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Comments and Replies

Proton extraction from transition metals using PLATONE

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ABSTRACT

In this work we present a study on proton beams extraction from a plasma generated by pulsed laser ablation of titanium and tantalum disks. The device used was the PLATONE laser ion source operating at the LEAS Laboratory in Lecce, Italy. It is based on a KrF laser operating at low irradiance (10^9–10^{10} W/cm^2) and ns pulse duration. The proton and ions emission was analyzed by the time-of-flight technique using a Faraday cup as ion collector and an electrostatic barrier to identify the particles. Studies on the produced protons and ions at different laser irradiance values were performed. The extracted beams showed high proton flux up to 10^{10} protons/cm^2.

1. Introduction

Recently, laser-driven acceleration (LDA) of ions from thin metal targets has attracted great interest in the scientific community, due to its possible applications in Ion Beam Therapy (IBT) and it has been suggested as a potential, cost saving alternative to common accelerator devices. In particular, new techniques for the production of proton beams made use of the interaction between high power femtosecond laser pulses and thin metallic foils [1]. In contrast with other techniques, this one has the advantage of obtaining energetic ion beams with a very good emittance from the target, but the beam qualities are far from being comparable to those required for IBT, that needs high flux, high current, low divergence, high energy and low energetic spread.

Despite the high value of laser irradiance required in LDA to get into Target Normal Sheath Acceleration [2] (TNSA) and Radiation Pressure Acceleration [3] (RPA) regimes, other laser–matter interaction frameworks such as Pulsed Laser Ablation (PLA) (which works at lower irradiances) allow to easily obtain ions from solid targets, whose energy can be increased up to few hundreds of keV by means of post acceleration systems [4,5]. Laser irradiances of the order of 10^8–10^{10} W/cm^2 and nanosecond pulse duration are sufficient to produce hot plasmas [6]. From these plasmas, ion and proton beams of moderate energy can be extracted [5]. These beams have a wide range of applications (ion implantation for material modification, thin film deposition, etc), from scientific to industrial ones [7–9].

In this work, we present the results regarding proton generation by an UV laser ion source (LIS) with the PLATONE device. The resulting protons beams could be utilized in various fields, for example as injector source for common particle accelerators [10]. The solid targets used to generate protons were disks of Ti and Ta, pure at 99.99%. It is well renowned in literature that some of the transition metals, such as Ta, Nb, Pd and Ti, are good hydrogen adsorbers[11,12]. Despite this advantageous characteristic, these elements are not usually considered as targets for the production of protons in LIS. Instead, materials such as aluminum, polymers and metal hydrides are generally employed for proton sources [13–16]. Our aim is to study and characterize these targets and possibly to enlarge the set of materials usable for the production of proton beams by PLA.

2. Experimental setup

The laser ion source employed in this experiment is the PLATONE apparatus [7] available at the LEAS Laboratory in Lecce, Italy. It consists of a Compex 205 KrF excimer laser (λ=248 nm, τ_{FWHM}=23 ns), which works at laser irradiances of 10^8–10^{10} W/cm^2, and an interaction chamber (GC) where the plasma is produced by PLA and diagnosed by different devices. Fig. 1 shows the sketch of the PLATONE setup.

The laser beam entered in GC with an angle of 70^0 with respect to the target normal. It was focused by a thin lens onto the target surface, resulting in a spot of 0.005 cm^2. The targets were mounted

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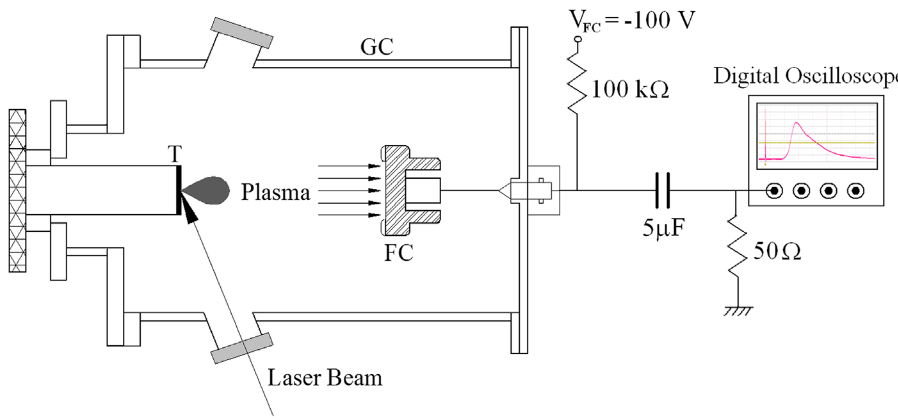

Fig. 1. Sketch of the PLATONE apparatus. GC: generating chamber, T: target, FC: Faraday cup, and V_{FC}: Faraday cup bias.

