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Proton driven acceleration by intense laser pulses irradiating thin hydrogenated targets

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ABSTRACT

The Asterix iodine laser of the PALS laboratory in Prague, operating at 1315 nm fundamental frequency, 300 ps pulse duration, 600 J maximum pulse energy and 10^{16} W/cm^2 intensity, is employed to irradiate thin hydrogenated targets placed in high vacuum. Different metallic and polymeric targets allow to generate multi-energetic and multi-specie ion beams showing peculiar properties. The plasma obtained by the laser irradiation is monitored, in terms of properties of the emitted charge particles, by using time-of-flight techniques and Thomson parabola spectrometer (TPS). A particular attention is given to the proton beam production in terms of the maximum energy, emission yield and angular distribution as a function of the laser energy, focal position (FP), target thickness and composition.

1. Introduction

The production of proton beams from laser-generated plasmas represents an important aspect of the recent research activities because 1–10 MeV protons find many applications in different scientific fields, such as Bio-medicine, nuclear physics, microelectronics, chemistry and engineering. MeV protons can be employed in nuclear physics to excite nucleus and induce specific nuclear reactions, may be employed in bio-medicine to hit tumor cells and biological tissues, and in chemistry to modify the physical and chemical structural properties of different polymers [1,2].

Laser intensity to the order of 10^{16} W/cm^2 can be used to generate MeV proton streams at intensities higher than 10^{12} protons/pulse.

Higher proton energies can be obtained by using *fs*, and TW lasers irradiating thin-films. Literature shows many data concerning protons energy production above 50 MeV and intensities of the order to 10^9 protons/pulse, a result due to acceleration mechanisms so called "target normal sheath acceleration" (TNSA). These last data are particularly interesting for applications in the field of proton-therapy and radio-biology [3].

A further investigation concerns the nature and the geometry of the thin hydrogenated targets to be laser irradiated in order to generate forward protons, i.e., proton emission from the rear target sides. At the laser intensity given by Asterix PALS laser, the possibility to generate forward protons may be investigated in order to understand the base mechanisms producing high ion kinetic energy, directivity and current. Moreover, the different monitoring techniques, employable to investigate on the fast ion emission from plasma, would have to aim to separate the protons from the other ions, to measure their kinetic energy and to filter monochromatic proton beams. This goal may be reached thank to peculiar magnetic and electric filters that select monochromatic proton beams from other ions. Also the introduction of new ion detectors plays an important role because generally the ion detection is submitted to high background, due to different radiations emitted from the laser-generated plasma, and the use of special detectors, such as high gap semiconductors, allows not to be influenced by visible and soft UV radiations.

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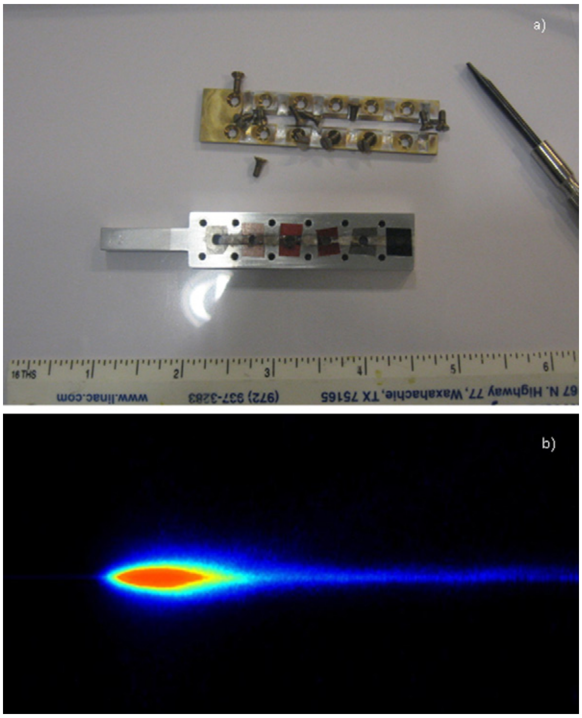

Fig. 1. Target holder during the film preparation (a) and typical streak camera X-ray image of the plasma emitted from the mylar/Al foil target surface irradiated at 230 J with FP = +240 μm (b).

