Controllable laser ion beam generation

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Abstract. In intense-laser plasma interaction, several issues still remain to be solved for a future laser particle acceleration. In this paper we focus on a bunching of ion beam, which is pre-accelerated by a strong electric field generated in a laser plasma interaction. In this study, a near-critical-density plasma target is illuminated by an intense short laser pulse. A moving strong inductive electric field is generated inside of the target. We have successfully obtained a bunched ion beam in our particle-in-cell simulations in this paper.

1. Introduction

Intense short-pulse lasers are now available. Based on the new laser technology, new mechanisms for particle acceleration have been proposed by the laser pulse, as an alternative of the conventional accelerators [1-3]. However, in the laser particle acceleration method there are issues, which include the controllability for the particle beam quality [3, 4] and for the particle energy [5-12]. Figure 1 shows a concept of an example future laser ion accelerator, which consists of post-accelerators, collimators and bunchers to improve the laser-produced particle beam quality [3]. In this study we focus on a bunching of the laser-produced proton beam. The buncher is a device to prevent the ion beam elongation during its propagation by reducing a velocity difference in the ion beam.

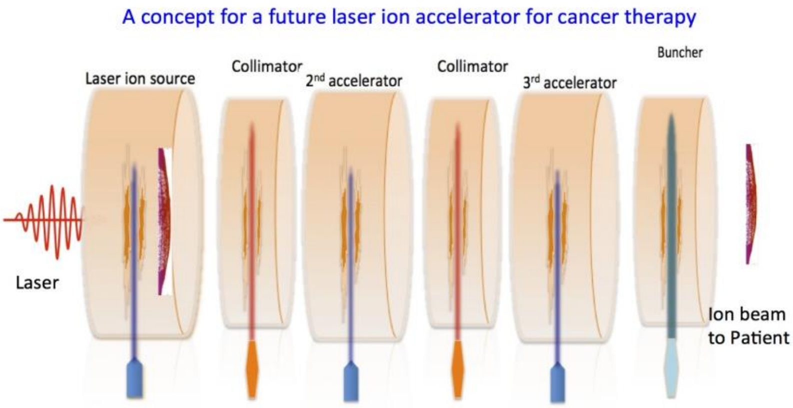

Figure 1. A concept of an example future laser ion accelerator.

Ion beam has been used in cancer treatment, ion beam inertial fusion, material sciences and other purposes, and has a unique preferable feature to deposit its main energy inside of a material [2-3]. In this paper a bunching of a laser produced ion beam is discussed for a future compact intense-laser ion accelerator [3].

In the laser ion acceleration, first electrons are accelerated in the near-critical-density plasma, and generate a current flow, which creates a strong magnetic field. The strong magnetic field moves together with the electron movement inside of the plasma. The inductive electric field is generated at the head of the electron current. The ion beam is accelerated by the inductive field. The inductive field would be also used for the ion post-acceleration and for the ion beam bunching. Figures 2 show the mechanism of the inductive field generation.

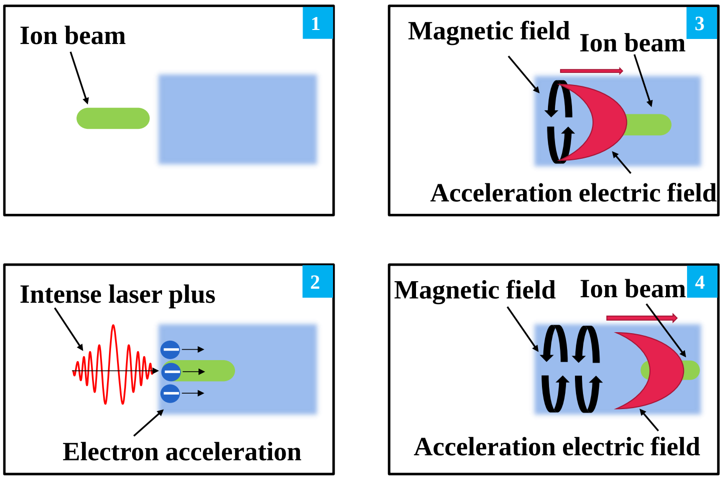

Figure 2. Mechanism of the moving inductive electric field generation in a near-critical density plasma.

