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Energetic Proton Acceleration and Bunch Generation by Ultraintense Laser Pulses

T.Okada, Y.Mikado, K.Ogawa, M.Sugie and A.Abudurexiti

TokyoUniversity of Agriculture and Technology, Tokyo, Japan

Abstract

Energetic proton acceleration from concave targets, the front of which were irradiated with 40 fs laser pulses with an intensity of 10^{20} W/cm^2, has been studied as a function of the depth of the concave shape. Three kinds of targets, a triangular concave target, a circular concave target and a parabolic concave target are considered. When the depth of the concave shape was varied, the peak proton energy showed a maximum. The underlying mechanism for the existence of a maximum peak proton energy is presented by tracing the proton trajectory. It is concluded that a parabolic concave target is the best, among the targets considered, for accelerating a proton beam, since a proton beam from a parabolic concave target goes through the strongest electric field.

1. Introduction

Energetic particles generated by laser-plasma interactions can be used in many applications, ranging from manufacturing to medicine, and for the initiation of tabletop particle accelerators for high-energy physics and fusion by fast ignition. The generation of energetic protons by the interaction of an ultrashort high intensity laser pulse with a plasma has been demonstrated in recent theoretical [1-4] and experimental [5] studies. It has been shown that the energy of a laser pulse can be efficiently converted into fast proton energy using foil targets. Simulations [1-4] have shown that the mechanisms for generating proton acceleration are the ambipolar field and Coulomb explosion. Energetic electrons ejected from the foil by the laser field create a strong electrostatic field, which is the main source of acceleration of protons ejected from the rear foil surface. Thus, a collimated proton beam can be produced by focusing an intense laser beam onto the surface of a solid film. It is clear that these protons can be focused if the foil surface has a curvature. This effect has been shown numerically for plasmas with sharp density gradients [2,3] and has also been experimentally demonstrated [6]; however, the process has not been optimized. 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. This density gradient plays an important role in laser energy absorption [7,8]. We have reported high energy generation of a proton bunch from a triangular concave target and a circular concave target including the density gradient [9,10]. The effect of a plane target thickness on peak proton energy has also been described [11]. The proton focusing effect by the parabolic concave target has been considered in reference [2].

This paper reports the investigation of the influence of the depth of the concave shape on energetic proton acceleration by ultraintense laser interaction.

2. Energetic proton bunch simulation with concave targets

Proton focusing effects were verified using a model in which protons are ejected from concave targets, as shown in Fig.1. Simulations were performed for a laser wavelength λ of 1.06μm , laser intensity *I* of 10^{20} W/cm^2, pulse dulation τ of 40 fs, length *W* of the concave target is constant at 3λ and the depth *D* of the concave target is changed from 0 to λ.

In Figs.2(a) and (b), 3(a) and (b), and 4(a) and (b), proton beam trajectories and contours at ω*t*=800 (*t*=449 fs), where ω is the laser frequency, are shown for the triangular concave target, the circular concave target and the parabolic concave target, respectively. It can be obviously seen from these figures that the proton beam, accelerated by the strong electric field induced by the region of heightened electron density, is collected near the *x*-axis direction when *y*/λ is around 6 - 10. For the triangular concave target, as in Fig.2(a), the peak proton energy is increased by changing *D* from 0 to 0.4λ because the proton beams go through the stronger electric field. However, after *D* = 0.4λ the peak proton energy decreased because the proton beams cross the stronger electric field, as seen in Fig.2(b). For the circular and parabolic concave targets, the acceleration mechanism of the proton beam is the same as for the triangular concave target.

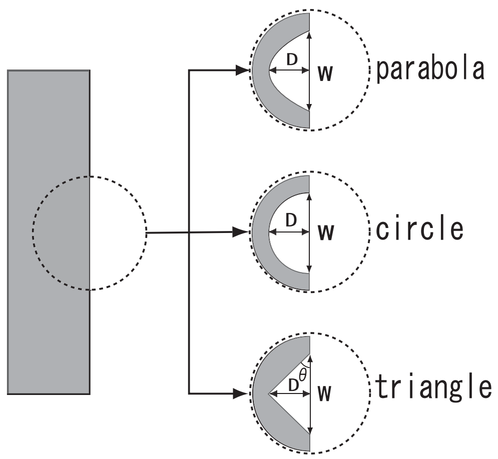

Fig. 1: The geometry of the target containing the concave cavity.

