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Plasma production in carbon-based materials

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ABSTRACT

High intensity lasers can induce in solid targets a charge separation resulting in a time-dependent induced polarization. In this work, the characterization of a plastic target subjected to a laser irradiation has been analysed. A focus was particularly devoted to the interaction of the target with the whole grounded chamber, manipulated through the change of the target-holder surface ratio. The targets are thick samples (thickness >1 mm) of polymers arranged in discs according to the metallic holder shape. A possible correlation between the target current and the main features of the produced plasma was analyzed, in order to acquire a deeper knowledge on laser–matter interactions with the laser pulse on the nanosecond scale. Collected signals were analyzed to reconstruct the time evolution of key observables as well as the charge space distribution in the chamber. The experimental setting allowing the target current observation and the measurement procedure is discussed.

1. Introduction

Laser–Ion Sources (LISs) are of great interest in many scientific fields, either because of the basic phenomena underlying the creation and propagation of charged particle beams, or because the potential applications are a still increasing framework of nowadays technology. LISs are especially convenient in the case when a high current of highly charged ions from solids is needed. The transport properties of the extracted ions are affected by the plasma free expansion into vacuum, a fascinating phenomenon whose full understanding is still far to be reached.

2. Theoretical aspects

The key process in LISs is the plasma production originated by high intensity laser pulses: the so - called laser ablation. The expansion of ablated particles starts when the laser pulse is on and continues after its end.

A commonly accepted idea on laser – induced plasma expansion is that photons strike a solid target surface and particles are therefore emitted during the laser pulse. When the density is small enough, a collisionless vapor is produced. At higher vapor densities, many collisions occur near the surface. In this case the so – called Knudsen layer is formed above the target surface. Simple analytical solutions can be obtained in the range employed in pulsed laser deposition under the assumption of an adiabatic expansion of the plasma plume in vacuum [1].

3. Experimental setup

The PLATONE configuration involves a vacuum chamber, where the target is placed, and detection devices finalized for the description of different aspects of laser–produced plasmas (see Fig. 1). The detection mechanism consists in two main parts: the target current detection, performed by an array of resistors placed between the chamber flange and the target support, so that eventual power peaks don't damage the diagnostic devices, and a Faraday cup, a charged particles collector placed in front of the target with an active surface area of 28.3 cm^2 [2,3]. Changing the cup's polarization, it's possible to detect either positive or negative charged species. The target holder is a steel cylinder of 2 cm in diameter, that can be rotated or translated in the vacuum chamber by an external support, which is galvanically isolated from the vacuum chamber.

The laser used for the experiments is a *KrF* excimer laser with a wavelength of 248 nm and laser energy running from 24 to 77 mJ, with a pulse duration of 23 ns (FWHM).

Following the symbols in Fig. 1, the voltage signal V_S detected on the voltage divider output by a scope can be converted to the voltage target $V_T(t)$ through the relation

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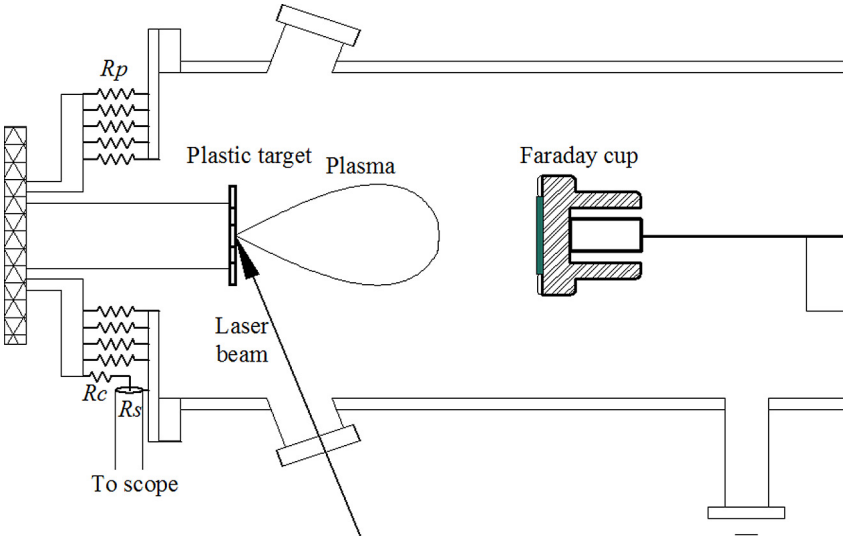

Fig. 1. Sketch of the PLATONE setup with a plastic target whose diameter overcomes the target holder size.

$$V_T(t) = \frac{R_C + R_S}{R_S} V_S(t). \quad (1)$$

The used targets are discs of PMMA (thickness: 1.1 mm) and UHMWPE with thickness 1.2 mm, but various diameters, so that the surface ratio target-to-holder can increase from 0.5 to 1.5, that means the disc diameter increases from 10 mm to 30 mm.

