NEUTRAL BEAM GENERATION BY LASER IRRADIATION OF THIN FOILS

Y. Wada, T. Kubota and A. Ogata
AdSM, Hiroshima University 1-3-1 Kagamiyama, Higashi-Hiroshima 739-8530, Japan

Abstract

We irradiated thin ($< 10\mu$m) plastic and metal foils by a 1 TW, 50 fs, T^3 laser. The foil surface was located at $\pi/4$ to the laser injection. Particle beams were obtained at both sides of the foil with respect to the laser injection. The beam at the rear side, flowing to the direction perpendicular to the foil surface, was insensitive to the magnetic field. Measurements using the track detector CR39 tell that it has small divergence ($\sim$ 200 mrad) and suggest that their particles could have high energies (up to 1 MeV). We therefore conclude that these particles make a neutral beam. To the contrary, ions were obtained at the same side of the foil with respect to the laser injection. They also have energies up to $\sim$ 1 MeV, but larger angler distribution.

1 INTRODUCTION

High energy ($>$ 100 keV) ion generations using high-energy ($\sim$ kJ) and long-pulse ($\sim$ ns) lasers with plasmas were reported in 1970s $\sim$ 1980s [1]. Recent experiments have used high-power ($>$ 10 TW) and short-pulse ($<$ 1 ps) lasers with solid targets to generate ions with much higher energies ($>$ 1 MeV) [2, 3, 4]. Many simulation studies have been made on this phenomenon [5, 6, 7]. These experiments and simulations indicate that lasers with intensities over $10^{17}\mathrm{Wcm}^{-2}$ can generate MeV ions.

In this paper, we report similar experiments to irradiate thin ($< 10\mu$m) plastic and metal foils by a laser with smaller power (1 TW) and shorter pulse width (50 fs). Our motivation had been to develop an ion source of an ion accelerator using a T^3 laser. Though ions were obtained at the same side of the foil, neutral particles were obtained at the rear surface of the foil with respect to the laser injection. As far as we know, this is the first observation of the neutral particles by the interaction of a high power laser with a thin foil target.

In the next section, we describe the experimental apparatus and the experimental results. The following section discusses the results. The final section gives conclusions.

2 EXPERIMENT

2.1 Experimental Apparatus

The experiment was performed with 1 TW (50 mJ, 50 fs) Ti:Sapphire laser, 800 nm in wavelength and 10 Hz in pulse frequency. A main pulse is accompanied with a pre-pulse, whose power is $\sim$ 1/2000 of the main. An f=300 mm lens located outside of a vacuum chamber focused the laser to a target in the chamber. The surface of the target foil was located at $\pi/4$ to the laser injection. The laser intensity on the target was $\sim 4 \times 10^{16}\,\mathrm{Wcm}^{-2}$. Three types of materials were tried as the target foils; Mylar $(\mathrm{C}_{10}\mathrm{H}_8\mathrm{O}_4)_n$, polypropylene $(\mathrm{C}_3\mathrm{H}_6)_n$ and aluminum (Al). Their thickness was mostly less than 10 μm. Once penetrated by a laser pulse, a target foil was bored, so the foil frame was moved after each laser shot so that the laser pulse always irradiates a virgin surface. Typical vacuum in the chamber was $\sim 10^{-3}$ Pa.

A CR39 was used to detect generated particles. It is a track detector sensitive only to ions (and neutrons generated by recoil protons or carbons) [8]. An energetic ion cuts chemical bonds of the CR39. Chemical etching enlarges and exposes these radiation damages so that we can observe the resultant pits by using a microscope. Typical etching used 7N NaOH solutions at 70°C for 5 hours, but other combinations of etching conditions were also tried. About 5 $\sim$ 20 μm of the CR39 surface was scraped away in this operation. The size of each pit enables us to estimate the energy of the particle, if the particles are identified and the size of a pit is calibrated to the beam energy beforehand. We had done so by using proton beams ($0.5 \sim 2.4$ MeV) of a Van de Graff accelerator in Hiroshima University.