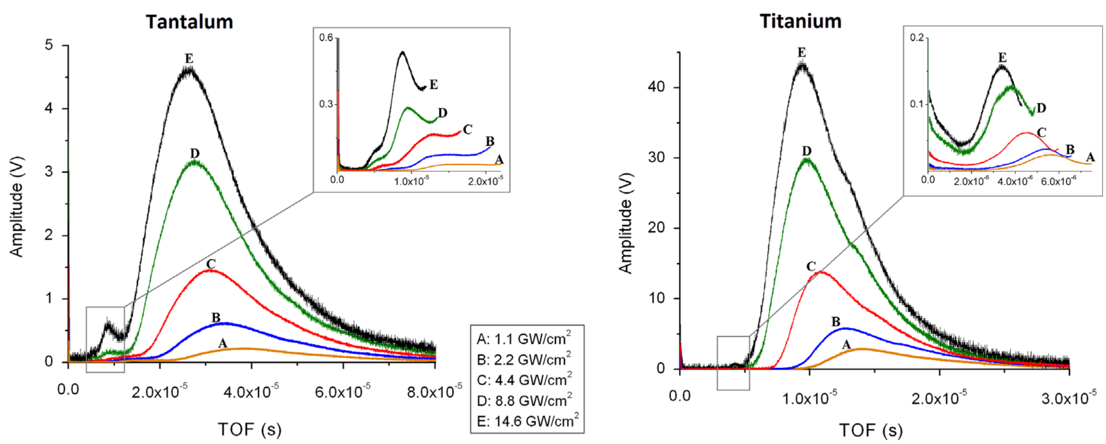

Fig. 2. Tantalum and Titanium TOF signals recorded by FC at different laser irradiances.

on a cylindrical support T and were irradiated in high vacuum (10^{-6} mbar) at different laser irradiances (1.1, 2.2, 4.4, 8.8 and 14.6 GW/cm^2). The diagnostic system consisted of a Faraday cup (FC) used as ion collector and an Electrostatic Barrier (EB) particle analyzer. The FC collector was biased at -100 V and positioned in front of the plasma plume. It was connected to a digital oscilloscope, LeCroy WaveSurfer 422 through a suitable RC circuit [17] able to separate the FC bias from the oscilloscope and to record the ion current signals. The total fly length available for ions, from T to FC, was 45.0 cm.

3. Experimental results

It is well known that during the free expansion of a laser plasma, the ions of the plume are accelerated by different processes [18]. In hydrogen rich targets, a small part of ionized hydrogen is located at the front side of the the main plasma plume, obtaining fast proton bunches. These are due to the presence of contaminants (mainly adsorbed molecular hydrogen for the considered targets) in the first surface and sub-surface layers that are weakly bounded to the host material. The ion current signals were measured by means of the FC collector and analyzed by the time-of-flight (TOF) technique.

In Fig. 2 the TOF signals for the tantalum e titanium targets at different laser irradiances are shown. We obtained main plasma peaks and fastest small peaks (further magnification is shown in the inset).

It is evident that the total charge extracted, deducible from Fig. 2, is higher for the titanium target. This behavior could be explained by considering the different reflectivity of the two metals for the UV radiation used. In fact, the reflectivity for Ta is an order of magnitude higher than those for Ti, resulting in a lower absorption of the laser energy on the target surface.

The fastest peaks represent energetic protons, since lighter contaminants become spatially separated from the heavier ones. The amplitudes of the main plasma signals are sensibly higher than those of protons. In fact, the main plasma signal contains a convolution of the signals of different charge states present in the plume (at these laser irradiances, the principal charge states [19,20] are $+1$ and $+2$). To confirm this last assertion, we performed a deconvolution study of the TOF signals, using the well known function introduced by Kelly and Dreyfus [21,22]

$$j(t) \propto \frac{L^2}{t^{-5}} \exp\left\{ -\frac{m}{2kT_{KL}} \left(\frac{L}{t} - u \right)^2 \right\}, \tag{1}$$

where L is the fly length, k is the Boltzmann constant, m is the mass, u is the center of mass velocity and T_{KL} is the Knudsen layer temperature of the expanding species. The results obtained for the Ta target at 14.6 GW/cm^2 are shown in Fig. 3.

As it can be seen from the deconvolution of the tantalum TOF spectra, three distinct curves were observed, corresponding to the contributions of protons, Ta^{1+} and Ta^{2+}. Similar results were found for the titanium target.

By means of the TOF signals we computed the proton kinetic energies (minimum, maximum and at the peak). The minimum