L.1: Laser wake-field acceleration of electrons in laser produced solid plasma plume

Laser wake-field acceleration (LWFA) in plasma using table top, high power, femtosecond duration laser pulses is well recognized as a promising alternative to the conventional RF based acceleration technology. The LWFA technique provides extremely high accelerating electric field of ~100 GV/m, generated by relativistic plasma waves excited behind an intense laser pulse propagating in the plasma. Electrons injected into such a fields are accelerated to several tens of MeV energy over sub-mm length, which promises compact and low cost high energy accelerators for future. The electrons to be accelerated are self-injected (from the plasma itself) into the wake-field in most of the experiments, because of its extreme simplicity, despite high non-linearity of this process. Through continuous research efforts by various laboratories in the world including Laser Plasma Division, RRCAT, the laser and plasma parameter regimes for generation of high quality electron beams from LWFA have been identified and various schemes for improving the stability and to control the electron beam parameters have been demonstrated. The electron bunches from LWFA have ultra-short duration (few fs) and high peak current (~kA). Application of these electron beams have already been demonstrated e.g. in soft x-ray generation using undulator and efforts are being made to realize free electron laser using these beams.

Supersonic fast pulsed gas-jet is the most commonly used target medium. Operation of the gas-jet at high repetition rate > 1 Hz, required for many applications of the electron beam, is limited by the requirement of high vacuum before each gas-jet pulse. As an alternative, we have investigated a novel scheme wherein laser ablated solid plasma plume is used as the target for LWFA. The laser ablation of the solid target releases negligible amount of material in the vacuum chamber in comparison to a gas-jet, and therefore allows high repetition rate ~ 1 kHz or more. A schematic of the experimental setup used for demonstration of LWFA in plasma plume target is shown in Fig. L.1.1. Ti:sapphire laser pulse (λ = 800 nm) of 45 fs duration and focussed intensity ~5×10^{18} W/cm^2 was used as a drive beam for LWFA. To produce plasma plume, a part of the second harmonic converted Nd:YAG laser pulse (λ = 532 nm), that pumps the final amplifier of the Ti:sapphire laser system, was focused on a solid target to produce its plasma with appropriate density and scale length before the arrival of the 45 fs laser pulse. The fs laser pulse self-guiding in plasma plume was imaged through the nonlinear Thomson scattering radiation from the plasma. Various target materials, target distances, and delay between the two laser pulses, were investigated to identify the appropriate conditions for accelerating electrons and to produce high quality electron beam.

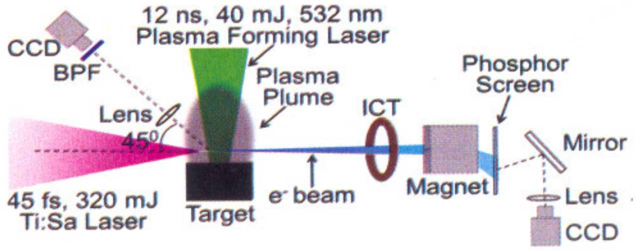

Fig.L.1.1: Schematic of the experimental setup. ICT-Integrating Current Transformer for electron beam charge measurement, CCD-Charge couple detector for recording images of laser guiding and accelerated electron beam, BPF-Band pass filter for selectively transmitting Thomson scattered radiation at = 400 nm from plasma.

After optimization, high quality quasi-mono-energetic electron beam with divergence ~10 mrad, energy ~12 MeV, and charge ~50 pC was produced (as shown in Fig.L.1.2) by laser wake-field acceleration of self-injected electrons in Nylon plasma plume at a target distance of ~150 μm and fs laser pulse delay of ~90 ns. The electron beam was reproducible in every shot and had reasonably pointing stability. The study showed that the target composition plays a critical role in optimization of the electron acceleration process.

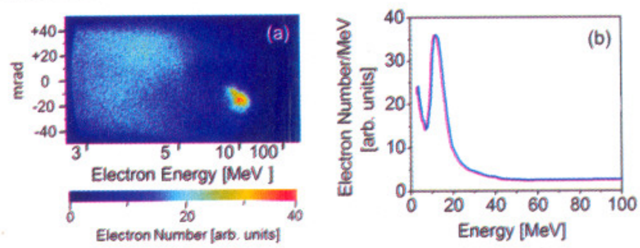

Fig.L.1.2: a) Image of the energy dispersed electron beam showing well collimated quasi-mono-energetic electron beam; and b) Energy spectrum of the quasi-mono-energetic electron beam shown in a).

The present demonstration of high quality electron beam is a big step forward in the effort to find suitable targets with high repetition rate capability, along with easy and low cost target setup, and broad choice of target composition. Further, deriving the laser pulses for plasma plume formation and laser wake-field acceleration from a single laser system (as done in the present experiment) allows perfect synchronization and makes the setup even more simple and of lower cost. With these advantages, plasma plume targets opens up wide range of possibilities for future investigations to further optimize several parameters in this scheme to generate higher energy electron beams with more stability and control. (For more details, please refer to *B. S. Rao et al., Appl. Phys. Lett. 102, 231108, 2013).*

Reported by :
B. S. Rao (sunnyb@rrcat.gov.in) and A. Moorti