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Influence of the ablation threshold fluence on laser-driven acceleration

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ABSTRACT

Laser ablation threshold measurements has been carried out by the nanosecond-class Nd:YAG laser at LNS-INFN in Catania. Advanced targets, such as hydrogen-enriched silicon slabs and sub-micro structured polymeric samples, have been investigated. The estimated ablation fluences are correlated to recent experimental and theoretical results on high intensity laser driven ion acceleration. Characteristics of H-atoms/protons and heavier atoms/ions coming out from the bulk of the irradiated target or from surface contaminants have been determined by optical and time-of-flight spectroscopy as well as mass quadrupole spectrometry.

1. Introduction

Recently we have performed theoretical and experimental investigations on laser-driven ion acceleration through advanced targets in order to improve the characteristics of the generated proton stream in terms of mean kinetic energy and beam charge [1–6]. Since the ASE (amplified spontaneous emission) nanosecond laser precursor plays a crucial role in the subsequent plasma heating by the main femtosecond laser pulse, it is essential to determine its effect on the target material vaporization and/or ionization prior the arrival of the main pulse.

We intend to provide a full characterization of the nanosecond laser plasma generated from advanced targets which are used in ion acceleration schemes at much higher laser intensity by: (i) establishing the laser pedestal intensity upper limit when advanced targets are used in TNSA (target normal sheath acceleration) regime [7]; (ii) optimizing the pre-plasma which plays an important role in the ion acceleration mechanisms when long-pulse, low-contrast lasers are used [8–10].

2. Materials and methods

The experimental setup used for the ablation threshold measurements is sketched in Fig. 1. The Nd:YAG laser (1 J, 9 ns, 1064 nm) available at the LNS-INFN in Catania is focused by a spherical lens ($f = 500$ mm) onto the massive target surface in a spot ranging from 0.1 mm to 1 mm in diameter. The laser-generated plasma expands backward along the target-normal direction. A full real-time diagnostics is used to characterize simultaneously the different plasma contributions (visible light, ions, neutrals) and estimate the ablation threshold fluences for the different investigated samples. In particular, a mass quadrupole spectrometer (MQS) placed at $\phi_{\mathrm{det}} = 90^\circ$ (detection angle) is used for the plasma neutrals' diagnostics. An optical spectrometer interfaced with a proper diagnostic setup (collimator, lens and optical fiber) is used for the time integrated visible spectroscopy which characterizes the light emission at about 1 mm from the laser-target interaction point. The plasma ion emission is detected through a ring Faraday cup (ICR) and an electrostatic cylindrical spectrometer (IEA). The whole diagnostic setup has already been used in our previous experiments and is fully described in literature [11,12].

The irradiated samples have been chosen on the basis of previous theoretical [1,2] and experimental investigations performed at PALS laser facility in Prague [4–6]. In particular, we intended to investigate the influence of the ablation threshold fluence on laser-driven acceleration at high intensities in the nanosecond laser pulse regime, when advanced semiconductor samples (pure silicon, H-enriched silicon, B-doped H-enriched silicon, H-enriched silicon nitride), fabricated at the MTLab of the Bruno Kessler Foundation (Trento), are used as targets. The comparison with a palladium target (naturally H-enriched metal) was

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performed. Moreover, we have established the damage threshold for some microstructured samples (polystyrene sub-microspheres on a hosting substrate) which can be used as targets in the TNSA regime with an optimized laser contrast, as discussed above.

Fig. 2 shows the SEM (JEOL 7500F) images of three different targets made of polystyrene spheres on a glass substrate with 920 nm (a), 535 nm (b), 266 nm (c) diameter, respectively, before laser irradiation. The “post mortem” SEM image of the laser-generated circular crater is also shown (d) with a detail on the spot edge (e). The damaged/not-damaged interface is also emphasized by the AFM (Park) image (f). No surface damage was found at laser fluences below 10 J/cm^2 (i.e. below an intensity of about 10^9 W/cm^2).

