§9. Relativistic Laser Interaction with Thin Foils

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Intense multi-MeV proton beams have been routinely obtained in experiments from both, the front and rear surface of the solid foils [1], [2] and supported by computer simulations [3], [4]. Over past years several mechanisms of the ion acceleration have been proposed [5] and it is widely accepted that the charge displacement due to the electron heating and formation of electrostatic sheaths can be the driving force for the ion acceleration.

In order to investigate the generation and transport of energetic particles in the laser-plasma interaction, a series of 2d relativistic electromagnetic PIC simulations with absorbing boundaries was carried out. A linearly *p*-polarized (along *y*-axis) laser beam was injected from the left boundary of the simulation box in *x*-direction and focused onto overdense plasma targets. The time and space profile of the laser beam was Gaussian with a full width at half maximum duration of 40fs (≈ 30T for $\lambda = 0.4\mu m$), the diameter of the focal laser spot was 2.4μm, and the laser strength at the peak was $a_0 = 0.7$ (for $\lambda = 0.4\mu m$, the laser intensity is $I \approx 4.2\times10^{18}$ W/cm^2). Here T denotes laser wave period and λ is the laser wavelength.

In the focus of our attention here is the interaction of the oblique laser beam with an electron-proton plasma foil at an angle of incidence of $\alpha = 45^\circ$. The foil thickness in this case is $L = 2.5\mu m$ (6.25λ) and the density is $n = 10n_{cr}$, where n_{cr} is the critical (cutoff) density. In the simulations the time $t/T = 0$ was set to the peak intensity of the laser beam at the focal spot with the center at $(x/\lambda,\ y/\lambda) = (0, 0)$.

The simulation results reveal that for parameters considered here, a majority of electrons are accelerated in directions between the normal to the plasma surface and the laser beam axis, with the hot electron population directed more towards laser beam axis. Reflection of electron clouds from the edges of the foil and their recirculation is a striking effect that is characterized by the breaking of the transversal symmetry (in respect to the laser beam axis) of the fast electron flow. Namely, it is found that the fast electrons quickly leave the interaction region drifting along the foil. The electric fields established by the charge separation reflect these electrons back and forth with an effective drift along the foil in the laser beam direction (see Fig. 1). Since the low energy electrons are generated more in the normal direction to the target surface, they re-circulate in the focal region and interact multiple times with the laser wave. This electron interaction dynamics can play an important role in increasing proton energies. Here, we found that at $t/T = 63$ the maximum ion energies are $E_f \approx 1.38$MeV and $E_b \approx 1.70$MeV in the forward and backward direction, respectively. As we can see, the energy of the backward accelerated ions exceeds the energy of the forward propagating ions. This can be explained by the fact that the charge separation induced on the front surface due to the electron circulation back and forth is well enhanced by significant ejection of the electrons in the backward direction. Moreover, in favor of efficient backward ion acceleration is also the fact that the front surface is sharp edged allowing strong field gradients.

It is found that the dominant mechanism of the ion acceleration in our simulations is target normal sheath acceleration (TNSA), and no significant presence of other mechanisms is seen. To confirm previous conclusions, a long run with the same laser-plasma conditions but with the laser pulse duration of 80fs has been carried out. In Fig. 2 we plot space distribution of protons with $E > 1$MeV from this run at $t/T = 25.9$ (Fig. 2a) and $t/T = 237.3$ (Fig. 2b). In Fig. 2a one can see the core of the accelerated ion beams normal to the foil surfaces with a small shift in respect to the target normal at the center of the focal spot. This shift is more pronounced for forward propagating proton beam reflecting the fact that the bulk of electrons is accelerated in direction between the target normal and the laser beam axes. The proton beam shift is preserved at later times, however due to the creation of the low energy proton wings in the preferred direction of the fast electron flow, the beams exhibit transversal asymmetry (see Fig. 2b). The fact that the fast electrons have preferred flow that depends on the laser incidence and the target geometry has important consequences on particle dynamics in more complex targets (e.g. cone target) in today's experiments on fast ignition [6].

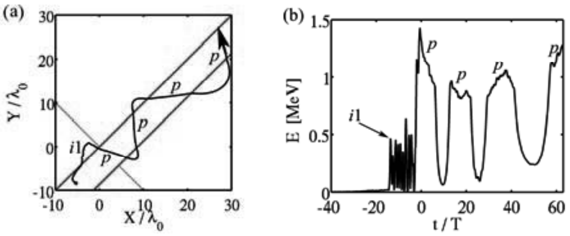

Fig. 1. (a) Trajectory of the test electron and (b) its energy history in the laser-foil interaction. i1 denotes laser-electron interaction, while p denotes electron motion in the plasma. The full and dashed lines show initial plasma boundaries and the normal to the plasma surface at the focal spot, respectively.

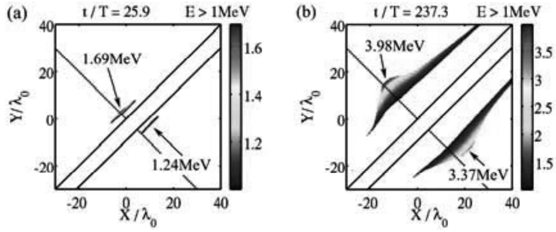

Fig. 2. Space distribution of protons with energies E > 1MeV at (a) t/T= 25.9 and (b) t/T=273.3.

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