Generation of Monochromatic Laser-accelerated proton beam: Numerical study

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1. Introduction

The advent of ultra-intense laser pulse and its rapid development has opened up a new regime of science called relativistic plasma. This regime has been attracted due to not only its fundamental physical interest but also its wide application such as high energy particle and radiation generation [1].

The laser-accelerated ion beam has several advantages over a conventional accelerator such as compact size, energy tunability, which make it feasible using in injection into conventional accelerators [2], the fast ignition of thermonuclear target [3], and hadron therapy in oncology [4]. The synchronization of the accelerated proton beam with driving laser pulse also makes it possible the measurement of plasma dynamics with high temporal resolution.

For the application to the hadron cancer therapy, the laser-accelerated proton beam should meet several requirements, which are energy (a few 10 – 150 MeV), number (10^{10}-5×10^{15}/sec), and energy spread ($\Delta E / E \leq 2\%$) [5]. The first requirements have been experimentally demonstrated and the second condition awaits just the appearance of high repetition laser. However the proton spectra obtained in laser-plasma experiments shows wide energy distribution with cut-off energy while in case of electron acceleration much progress has been made. Thus to fulfill the requirements for the hadron cancer therapy, much efforts should be devoted to the enhancement of the monochromacity of the proton energy distribution.

Recently a scheme utilizing double-layer target was proposed for the generation of high-quality laser-accelerated proton beams. And energy spread less than 5 % was obtained by an intensive three-dimensional PIC (Particle-In-Cell) simulation [6].

Adopting such an idea, one- and 2-dimensional PIC simulation was performed to investigate the characteristics of the accelerated proton beam in an experimental parameter space.

2. Numerical Methods

Since the high dimensional PIC simulation requires high computational capacitance, the parameter space has been examined using one-dimensional PIC code and then for a selected parameter a two-dimensional PIC simulation has been performed.

For one-dimensional simulation, LPIC++ code, this deals with one dimensional space and three dimensional particle motion. And XOOPIC code is used for two-dimensional simulation.

For computational system, a PC-cluster, dubbed as LAMP (LAser Matter interaction Physics) has been adopted considering computing efficiency and future extension, which currently consists of a master and four nodes, using 2.8 GHz Intel Pentium IV and 1 GB Gigabite Lan and is operated under Linux RedHat 8.0.

3. Results

The double-layer target uses an ultra-thin target of sub-micron. Thus it is very interesting to investigate the propagation of an intense-laser pulse through ultra-thin over-dense plasma. A 50 nm thick Ti target is irradiated by a laser pulse of 4×10^{19} W/cm^2, 20 fs, and 800 nm. The initial density of the target is prepared with 10 times of the critical plasma density, which is close to the solid density. Fig. 1 shows the two-dimensional distribution of laser electric field after propagating the target, which is calculated using XOOPIC. This result shows that the intense laser pulse transparently propagates through over-dense plasma once the thickness of the plasma is much shorter than the plasma skin depth, which is 200 nm around in this case.

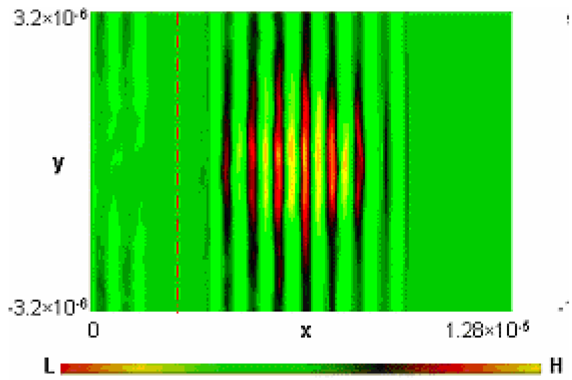

Figure 1. The propagation of intense laser pulse through a 50 nm-thick over-dense plasma. The laser pulse propagates from left to right and the dashed vertical line indicated the position of target.

The generation of proton beam for double-layer target is also investigated. Carbon target is used for the first layer with thickness of 1 μm and 160 nm proton layer is attached at the rear surface of the carbon target. The solid density of 7×10^{21} cm^{-3} is used, which corresponds to the four times of the plasma critical density for 0.8 μm laser pulse. For the laser pulse, an intensity of 1.4×10^{20} W/cm^2 and FWHM of 30 fs is adopted. Fig. 2 shows the schematic configuration of the computational system and proton energy spectrum. First of all, in both directions peaked proton spectra have been obtained instead of wide energy spectrum usually obtained in experiments. And higher peak proton energy in the forward direction (5 MeV) is obtained than that in the backward direction (3 MeV). The calculated energy spread is a few 10 %, which is large compared with the three-dimensional PIC simulation [6].

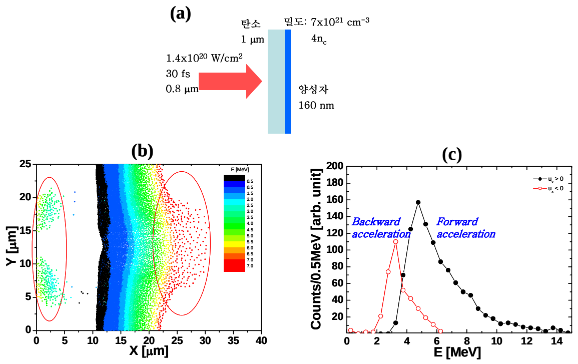

Figure 2. Generation of proton beam in a double-layer target (a) system configuration of simulation, (b) spatial distribution of particle at 584 fs, and (c) proton energy spectrum for two different direction (indicated by the circles in (b)).

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