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Short Communication

EFFECT OF LASER CONTRAST ON MeV PROTONS FROM RELATIVISTIC LASER-SOLID INTERACTIONS

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ABSTRACT

Results on acceleration of MeV protons from 100 TW Ti:Sapphire laser system is presented in this paper. By irradiating few micrometers thick aluminum foils with 30 fs laser pulse with intensity of 10^{20} W cm^{-2}, protons with energy exceedingly more than 10 MeV were detected. However, on increasing our laser contrast by 2 orders of magnitude (10^{-8} to 10^{-10}), we observe a nearly 4.5 times enhancement in the proton flux, with a slight reduction in the proton cut-off energy. These results open a prospect of producing high flux of MeV-class proton beams.

Keywords: *Laser contrast, Proton flux, Ti:Sapphire laser system*

1. INTRODUCTION

Interaction of intense ultrashort laser pulse with thin solid foils leads to acceleration of laminar proton beams, with energy extending up to 10's of MeV [1, 2]. Generation of bright flux of proton beam is necessary for many fields in plasma such as probing of electromagnetic fields in overdense plasmas, fast-ignition scheme of laser driven fusion and radiobiology [3-5]. For efficient realization of the above-mentioned applications, it becomes impertinent to improve laser-to-proton energy conversion. In the past there have been some efforts to achieve this goal by improving the intensity contrast of the laser pulse [6-8].

The successful realization of the above applications relies on reproducible ion sources with high particle energy and flux. While there are various novel ion acceleration mechanisms, the well-established so-called target normal sheath acceleration (TNSA) mechanism [1] has proven being capable of reproducibly generating relatively high flux of energetic particles under a vast range of laser and target parameters. In practice nowadays extreme intensities have been realized by tight focusing [9] of the laser pulses with a small f-number (or large numerical aperture) focusing elements. However, tight focusing of light pulse led to extreme shortening of confocal parameter and consequently results in drastic variation of the laser intensity over a distance of only few micro meters.

In this paper we present our results on acceleration of MeV protons from 100 TW laser system (Ti: Sapphire). By irradiating few micrometers thick aluminum foils with 30 fs laser pulse of 10^{20} W cm^{-2} intensity, protons with energy exceedingly more than 10 MeV were detected. However, on increasing our laser contrast by 2 orders of magnitude (10^{-8} to 10^{-10}), we observe a nearly 4.5 times enhancement in the proton flux, with a slight reduction in the proton cut-off energy. These results open a possibility of producing bright flux of proton beams that can be used for above mentioned applications.

2. EXPERIMENTALS

The experiment was carried out using 100 TW Ti: Sapphire laser system (10 Hz) for a pulse duration of 30 fs, set up at the Center for Relativistic Laser Science (CoReLS), Gwangju, Korea. Figure-1(a) describes the experimental set up. A p-polarized, infrared laser pulse (wavelength 800 nm, pulse 30 fs) with energy of nearly 4 Joule was focused by an f/2 dielectric off-axis parabola on a 2 µm thick aluminum target at an angle of 45-degree. Nearly 50 % of laser energy was confined in the 23 µm^2 focal spot which results in the peak intensity of 2×10^{20} W cm^{-2}. The energy distribution and the resultant intensity of the laser focal spot are shown in the Figure 1(b) and 1(c), respectively. A target position monitoring diagnostic, having a sensitivity of few micrometers was used for the alignment of thin foil at the laser focus plane. The alignment system mainly consists of an infinity corrected long working distance objective, a broadband illuminating source, and a CCD camera. The objective placed along the axis of incident laser pulse ensures the precise positioning of the target in all three dimensions. The effectiveness of the entire alignment system is already verified [10] in details.

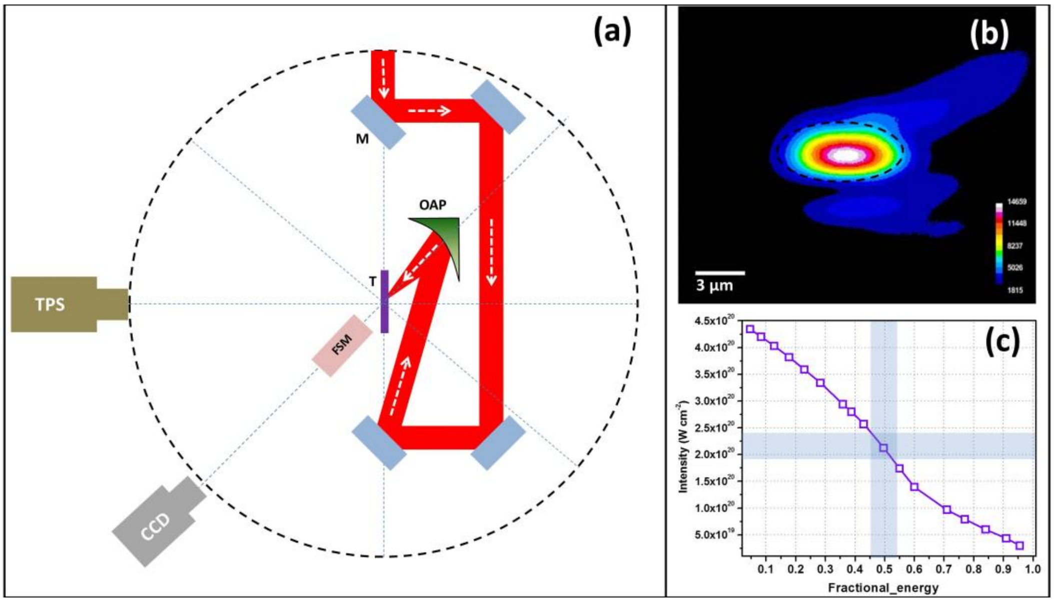

Fig.1: (a) Sketch of the experimental set up. CCD: charged-coupled device, FSM: focal spot monitor, M: mirror, OAP: off-axis parabola, T: 2 µm thick aluminum target, TPS: Thomson parabola spectrometer. (b) Intensity distribution of the laser focal spot. (c) Estimation of the laser intensity based on the fraction of energy concentration in a given area.

