RECENT PROGRESS OF LASER PLASMA PROTON ACCELERATOR AT PEKING UNIVERSITY*

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Abstract

Recently, radiation pressure acceleration (RPA) has been proposed and extensively studied, which shows circularly polarized (CP) laser pulses can accelerate mono-energetic ion bunches in a phase-stable-acceleration (PSA) way from ultrathin foils. It is found that self-organizing proton beam can be stably accelerated to GeV in the interaction of a CP laser with a planar target at $\approx 10^{22}W/cm^2$. A project called Compact LAser Plasma Proton Accelerator (CLAPA) is approved by MOST in China recently. A prototype of laser driven proton accelerator $(1to15MeV/1Hz)$ based on the Phase Stability Acceleration (PSA) mechanism and plasma lens is going to be built at Peking University in the next five years. It will be upgraded to 200MeV later for the applications such as cancer therapy, plasma imaging and fast ignition for inertial confine fusion.

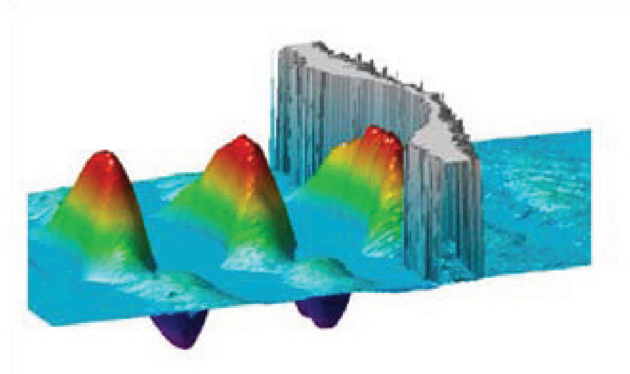

Figure 1: (Color online) Schematic view of Phase Stable Acceleration for ions by irradiating a thin foil using a circular polarized laser pulse (wave denotes the laser pulse, the gray wall is the foil).

PHASE-STABLE-ACCELERATION (PSA)

In the intense-laser interaction with solid foils, usually there are three groups of accelerated ions. The first two occur at the front surface, moving backward and forward, respectively, and the third one is sheath acceleration (TNSA) that occurs at the rear surface [1, 2]. As these output beams are accelerated only by electrostatic fields and have no longitudinal bunching in (x, p_x) plane, their distribution profiles used to be exponential nearly with 100% energy spread. Although some techniques can be used to decreasing the energy spread, however, they rely on relatively complicated target fabrication [3–5]. Recently, radiation pressure acceleration (RPA) has been proposed and extensively studied, which shows ultra-intense laser pulses can accelerate mono-energetic ion bunches in a phase-stable-acceleration (PSA) way from ultrathin foils [6–9]. For appropriate parameters, CP pulses may accelerate foils as a whole with most of the transferred energy carried by ions. The basic dynamics are well described by a one-dimensional (1D) PSA model. Acceleration terminates due to multi-dimensional effects such as transverse expansion of the accelerated ion bunch and transverse instabilities. In particular, instabilities grow in the wings of the indented foil, where light is obliquely incident and strong electron heating sets in. Eventually, this part of the foil is diluted and becomes transparent to the driving laser light. This process of foil dispersion may stop before reaching the center of the focal spot and that a relatively stable ion clump forms near the laser axis which is efficiently accelerated. It is found that self-organizing proton beam can be stably accelerated to GeV in the interaction of a CP laser with a planar target at $10^{20}W/cm^2$.

