23P178-B

Ion Post Acceleration in Laser-Plasma Interaction
レーザー・プラズマ相互作用によるイオンの追加速

D. Satoh[1], K. Takahashi[1], T. Izumiyama[1], D. Barada[1], S. Shigeo[1], Y. Y. Ma[2], W. M. Wang[3], Z. M. Sheng[3]

佐藤大, 高橋孝紀, 泉山豪, 茨田大輔, 川田重夫, Y. Y. Ma, W. M. Wang, Z. M. Sheng

[1]*Utsunomiya University*
7-1-2, Yotoh, Utsunomiya 321-8585, Japan
宇都宮大学　〒321-8585　宇都宮市陽東7-1-2
[2]National University of Defense Technology, Changsha 410073, China
[3]Fudan University, Shanghai 200433, China

A remarkable ion energy increase is demonstrated for a post acceleration by a Laser-plasma booster. Intense short-pulse laser generates a strong current by high-energy electrons accelerated, when an intense short-pulse laser illuminates a plasma target. The strong electric current creates a strong magnetic field along the high-energy electron current in plasma. During the increase phase in the magnetic field, the longitudinal inductive electric field is induced for the forward ion acceleration by the Faraday law. Our 2.5-dimensional particle-in-cell simulations demonstrate a remarkable increase in ion energy by several tens of MeV.

1. Introduction

By chirped pulse amplification, a higher laser intensity has been realized, and high intensity short pulse lasers are now available for experiments and applications. On the other hand, ion beams are useful for basic particle physics, medical ion therapy, controlled nuclear fusion, high-energy sources, and so on [1-3]. The energy of ions, which are accelerated in an interaction between an intense laser pulse and the near-critical density target, are over a few tens of MeV [4]. The issues in the laser ion acceleration include an ion beam collimation, ion energy spectrum control, ion production efficiency, etc [1-5]. Depending on ion beam applications, the ion particle energy should be controlled. For example, ion beam cancer therapy needs 100~150MeV for proton energy. Therefore, in this paper we focus on a boost of ion beam energy by post-acceleration in laser plasma interaction. In this paper we propose a Laser-plasma booster as ion post acceleration. In our study, we employ an intense short-pulse laser and the near-critical density plasma target, which consists of hydrogen. Figures 1 shows the conceptual diagram of the Laser-plasma booster.

2. The Near-Critical Density Plasma Target Simulation

We perform 2.5-dimensional particle-in-cell simulations. The target model is shown in Fig.1. The near-critical density plasma target is located in $9.5\lambda < x < 49.5\lambda$ and $19.0\lambda < y < 31.0\lambda$. The plasma target has the flat-top. The edge region has a linear density gradient from $0n_c$ to the maximum density of $0.5n_c$, and has a linear density gradient in 2λ in the X and Y directions at the target edges. The laser intensity is $I=1.0\times10^{20}$ W/cm^2, the laser spot diameter is 4.0λ, and the pulse duration is 40fs. The laser transverse profile is in the Gaussian distribution, and the laser temporal profile is also Gaussian. The laser wavelength is $\lambda=1.053\mu$m. The near-critical density plasma target density is $0.5n_c$ and the ion beam density is 10^{16}cm^{-3}. The pre-accelerated beam protons here the initial energy of 110MeV and is located at the left of the plasma target initially. The initial proton beam size is 2λ in X and 5λ in Y.

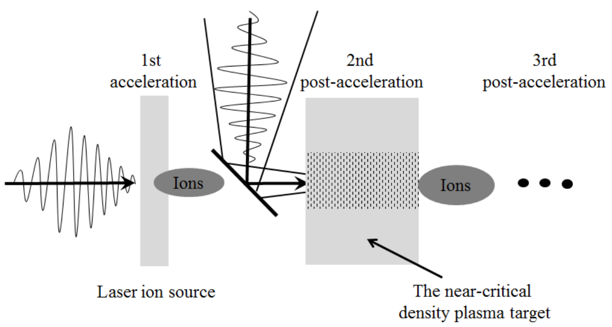

Fig.1. Ion post acceleration scheme and the near-critical density hydrogen plasma target. The near-critical density plasma booster target provides a stable inductive acceleration field, as a post acceleration of laser produced ions.

