams for the fast electron generation with the use of 2D PIC code, and have also evaluated these effects on core heating with the use of FI^3.

2. Interference of Multi Laser Beams

In the LFEX system, four laser beams are derived from one seed beam, amplified by each laser media beam line, compressed by each diffraction grating, and finally focused on the target by one large off-axis parabolic mirror. Therefore, each laser beam can be assumed to have coherent phase, and four beams are coherently combined [7]. If two coherent laser beams are injected onto the target with the incident angle ±θ, the size of interference pattern (*L*) can be estimated with the following equation [8]:

$$L = \frac{1}{2}\frac{\lambda_L}{\sin\theta} \tag{1}$$

where λ_L is the laser wavelength.

To combine the laser beams in the LFEX system, one beam must be transversely shifted by 20 cm during 4 m longitudinal propagation. As the incident angle is calculated as 2.86° and the wavelength of LFEX is 1.06 μm, the interference size is estimated to be 10 μm with Eq. (1). The spot size of LFEX on the target is expected to be 40 μm and it is larger than the interference size. Thus fast electron generations by the LFEX laser would be affected by the beam interference. The profile of the laser electric field amplitude is shown as the typical interference pattern in Fig. 1 when laser propagations for two flattop Gaussian beams aimed to the origin with λ_L=1.06 μm, ϕ_{FWHM}=10 μm, θ=±15° are simulated. In this case, the interference size can be estimated to be 2.05 μm by Eq. (1), and the simulated size agrees quite well.

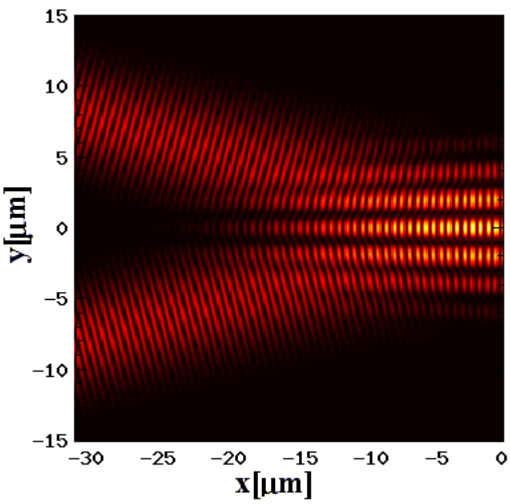

Fig.1 The profile of the laser electric field amplitude for two flattop Gaussian beams.

3. Fast Electron Characteristics

To investigate effects of the laser beam interference on fast electron characteristics, the Au (A=197, Z=30) cone tip is introduced as a 10 μm thickness, 35 (±17.5) μm wide, 20n_{cr} flat profile with a preformed plasma, which has a exponential profile of the scale length (L_{pre}=1 or 4 μm) with density from 0.1 to 20n_{cr} in 2D PIC simulations. The *p*-polarized heating laser is set to λ_L=1.06 μm, ϕ_{FWHM}=10 μm, $\tau_{rise/fall}$=5 fs, τ_{flat}=600 fs, and I_L=10^{20} W/cm^2, θ=0° as the single beam or I_L=5×10^{19} W/cm^2, θ=±7° as the double beam. Fast electrons are observed at

4.5 μm from the right plasma edge and ±15 μm wide. To ignore a circulation of fast electrons, we introduce an artificial cooling region (1 μm width), in which fast electrons are gradually cooled down to the initial temperature, behind the observation point, top and bottom region of the flattop plasma.

Electron density profiles at 500 fs are shown in Fig. 2 for (a) L_{pre}=1 μm, the single beam, (b) L_{pre}=1 μm, the double beam, (c) L_{pre}=4 μm, the single beam, and (d) L_{pre}=4 μm, the double beam. In the case of the single beam with short scale length preformed plasmas, plasmas near the center are strongly pushed by the Ponderomotive force because the laser beam is Gaussian, and hole boring is clearly found. On the other hand, the interference of the double beam makes individual beams with narrower width and higher peak intensity than that of the single beam. They deeply drill plasmas and make holes with a small diameter. Fast electrons generated at the wall of smaller holes should have larger energy and divergent angle. Thus the double beam irradiation would cause lower energy coupling rate from the heating laser to the core than that of the single beam. In the case of the double beams with long scale length

