24F03

Interference Effects of Laser Beams for Fast Electron Generation
高速電子生成におけるレーザービームの干渉効果

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Four beams of LFEX will be combined to maximize the heating energy for next incorporated FIREX-I experiments. Overlapping four beams, however, would introduce a beam-interference pattern, which could affect core heating. Thus interference effects of laser beams for fast electron generation is investigated with the use of 2D PIC code. When the scale length of the preformed plasma is 1 μm, the beam-interference causes enhancement of fast electron divergence. On the contrary, the beam-interference suppresses the filamentation, hence the divergence if the scale length is 4μm.

1. Introduction

FIREX-I (Fast Ignition Realization EXperiment project, Phase-I) [1] aims to demonstrate that the imploded core could be heated up to 5 keV, and incorporated experiments for FIREX-I, in which heating is combined with implosion, have started at Institute of Laser Engineering, 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 [2,3]. First series of the incorporated experiments was performed in 2009, and only 30-fold enhancement in neutron yield, which was ~ 1/30 smaller than that in 2002 experiments [4], was achieved and lower energy coupling from the heating laser to the imploded core was expected [5]. The heating laser LFEX (Laser for Fast ignition EXperiment) was designed to consist of four beams, but only one beam was actually used and lack of the heating energy was serious problem in 2009 experiments. Next incorporated experiments will use four beams to maximize the heating energy. Combining four beams, however, would introduce a beam-interference pattern, which could affect the coupling rate from the heating laser to the core. Thus we have been investigating interference effects of laser beams for fast electron generation with the use of 2D PIC code.

2. Interference of Laser Beams

Four beams can be combined with two different ways. One way is a train of four pulses in time, and the other is an overlap in space. The time train method has no interference of beams, but maximum energy that we can get is limited by a damage threshold of laser media for one beam even we want as much energy as possible. If we use the space overlap method, we can get 4 times higher maximum energy than that by the time train method with the same damage threshold, but the beam interference occurs. Therefore we must decide which beam combining method is better, namely lower energy without interference or higher energy with interference. Amplitudes of laser electric field are shown in Fig. 1 for two Gaussian beams (λ_L=1

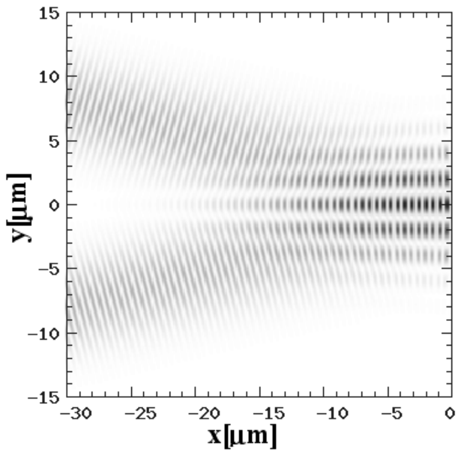

Fig. 1. Typical interference patterns

μm, ϕ_{FWHM}=5 μm and θ=±15°) that are injected toward the origin, and typical interference patterns can be seen. Assuming two beams with incident angles of +θ and -θ are injected, interference patterns are stably built up like as a standing wave. The pattern length L can be calculated by

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

Parameters for Fig. 1 leads to L=1.89 μm and it agrees well with the length in the figure.

As one beam of LFEX must be shifted with 20 cm by 4 m to aim the target and λ_L=1.06 μm, it leads that θ=2.86° and L=10 μm. This length is less than an expected spot size 40 μm, and fast electron generation would be affected.

3. Characteristics of Fast Electrons

In 2D PIC simulations, 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 up to 20n_{cr}. The proton-electron mass ratio is set to1836, and initial temperatures of electrons and ions are set to 10 and 1 keV, respectively. The heating laser is set to λ_L=1.06 μm, $I_L=10^{20}$ W/cm^2, ϕ_{FWHM}=10 μm, $\tau_{rise/fall}$=5 fs, τ_{flat}=600 fs and θ=0° as a single beam, and $I_L=5\times10^{19}$ W/cm^2 and θ=±7° (This leads to L=4.3 μm) as double beams. Fast electrons are observed at 4.5 μm from the right plasma edge. To ignore a circulation of fast electrons, we introduce three artificial cooling regions, in which fast electrons are gradually cooled down to the initial temperature, behind the observation point and at top/bottom plasma boundaries (2 μm width).

Electron density profiles with L_{pre}=1 μm at 500 fs are shown in Fig. 2 for (a) single beam and (b) double beams. In the case of the single beam, plasmas near the center (y=0 μm) 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 double beams makes individual beams with narrow width (~4 μm) corresponding to L 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 divergent angle. Thus the double beam irradiation causes lower energy coupling rate from the heating laser to the core than that of the single beam.

Electron density profiles with L_{pre}=4 μm at 500 fs are shown in Fig. 3 for (a) single beam and (b) double beams. In the case of the double beams, interference patterns are still imprinted onto preformed plasmas and holes that have almost same size with the L_{pre}=1 μm case are drilled. As the laser must propagate longer distance in underdense plasmas than the L_{pre}=1 μm case, the filamentation of the single laser pulse occurs. 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 double beams contrary to the L_{pre}=1 μm case.

To compare the core heating properties between the single and double beams, we will perform integrated simulations by FI[3].

Acknowledgments

This work is partially supported by JSPS Grant-in-Aid for Scientific Research(C)(22540511).

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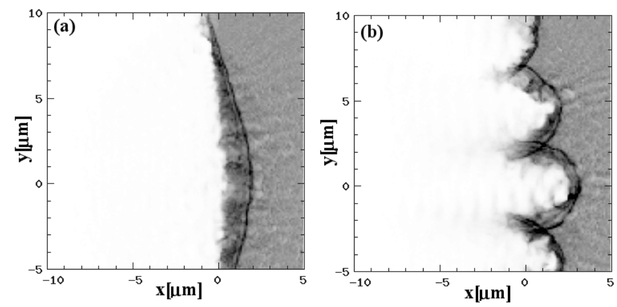

Fig. 2. Electron density profiles with L_{pre}=1 μm for (a) single beam and (b) double beams

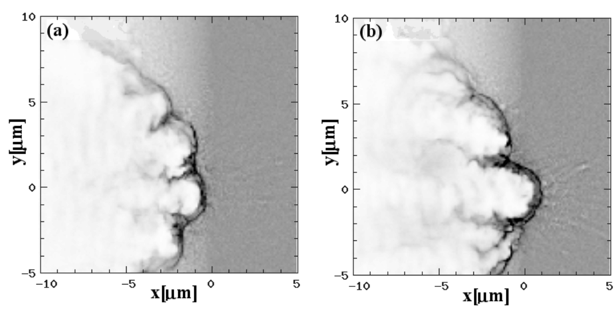

Fig. 3. Electron density profiles with L_{pre}=4 μm for (a) single beam and (b) double beams