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Ion acceleration from ultra thin foils on ASTRA-Gemini laser with 50fs, 10^{20}-10^{21} W/cm^2 pulses

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We report on experimental investigations of ion acceleration from thin foil targets irradiated with ultra-short (~ 50 fs), high contrast (~10^{10}) and ultra-intense (up to 10^{21} W/cm^2) laser pulses. These measurements provided for the first time the opportunity to extend the scaling laws for the acceleration process in the ultra-short regime beyond the 10^{20} W/cm^2 threshold, and to access new ion acceleration regimes. The scaling of accelerated ion energies was investigated by varying a number of parameters such as target thickness (down to 10 nm), laser light polarization (circular and linear), angle of laser incidence (oblique-35^0, normal) and laser energy. The effect of target thickness on the ion flux produced was also investigated at 35^0 and normal laser incidence on target.

Recent advances in laser technology have led to laser systems with high contrast and extreme intensity values, which have opened up new perspectives in the field of laser-matter interactions. Rapidly growing interest in laser driven ion sources has been stimulated by their potential applications such as high resolution charged-particle radiography [1], production of high energy density matter of interest for astrophysics [2], high brightness injectors for accelerators [3], sources for proton therapy (requisite energy>200 MeV) [4] and ignition of controlled thermonuclear fusion. However, it is clear that all these potential applications are demanding further improvement of the beam specifications and the development of high repetition-rate bright sources. In these contexts, the main trend of current research concerns the increase of maximum ion energy.

The laser acceleration of ions to multi-MeV energies from thin foils has been investigated extensively over the last decade using intense laser pulses reaching intensities up to the 10^{20}-10^{21} W/cm^2 range. These intensities were reached by using high energy, ps-scale pulses [5-7]. The ions are mainly accelerated in space-charge fields created by laser generated relativistic electrons which are penetrating through the target and creating the electrostatic sheath field up to several MV/μm at the target rear (Target Normal Sheath Acceleration – TNSA mechanism [8]). These accelerated ion beams have unique properties e.g. small angular divergence and high laminarity but also have large energy spread, slow energy scaling with the laser intensity and low laser to ion energy conversion efficiency.

Recent progress in laser technology has enabled access to intensities exceeding 10^{20} W/cm^2 also using short (~50 fs) laser pulses. At these intensities, PIC simulations using circularly polarised light have shown a transition from the usual TNSA process to a regime of radiation pressure acceleration (RPA) [9, 10]. The advantage of using circularly polarised pulses lies in the fact that the oscillating components of the Lorentz force in the direction perpendicular to the sharp density gradient is quenched, and hence the motion of the electrons at the interaction surface is mostly adiabatic and electron heating is strongly reduced [9]. The ions are accelerated via space charge fields which balance the radiation pressure (i.e. the ponderomotive force). In fact recent experiments have come to unveil new features e.g. quasi mono-energetic spectra and higher ion energy as signature of new radiation pressure regime [11].

In this paper we discuss the dependence of protons energy on target thickness measured along several directions: rear surface target normal-RSTN, 10^0 to RSTN, front surface target normal-FSTN, under 35^0 laser irradiance on the target with linearly polarised light.

Our experiments have been carried out on ASTRA-Gemini laser at Rutherford Appleton Laboratory, which delivers 12 J ultra-short (~50 fs) pulses at central wavelength 800 nm. The intrinsic intensity contrast of 10^7 at 20 ps prior to the pulse peak was enhanced to the level of ~10^{10} employing a "double plasma mirror" system, which preserves the spatial focal spot qualities although the throughput laser energy is reduced to ~6J. An f/2 off axis parabola was used to focus the laser pulses to a spot size of diameter ~2.5 μm containing 35% of laser energy. Thus, unprecedented intensities of about 5×10^{20} W/cm^2 could be reached. Al targets with the thicknesses varying from 10 nm up to 10 μm were irradiated to this intensity.