An absolutely calibrated micro channel plate (MCP) used as detector in Thomson parabola spectrometer for protons. The MCP phosphor screen is imaged using a 16 bit CCD (PIXIS 1024), which captures the parabolic ion traces. Due to very high level of detection sensitivity, measurement of absolute energy spectrum of laser driven ions is possible in a single laser shot. The recorded parabolic traces of protons are analyzed with a MATLAB code. By inserting a saturable absorber in the laser chain, the laser intensity contrast was changed from 10^{-8} to 10^{-10}.

3. RESULTS AND DISCUSSION

Figure 2(a) shows a typical image of parabolic ion traces recorded during the experiment. A strong proton trace, along with carbon ions of several charge states can be seen. However, on changing the laser contrast by two orders (10^{-8} to 10^{-10}), a drastic change in the ion energy spectrums can be seen (Figure 2(b)). Under the high contrast irradiation, very bright fluxes of ions are accelerated.

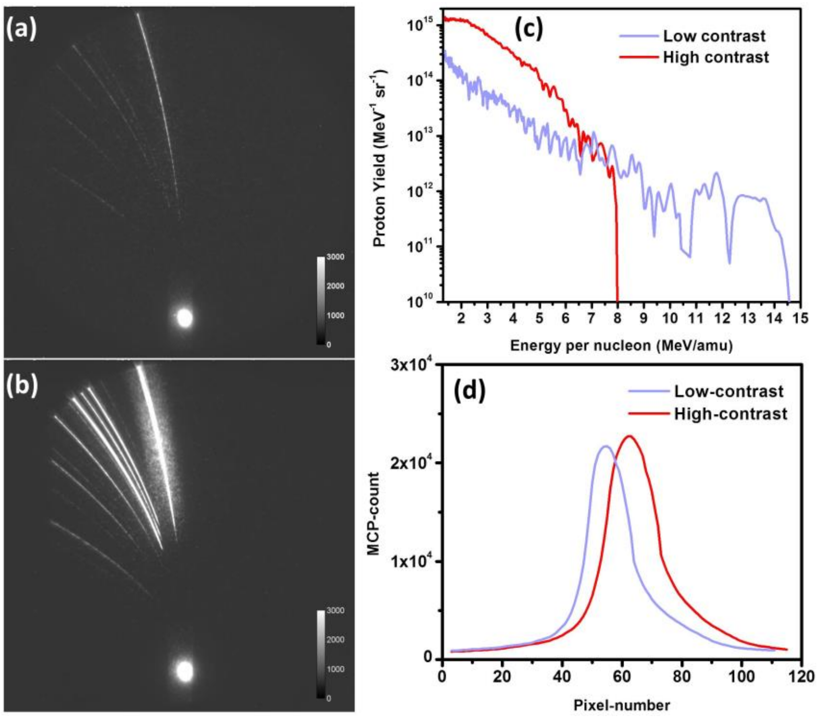

Fig. 2: Parabolic traces of the accelerated ions for (a) low contrast (10^{-8}). (b) and high contrast (10^{-10}) cases. (c) A comparison of the proton kinetic energy spectra relevant to low and high contrast of laser pulse. (d) Similar strength of zero-point signals obtained from figure (a) and (b).

A direct comparison of the proton traces under two different condition of laser contrast is shown in the figure 2(c). The proton spectrum for low contrast shows much higher cut-off energy (14.5 MeV as opposed to 8 MeV for high contrast). However, the high contrast proton spectrum shows a 4.5 times enhancement of the proton flux in the 1.5 – 8 MeV interval.

The reason behind this enhancement can be explained with the help from theoretical, experimental and simulation-based work [11-14]. At high intensity and high contrast laser pulse, the ponderomotive force pushes the electrons deep into a foil target in the form of moving electron density spike. This produces a charge separation cavity at the target front with a radius similar to the laser beam radius at the focus and on a certain length [10, 13-14]. The electron spike experiences a strong restoring electrostatic field due to the charged layer left behind, unless a balance between the Coulomb force and the ponderomotive force is achieved. Interestingly, the signal level near the zero point stays the same for both cases, as shown in figure 2(d). Target thickness does not play any role here as we have seen in simulation [14]. So, for a terawatt laser system and for same setup, one can get higher proton flux by increasing the laser contrast.

4. CONCLUSIONS

In conclusion, results on acceleration of MeV protons from 100 TW Ti:Sapphire laser system is discussed. The 2 μm thick aluminum foils, irradiated with relativistic intense laser pulse of 10^{20} W cm^{-2} intensity, results in acceleration of protons with energy exceedingly more than 10 MeV. The variation in the laser intensity contrast by two orders of magnitude (10^{-8} to 10^{-10}) lead to nearly 4.5 times enhanced flux of proton beam. These MeV-class proton beam with high brightness could be very promising tool for probing transient electromagnetic field of hot dense plasmas with high temporal and spatial resolution radiographs, fast ignition, production of warm dense matter and, later on, high intensity injectors for accelerators and sources for proton therapy or radio-isotope production. Moreover, these protons, with energies of several tens of MeV (20 - 30% of the velocity of light) are neutralized by the co-moving low energy electrons. Due to very high flux of particles generated during such interactions, this could be used in counter-propagating beams experiment to investigate the collision of fast plasmas and the formation of collision-less shocks [15-16].

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