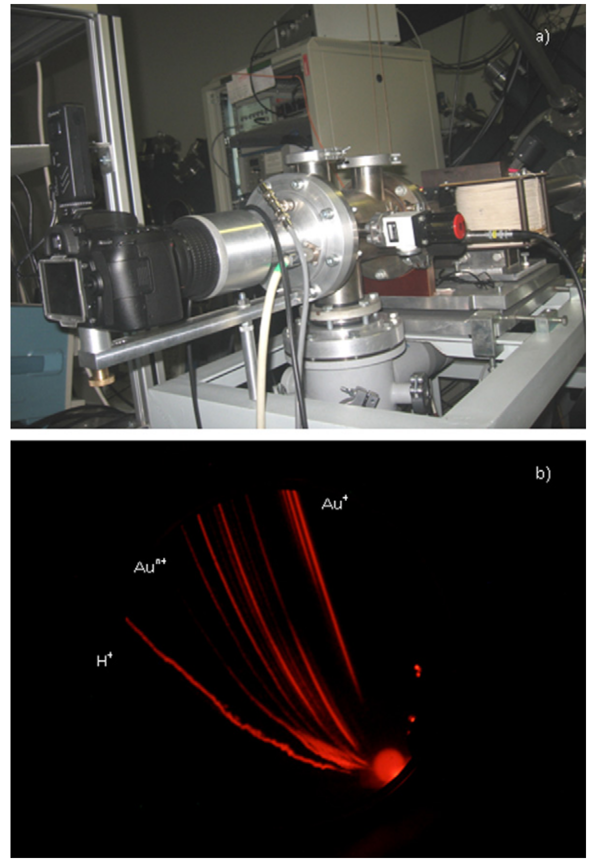

Fig. 2. Thomson parabola spectrometer mounted in forward along the normal direction to the target surface (a) and typical parabolas image obtained by irradiating at 520 J an Au target, 2.48 μm thickness, with a focal position of −200 μm (b).

2. Materials and methods

The experimental measurements are carried out with the Asterix iodine laser of PALS laboratory operating in single pulse at 1315 nm, 300 ps pulse duration, 70 μm laser spot diameter, 10^{16} W/cm^2 pulse intensity [4]. Usually, thin films, with a thickness lower than 10 μm, are laser irradiated with an incidence angle of 0°. Hydrogenated targets based on polymers, doped polymers, hydrates, multilayers and metals were employed to generate plasmas in forward and in backward directions.

The target holder has a special geometry to permit the plasma observation from the streak camera detector, which enables the measurements of the X-ray images of the plasma generation from the target surface giving information on the spatial and temporal evolution of the first instants of plasma formation. This method allows the evaluation of the laser focal position (FP distance) from the target surface, in order to control the plasma properties. The FP values can be changed moving the target holder with micrometric step motors, from negative values (that means FP placed in front of the target surface) until positive values (FP inside the target). The streak-camera was employed in order to monitor the initial position of the plasma formation though the X-ray plasma emission as a function of the different laser focal position (FP).

Fig. 1a shows a photo of the target holder during the delicate preparation of six thin films; they are stuck to the back of the support (down) and pressed by the mask coverage part (top).

Plasmas are monitored "on-line" through a micro-channel-plate (MCP) placed in the focal detection plain of a Thomson parabola spectrometer (TPS). TPS is located in forward direction along the normal to the target surface and it is preceded by two pin holes, the first 1 mm in diameter and the second 100 μm in diameter, in order to collimate fine the detected ions. The spectrometer uses a 0.05 T horizontal magnetic deflection and +2 kV (from the top) voltage for the vertical electric deflection. The distance between the electric deflectors and the MCP detector plane of the parabola ions is D = 16.5 cm, as in similar apparatuses reported in literature [5]. A photo of the experimental TPS, placed along the forward direction at PALS Laboratory, is reported in Fig. 2a.

Inside the TPS the ions are deflected by the Lorentz force, $F = q(E + vB)$, with a magnetic (B) and electric (E) fields, which are parallels between they and perpendicular to the ion incidence direction. v is the velocity of the ions and $q = Ze$ is the ion charge. Assuming non relativistic velocities and with a field length $l \ll D$, the deflections orthogonal to the ion incidence direction, z, are given by the following equations:

$$x = \frac{qElD}{2\varepsilon_{kin}}; \quad y = \frac{qBlD}{\sqrt{2m\varepsilon_{kin}}}; \quad y^2 = \frac{qB^2lDx}{mE} \qquad (1)$$

Here x and y are the deflections due to the electric and magnetic fields, respectively, B and E are the field amplitudes, and q, m, and ε_{kin} are the charges, the masses, and the kinetic energies of the ions, respectively. The parabolic equation is a combination of the two deflection equations and shows that TPS provides a separation of all ion species and charge states according to q/m ratio. Every single parabola on the detector belongs to a different ion charge-to-mass state ratio. The deflection along the parabola contains the information about the ion energy.

Different ring ion-collectors (ICRs) and semiconductor silicon carbide (SiC) detectors were fixed at different angles with respect to the normal direction, both in forward and in backward space, in order to detect ions and to measure their kinetic energy via time-of-flight technique. Details on these detectors are reported in literature [6]. TOF spectra are recorded with a fast oscilloscope operating to 20 GS/s recording the laser shot as a start signal and the ion peaks as stop signals.