A magnetic energy analyzer combined with a CR39 plate was used to measure energies of the charged particles. The analyzer consists of a pair of dipole magnets behind a 200 μm slit. The computer code MAFIA[1] was used to estimate the tracks of the charged particles under the magnetic field. This setup was designed to detect down to 50 keV protons, 150 keV C^{6+} ions and 300 keV Al^{13+} ions.

2.2 CR39 Measurement of Particle Distributions

In order to measure particle distributions, we placed the CR39 plates in both forward and backward directions across the target, and also in the direction on the laser axis. In the forward and backward directions, the CR39 plates accept particles generated in the normal direction to the target. In the on-axis direction, the CR39 plate accepts particles on the laser axis. Each CR39 plate is located with distance of 40 mm away from the interaction point. Figure 1 shows a photograph taken at the moment of the laser irradiation, from the direction parallel to the laser axis and perpendicular to the foil surface, Al in 3 μm-thick in this case. It shows a fine but bright trace to the forward direc-

[1] See http://www.cst.de

tion, besides the backward laser reflection.

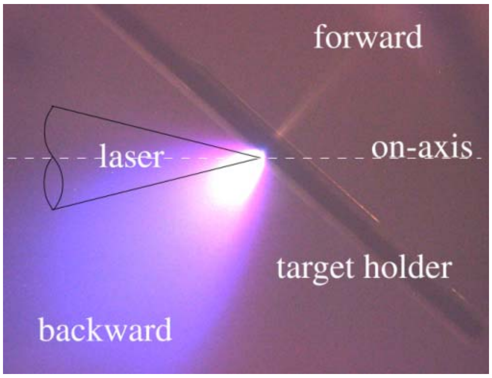


Figure 1: A photograph at the laser irradiation taken from the direction parallel to the laser axis and perpendicular to the 3 μm-thick Al target foil surface

The target irradiation left many particle tracks on the CR39 detectors in the forward and the backward directions, while few tracks in the on-axis direction. In the forward direction, the tracks were concentrated within angular divergence of$\sim$ 200 mrad. On the other hand, tracks in the backward direction had a larger angular distribution ($> \pi/2$).

Figure 2 shows the number densities of etched pits in the forward(a) and the backward(b) directions. In the forward direction, the number of pits increases as the foil thickness decreases in each material. Aluminum targets left more pits than plastics. The total number of the pits was $\sim 6 \times 10^5$ at the most. In the backward direction, the number of pits shows weak but opposite dependence on the foil thickness; i.e., the thicker targets leave the more particles. The total number of the pits was $\sim 1 \times 10^6$ at the most.

2.3 Particle Energy Measured by a Magnetic Energy Analyzer

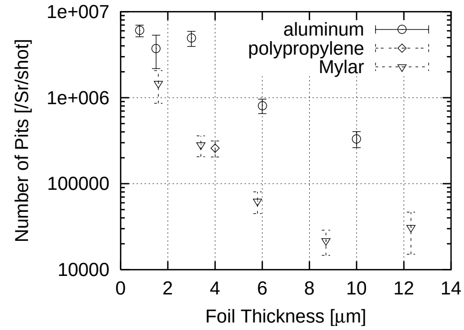
Figure 3 shows two distributions of etched pits in the forward direction, each of which was with or without the magnetic field for energy analysis, caused by 10 laser shots irradiation onto an Al foil in 3 μm-thick. They coincided within statistical errors. Similar results were obtained with plastic targets. Because these particles are insensitive to the magnetic field, we conclude that they are neutral. On the other hands, particles in the backward direction were deflected to a certain degree by the magnetic field. Figure 4 shows their energy spectrum caused by the irradiation of 4 μm-thick polypropylene, under assumption that all the particles were protons. Maximum proton energy then became $\sim$ 1 MeV.

