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Efficient Laser-Proton Acceleration from an Insulator Foil with an Attached Metal Disk

局所的に金属蒸着した絶縁薄膜を用いたレーザー生成陽子線の高エネルギー化

Kazuto Otani[2], Shunsuke Inoue[1,2], Shigeki Tokita[1,2], Masaki Hashida[1,2] and Shuji Sakabe[1,2]
大谷一人, 井上峻介，時田茂樹，橋田昌樹，阪部周二

[1]*Graduate School of Science, Kyoto University, Kitashirakawa Oiwakecho, Sakyo-ku, Kyoto 606-8502, Japan*
[2]*Institute for Chemical Research, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan*
京都大学大学院理学研究科　〒606-8502　京都市左京区北白川追分町
京都大学化学研究所 〒611-0011　宇治市五ヶ庄

A new scheme of laser-proton acceleration under the interaction between a solid foil and an intense femtosecond laser pulse is demonstrated. A polyethylene foil (88 mm in diameter and 10 μm in thickness) coated with 0.2 μm thick aluminum around laser spot is employed to the target. As reducing the coating size from 88 mm to 150 μm in diameter, the proton acceleration was enhanced. From the measurement of fast electron distribution under some different aluminum disk size, the sheath field distortion was suggested. We consider that the target conductivity affects to the sheath confinement and proton acceleration.

1. Introduction

Proton acceleration under the irradiation of an intense femtosecond laser pulse is expected to several fields such as scientific, medical, and industry [1]. Some schemes have been proposed to increase the proton energy [2]. The mechanism of laser-proton acceleration is generally understood by target normal sheath acceleration (TNSA) model under the intensity of $\sim 10^{19}$ W/cm^2 [3]. Since it is considered that the proton is accelerated by not only fast electron but also positively-charged foil, confinement of charge of the foil would be effective to enhance the proton acceleration [4]. If the positive charge diffuses in the conductive plasma and target foil, isolation of the target in vacuum is a solution to keep the charge much longer than a large foil. The effect of conductivity of the target foil to the proton acceleration by using a metal-coated plastic target has been reported [5]. The proton spectra and fast-electron distributions from a plastic target coated with aluminum coating of several different sizes are shown in this presentation.

2. Experiments

The experiment has conducted on T^6, Ti:sapphire laser system in Institute for Chemical Research, Kyoto-university. The central laser wavelength was 800 nm, and the pulse duration was 150 fs. The laser pulse was focused on the target with the spot size of 3 × 5 μm in FWHM by an F/3.2 off-axis parabolic mirror. The laser intensity and energy at the focal spot were calculated to 2×10^{18} W/cm^2, 40 mJ, respectively. The laser contrast was 10^{-7} of the main pulse intensity at 200 ps prior to the main pulse. The laser pulse was irradiated with the angle of 10 degree from the normal incidence of the target foil.

Three types of target foil were employed to the experiment. The first is a polyethylene (PE) foil with the thickness of 10 μm as standard target. The second target was PE foil coated whole irradiation surface with 0.2-μm-thick aluminum. The third target was PE foil coated with aluminum as thick as second target around the laser spot. The diameters of the aluminum coating were from 0.15 to 15 mm on third target. Note that these targets are called to PE, Al-coated, and Al-disk foil in this presentation. The target foils were fixed on 8.8 cm metal ring, and corrected its position within 10 μm in RMS.

The ion spectrum and fast electron distribution were observed in experiment. The ion spectrum emitted from opposite side of laser-irradiation surface was measured by using a Time-of-Flight (TOF) technique. The scintillator and photo multiplier tube was set 2.0 m away from the target foil. The fast electron was deflected by a pair of dipole magnet set at the midstream of the TOF tube. The fast electron distribution was measured by imaging plates (IPs). The IPs were arranged at a distance of 80 mm behind the target over 180 degree horizontally on the laser incidence plane. The IPs were stacked in two layers, and covered with 11 μm-thick aluminum filter. The second IP was sensitive for electron with the energy of more than 400 keV.

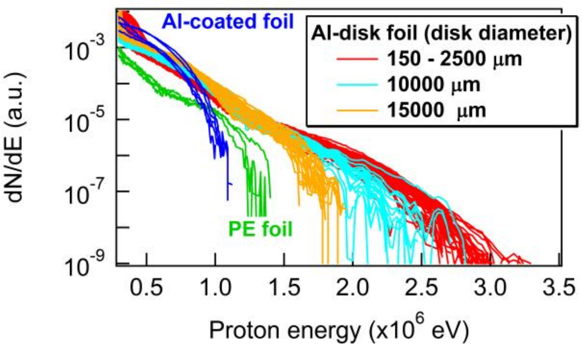

Fig. 1. Ion spectra from various target foils irradiated by a laser pulse.

3. Results and Discussion

The ion spectra are shown in Fig. 1. In these spectra, the upper half signal is composed only proton. The maximum proton energy is 1.3 MeV from PE foil. The proton energies from Al-disk foil are increased more than twice of that from PE foil. It is due to the fast electron yield is increased by employing metal coating. With increasing the disk diameter of aluminum coating, the maximum energy is reduced. The proton energy from Al-coated foil is lower than one from PE foil, despite the proton yield with the energy of 0.7-1.0 MeV is significantly increased.

The fast electron distributions in horizontal plane from rear surface of the target foil are shown in Fig. 2. The distribution from PE and Al-disk foil (diameter: 200 μm) are similar. The intensity of the electron signal from Al-disk foil is larger than PE foil because the yield of fast electron is considered to be increased by aluminum coating. The electron distribution from Al-coated foil is significantly different from the others. Especially the electron signal in lateral direction is much increased.

Since the experimental result of fast electron distribution, differences between the Al-disk and Al-coated foils are considered to be induced by difference of the sheath electric field. The relaxation of sheath field is affected by the disk size. The positive charge would diffuse in the disk as flowing of electron into the charged area, then the final peak intensity of the positive charge is reduced and the area is broadened. The electric field near the target foil is distorted from radial to parallel direction. As the result, much fast electron with the lateral momentum to the target can escape from the charged target.

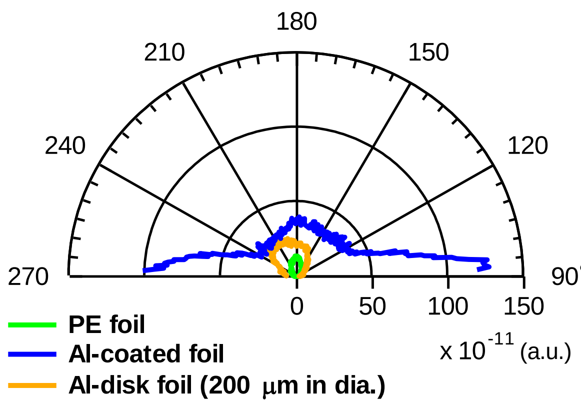

Fig. 2. Fast electron (E > 400 keV) distribution from rear side of target foil.

4. Summary

A new scheme to enhance the proton acceleration under an intense femtosecond laser irradiation is demonstrated. The proton energy was clearly increased from a plastic foil restrict coated with aluminum. The proton energy is related to the coating size. The sheath field distortion is suggested by the measurement of the fast electron distribution. In Al-disk target, the sheath field is possibly confined by restricting of conductive area.

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