Energetic Proton Beam Acceleration on LFEX Laser

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The advent of multi-kJ, Peta-Watt class laser systems such as LFEX laser at Institute of Laser Engineering opens a new vista on intense laser-plasma interaction with pulses characterized by longer (multi-ps) duration and multi-beamlet interaction with energies exceeding the kJ level. LFEX laser is composed by four beamlets, each carrying currently up to 500 J of laser energy at maximum compression (1.5 ps) that can be spatially and temporally overlapped onto a 60 μm spot containing 40% of the laser energy, or arranged in temporal sequence resulting in a single, flat-top laser pulse, as well as a pulse train. Taking advantage of LFEX laser's unique specs and of the recent laser contrast improvement ($\geq 10^9$ for ns-level pedestal) we explored proton acceleration from thin foils with multi-ps flat-top temporal laser profile and with temporally and spatially overlapped beamlets.

Keeping constant laser intensity of $> 10^{18}$ W/cm^2 and increasing the pulse duration from 1.5 to 6 ps by arranging the beamlets in a flat-top temporal profile irradiating 5 μm Al foil, we observed a 3-fold increment in the peak proton energy and an order of magnitude increment in the laser-to-proton energy conversion efficiency, from 0.5 to 5% for the longest pulse duration. The results are well described by Particle in Cell (PIC) simulations together with a plasma expansion model that accounts for the evolution of the fast electron temperature for multi-ps laser irradiation [2].

By temporally and spatially overlapping the LFEX beamlet at maximum compression (~1.5 ps) we demonstrate, experimentally and through 2D particle-in-cell simulations, that the combining beamlets with a small angle, hence having interference patterns at the overlapping point, improves the laser absorption and the conversion efficiency from laser to hot electrons, compared to results with only one beam with same laser energy and intensity [3]. This effect is significant even for high contrast laser pulses. 2D PIC simulations support the experimental results, showing that the beamlets interference pattern on target is responsible for the periodical shaping of the critical density and the formation of large surface magnetic fields localized around the interference maxima, as in a mosaic structure. The shaping of the critical surface increases the average laser incidence angle on target as well as the effective area where the interaction takes place, resulting in higher absorption into fast electrons. The large surface B-fields efficiently de-phase and de-couple the oscillating electrons from the laser field. Both effects contribute to the increase of the laser energy absorption into fast electrons by factors.

These results are of great interest for laser-generated proton beam application to High Energy Density (HED) Physics with multi-kJ, multi-ps and multi-beamlet petawatt laser systems and are applicable to other existing laser facilities.

[1] N. Miyanaga et al, J. Phys. IV 133, 81 (2006).
[2] A. Yogo et al. Scientific Reports 7, Article number 42451 (2017).
[3] A. Morace et al., to be submitted.