FAST PROTON GENERATION BY LASER IRRADIATION OF THIN FILMS

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Abstract

Fast proton generation by laser irradiation of plastic films such as polyvinylidene chloride, mylar etc. is investigated. We irradiated 1 TW, 50 fs, 800 nm laser pulses onto thin film surfaces. Energy of protons generated normal to the film surface is analyzed by CR39. Protons with energy up to 1 MeV were observed perpendicular to the thin film.

1. INTRODUCTION

Recently, high-energy ion generation up to several tens of MeV/nucleon by high-intensity laser irradiation of solid target is reported by Michigan University [1], Rutherford Appleton Laboratory (RAL) [2-4], Lawrence Livermore National Laboratory (LLNL) [5-7]. There are also many theoretical studies [8-10]. These experiments use lasers whose powers exceed 10 TW and pulse lengths exceed 100 fs. If this phenomenon were reproduced by a compact laser, it could be applied in construction of an ion/proton source of an accelerator. This is the motivation to start the present work.

The next section describes our laser system and experimental setup. Section 3 describes the results of the experiments and their discussion. Section 4 describes the present summary.

2. EXPERIMENTAL SETUP

Our experiments used a 1 TW, 50 fs, 800 nm laser with 10 Hz pulse frequency. This laser system equips no pulse cleaner, so there exists a pre-pulse at ns area with 100 fs to 1 ps pulse duration and 5 μJ to 50 μJ pulse energy.

Figure 1 is the schematic of the experimental setup. A cylindrical vacuum vessel with 180 mm in radius and 170 mm in depth is used under typically pressure of 2×10^{-3} Pa. An f = 300 mm lens outside of the vacuum vessel focused the laser enabling the peak intensity of 5×10^{16}-10^{17} W cm^{-2} at the focal spot with diameter of ~ 20 μm. We used as the target polyvinylidene chloride $(C_2H_2Cl_2)_n$ films with thickness of ~10 μm and density of 1.7 g cm^{-3}, and mylar (polyethylene terephthalate, $(C_{10}H_8O_4)_n$) films with various thickness. We put the target surface at an angle of 45° to the laser axis, and put CR39 detectors [11] parallel to the target surface. A Faraday-cup is also used for the proton detection.

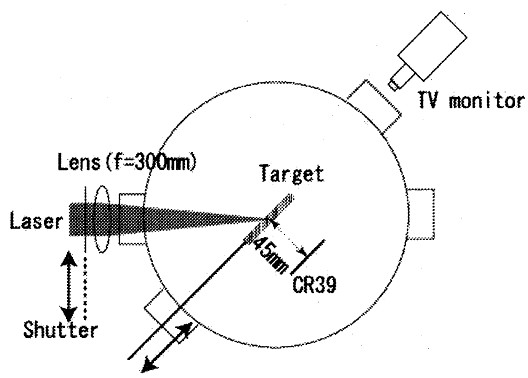

Fig. 1. Schematic of the experimental setup.

We have found that, if both the target and the CR39 are put on the laser axis normal to it, we cannot distinguish the tracks produced by laser and those by protons.

The target is bored by a single irradiation of the laser, so it is moved after each shot so that the laser pulse hits the virgin surface. A shutter extracted a fewer pulses from the 10 Hz pulse train lest the target should be exposed to the laser during the move.

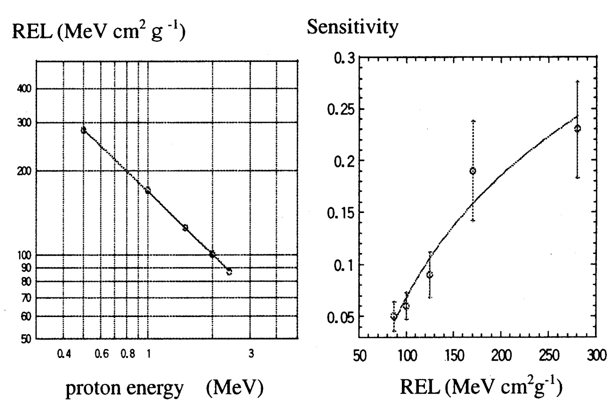

Fig. 2. Left is the relation between proton energy and restricted energy loss (REL) at CR39. Right is the relation between restricted energy loss (REL) and sensitivity at CR39.