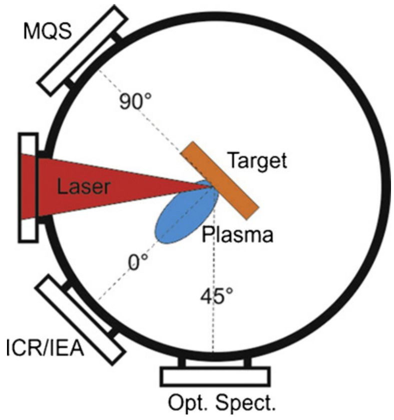

Fig. 1. Experimental setup (MQS, mass quadrupole spectrometer; ICR, ring ion collector; IEA, ion energy analyzer).

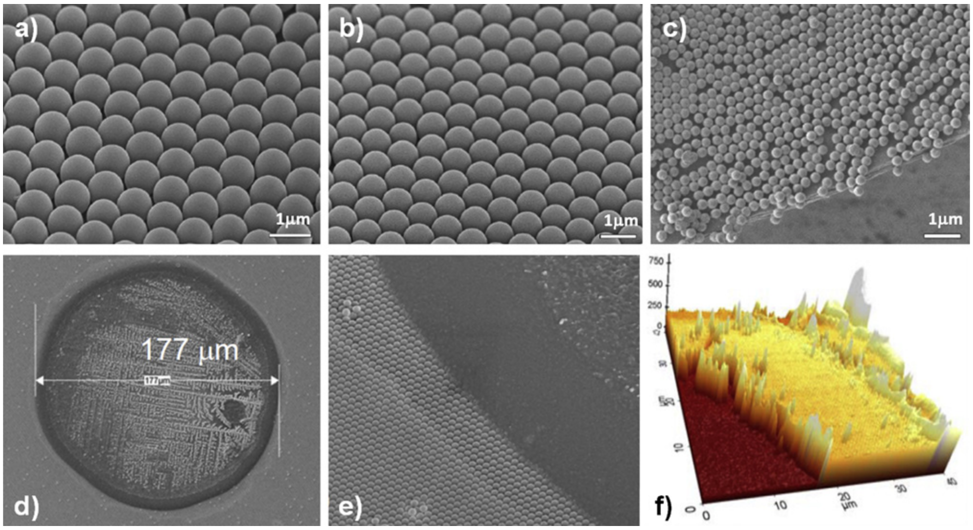

Fig. 2. SEM images of 920 nm (a), 535 nm (b), 266 nm (c) diameter polystyrene spheres before the laser irradiation. SEM images of the laser damaged target surface (d) and zoom of the crater edge (e). AFM image of the damaged target area after laser irradiation (f).

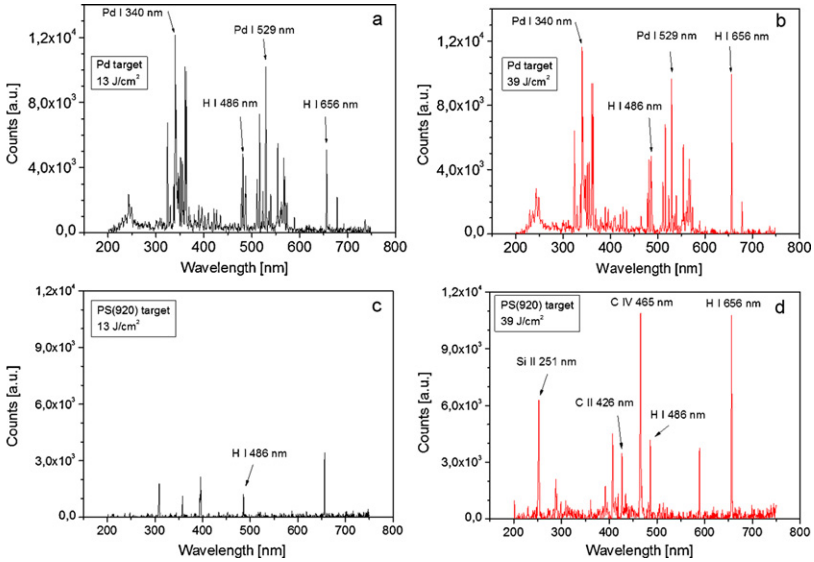

Fig. 3. Optical spectroscopy line distribution during the laser irradiation of palladium (a and b) and polystyrene (c and d) targets at low and high laser fluence, respectively. Elements labeled with I/II/IV refer to the neutral/ion-1$^+$/ion-3$^+$ species, respectively.