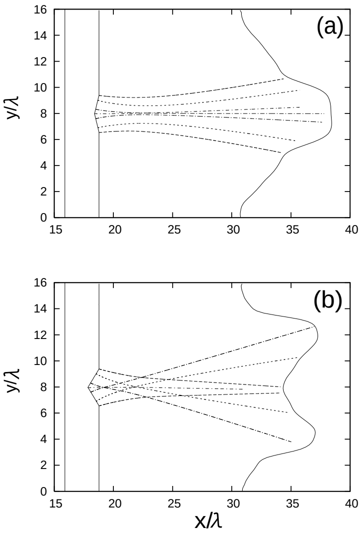

Fig. 2: Proton beam trajectories and contour of (a) D=0.4λ and (b) D=λ from a triangular concave target at ωt=800.

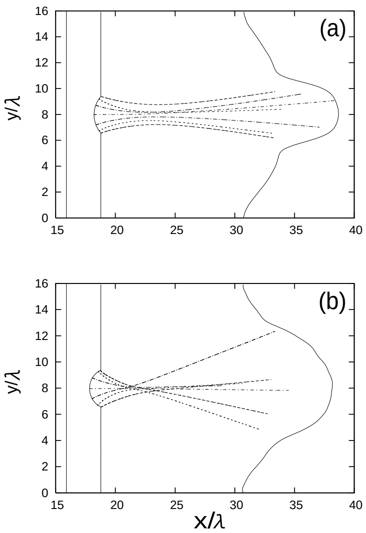

Fig. 3: Proton beam trajectories and contour of (a) D=0.6λ and (b) D=λ from a circuler concave target at ωt=800.

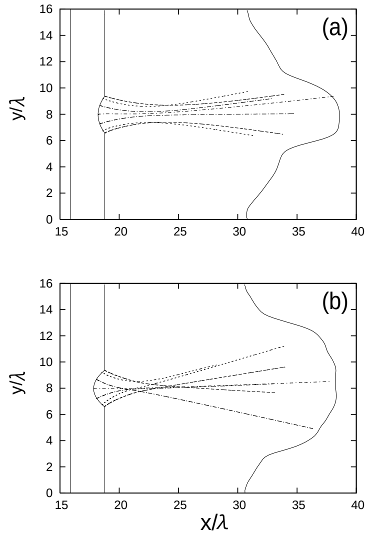

Fig. 4: Proton beam trajectories and contour of (a) D=0.6λ and (b) D=λ from a parabolic concave target at ωt=800.

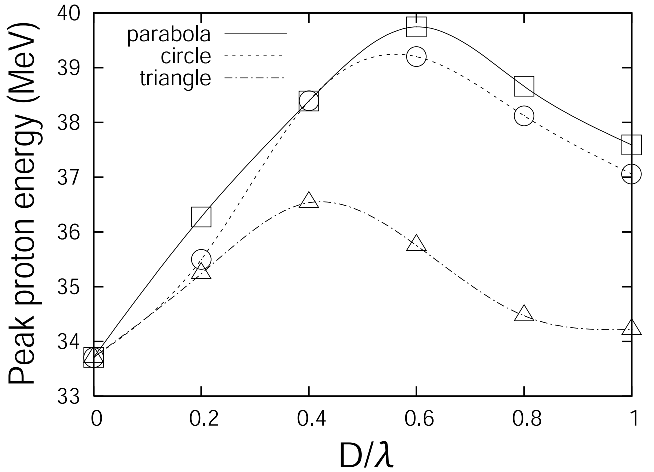

Fig. 5: Peak proton energy vs depth of the concave shape (D/λ) from the triangular, circular and parabolic concave targets at ωt=800.

3. Conclusions

There is a maximum for the peak proton energy as shown in Fig.5. For the triangular concave target, the peak proton energy is maximum at D = 0.4λ which corresponds to θ = 15 degrees . For the circular concave target, the peak proton energy is maximum at D = 0.6λ which corresponds to the radius of the circle r = 2.2λ. For the parabolic concave target, the peak proton energy is maximum at D = 0.6λ which corresponds to a = 0.27 for the formula of the parabola of $x = a\,(y - 8\lambda)^2/\lambda + 18\lambda$. These results show that the parabolic concave target is the best for accelerating a proton beam among the three targets examined in this study.

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