J. Plasma Fusion Res. SERIES, Vol.7 (2006) 142-144

Energetic Ion Generation by an Ultra-Intense Laser Pulse on Various Plasma Foil Targets

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(Received: 4 October 2004 / Accepted : 24 May 2005)

Abstract

High energetic ion generation from thin foil targets irradiated by 30 fs laser pulses at intensity 10^{20} W/cm^2 has been studied as a function of various targets with various concaves. We have demonstrated an increased acceleration and higher ion energies for the targets with triangle concave by using particle-in-cell (PIC) simulations. The optimum target plasma conditions for the maximum ion acceleration are found. Mechanism of fast (multi-MeV) ion acceleration in the rear of the targets with triangle concaves is analyzed.

Keywords:

intense ultra-short laser pulse, fast electron generation, fast ion generation

1. Introduction

Fast particles generated by laser-plasma interactions can be used in many applications, from manufacturing to medicine and even for the initiation of tabletop nuclear reactions. Fast ion generation by the interaction of an ultra-short high intensity laser pulse with a plasma has been demonstrated in recent theoretical [1] and experimental [2] papers, with maximum ion energies of up to 55 MeV having been observed. Different methods of fast ion generation have been proposed for both gas [3] and solid [4] targets. It has been shown that the energy of a laser pulse can be efficiently converted into fast ion energy using foil targets. Simulation [5] has shown that the mechanisms for generating ion acceleration are the ambipolar field and the Coulomb explosion. It has also been shown that fast electrons ejected from the foil by the laser field create a strong ambipolar field, which is the main source of acceleration of ions ejected from the back of the foil. Thus a collimated ion beam can be produced by focusing an intense laser onto the surface of a solid film. Fast ions accelerate normally to the foil surface because this is the direction of the ambipolar field [6]. We have demonstrated fast ion generation to get a most energetic proton generation for the slab target, the target with triangle concave and the target with circle concave [7]. Most experimental high power lasers produce a pre-pulse, which generates a plasma layer with a smooth density gradient on the surface of the foil. In this paper, we attempt to study fast ion bunch generation by ultra-intense laser pulse in front plasma layers with smooth density gradients and rear plasma layers with triangle concaves.

2. PIC simulation

We apply a PIC method to simulate the interaction of a plasma layer with an intense ultra-short laser pulse. The method is based on the electromagnetic PIC and is appropriate for analysis of the dynamics of over dense plasmas created by arbitrarily polarized, obliquely incident laser pulses. The 2D (using a Cartesian coordinate system) relativistic, electromagnetic code is used to calculate the interaction of an intense laser pulse with an over-dense plasma. Simulations are performed for laser wave length of 1.06 μm and laser intensity 10^{20} W/cm^2 with a 30 fs pulse width. The transverse focal spot profile is Gaussian with a diameter of 4 μm. The background electron density is 20 n_c. Simulations are made for target thickness of 3 μm with 1 μm density gradient. Simulation box is 12 μm wide 70 μm long. The time step is chosen to be $0.1/\omega_L$ where ω_L is the laser frequency, and the grid size is chosen to be 0.2 c/ω_L where c is the speed of light. The time step normalized by the electron plasma frequency becomes about 0.447 which is large for the simulation, but the simulation results are valid because that the total energy is conserved in the simulation time. The number of spatial grids and particles are 2000×360 and 10^6, respectively.

3. Fast ion production from the rear surface of the foil

Ions begin to accelerate as soon as the ambipolar field is generated. We note that ions are ejected from both sides of the target but fewer fast electrons, and

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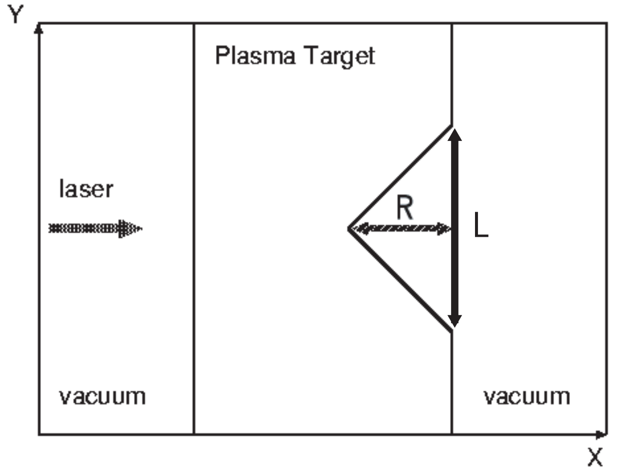

Fig. 1 Profile of a target containing a concave.

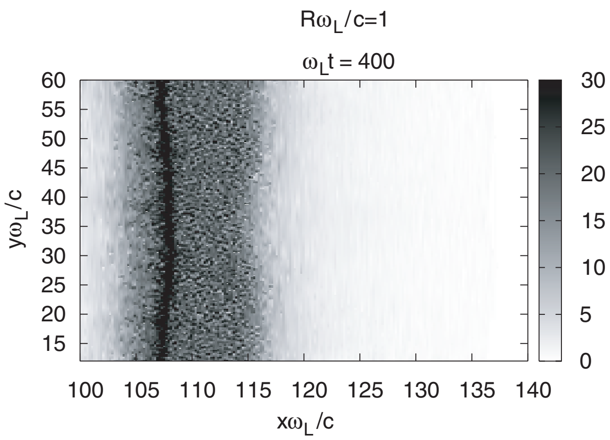

Fig. 2 Spatial distribution of ion density.

