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Control in Intense-Laser Ion Acceleration
高強度レーザーによるイオン加速の制御

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The paper shows a concept for a laser ion accelerator, which should have an ion source, ion collimators, ion beam bunchers, ion beam stackers, an ion beam storage and ion post acceleration devices. Based on the laser ion accelerator components, a future compact laser ion accelerator could be designed for ion cancer therapy or for ion material treatment. Each component is realized in a laser-plasma interaction in the concept. Especially in the post acceleration, a higher ion particle energy and an energy spectrum control are realized in a laser plasma interaction; a few hundreds of MeV of the proton beam energy is successfully achieved by several times of the ion post-accelerations in the laser-plasma interaction. In addition, a mono-energetic proton beam is also produced.

1. Introduction

The present paper shows a concept for a future laser ion accelerator, which should have an ion source, ion collimators, ion beam bunchers, iion beam stackers, an ion beam storage and ion post acceleration devices [1]. Based on the laser ion accelerator components, the ion particle energy and the ion energy spectrum are controlled, and a future compact laser ion accelerator could be designed and realized for ion cancer therapy or for ion material treatment.

In the post acceleration, a higher ion particle energy and an energy spectrum control are realized in a laser plasma interaction; a few hundreds of MeV of the proton beam energy is successfully achieved by several times of the ion post-accelerations in the laser-plasma interaction. In addition, a mono-energetic proton beam is also produced.

2. A Concept of Multi-Stage Laser Accelerator

Figure 1 shows a concept proposed for a future laser ion accelerator. In an intense laser interaction with a target, initially ions are generated at an ion source device. The laser ion accelerator would need post-acceleration devices to enhance the ion energy and collimators to suppress the ion divergence, as well as beam bunchers to compress the ion beam longitudinally.

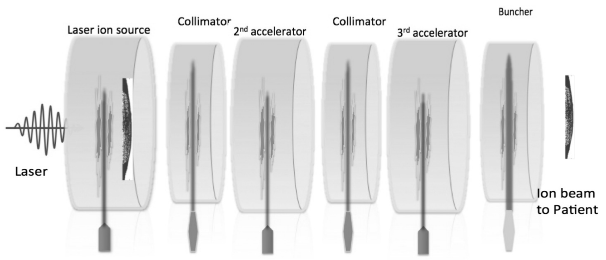

Fig. 1. Concept of an example laser ion accelerator.

The laser ion accelerator would consist of an ion source [2], ion beam collimators, ion beam bunchers, an ion beam stacker, an ion beam storage device and post-accelerators depending on the requirements for the ion particle energy, the ion energy spectrum, the beam radius and the ion beam pulse length. A part of the components required is also proposed and studied in this work. The acceleration field gradient is rather large (>10GV/m) compared with that (<100MV/m) of conventional accelerators. Each component and combinations of the components provide a high controllability of the ion beam quality generated by the laser ion accelerator to meet variable requirements for laser ion accelerator [1].

3. Intense-Laser Plasma Interaction

In this paper, we perform 2.5-dimensional particle-in-cell simulations to investigate the laser ion acceleration. 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/mm, 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. 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 concept in Fig. 1 we employ a solid target, which has holes behind the target for the collimation. The holes behind the target suppress the source protons' divergence by reducing the ion source edge field. The target high-energy electrons also form a high current and generate the azimuthal magnetic field, for example, ~kT. In the laser plasma interaction, the ion dynamics is affected directly by the electric field and the behavior of the electrons. Especially in an underdense gas target, the electron current forms the strong magnetic field inside the gas target, and during the increase in the azimuthal magnetic field the inductive strong electric field is generated by the Faraday law. The ions are also accelerated by the inductive electric field in the gas plasma target. When the inductive field speed coincides with that of the ion beam speed, the ions are continuously accelerated.

4. Post Acceleration

After a generation of an ion beam, additional post-acceleration elements would be required to enhance the proton energy to achieve 200-250MeV or more of the proton energy and also to control the ion energy spectrum as shown in Figs. 2. Figures 2b) and c) show a typical multi-stage ion acceleration. The proton energy of 200-250 MeV was achieved and the mono-energetic energy spectrum was also realized (see Fig. 2c)).

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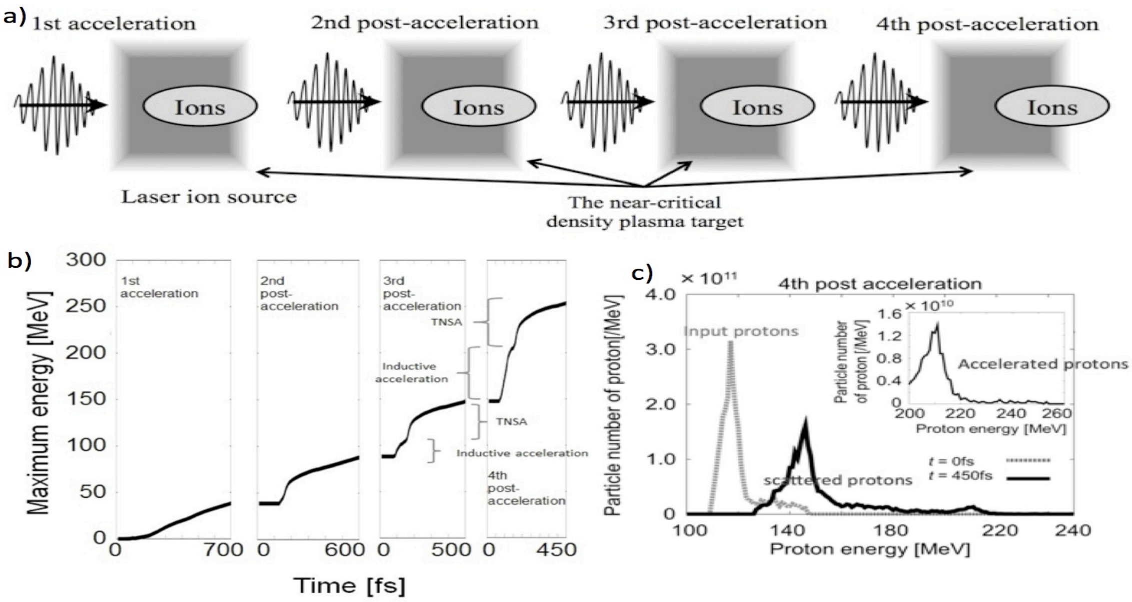

Fig. 2. a) Conceptual diagram for the 4-stage example post-acceleration in the laser plasma interaction, b) a history of the maximal proton energy, and c) energy spectra at the 4th stage.