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Enhanced proton acceleration with energy over 100 MeV in a laser plasma

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Laser-produced plasma has been intensively investigated for accelerating protons in an extremely large acceleration field. Laser-accelerated protons with high brightness and picosecond duration are invaluable for applications including proton imaging and hadron therapy. At Center for Relativistic Laser Science (CoReLS) a multi-PW laser [1] has been utilized for exploring strong field physics including the acceleration of electrons and protons/ions. By driving micro-structured ultrathin polymer targets with the multi-PW laser, we could accelerate protons to an energy over 110 MeV, thanks to the superb pointing stability and extremely good prepulse contrast of the PW laser [2].

We performed proton acceleration experiments by employing tailored nanometer-thick polymer targets driven by a multi-petawatt femtosecond laser using the setup shown in Fig. 1. The proton energy was measured using the stacked detector containing RCF, radioactivated Cu plate, and CR-39 as well as two Thomson parabola spectrometers. The energy-dependent spatial profile of the protons could be obtained from the RCFs installed in the stack detector in a single shot. The major challenge in enhancing the proton energy by irradiating a petawatt femtosecond laser on micro-structured targets is to preserve the nanometer-thick micro-structure until the arrival of the main pulse. A high temporal contrast of laser is, thus, essential for such experiments, since the intensity of prepulses should be suppressed to below the damage threshold of the target. In addition, the long petawatt laser chain increases the difficulty of maintaining excellent pointing accuracy within a few microns, which is crucial to precisely align the focal spot on the center of micro-structured targets.

The acceleration of 110 MeV protons from a 30-µm-wide, 100-nm-thick tailored polymer target was realized. For the achievements of efficient proton acceleration, several obstacles, including the difficulty to maintain a long acceleration structure and the deflection of protons by a self-generated magnetic field, have to be overcome. The proton profiles measured by the RCF, radioactivated Cu plate, and CR-39 plate agreed well with each other, manifesting the emission of high-energy protons at angles between the laser axis and the target normal direction. It should be noted that the result from CR-39 can provide a faultless proton cutoff energy, because RCF is sensitive also to electrons and the radioactivation measurement is affected by noises due to gamma rays. A series of PIC simulations showed that energetic protons were accelerated by a hybrid mechanism of radiation pressure acceleration [3] and Coulomb repulsion. They also confirmed that a long acceleration structure could be maintained in such quasi-isolated foils, since the refluxing of cold electrons was restricted and a strong charge separation field was established by carbon ions. Our experimental result demonstrating the enhancement of proton energy with micro-structured nanometer targets will be valuable for further enhancement of proton energy by optimizing the target design with controllable acceleration structures.

References

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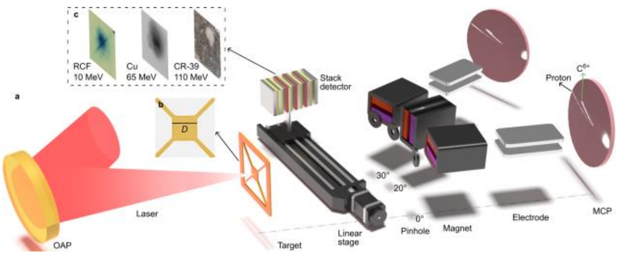

Figure 1. Experimental layout for high energy proton acceleration from micro-structured nanometer polymer targets, shown in the inset **b**, driven by a multi-PW laser. The proton energy was measured using a stacked detector as well as two Thomson parabola spectrometers installed at 0° and 30°.