LASER PLASMA LENS [10]

In principle higher proton energy (for example,GeV) can be realized by using a higher laser intensity, however, in order to accelerate ions to a relativistic velocity, hole-boring effects and transverse instabilities should be restrained, which normally require extremely high laser intensity ($> 10^{21}W/cm^2$), sharp rising front, and high temporal laser contrast($> 10^{10}$), which are very challenging for state of art laser technology. We propose a plasma lens to make high intensity, high contrast laser pulses with a steep front. When an intense, short Gaussian laser pulse pass through nearly critical dense plasma, the laser pulse will be compressed and focused into a channel due to self-focusing and self-modulation. If it is used as a plasma lens, three pulse shaping effects are realized synchronously: 1) pulse focusing that results in laser intensity enhancement; 2)laser profile steepening; 3)absorption of non- relativistic prepulse. The transmission efficiency of the lens can be as high as 60% and it will be useful for many applications such as generation of high-energy ions and electrons.

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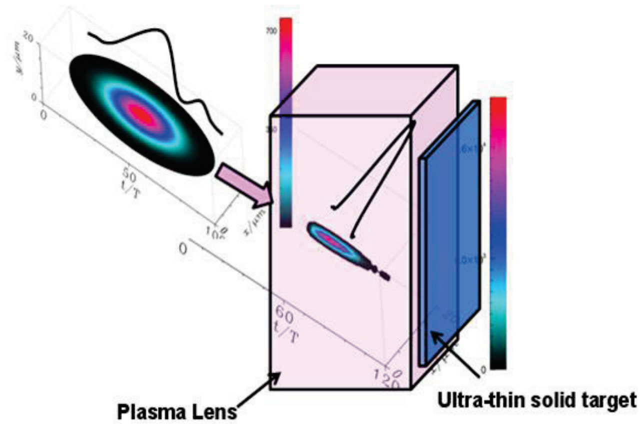

Figure 2: (Color online) Laser plasma lens for pulse shaping and cleaning.

TARGET FABRICATION

In order to do Phase Stable Acceleration of ions, it is necessary to have free-standing nanometer-thickness target. By using the filtered cathodic vacuum arc system, we have successfully manufactured free standing, diamond-like-carbon (DLC) films and Cu foil. The structure and thickness of film has been measured by the Raman spectrum and atomic force microscope.

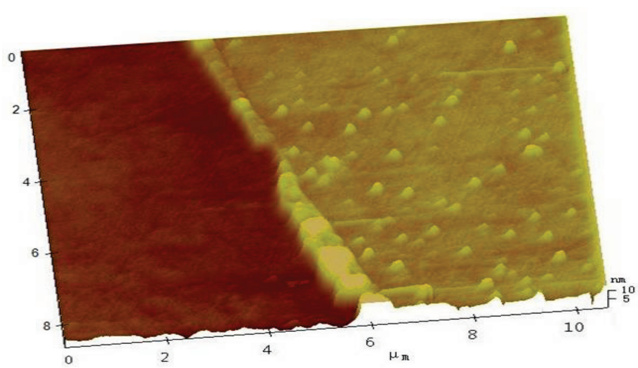

Figure 3: (Color online) AFM image of DLC coated on Si substrate.

PROTON ACCELERATION FROM TWO LAYER TARGETS [11]

A novel efficient and stable mechanism to generate 200MeV proton bunch by irradiating a two-layer targets (near-critical density layer+solid density layer with heavy ions and protons) with a p-polarized Gaussian pulse at intensity of $6 \times 10^{20} W/cm2$. The laser intensity is enhanced by the laser self-focusing effect in the near-critical density layer. Meanwhile the electrons are efficiently accelerated in the laser propagation direction by the direct laser acceleration. A stronger sheath field is build up at the rear side of the solid density layer by the combination interaction of the shaped laser pulse and the energetic electrons, leading to more efficient and stable proton acceleration. Compared to a single-layer solid target, the proton peak energy is increased by a factor of three and the energy spread is remarkably decreased from the two-layer target [12].