We mainly used CR39 [11] for energy measurement. It is a plastic nuclear track detector sensitive only to ions with energy greater than 100 keV/nucleon. The irradiated CR39 plates were etched in NaOH solution. Typical conditions of the etching are use of 5N solution for 15 hours at 70 °C.

Figure 2 was obtained by exposing proton beams from Van de Graaff accelerator in Hiroshima University. It gives the relation between proton energy and restricted energy loss (REL is linear energy transfer (LET) including effects of recoil electrons), and that between REL and sensitivity at CR39. Sensitivity is defined by $S = 2D^2/(4B^2 - D^2)$, where D is a pit diameter and B is the etched depth of unbombarded surface.

We measured D and B, and convert the data into particle energies using Fig. 1. We have assumed that the all pits are caused by protons.

3. RESULTS AND DISCUSSION

In the first experiment using polyvinylidene chloride targets, we observed the Faraday-cup signal by an oscilloscope, in which a first negative signal was taken over by a large positive signal. The maximum value of positive signal appeared 20 ns after the peak of the negative signal. Assuming that negative signal is caused by electrons with the light speed, and that the positive signal is caused by protons, we calculate the mean energy of proton as ~ 300 keV.

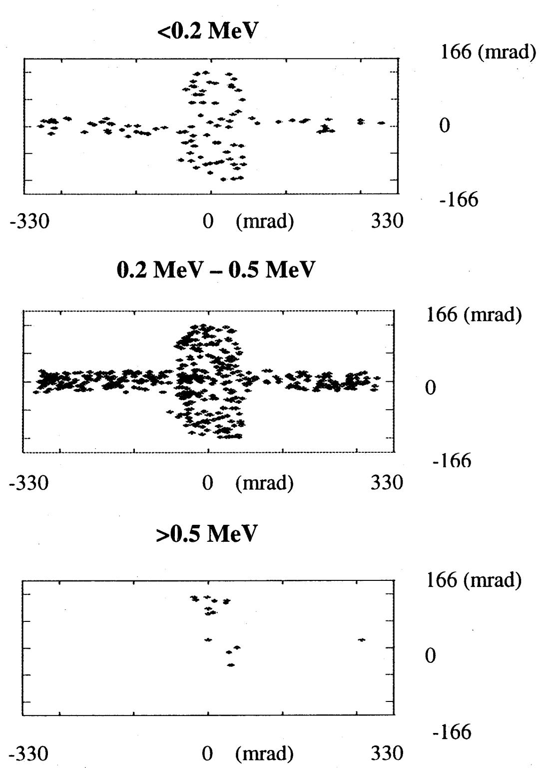

FIG. 3. Distributions of the etched tracks on CR39 caused by polyvinylidene chloride target in three proton energy regions.

We then recorded the proton tracks caused by ten successive laser pulses onto five pieces of 20 mm x 10 mm CR39 plates located 150 mm behind the target. Figure 3 shows the distributions of the etched tracks whose diameters are larger than 5 μm. It contains three figures corresponding to three proton energy regions; < 0.2 MeV, 0.2 - 0.5 MeV, and > 0.5 MeV. We found that the protons with higher energies concentrate around the center of the distribution.

Figure 4 shows the energy spectrum. Horizontal error bars were estimated from Fig. 2. Decrease of the number of pits at the low energy side is due to the lack of sensitivity of the detector against low energy protons. We can observe here protons with energies exceeding 1 MeV.

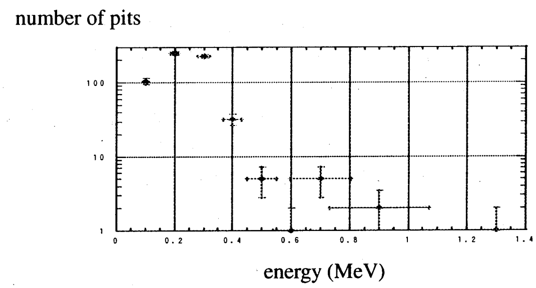

Fig. 4. Energy spectrum of protons from the polyvinylidene chloride targets.

