High-Energy Ion Generation by an Intense Laser Pulse Irradiated on Overdense Plasmas

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Abstract: Particle-in-Cell (PIC) simulations of fast particles produced by a short laser pulse with duration of 40fs and an intensity of 10^{20}W/cm^2 interacting with a foil target are performed. The experimental process is numerically simulated by considering a elliptic concave target illuminated by an ultra-intense laser. We have demonstrated increased acceleration and higher ion energies for elliptic concave targets. 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 concaves is analyzed.

Key word: Particle-in-Cell simulation; ultra-intense laser pulse; Energetic ion, elliptic target

1. Introduction

The generation and transportation of energetic particles stimulated by high intensity pulse laser have been developed along the research on the laser-plasma interaction, and many theoretical results have been achieved [1-5]. In practical utilization, these theories have an important and potential application in various fields, such as the x-ray lasers, fast ignition in laser fusion [4-9] and laser-plasma accelerator [4] as well as the fast ion and proton generation. Laser intensity has been exceeded by an available margin and the value of electron quiver energy becomes relativistic. When propagation is ready in plasma, the radiation of ultra intense laser displays the effects on relativistic nonlinearities. However, the most of previous works were limited in underdense plasma. In an overdense plasma configuration, the role of the nonlinearity becomes much more important. In this paper, we indicate the recent results of two-dimensional PIC (Particle-in-Cell) simulation of the ultra intense laser propagation in overdense plasma.

The focused laser intensity is typically expressed in terms of the characteristic parameter a, which is the classical normalized momentum of electron quivering in the laser electric field [6]: $a = eE_0 / mc\omega_0 = 0.85\times 10^{-9}\lambda_0\sqrt{I}$, here e is the electron change, E_0 is the maximum electric field, m is the electron mass, ω_0 is of the laser frequency, c is the speed of light , I is the laser intensity in W/cm^2 , λ_0 is the laser wavelength in microns. For a >1, atoms are easily ionized by optical field ionization, and free electrons can quiver within a laser focus, relativistically with ponderomotive force: $F_p = -\left(n_e mc^2 / 4\right)\nabla a^2$ .where n_e is the electron density. When an ultra-intense laser pulse interacts with a plasma surface, the temperature of fast electrons driven into the plasma is dominated by the oscillating component of the ponderomotive force. The temperature (eV) of fast electron is related to the ponderomotive potential and is given by

$$k_B T \approx \Phi_{pond} = (\gamma - 1)mc^2 = \left\{\left[1 + I_{18}\lambda_\mu^2 / \alpha\right]^{1/2} - 1\right\}mc^2 \qquad (1.1)$$

where I_{18} is the laser intensity in units of $10^{18} W/cm^2$,α is 1.37 for circular polarized light, and 2.74 for linear polarized light[7].

The acceleration electrostatic field E_s at the rear surface can be expressed as [3, 4]

$$\frac{eE_s}{mc\omega_0} == \sqrt{2\frac{n_0^h k_B T}{mc^2 n_c}} \qquad (1.2)$$

where n_0^h is the hot electron density at the rear surface and ,$k_B T$ is their effective temperature, n_c is critical density. It is clear that the distribution of hot electron current will affect the contour of E .

2. Ion- acceleration

Plasma ions can be accelerated to high energies by the formation of an electrostatic sheath due to charge displacement. The latter results from the initial preferential acceleration of electrons; the heavier ions are left behind due to inertia. Among the many mechanisms that can accelerate the electrons are: thermal expansion, plasma waves, ‘‘$J\times B$ heating’’ or ‘‘vacuum heating.’’[8] Energetic ions have been accelerated by thermal expansion in long-pulse (low power) laser-plasma experiments for over a decade. In this study, we investigate in the rear surface by using PIC to achieve high maximal ion energy. In this case electrons accelerated by the laser have exited the target, and from an electron cloud in vacuum at the rear surface of the target. The ions at the rear target surface are pulled out of the target by the electron cloud. The angular spread of the spread of the energetic ions is quite small.

3. PIC simulation

In solid target experiments with focused intensities exceeding 10^{20}W/cm^2, high-energy electron and ion generation has been observed on the rear surface of the target [4].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 overdense plasma. Calculations with ion mobility allowed were carried out for plasma with the initial density profile.

In order to simulate the interaction process of ultra intense laser and plasma by numeral technology, suppose one bunch of ultra-intense laser is vertically illuminating from the air vacuum to the even plasma target with slab and elliptic concaves, the incidence plane is within the *x, y* plane and laser pulse is in the form of Gaussian shape.

Simulations were performed for laser wave length of 1.0 μ m and laser intensity I=10^{20} W/cm^2. The maximum electron density is 4n_c, where n_c is the critical density. the constant plasma density was in the range of 2.0μm.