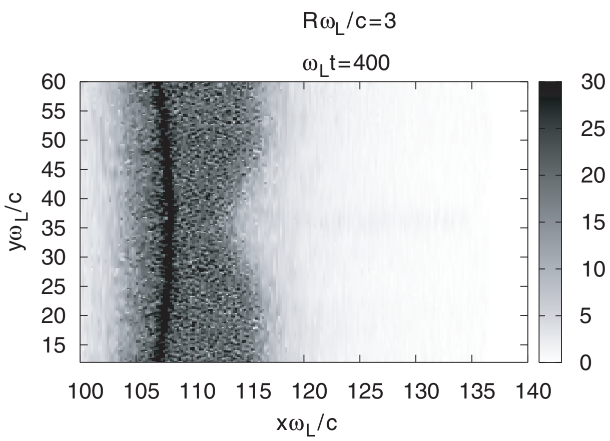

Fig. 3 Spatial distribution of ion density.

hence fewer ions, are ejected from the front side. Thus, we only consider the rear side of the target. In Fig. 1, profile of a target containing a concave is shown. The width of the concave L is fixed at 4 μm and the depth R is changed. In Figs. 2-4, spatial distributions of ion density are shown at $\omega_L t = 400$ from the targets containing various concave depth. In Fig. 5, average ion energy is shown for the concave depth R. Figure 6 shows how the

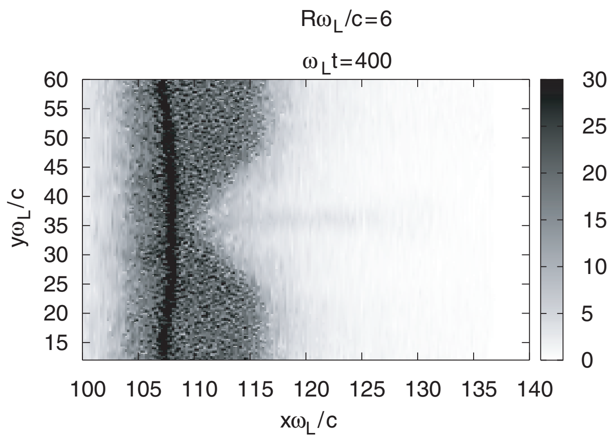

Fig. 4 Spatial distribution of ion density.

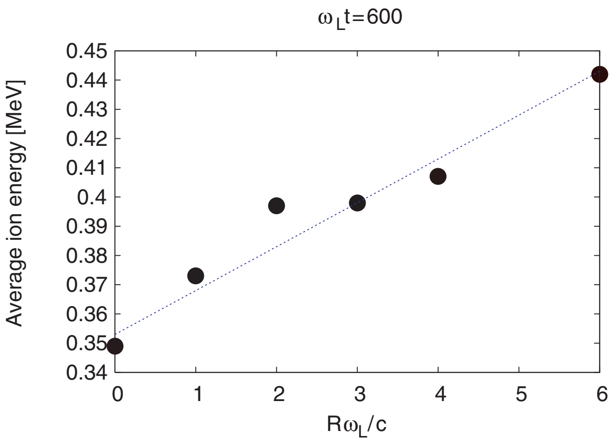

Fig. 5 Average ion energy vs $R\omega_L/c$.

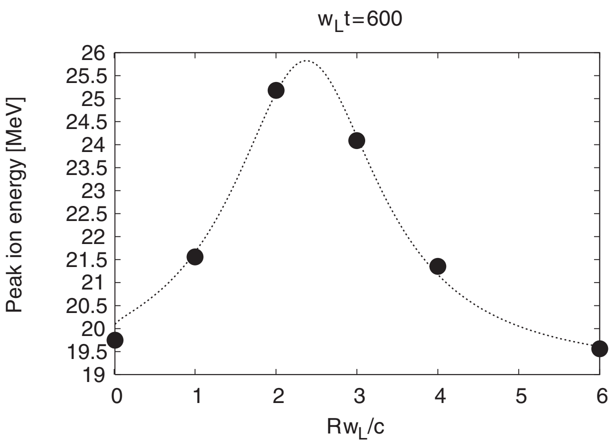

Fig. 6 Peak ion energy vs $R\omega_L/c$.

peak ion energy is changed from 19.8 to 25.2 MeV as the concave depth is increased from 0 to 1 μm.

4. Conclusion

We have shown numerically that a laser pulse of intensity 10^{20} W/cm^2 and duration of 30 fs will generate an intense ion bunch that propagates directly from the rear surface of the foil. It is clear that the peak ion energy is maximum at $R\omega_L/c = 2.3$ in Fig. 6. The physical mechanism of the existence of maximum ion energy will be the difference of the electron density distribution. The more detailed explanation will be appeared in forthcoming paper.

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