COMPACT LASER PLASMA ACCELERATOR AT PEKING UNIVERSITY

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Abstract

Compact LAser Plasma Accelerator (CLAPA), a novel accelerator based on the interaction of high intensity ultrafast laser and plasmas, was recently built at Peking University, Beijing, China. The system was designed to demonstrate the feasibility of plasma based accelerators for medical/biological applications with accelerated protons of energies ranging from 1 to 60MeV. It will also be used to generate high quality electron beams, brilliant X-rays through laser plasma interactions (LPI).

INTRODUCTION

Since the concept of laser plasma based accelerators was first proposed in 1979 [1], laser plasma accelerators have made great progresses in the past decades [2-23]. Thanks to the invention of chirped pulse amplification (CPA) technique [24], ultrahigh intensity lasers can produce acceleration fields of higher than 100GV/m, surpassing those in conventional accelerators by at least five orders of magnitude. Recent experimental demonstrations have proved the generation of GeV-class electron beams[5-7, 9, 14-16], and high energy ions with multi-MeV per nucleon [17-19, 21, 22].

The laser generated ions exhibit very prominent characteristics for ultrafast applications – short pulse lengths, high currents and low transverse emittance[25] – but their exponential energy spread remains the biggest obstacle for the wider use of this technology. Further attempts have been made to achieve mono-energetic ion beams both theoretically [26, 27] and experimentally [23, 28].

Much progresses were achieved in electron acceleration compared with the ion acceleration through laser plasma interactions as the electrons are easier to accelerate. Many kinds of injection methods, such as head-on colliding[8, 29], ionization[29-33], and density ramp[34, 35], were proposed to reduce the energy spread within the regime of laser wakefield acceleration (LWFA). Also, attempts were made with different guiding methods to achieve longer acceleration distance without defocusing the laser beam, such as ablative capillary discharge [12, 15], gas-filled capillary [16].

The quality of the accelerated beams both for electrons and ions is highly rely on the quality of the lasers as well as the choice of targets with appropriate accelerating mechanisms. However, there will be no doubt that this kind of new technology will be widely used in many research and applications fields, such as ultrafast imaging, medical physics, high energy density physics, and so on.

Here we present the brief introduction of the laser facility recently build in CLAPA at Peking university. The laser facility is a Ti: sapphire based double CPA system. Cross- polarized-wave (XPW) generation technique was employed in the system to provide a laser pulse with the contrast of 10^{-10}. The total energy the system can delivered is 5 J in the output of the compressor, and the pulse duration is 25 fs. It is possible to achieve a peak intensity of 10^{20}W/cm^2 with the focusing the beam into 6 um in diameter (FWHM， considering the transportation efficiency of 90% into target chamber and 30% in the focus spot). As noted in Fig. 1 that beam transportation line was designed with a double plasma mirror chamber for further increase the contrast for ultrathin target experiments. Then the beam can be delivered into different target chambers for multipurpose experiments.

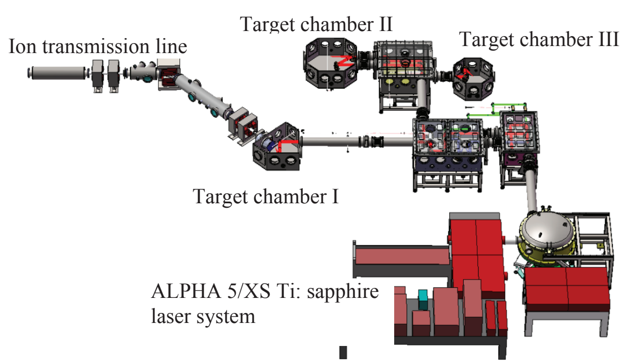

Figure1: Layout of the CLAPA facility at Peking University.

CLAPA LASER SYSTEM

The CLAPA laser was a system based on Ti:Sapphire with double CPA structure operating at 5-Hz, the center wavelength is 800 nm, the setup is shown in Fig. 2. KHz pulses are generated through one stage of CPA from an 82 MHz oscillator, the beam is sending into XPW stage for pulse cleaning and then stretched in the second CPA stage for further amplifications. The total pulse energy that can be achieved in the output of the amplifier is over 7 J, which is then sending into a vacuum compressor. Finally, a pulse energy of 5 J with full width at half maximum (FWHM) pulse duration of 25 fs can be achieved. A deformable mirror is installed for pulse shaping which may facilitate for better focusing on the target.

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Figure2: The 200-TW laser setup.