In this study, we perform 2.5-dimensional PIC (Particle-In-Cell) [13] simulations to study the ion beam bunching.

2. Ion beam bunching

In order to reduce the proton energy divergence and to reduce the ion beam longitudinal length, a bunching device would be required. When a near-critical-density plasma target is illuminated by an intense laser, the strong inductive electric field is generated inside of the plasma target. The inductive electric field contributes to the ion beam tail acceleration to reduce the ion beam energy divergence. The moving speed of the inductive electric field becomes higher as the plasma density decreases.

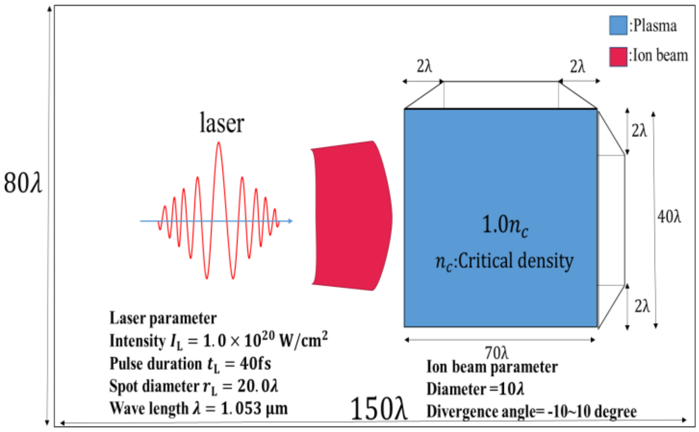

Figure 3. Simulation model for the ion beam bunching.

Figure 3 presents our particle simulation model for the bunching. The laser intensity is 1×10^{20} W/cm^2, the laser spot size 20λ, and the laser pulse length 40fs. The laser transverse profile is in the Gaussian distribution, and the laser temporal profile is also Gaussian. The laser wavelength is λ=1.053µm. The simulation box is 150λ in the longitudinal direction and 80λ in the transverse direction.

Figures 4 show the simulation results for the inductive electric field inside of the plasma target. The inductive field for the acceleration moves in the *x* direction. The electric field accelerates the tail of the ion beam. Figures 5 show the spatial distributions of the proton beams. When the buncher is employed, the longitudinal length of the proton beam becomes relatively shorter as shown in Fig. 5(b). If the buncher is not used, the length of the proton beam (Δx) is 17.8λ. However, the buncher is employed, the proton beam spatial distribution is kept short as shown in Fig. 5(b), and the beam length is 14.8λ.

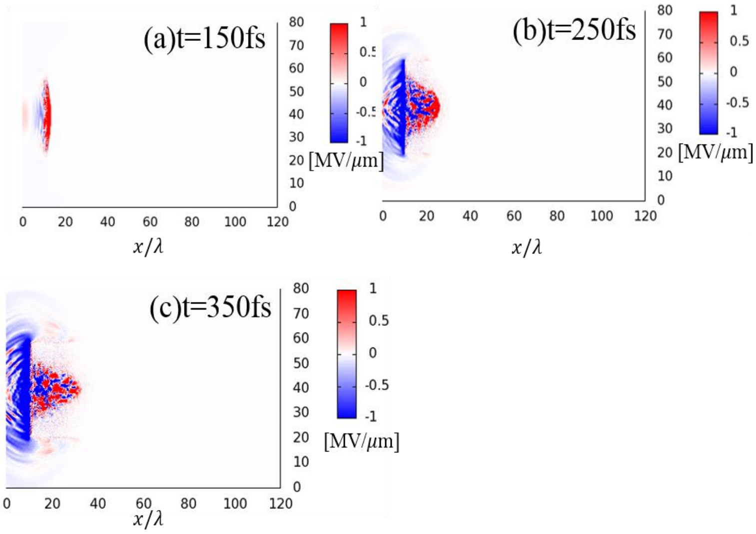

Figure 4. Inductive electric field inside of the plasma target at t=150fs, 250fs and 350fs. The inductive electric field accelerates the tail of the ion beam.