Absolutely calibrated micro-channel-plate (MCP) detectors coupled to phosphor screen were used to registered ion emission. A Thomson spectrometer, placed in front of the MCPs, enables to resolve energy and species of ions emitted according to their mass and charge. This ion diagnostic allowed single-shot, absolutely calibrated real time spectrum registration. Fig.1 shows the experimental setup and a typical image of accelerated ions captured by MCP and imaged by a CCD camera.

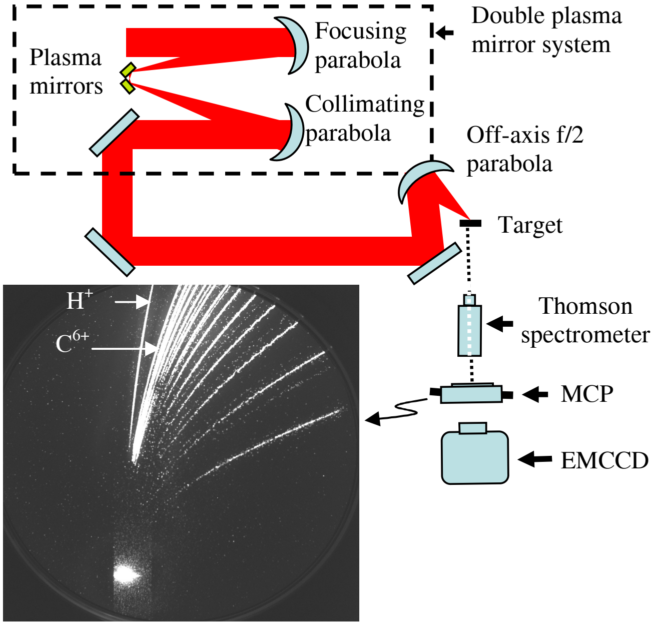

Fig.1. Experimental set up: A double plasma mirror system was used to enhance the contrast and MCP detector coupled to phosphor screen was employed for ion diagnostic.

Fig.2 shows, the maximum proton energies detected along the different lines for a laser incidence angle on target of 35^0 are plotted versus the target thickness. These maximum values of proton energies are out of at least 4-5 shots at the same thickness. The fact, that the accelerated proton energy from the front surface target normal (FSTN) are relatively constant suggests that the interaction conditions during for these shots are similar. In the RSTN direction, the data show a slow increase in proton energies, which stay almost constant below the 100nm. Similar trend is observed along the 10^0 direction.

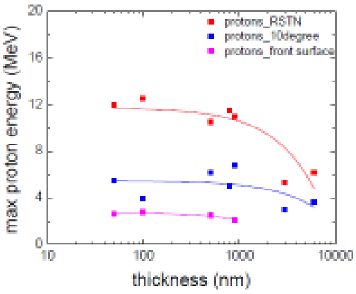

Fig.2 Maximum proton energy variation with target thickness along the measured directions: rear surface target normal (RSTN), 10^0 to RSTN and front surface target normal (FSTN). The solid lines are guide for the eye. Aluminium targets were irradiated under 35^0 laser incidence.

The effect of target thickness on proton/ion energy were investigated also for normal laser incidence on target and it was found that the proton/ion energy increases with decreasing target thickness for carbon while with aluminium target and with linear polarisation we found, surprisingly, effectively constant maximum energy for all the thicknesses from 10 μm down to 50 nm. As a signature of radiation pressure regime, quasi-monoenergetic spectral features and a fast scaling of maximum energy with intensity have been observed below 50nm target thickness, particularly when using circularly polarized pulses.

Acknowledgements:

This work was funded by EPSRC grants EP/E035728/1(LIBRA consortium), EP/F021968/1 and EP/C003586/1, and by STFC Facility access. We acknowledge the support and contribution of the Target Preparation Laboratory, ASTRA laser staff and the Engineering workshop at CLF, RAL.

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