PROTON ACCELERATION SCHEME

The better beam quality of accelerated protons can be achieved by using ultrahigh contrast laser pulse as well as thinner nano-scale targets. The both needs very critical experimental conditions and a big sacrifice of laser pulse energy. Recently, near critical density (NCD) plasmas ($0.1n_c < n_e < n_c$) was found to be a prominent medium for both increase the laser intensity, steepen the front [36, 37] and compress the beam spot into near diffraction limit[38].

CLAPA is aiming to generate 1-15MeV tuneable energy proton beam with less than 5% energy spread based on the Phase-Stable-Acceleration (PSA) mechanism[26] with diamond-like-carbon (DLC) target. With prospect NCD plasma technology, it is possible to generate high quality proton beams which is also experimentally demonstrated [37]. CLAPA has formed the ability to made single/double layer targets, such as nanometre scale DLC target or DLC target with density and thickness controlled carbon-nanotubes (CNT) film. The CNT layer will both steeping the pulse front and focusing the laser beam to higher intensity before it shot on the DLC target.

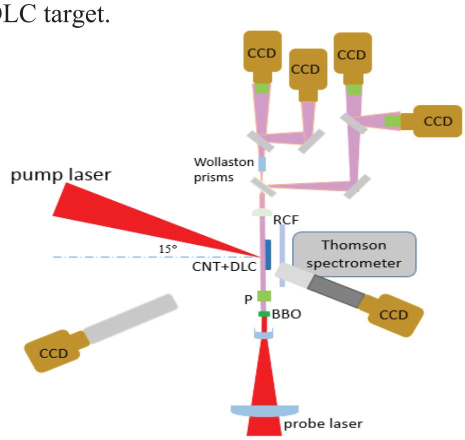

Figure 3: Schematic design of laser ion acceleration based on double layer targets.

Theoretical attempts were made to optimizing the pre-pulse effects for proton acceleration and simulation results shows that three times higher energetic proton beam can be achieved by ablation compared with single pulse[39]. A special design was made for the laser system to provide a prepulse with pulse energy ranging from 2 mJ to 12 mJ and pulse duration ranging from 25 fs to 200 ps. The experimental will be conducted with the optimized prepulse with respect to the main pulse for double layer target (CNT+DLC), and expect for generating higher energy proton beams.

ELECTRON ACCELERATION SCHEME

Electron beams generated through laser plasma acceleration is a prominent source for its ultrashort pulse which is temporally coherence and the compact size of the accelerator as it have 5 orders of magnitude higher acceleration field than conventional accelerators. A great progress has been made in achieving good quality, such as high energy, low spread, significant charge and small emittance. There are usually thought to be two main mechanisms in the filed which is said to be LWFA[7, 9, 10, 14, 16] and direct laser acceleration (DLA)[2, 3]. The two mechanisms were claimed to be completely different from each other at the beginning but incorporated each other recently [40, 41]. All of these efforts were made to achieve better beam quality at the same time.

The main goal for laser electron acceleration in CLAPA is focused on generating multi-hundreds-MeV to GeV-class quasi-monoenergetic electron beams, with large beam charge. To achieving the goal, two possible approaches based on ionization injection will be tried in the laser facility: beam guiding and density ramp.

Dual laser beam experiments is also considered in the future plan for better control of the accelerated electron beams, which may provide versatile experimental techniques for experiments or diagnostics.

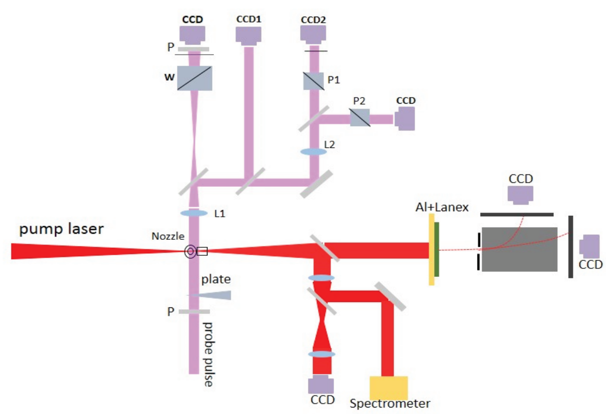

Figure 4: Schematic of experimental arrangement for laser electron acceleration.

CONCLUSION

A 200TW Ti:Sapphire laser facility -CLAPA was recently built at Peking University. CLAPA was aiming to generate proton beams with energy more than 15MeV utilizing DLC targets together with CNT for NCD plasma technology. CLAPA will also be used to generate high energy large bunch charge electron beams by considering ionization injection schemes as well as dual laser beams for better control of the electron beam or diagnostics during the interaction.

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