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POLYMERS CONTAINING Cu NANOPARTICLES IRRADIATED BY LASER TO ENHANCE THE ION ACCELERATION

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Abstract. The Target Normal Sheath Acceleration method was employed at PALS to accelerate ions from laser-generated plasma at intensities above 10^{15} W/cm^2. Laser parameters, irradiation conditions, and target geometry and composition control the plasma properties and the electric field driving the ion acceleration. Cu nanoparticles deposited on the polymer promote resonant absorption effects, increasing the plasma electron density and enhancing the proton acceleration. Protons can be accelerated in the forward direction at kinetic energies up to about 3.5 MeV. The optimal target thickness, the maximum acceleration energy and the angular distribution of the emitted particles were measured using ion collectors, an X-ray CCD streak camera, SiC detectors and a Thomson Parabola Spectrometer.

Keywords: TNSA, hydrogenated target, resonant absorption.

1. Introduction

In a laser-matter interaction, the electromagnetic energy of the laser radiation is converted initially into electronic excitation and later into thermal, chemical and kinetic energy [1]. The characteristics of the laser-generated plasma, the amount of emitted ions and their distribution into energy, charge states and angle emission depend on many important factors. The propagation of the ions in forward direction and in backward direction, for example, is tied to the thickness of the target [2]. The focal position and the laser pulse duration have a crucial role on the characteristics of the generated plasma [3]. The laser intensity is the main factor influencing the ion distribution of the energy and the charge state [4]. The mechanisms for ion generation, acceleration and expansion in a vacuum, are complex. Above the ablation threshold, and at laser intensity higher than 10^{15} W/cm^2, plasma may be full ionized, and non-linear effects, ponderomotive forces, relativistic electrons and magnetic self-focusing effects promote high charge states and accelerate the emitted ions [5]. Using the target normal sheath acceleration (TNSA) regime, in which a double layer of charges generated in the rear side of the foil drives the ion acceleration in the forward direction, along the normal to the target surface, charge states may reach 60+ and ion acceleration values may be higher than 1 MeV per charge state [6]. A plasma rich in protons, carbon and copper ions can be obtained by irradiating thin polyethylene foils covered by Cu films or containing Cu nanostructures. The composition and the geometry of the target absorb high laser energy and generate hot plasmas and high charge separation, inducing high ion acceleration, as will be reported. In this context, investigations into optimal laser parameters and irradiation conditions will be aimed at maximizing the ion kinetic energy.

2. Material and Methods

The high-power photodissociation iodine laser system of the PALS Research Center in Prague, operating at 1.315 µm wavelength, laser energy ranging between 450 and 600 J, pulse duration 300 ps, and intensity of 10^{15} W/cm^2, was employed for the experiments presented here [7]. The focalization setting of the laser beam consists in an aspherical lens ($f = 627$ mm for $1\,\omega$) 29 cm in diameter focusing the laser beam on to the target with a nominal spot of 70 µm. Sheets of pure Mylar, pure Copper, and Mylar covered by thin Cu films were irradiated at 30° with respect the normal to the target surface. The original stoichiometry of the Mylar or polyethylene terephthalate is $(C_{10}H_8O_4)_n$. The thickness of the mylar ranges between 0.6 µm and 100 µm, and the thickness of the Cu film ranges between 0.01 µm and 1 µm. The targets were produced by the physical vapor deposition (PVD) method, using a Leybold-Heraeus evaporator, at a vacuum of 10^{-6} mbar. A mylar substrate, 0.6 µm in thickness was covered by the evaporated Cu thin film, the thickness of which was measured online, with a calibrated quartz crystal, and offline, using the transmission energy loss spectroscopy of the ^{241}Am

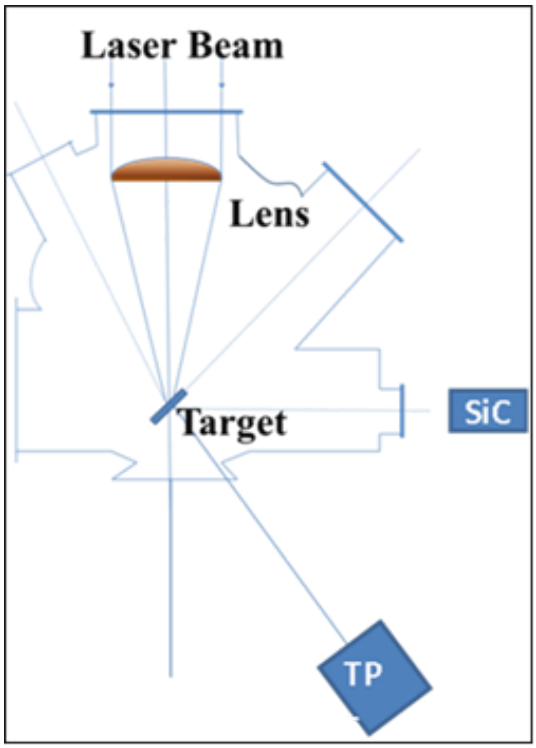

FIGURE 1. Experimental setup.

