Ion acceleration efficiency in laser thin-foil interactions and the impact of structured surface

O. Klimo[1], J. Limpouch[1], J. Psikal[1], S. Kawata[2]
[1]*Czech Technical University in Prague, FNSPE, Brehova 7, 11519, Prague 1, Czech Republic*
[2]*Graduate School of Eng. Utsunomiya University, Utsunomiya 321-8585, Japan*

Abstract: Energetic ions accelerated from thin foil targets by short intense laser pulses are interesting for various applications. It is of particular interest to increase the efficiency of the ion acceleration process and the maximum ion energy. It has been proposed and experimentally confirmed that this may be achieved by decreasing the thickness of the foil. However, decreasing the thickness of the foil, the contrast of the laser pulse must be increased to avoid premature disruption of the foil by laser prepulses. Ultra-high contrast laser pulse produces plasma with a very sharp density profile on the surface of the foil. The absence of plasma density gradient may result in reduction of the laser pulse absorption. It has been demonstrated that laser absorption may be significantly boosted by the presence of laser wavelength scale structures (eg. nanoparticle arrays) on the irradiated target surface. Our 2D PIC simulations demonstrate the impact of such nanoparticle array on the surface of an ultrathin foil on the laser absorption and the ion acceleration.

1. Introduction

The laser energy absorption may be boosted by the presence of microscopic structures on the laser irradiated target surface as demonstrated in recent experiments (e.g. with polystyrene microspheres [1]). Recently, such targets have been used to study ion acceleration by short intense laser pulses [2] but with no evidence for the maximum ion energy increase. However, the target used in the experiment was relatively thick so that recirculation of hot electrons could not be efficient and the accelerated ions have been recorded at the front side. We propose to use a thin foil covered by a monolayer of polystyrene microspheres as a target for proof of principle experiments to demonstrate the influence of the structured surface on ion acceleration. This target should benefit from both high absorption and efficient hot electron recirculation and it is thus suitable for efficient ion acceleration. Such target has already been prepared in our institute. Ion acceleration by short intense high contrast laser pulses from thin foils covered by a monolayer of microspheres or foils with a kind of surface grating is studied in this paper using 2D PIC simulations.

2. Simulation model and results

The 2D simulations have been performed with our relativistic electromagnetic parallel PIC code [3]. The targets used in our simulations consist of 200 nm thick foil with and without a kind of periodic surface structure attached to the front side. The shape of the structure is spherical, rectangular or triangular. The target consists of 2 species of ions (homogeneous 1:1 mixture of C^{4+} and protons) and free electrons with the initial density of 50 times critical density. The initial temperature is very low (10 eV) to avoid preexpansion of the target prior to the laser pulse arrival. The 20 fs long p-polarized laser pulse with the wavelength 800 nm and the maximum intensity of 2×10^{19} W/cm^2 is used.

Structure shape	Electron temp.	Electron div. angle	Absorption	Max energy (protons)
None	0.1 MeV	14.8°	3.8 %	0.85 MeV (0.88 %)
Sphere	0.4 MeV	39.7°	55.2 %	3.76 MeV (7.3 %)
Triangular	0.42 MeV	41.8°	80.5 %	4.85 MeV (11.3 %)
Rectangular	0.37 MeV	40.9°	43.9 %	3.73 MeV (5 %)

Table 1.: Comparison of the 2D PIC simulations results with different surface structure shape. The transformation efficiency of laser energy into fast protons is in the parenthesis next to their max. energy.

The results of simulations with different shape of the surface structure are summarized in Tab. 1. The size of the structure elements (spheres, triangles, rect.) is equal to the laser wavelength. In the case of flat foil surface, the temperature and the number of hot electrons are much lower but on the other hand, hot electrons propagate in a collimated beam. The presence of any structure on the target surface causes higher absorption but the hot electron beam is very divergent. Therefore, the increase in the maximum proton energy is not so big. Nevertheless, the energy transformation efficiency into fast protons scales almost linearly with laser absorption in our collisionless simulations.

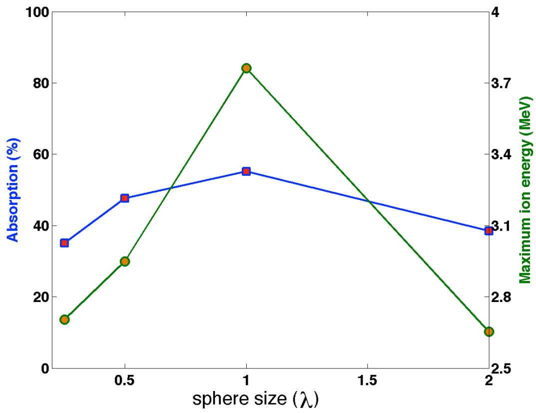

Figure 1.: The dependence of laser energy absorption and of the maximum proton energy on the diameter of microspheres.

In the case of monolayer of microspheres, we have performed simulations with various sphere diameters to see the influence on the maximum energy of accelerated protons. The results of this optimization are summarized in Fig. 1. The maximum absorption and the maximum energy of accelerated protons approximately coincide when the diameter of spheres in the monolayer on the target surface is about the laser wavelength. From the experimental point of view, it might be difficult to prepare a homogeneous monolayer of mircospheres, all of the same size. We have performed an additional simulation with the spheres of random diameter, which is in the range 0.25-1 laser wavelength and the resulting absorption of 57% and the maximum proton energy of 3.74 MeV are even slightly higher than in the best case of Fig. 1.

For the rectangular shape of the structure, we have studied the influence of the structure height. The energy laser absorption increases with the height of the structure and the absorption of more than 90% is possible. On the other hand, the structure expands very rapidly after the end of the laser target interaction and it contributes to the thickness of the target reducing the efficiency of the electron recirculation process. Thus there exists some optimum height of the structure for ion acceleration, where the absorption is high and the electron recirculation process is still efficient.

3. Conclusions

In this paper, we study target normal sheath acceleration of ions from thin foil targets with flat or structured front surface using 2D PIC simulations. The structure on the front surface significantly increases laser energy absorption and hot electron temperature and density. This results in higher ion acceleration efficiency and maximum ion energy in the case of thin foil targets used in this paper. The ion acceleration process depends on the shape and size of the structure on the surface. The maximum ion energy is obtained for such characteristic dimensions of the structure, which lead to high absorption but do not inhibit efficient electron recirculation.

[1] H. A. Sumeruk, S. Kneip, D. R. Symes et al., "Control of Strong-Laser-Field Coupling to Electrons in Solid Targets with Wavelength-Scale Spheres" Physical Review Letters **98**, 045001 (2007).

[2] S. Bagchi, P. Prem Kiran, M. K. Bhuyan et al., "Hot ion generation from nanostructured surfaces under intense femtosecond laser irradiation" Applied Physics Letters **90**, 141502 (2007).

[3] J. Psikal, J. Limpouch, S. Kawata et al., "PIC simulations of femtosecond interactions with mass-limited targets" Czechoslovak Journal of Physics **56**, B515 (2006).