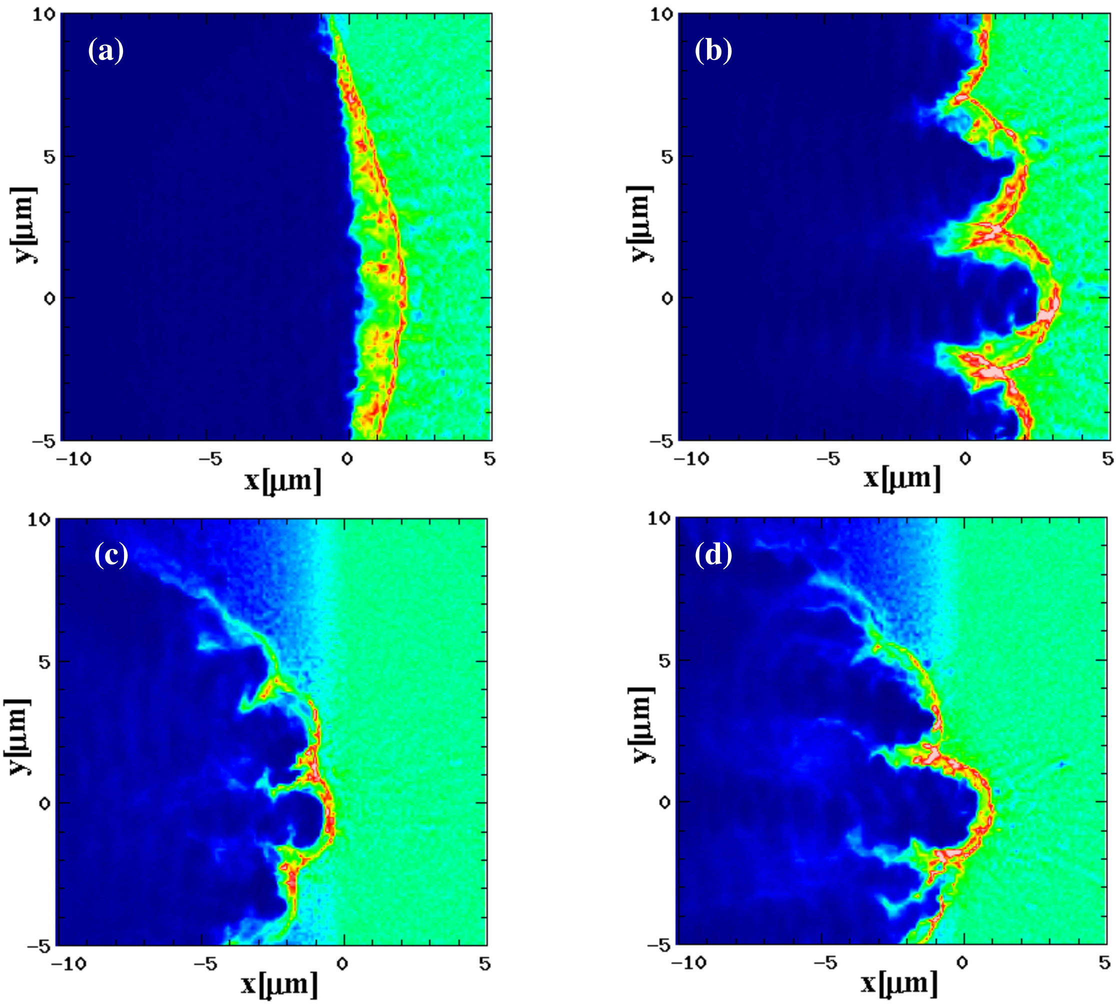

Fig.2 Electron density profiles at 500fs for different pre-plasma scale lengths and the single/double beam.

preformed plasmas, interference patterns are still imprinted onto preformed plasmas and same size holes are drilled. On the other hand, the filamentation of the single laser pulse occurs as the laser must propagate longer distance in underdense plasmas. The size of each broken up filament is smaller than that of the interference patterns, so fast electrons diverge much more compared to the double beam case. It leads to worse coupling efficiency than that of the double beam.

4. Integrated Simulation for Core Heating

Using observed fast electrons by the 2D PIC code as the time-dependent source for 2D Fokker-planck code, we have performed FI[3] integrated simulations to estimate core heating performance by fast electrons. Time evolutions of core electron temperatures, which are averaged over the dense region (ρ>5 g/cm^3) by weighting with DD reaction rate, are shown in Fig. 3 for all four cases. If the preformed plasma is short, small holes are drilled corresponding to the interference in the double beam case and it leads worse heating efficiency than that of the single beam case. On the other hand, heating efficiency in the single beam case is lower than that in the double beam case when L_{pre} is 4 μm.

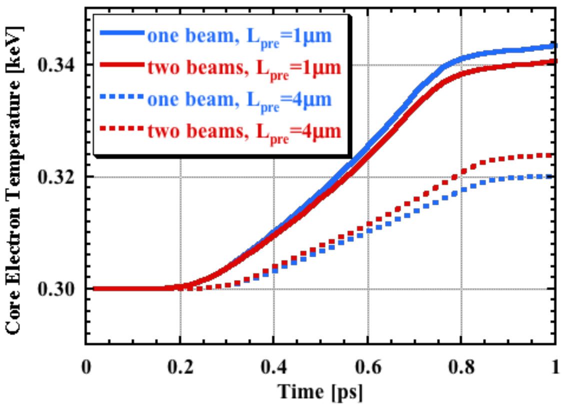

Fig.3 Time evolutions of core electron temperatures for all four cases.

Acknowledgments

This work was supported by MEXT, Grant-in-Aid for Scientific Research (C)(22540511).

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