alpha source. At very low thicknesses, of the order of 5–10 nm, the Cu film is not uniform; it consists of nucleated Cu cluster with dimensions comparable with the thickness, as observed at SEM. The laser beam was focused 100 microns in front of the the target surface (FP = −100 µm) [8]. The scattering chamber is equipped with a target holder movable in x, y, z directions with 1 µm minimum steps [7]. A KENTECH X-ray streak camera, fixed in a side view having 2 ns exposition time, is employed to monitor the initial position of the plasma formation. Ion collectors (IC) and SiC semiconductors are employed in time-of-flight (TOF) configuration for the ion detection at an angle of 30° and at a distance of 1.03 and 0.6 m from the target [9]. SiC is a promising detector not sensitive to the visible, soft UV, and infrared light, where optical photons are not able to produce electron-hole pairs because their energies are below the 3.2 eV of the 4H-SiC gap energy. The photons, electrons and ions absorbed in the sensitive volume of the detector generate e-h pairs, losing 7.8 eV for a pair production, which results in voltage signal at the device electrodes proportional to the deposited radiation energy [10]. A Thomson Parabola Spectrometer (TPS) was placed in forward direction at 0° angle and 1.67 m distance from the target [11].

TPS consists in a magnetic-electrostatic system; it is equipped with two input pin-holes, 1 mm and 0.1 mm in diameter. The emitted ions undergo a magnetic deflection of about 0.1 T and an electrostatic deflection voltage of the order of 3 kV. The trajectories of the emerging are parabolic. They are detected on a plane orthogonal to the incident ions by a Multi-Channel

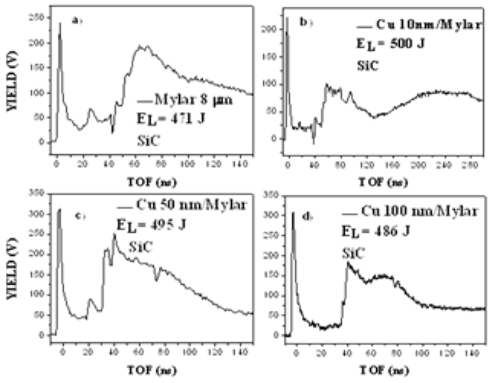

FIGURE 2. SiC spectra for irradiation of pure mylar (a) and of irradiation of mylar covered with a layer of Cu 10 nm in thickness (b), 50 nm in thickness (c) and 100 nm in thickness (d).

Plate (MCP) coupled to a phosphorus screen and a CCD camera. the recorded spectra were stored into a fast oscilloscope operating at 20 GS/s. A schematic view of the experimental arrangement is shown in Fig. 1.

3. Results and Discussion

The SiC spectra of ions accelerated by a laser irradiating mylar and Cu are presented in Fig. 2. Irradiating a pure mylar thin film, 8 µm in thickness, with 471 J pulse energy and −100 µm focal position, the kinetic energy of faster protons is 0.9 MeV (a). Due to the conditions of the focal position, this relatively high proton energy is controlled accurately by the streak camera. At the value used here, self-focusing may be induced, decreasing the laser spot on the target and increasing the laser intensity [4]. However the laser energy released in the thin mylar remains low because the pure mylar has a very low absorption coefficient for the IR laser wavelength that is used, with evaluated transmission of the order of 90 % [12]. Using the same experimental condition, in a pure Cu target, 1 µm in thickness, the maximum proton energy was evaluated to be 1.2 MeV. The proton energy increases with the Cu deposition thickness, from 10 nm (b) to 50 nm (c) and to 100 nm (d), and assume an energy of 1.1 MeV, 3.2 MeV and 1.5 MeV, respectively, as demonstrated by the TOF measurements of the four spectra. This result is due to two causes: enhancement of the plasma electron density responsible for the electric field driving the proton acceleration, and enhancement of the laser absorption in the thin target obtained using the Cu metal. The optimal Cu thickness seems to be 50 nm according to the replicability of the measurements under the same experimental conditions. C ions are accelerated to maximum kinetic energies approximately proportional to six times the maximum proton energy, in agreement with the Coulomb acceleration in the charge space separation generated in the rear side of the thin target.