From the time resolved ion signals, it's possible to get an ion charge density distribution along the cylindrical axis of the vacuum chamber [4]. Knowing the distance L of the detector and the time-resolved current density at time t, $j(L,t)$, the ion front at the distance from the axis x at time τ can be expressed as [5]

$$q(\tau, x) = j(x) L^3 \tau x^{-4}. \quad (2)$$

4. Results and discussion

The diagnosed plasma particles have a typical waveform shown in Fig. 2. Ions and electrons were detected at a distance of 29.3 cm from the target. The Faraday cup signal starts to be significantly different from zero after about 7 μs and reaches a maximum earlier in the electron signal, since the ion current reaches a saturated level by the applied bias of −100 V while the electron current doesn't reach the saturation at a voltage of 100 V.

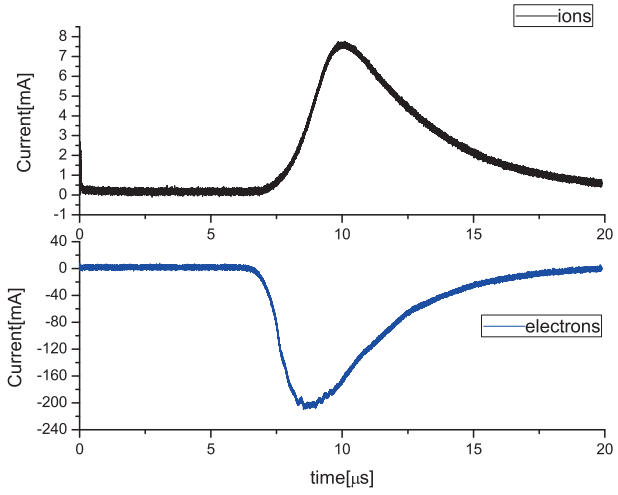

Fig. 2. Electron and ion signals detected on a Faraday cup for a PMMA target irradiated at 77 mJ. The Faraday cup bias was −100 V (ions) and 100 V (electrons).

The setup allows to observe the time-resolved target polarization together with the corresponding detected Faraday cup signal, see Fig. 3.

The full width at half maximum of the positive target current peak (see Fig. 3(a)) is shorter up to factor of about 5 with respect to metallic materials (mainly of heavy elements) irradiated with the same laser intensity [5]. The polarization on the target sussists up to the vanishing of the plasma.

The target-to-holder surface ratio variation leads to different behaviors in the two plastic materials: the UHMWPE samples have a well defined trend when varying different parameters, whereas the PMMA samples have not in the explored range of parameters.

As one could expect, electrons are escaping faster from the target, and the resulting detected current will be positive in order to restore material neutrality. At $t = 600$ ns a positive peak of charge occurs. At time $t = 850$ ns the current changes sign (Fig. 3): the energy is sufficient to ionize heavier particles and an overall negative current occurs. From now on, the charge exhibits a maximum in negative charge around $t = 1$ μs and then raises up, reaching a vanishing condition. Energy and target size variations can induce intensity variations in the peaked structure, but the occurring time remains the same.

The amount of total charge produced in UHMWPE ablation process is, in absolute value, greater than in the PMMA case. As can be seen in Fig. 4, the maximum ion charge in UHMWPE is about twice the maximum ion charge detected for PMMA. In UHMWPE samples, ion and electron charges have a preferred configuration when the diameter of the samples is 20 mm, i.e. when the target-to-holder surface ratio is 1.

The ion front along the chamber axis x follows the same trend. In UHMWPE (see Fig. 6) the configuration with the target diameter of 20 mm has a wider range and higher density values with respect of the other diameters. In PMMA, although the peak charge density can reach higher values than UHMWPE, the range is narrower, that means the produced ions are on average heavy ionized compounds.

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