3 DISCUSSION

In this section, we discuss particles obtained in the forward and the backward directions separately.

The particles in the backward direction were deflected by the magnetic field. Their energies range from $\sim$ 50 keV

(a)



(b)

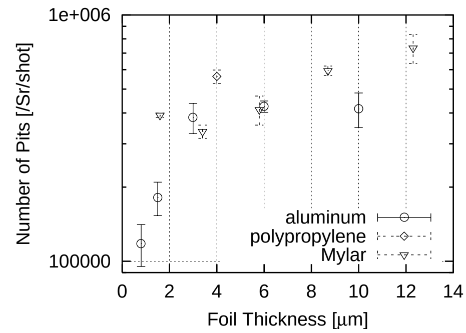


Figure 2: The relation between the number density of etched pits and target thickness. (a): The forward direction. (b): The backward direction.

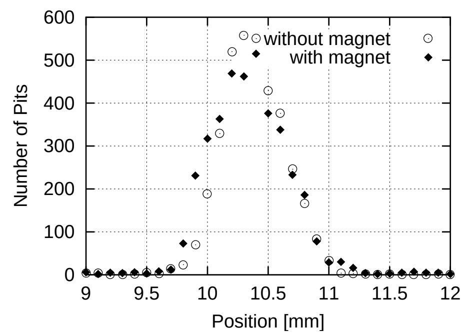


Figure 3: Deflections of etched pits caused by the magnetic energy analyzer (filled diamonds). White circles represent the distribution without magnetic field. Target was Al in 3 μm-thick.

up to 1 MeV. These results are consistent with the hitherto experiments [1, 3] using lasers of $\sim 10^{16} - 10^{17}\,\mathrm{Wcm}^{-2}$, except that the maximum energy of 1 MeV is somewhat high. This may be because the assumption is wrong that all the particles were protons. Generated particles can include carbon ions (in plastic targets) or aluminum ions (in Al targets). We are going to introduce a Thomson parabola to identify the charges of the particles.

The particles in the forward direction are neutrals. The effect of the neutral atoms onto the CR39 detectors has not been reported so far. However, studies of CR39 response to D-T neutrons report that neutrons with energies between 0.1 and 1 MeV knock out hydrogen atoms consisting CR39

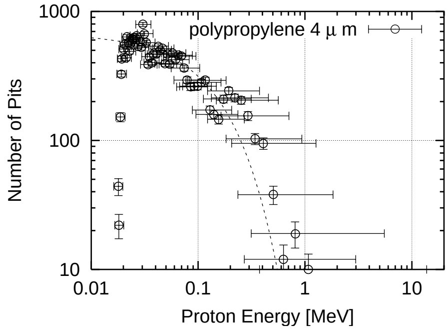


Figure 4: The energy spectrum estimated from the magnetic deflection in backward direction. Target was polypropylene in 4 μm-thick. The reduced curve is $\sim \exp[-\mathrm{E[MeV]}/0.13]$.

and these hydrogen atoms leave tracks an it[9]. The conversion efficiency from neutrons to hydrogen atom is very low, $\sim 10^{-4}\,\mathrm{pits/n}$.

We cannot tell the components of the neutrals at present. They can be hydrogens, carbons, oxygens, and/or metals. We can neither tell whether the neutrals form clusters or not. The sizes of pits etched on the CR39 plates are various. These pits distribute homogeneously. Covering a CR39 by an up-to 3 μm-thick Al foil, we found that particles penetrated it leaving fairly large ($\sim 5\mu$m in diameter) holes on the foil. If the sizes of these holes were comparable to the particle size, the particles could be clusters.

Comparing the pit sizes left on the CR39 with those caused by high-energy accelerator protons, we depicted energy spectra of particles in the forward direction as shown in Figure 5. Their energies would range up to 1 MeV and their temperatures would range between 200 and 500 keV.