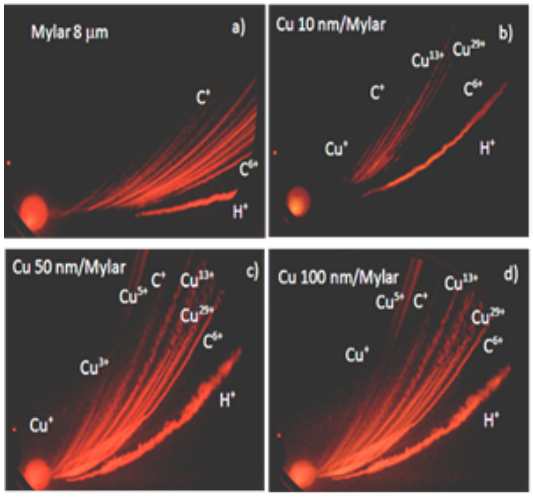

Figure 3. TPS spectra for irradiation of pure mylar (a) and of mylar covered with a Cu thickness of 10 nm (b), 50 nm (c) and 100 nm (d).

Thus, in the case of a 50 nm Cu/mylar target, the carbons are accelerated up to about 20 MeV, due to the six charge states of carbon ions. The corresponding TPS spectra of the targets irradiated in the conditions reported for Fig. 2 are presented in Fig. 3. This figure compares the TPS protons and carbon parabolas achieved by irradiating a pure mylar (a) and the parabolas obtained when we increase the thickness of the Cu film deposited on mylar, from 10 nm (b) to 50 nm (c) and to 100 nm (d). The parabola recognition was obtained for comparison with simulation programs based on the real TPS geometry and used value of deflecting magnetic and electric fields used here, as presented in literature [11]. Recognition of the Cu parabolas permits full Cu ionization, up to Cu^{+29}, to be evinced.

For the pure mylar foil the parabola luminosity decreases, as a consequence of the lower plasma electron density and the lower absorbed laser energy in the polymeric film, which absorbs only about 10 % of the laser pulse energy [12]. The parabolas obtained in the other cases shows more energetic ions and may be more luminous. The most energetic ions, less deflected by the magnetic and electric fields, are produced for a Cu thickness of 50 nm deposited on the mylar substrate, in agreement with measurements obtained by SiC. Such a thin film produces high laser absorption due to the presence of the metal which absorbs the IR laser radiation and also due to the Cu nanoparticles in which surface plasmon resonant absorption effects are induced by the laser electromagnetic wave [13]. Thus laser absorption enhancement is induced in the target and transferred to the plasma, the Cu thin film increases the plasma electron density and consequently the charge separation developed in the rear side of the target and higher ion acceleration is developed. The Cu nanoparticle absorption plays an important role in laser absorption in the thin mylar target, depending on the size of the Cu nanoparticles, which is very high for particles with dimensions of the order of hundreds nm absorbing in the range of visible and IR wavelengths.

Target	Thickness	El (J)	Ep(H+)
Mylar	8 µm	471	0.9 MeV
Cu/Mylar	10 nm/8 µm	500	1.0 MeV
Cu/Mylar	50 nm/8 µm	495	3.2 MeV
Cu/Mylar	100 nm/8 µm	486	1.5 MeV
Mylar/Cu	8 µm/100 nm	472	1.1 MeV
Cu	1 µm	608	1.2 MeV

Table 1. Summary of results of proton acceleration obtained irradiating different thin films.

4. Conclusions

Bilayer targets, consisting of milar foil 8 µm in thickness covered with thin Cu PVD depositions, with thicknesses ranging between 10 nm and 100 nm, are suitable for high energy proton acceleration in the forward direction from laser intensity of about 10^{15} W/cm^2 in the TNSA regime.

A summary of our results is given in the Table 1, demonstrating that the Cu nanostructures increase the proton acceleration as result of the enhanced laser absorption in the thin film. Mylar covered by Cu was laser irradiated from the Cu face. Irradiating on the converse face, from mylar to Cu, the maximum proton energy decreases with respect to the value obtained when irradiating from the Cu face, as presented in the table. A possible explanation involves the plasma electron density which is higher in the case of Cu/mylar irradiation due to high Cu electron injection in the Mylar plasma. In conclusion three main parameters play an important role in ion acceleration in the forward direction from the TNSA regime: (1) the plasma electron density, which can be increased using metals to cover the polymer filmsthat inject the electrons into the polymer plasma; (2) the use of metallic nanostructures depsited on the polymer, which significantly increase the laser absorption due to surface plasmon resonance effects at wavelength in the visible and IR regions; (3) the use of an optimal laser focal position to induce self-focusing effect in thin films. For polymers a distance of −100 µm in front of the target surface is used. This enables the laser light due to the formation of the first ionized vapor to be focused, and enables the self-focusing effect to be made use of.

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