3. Post-Acceleration of The Ion Beam

Figures 2 show the distributions of acceleration electric field E_x in MV/μm at (a) t=110fs and the distributions of magnetic field B_z in T at (b) t=110fs. The laser generates the high-energy electron inside of the target. A magnetic field is also formed along the channel in the laser plasma interaction [6-8]. When the intense laser pulse propagates through the plasma, it accelerates a part of electrons. The electrons form a high current and generate the magnetic field. In the laser plasma interaction, the ion dynamics is affected directly by the electric field and the behavior of the electrons. The electrons form a strong magnetic field, and during the increase in the azimuthal magnetic field the inductive strong electric field is generated [3]. The ions are accelerated by the inductive electric field. The inductive acceleration field moves with a speed is less than c, depending on the plasma density. At this target density of $0.5n_c$, the speed of the inductive electric field is about 0.66c. Therefore, the inductive acceleration field is appropriate for the ion post acceleration and is rather stable. Figures 3 shows the ion beam energy distribution at t=50fs, 230fs and 450fs for the near-critical density plasma target. At t=50fs shown in Fig.3 is the initial energy of the ion beams which is not yet accelerated. The maximum ion beam energy reaches 171.2MeV from the initial energy of 110MeV.

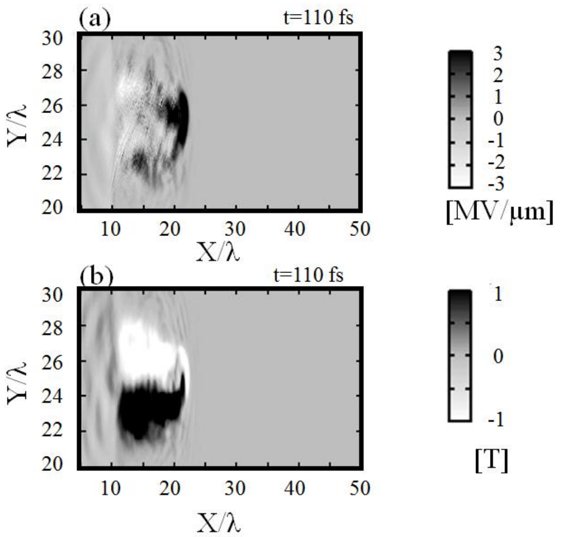

Fig.2. The distributions of acceleration electric field E_x in MV/μm at (a) t=110fs and the distributions of magnetic field B_z in T at (b) t=110fs.

4. Conclusions

In this paper we have proposed a laser-plasma booster as an ion post-acceleration. We succeeded

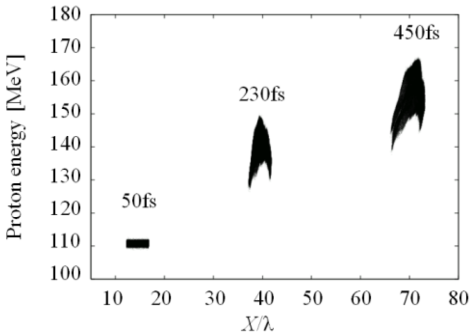

Fig.3. The ion beam energy distributions at t=50fs, 230fs and 450fs for the near-critical density plasma target. At t=50fs, the ion beam is not yet accelerated.

to increase the energy of the ion beam by the inductive acceleration field in the near-critical density plasma target illuminated by an intense short-pulse laser. The post-accelerated ion maxmum energy increases from 110MeV to 171.2MeV by the strong inductive acceleration electric field. The work in this paper presents an important method for an ion energy control in laser plasma acceleration.

Acknowledgement

This work is partly supported by MEXT, JSPS ILE/Osaka Univ. and CORE (Center for Optical Research and Education, Utsunomiya Univ., Japan). J.L. and O.K. gratefully acknowledge partial support by Czech Science Foundation (P205/11/1165) and Czech Ministry of Education (MSM6840770022).

References

[1] K. Takahashi, S. Kawata, D. Satoh, Y. Y. Ma, D. Barada, Q. Kong, and P. X. Wang: Phys. Plasmas **10** (2010) 093102.
[2] Y. Nodera and S. Kawata: Phys. Rev. E **78** (2008) 046401.
[3] I. Velchev, E.Fourkal, and C. M. Ma: Phys. Plasmas **14** (2007) 033106.
[4] T. Nakamura, S. Kawata: Phy. Rev. E **67** (2003) 026403.
[5] Y. Nodera and S. Kawata: Phys. Rev. E **78** (2008) 046401.
[6] Y. Y. Ma, Z. M. Sheng, J. Zhang, Y. T. Li, W. W. Chang, X. H. Yuan, M. Chen, and J. Zheng: Phys. Plasmas **13** (2006) 110702.
[7] T. Nakamura, S. V. Bulanov, T. Z. Esirkepov, and M. Kando: Phys. Rev. Lett. **105** (2010) 135002.
[8] Y. J. Gu, Q. Kong, Y. Y. Li, H. Y. Ban, Z. Zhu, and S. Kawata: Phys. Rev. Lett. **18** (2011) 030704.
[9] S. V. Bulanov, T. Zh. Esirkepov, J. Koga, T. Tajim, and D. Farina: Plasma Phys. Rep. **30** (2004) 18.