Figures 6 show the results for the energy distributions of the proton beams. When the buncher is not used, the proton beam is elongated as shown in Fig. 6(a), and the longitudinal velocity tilt ΔV_x is 0.121*c*. However, when the buncher is employed, the proton beam velocity divergence is reduced successful (ΔV_x=0.071*c*) and the proton beam length is kept short as shown in Fig. 5(b).

Based on the results presented here, we have succeeded to reduce the longitudinal spread of the entire proton beam by the bunching device.

3. Conclusions

In this study, we focused on the ion beam bunching using the near-critical-density plasma target. The inductive field acceleration also contributed to reduce the ion energy spread in this study inside of the target. The results presented in this paper contribute to the high-quality proton beam generation in laser plasma interaction. We have succeeded to reduce the energy spread and so to shorten the ion beam longitudinal length through the bunching device. The laser-illuminated near-critical-density plasma target also provides the new bunching device for the laser ion acceleration system.

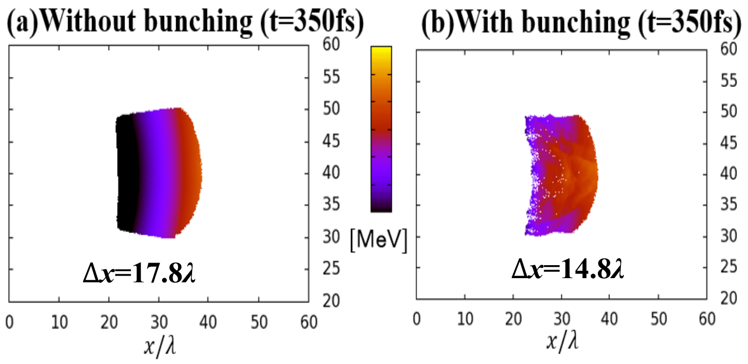

Figure 5. Spatial distributions of the proton beams. If the buncher is not used, the length of the proton beam (Δx) is 17.8λ in Fig. 5(a). However, when the buncher is employed, the proton beam spatial distribution is kept short as shown in Fig. 5(b), and the beam length is 14.8λ.

The remaining issues in the laser ion accelerator include the energy efficiency from the laser to the ions, the ion beam spread in the *y* direction, the ion energy spectrum control, the ion particle energy control, the repetitive operation of the laser particle acceleration system, the laser generation efficiency, the laser target alignment, etc., as well as, the ion beam spread in the *x* direction. These issues should be studied further toward a real laser particle accelerator.

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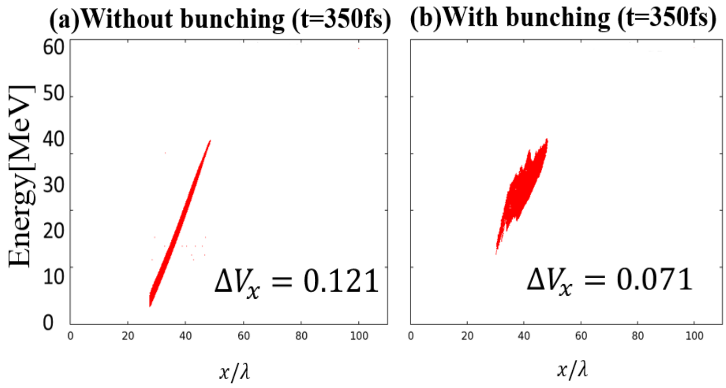

Figure 6. Ion beam energy spatial distributions. When the buncher is not used, the proton beam is elongated as shown in Fig. 6(a) and the longitudinal velocity is 0.121c. However, when the buncher is employed, the proton beam velocity divergence is reduced successfully (ΔVx=0.071c) as shown in Fig. 6(b).

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