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Fast ion generation by a ultra-intense laser pulse on a plasma foil target

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Particle-in-cell (PIC) simulations of fast particles produced by a short laser pulse of duration of 40 fs and intensity $\geq 10^{20} W/cm^2$ interacting with a foil target are performed. Dependence of the generated fast ion energy on the target geometry is examined. The absorbed laser energy is transferred to fast electron, which interact with the foil and are partially ejected from the foil surfaces. These electrons produce an electric field that causes an ion beam to be emitted from the foil rear surface. Mechanism of fast (multi-MeV) ion acceleration in the foil plasma and the influence of the front density gradient and other laser and plasma parameters on ion acceleration are analyzed.

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 0.5 GeV 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[5,6)] 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[4)]. Fast ions are accelerated normally to the foil surface. 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 develop a simulation model to analyze the mechanism of ion acceleration in plasma layers with smooth density gradients. We select a very short (40 fs) laser pulse and thin foil (2 μm).

2. PIC simulation

In solid target experiments with focused intensities exceeding 10^{20} W/cm^2, high-energy electron generation and energetic protons have been observed on the backside of the target[7)]. 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[6)] is used to calculate the interaction of an intense laser pulse with an over-dense plasma. Calculations with ion mobility allowed were carried out for a plasma with the initial density profile shown in figure 1. Simulations were performed for laser wave length of 1 μm and laser intensity 10^{20} W/cm^2. The time step is chosen to be $0.03/\omega_L$ where