Figure 5 shows the energy spectra obtained using mylar targets with various thickness, recorded by a single laser shot. The length between the targets and CR39 was 45 mm. Figure 6 summarizes the data in Fig. 5. It gives the number of the traces and the slopes of the fits or the ion temperature defined by $1/e$, in which 1 mm^2 correspond to 10^{-4} str. The thinner foils give the more particles and the lower temperature. Tracks concentrate on the area 10 mm in length and 5 mm in width. The total number of particles is ~ 25,000, if the average particles density is ~ 500 mm^{-2}.

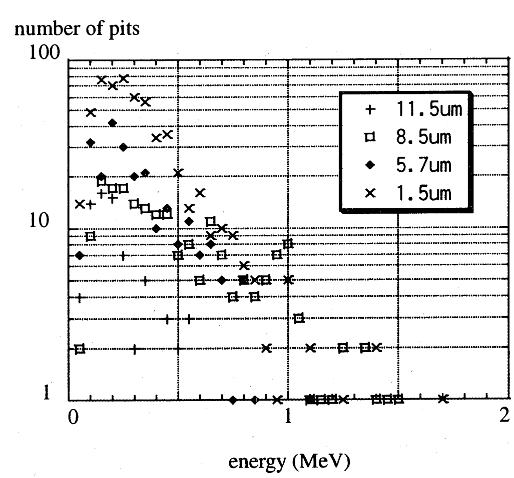

FIG. 5. Energy spectra of protons from mylar with various thickness.

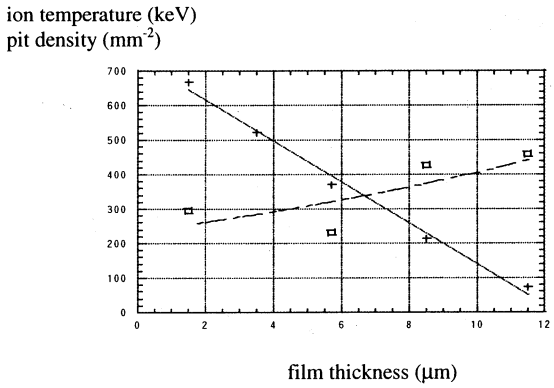

FIG. 6. The number of particles (solid line) and ion temperature (broken line) dependences on myler film thickness.

In spite that our laser has smaller energy and shorter pulse width than those of other experiments [1-7], Figures 4-5 show that the maximum proton energy exceeds 1 MeV. Certainly, there have been some experiments [3] and simulations [8] reporting the production of MeV protons at the laser intensity of $10^{16\text{-}17}$ W cm^{-2}, but the shortest laser pulse width among their works were around 1 ps.

According to the LLNL model [9], the proton energy gained at rear side of the irradiation is proportional to the electron temperature. No data of the electron temperature are available. If we estimate it using the formula $T_{hot} \sim [(1 + I\lambda^2 / 2.8\text{x}10^{18})^{1/2} - 1]$ x 511 keV [12], T_{hot} becomes about 6 keV. The proportion constant between the proton energy and the electron temperature lies between 2 and 12 [9]. Even if we take the maximum, the proton energy is only 70 keV in this model.

It has been said that the energy identification using the CR39 detectors requires good skill. We however have an indirect evidence that support the maximum proton energy. We placed Al foils (0.8 μm, 5.0 μm or 2 x 5.0 μm) in front of CR39. The 0.8 μm and 5 μm Al foil was drilled to have holes, the numbers of which are almost equal to the CR39 tracks. However, when we placed two 5.0 μm foils, the second foil was not drilled. The SRIM code[13] tells that the range of 450 keV proton is about 5.0 μm in Al. The maximum proton energy should be larger than ~ 500 keV.

4. SUMMARY

We have studied fast proton generation by 1 TW laserirradiation of thin films. The CR39 detectors tell that the maximum proton energy exceeds 1 MeV.

It has been reported that plasma generated by a pre-pulse lowers the energy of the protons [7], because the electric field gradient decreases as the plasma expands. Though our laser has prepulses, we do not observe any harmful effect of it. In order to clarify the effect of the pre-pulses, we plan to equip a pulse cleaner in the laser system which kills them.

We are going to introduce a Thomson parabola to obtain two-dimensional spectra of mass and energy of the ions [14]. We expect that it will give better energy spectra. Moreover, it will enable us to locate both the target and the CR39 detector on the laser axis. Hitherto experiments report that the normal incident laser produces ions with higher energy. We will verify it in the nearest future.

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