4. Results

In this simulation, we assume that the length *R* of the concave target is constant at 2.0μm and the depth D of the concave target is changed from 0 to 0.8. In Fig.1 and Fig.2, spatial distributions of proton densities at $\omega_L t$ =480 are shown for the slab and the elliptic concave target with D= 0~0.8, respectively.From these figures, bunches of ion can be focused at a given point in space through the curvature of the rear surface of the foil. Simultaneously, the collection efficiency and the maximum Ion energy become more obvious with a deeper of the concave shape as shown in Fig. 3. The collected ion beams with high energy thus could play a large role in realising the fast ignition of inertial confinement fusion (I C F).

5. Conclusions

We have shown numerically that a laser pulse with an intensity of 10^{20} W/cm^2 and duration of 40 fs will generate an intense ion bunch that propagates directly from the rear surface of the foil. Finally, We obtain a maximum ion energy of 20.8 MeV at $\omega_L t$ =800 with the slab target, a maximum ion energy of 28.1 MeV at $\omega_L t$ =800 with the elliptic concave target from Fig.3.

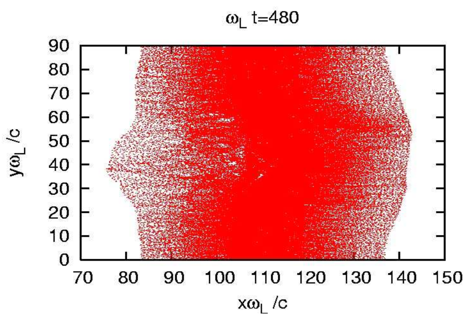

Fig.1. Ion distribution in rear space(*x, y*) from a slab target at D=0 and $\omega_L t$ =480

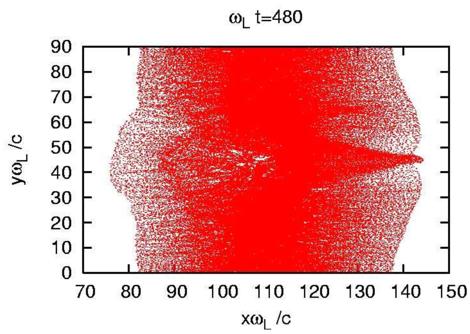

Fig.2. Ion distribution in rear space(*x, y*) from a elliptic concave target at D=0.8 and $\omega_L t$ =480

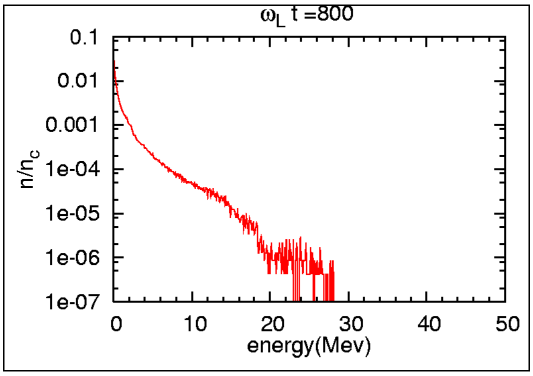

Fig.3. Maximum ion energy distribution from a elliptic concave target at D=0.8 μm and $\omega_L t$ =800

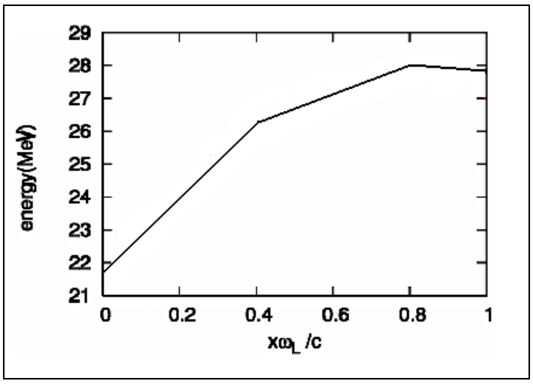

Fig.4. Maximum ion energy distribution from a elliptic concave target at D= 0~1.0 μm.

Figure 4 shows the maximum ion energy as the concave depth is increased from 0 to 1.0μm. We can conclude that there is maximum ion energy for a specific depth of the slab and the elliptic concave target. The optimum target condition with a elliptic concave target for the maximum ion energy has thus been found.

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References

[1] C.Wilks, *Phys. Fluids* **B5**, 2603 (1993).

[2] K.A.Tanaka, R.Kodama, H.Fujita *et al*., *Phys. Plasmas* **7**, 2014 (2000).

[3] A .Pukhov. , *Phys. Rev. Lett* . **86**, 3562 (2001).

[4] S.C.Wilks, A.B.Langdon, T.E.Cowan *et al*., *Phys. Plasmas* **8**, 542 (2001).

[5] Y.Sentoku, T.V.Liseikina, T.Zh. *et al*., *Phys. Rev.* **E 62**, 7271 (2000).

[6] A.A.Andreev, K.Yu.Platonov, T.Okada and S.Toraya, *Phys. Plasmas* **10**, 220 (2003).

[7] S.Okihara, Y.Sentoku et al.,Jnp J.Nuclear Science and Technology 39,1(2002)

[8] S.P.Hatchett et al., Phys.Plasmas **7**,2076 (2000)

[9] T.Okada, Y.Mikado, T.Kitada, M.Sugie and A.A.Andreev, *Jpn J. Appl. Phys*. **44**, 1431 (2005).