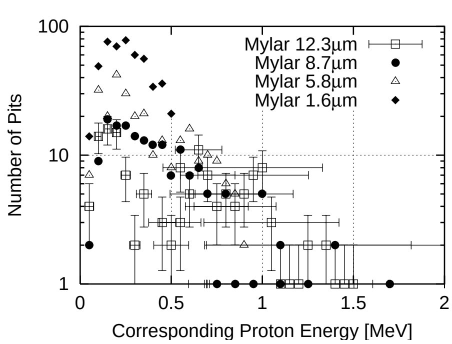


Figure 5: Energy spectra of particles in the forward direction under the assumption that all the particles were protons. The targets were Mylars with various thicknesses. Error bars are given only for the case of 12.3 μm thickness, but other data points also have similar errors.

We have made another experiment to study the ability of penetration of particles, putting Al filters in front of CR39 plates. Some particles penetrated 6 μm-thick Al. If the particles were protons, they would have kinetic energies over 600 keV and if Al^{13+} ions they were over 18 MeV. The SRIM code[2] was used in these calculations of penetration.

The particles in the forward direction could be neutrons. However, we do not have any conditions favorable for production of neutrons [10]. Assuming that the neutral particles were atoms or molecules, we tried to strip electrons from them using carbon foils with 30 to 100 nm thickness, locating them in front of the magnetic analyzer. Such stripping foils have been used for the purpose of charge exchange in ion accelerators [11]. The results were unsuccessful. We only observed that the particles were scattered without regard to the magnetic field. Improvement of the vacuum ($\sim 5 \times 10^{-5}$ Pa) at the target did not bring any remarkable change.

4 CONCLUSIONS

We have detected neutral beams in the interaction between high intensity ($< 10^{17}\,\mathrm{Wcm^{-2}}$) laser and thin foil. The neutral beams were detected at the rear side of the foil with respect to the laser injection. They were concentrated in an angle of $\sim$ 200 mrad, and possibly had fairly high energies. Ions were detected at the same side of the foil with respect to the laser injection. They have larger angular distribution and energies up to $\sim$ 1 MeV if they were protons. We have to refrain from telling what are the components of the neutrals and what is the mechanism to generate them at present.

5 ACKNOWLEDGEMENTS

We thank Fumitaka Nishiyama, for providing us plastic foils, Ryoko Katsube and Akio Seiki for calibration of CR39 detector, Yuji Tsuchimoto for software development for CR39 data processing, Koji Matsukado and Daisuke Fukuta for their help in experiments, Osamu Kamigaito, Naruhiko Sakamoto and Makoto Tobiyama for running the MAFIA code. This work was supported by Nuclear Research Promotion Program of JAERI, Advanced Compact Accelerator Development Project of MEXT and NIRS.

6 REFERENCES

[1] S. J. Gitomer *et al.*, Phys. Fluids **29** (1986) 2679.

[2] E. L. Clark *et al.*, Phys. Rev. Lett. **84** (2000) 670.

[3] A. Maksimchuk *et al.*, Phys. Rev. Lett. **84** (2000) 4108.

[4] R. A. Snavely *et al.*, Phys. Rev. Lett. **85** (2000) 2945.

[5] A. Zhidkov *et al.*, Phys. Rev. E **61** (2000) R2224.

[6] S. C. Wilks *et al.*, Phys. Plasmas **8** (2001) 542.

[7] A. Pukhov, Phys. Rev. Lett. **86** (2001) 3562.

[8] B. G. Cartwright *et al.*, Phys. Rev. Lett. **84** (2000) 670.

[9] K. Oda *et al.*, Bulletin of Kobe Univ. Mercantile Marine **36** (1988) 175, in Japanese.

[10] L. Disdier *et al.*, Phys. Rev. Lett. **82** (1999) 1454.

[11] I. Yamane and H. Yamaguchi, Nucl. Instrum. Meth. A **254** (1986) 225.

[2] The program code can be downloaded from http://www.srim.org/