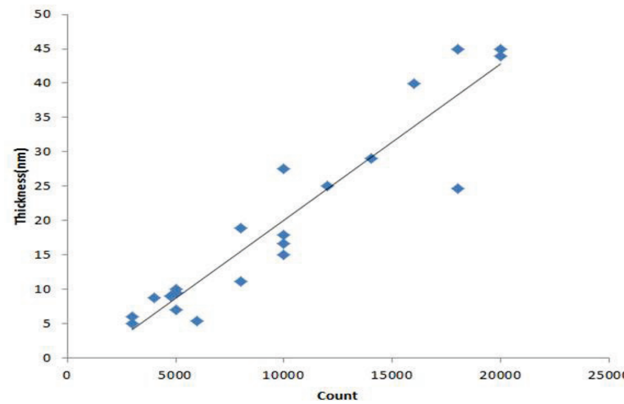

Figure 4: (Color online) DLC film thickness versus arc counts.

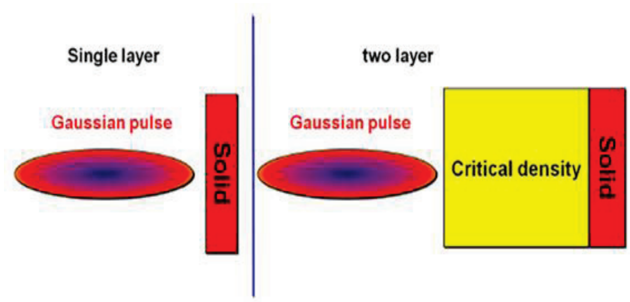

Figure 5: (Color online) From single nanometer target to two layer target.

CLAPA PROJECT AT PEKING UNIVERSITY

A project called Compact LAser Plasma Proton Accelerator (CLAPA) is approved by MOST in China recently. A prototype of laser driven proton accelerator $(1to15MeV/1H_z)$ based on the PSA mechanism and plasma lens [11] will be built at Peking University in the upcoming five years. It will be upgraded to 200MeV later for the applications such as cancer therapy, plasma imaging and fast ignition for inertial confine fusion.

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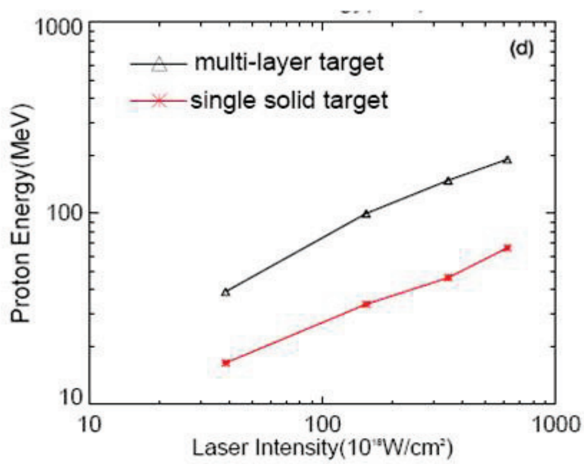

Figure 6: (Color online) Parameter scanning for proton energy scaling law Energy scaling for two-layer target with fixed near-critical plasma skin length and single-layer solid target.

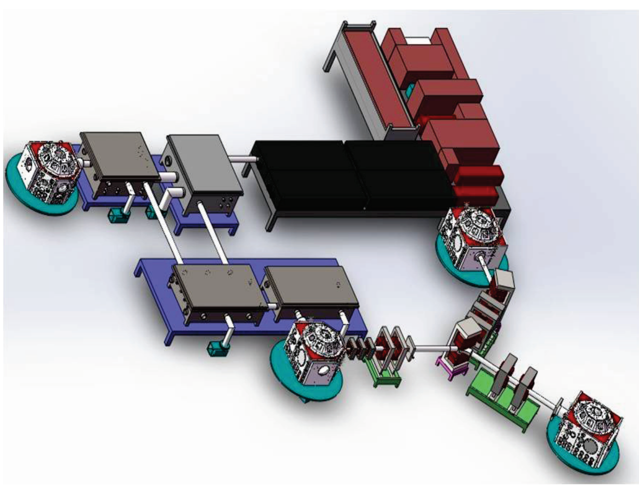

Figure 7: (Color online) Compact LAser Plasma proton Accelerator (CLAPA)at Peking University.

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