18PB-095

Collimation of intense-laser-produced ion beam
高強度レーザーによるイオンビームのコリメーション

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Ion beam has a unique feature to deposit its main energy inside a human body to kill cancer cells or inside materials. However, conventional ion accelerators tend to be huge in its size and its cost. In this paper a future intense-laser ion accelerator is discussed to make the laser-based ion accelerator compact and controllable. The issues in the laser ion accelerator include the energy efficiency from the laser to the ions, the ion beam collimation, the ion energy spectrum control, the ion beam bunching and the ion particle energy control. In the study each component is designed to control the ion beam quality by particle simulations. The energy efficiency from the laser to ions is improved by using a solid target with a fine sub-wavelength structure or a near-critical density gas plasma. The ion beam collimation is performed by holes behind the solid target or a multi-layered solid target.

1. Introduction

By chirped pulse amplification, a higher laser intensity has been realized, and high intensity short pulse lasers are now available for applications. On the other hand, ion beams are useful for medical ion cancer therapy, basic particle physics, controlled nuclear fusion, high-energy sources, and so on [1-6]. The energy of ions, which are accelerated in an interaction between an intense laser pulse and a gas target, is over a few tens of MeV. The issues in the laser ion acceleration include an ion beam collimation, ion energy spectrum control, ion production efficiency, ion energy control, ion beam bunching, etc. Depending on ion beam applications, the ion particle energy and the ion energy spectrum should be controlled as well as the ion beam quality.

In this paper we perform 2.5-dimensional particle-in-cell simulations to investigate a laser-generated ion-beam collimation [6]. When an intense laser pulse interacts with a target plasma, it accelerates a part of target electrons. The electrons are accelerated by the intense laser and create an electric charge separation. The charge separation provides a strong electric field, for example, typically a few MV~10 MV/m, by which the target ions are accelerated. This ion acceleration mechanism is called as TNSA (Target Normal Sheath Acceleration). In TNSA, the acceleration electric field is normal to the target surface. The TNSA is widely used for the ion source. However, the target deformation and the edge effect of the acceleration electric field induce the ion beam divergence transversely. Therefore, a collimation device is required. In the paper we present a solid target, which has holes for the collimation. The holes behind the target suppress the source protons' divergence.

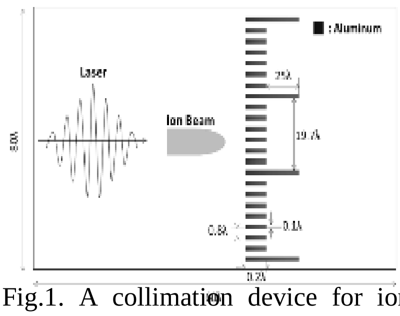

Fig.1. A collimation device for ion beam. The Al structured target is illuminated by an intense laser. The fine structure absorbs the laser energy efficiently, and generates high-energy electrons. The electrons move around the target, and at the right hand side the electric field is created normally to the target surface. The transverse field is generated by the electrons and collimates the proton beam.

2. Ion beam collimation by a solid target

The laser-based ion accelerator also needs a collimation device, which reduces the ion beam transverse divergence. The ion beam has a small transverse velocity due the plasma target deformation and also the beam self charge. The collimation device reduces the ion transverse velocity to collimate the ion beam. In this subsection, a structured target shown in Fig. 1 is employed.

The fine structure of the target left layer in Fig. 1 absorbs the laser energy efficiently, and generates high-energy electrons. The electrons move around the target, and create the strong electric field normally to the target surfaces. At the collimation target right hand side there is a larger scale structure, at which the TNSA field is created. The transverse electric field is also generated at the right area of the target, and reduces the proton transverse divergence. In this case, the laser intensity is $5.0\text{x}10^{19}\text{W/cm}^2$, the pulse length is 100fs, and the spot size is 30 λ. Figure 2 shows the electric field distribution; the transverse field reduces the proton transverse divergence. Figure 3 presents the original proton beam and the proton beam without the collimation device and for the proton beam with the collimation device. The proton beam is successfully collimated by the collimation device shown in Fig. 4. Figure 5 shows a spatial distribution of the ion beam entering at the center of the target wall, which induces the ion beam split and its collimation.

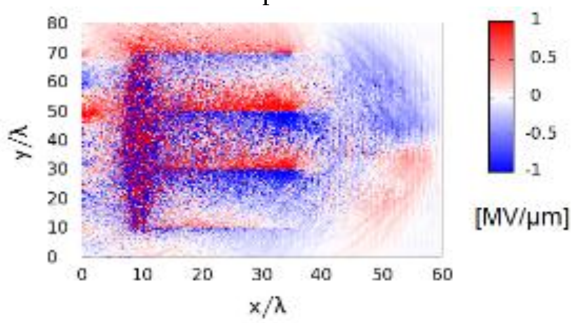

Fig.2. The transverse electric field is successfully generated,

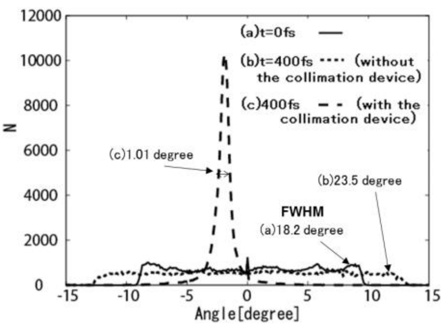

Fig.3. Divergence angle distributions for (a) the original proton beam (solid line), for (b) the proton beam without the collimation device (short-dotted line) and for (c) the proton beam with the collimation device (long-dotted line). The collimation device reduces the proton

3. Conclusions

We proposed the collimation device in intense laser plasma interaction. The simulation results demonstrated that the collimation device reduced the proton divergence successfully. We found that there is an optimum value for the laser intensity in the thin film target collimation device.

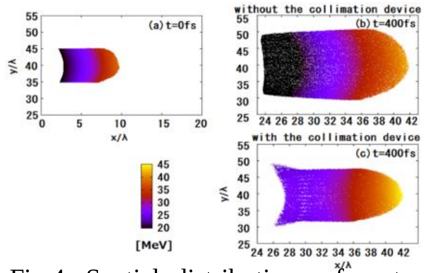

Fig.4. Spatial distributions of protons for (a) the original proton beam at t=0fs, for (b) the proton beam without the collimation device and for (c) the proton beam with the collimation device at t=400fs. The collimation device reduces the proton beam divergence.

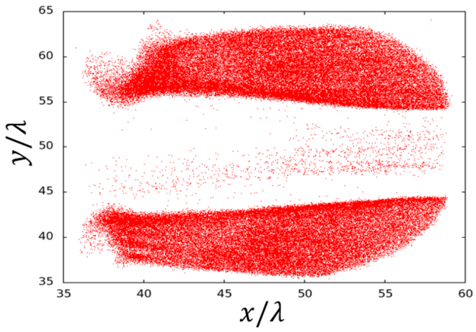

Fig.5. Spatial distribution of the ion beam entering at the center of the target wall, which induces the ion beam split as well as the beam collimation.

Acknowledgments

This work was partly supported by MEXT, JSPS, ASHULA project / ILE, Osaka University, CORE (Center for Optical Research and Education, Utsunomiya University, Japan), Fudan University, High-End Foreign Expert program, China and Shanghai University. The authors would also like to express their appreciations to Prof. Daniel Margarone, Prof. Z. M. Sheng for their fruitful discussions on the subject.

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