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Ion and photon emission from laser-generated titanium-plasma

L. Torrisi *, D. Margarone, A. Borrielli, F. Caridi

Dipartimento di Fisica dell'Università di Messina, INFN-LNS and INFN-Section of Catania, S. Agata, Messina, Italy

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Abstract

Titanium-plasma was obtained by nanosecond pulsed laser ablation technique. A Nd:Yag laser was employed to irradiate titanium in vacuum. The ion emission from plasma was on-line monitored by an electrostatic ion energy analyzer which permitted to measure the ion kinetic energy and charge state. The visible photon emission was monitored by an optical spectrometer. The ion energy, charge state and angular distributions, the temperature and density of the non-equilibrium plasma were investigated. The temperature gradient of the plasma plume was evaluated and discussed.
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Keywords: Optical spectroscopy; Laser-generated plasma; Ion energy distribution

1. Introduction

It is well known, considering metallic materials, that the infrared radiation of nanosecond pulsed lasers irradiating solid targets in vacuum induces thermal processes leading to material melting, vaporization and ionization effects on the expanding vapour. Nanosecond laser can interact with the expanding plasma so that temperatures, electronic densities and charge states of the excited species depend strongly on the laser pulse intensity [1].

Thermal diffusion and plasma adiabatic expansion characterize the ns-laser- matter interaction. Processes induced by laser beams are characterized by a rapid ejection of electrons and a subsequent removal of target material emitted along the normal to the target surface. The effect, due to the large charge separation caused by electrons and ions so formed, might induce the characteristic high acceleration occurring during the ablation process [2].

The used approach is based on the plasma temperature and density characterization by different techniques, such as the optical and the ion energy analyzer spectroscopy. The ion energy distributions follow Boltzmann functions and permit to determine the equivalent acceleration voltage developed in the non-equilibrium charge generation inside the plasma [3]. The validity of local thermal equilibrium (LTE) conditions for these systems has often been assumed for the high value of electron density ($>10^{16}$/cm^3) and the Boltzmann shape of the observed distribution for the emission lines [4]. Some authors have discussed about the deviation from equilibrium even if the Boltzmann distribution is held and a high ionization degree is observed. It has been deduced that this effect can be related to the typical recombination processes of expanding laser-induced plasmas [5].

Our investigation concerned the ns-laser ablation of a Ti target and the characterization of plasma elementary processes involved during its formation and expansion. The Boltzmann distributions of all emitting species evidence thermal and Coulomb processes involving high ionization states in the plasma core and lower ionization and de-excitation mechanisms in the coronal zone of the plasma. The following experimental work has therefore been carried out with the aim of highlighting the process that can occur, such as deviations from equilibrium conditions, when the emission spectra are acquired at short time delays from the ablating laser pulse.

The interest for the Ti plasma comes from the wide variety of its possible applications, from biomedical field, where this element is used as bulk and biomaterial thin film, to engineering, where this material is employed as pure or as alloy, for its excellent mechanical and chemical properties [6].

* Corresponding author.
E-mail address: torrisi@lns.infn.it (L. Torrisi).

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2. Experimental

The employed laser is a Q-switched Nd:Yag pulsed laser with 1064 nm wavelength, 9 ns pulse width and 1–900 mJ pulse energy. The pulse energy was measured with a high sensitive calorimeter. The laser beam is focused through a convergent lens on a titanium target placed inside a vacuum chamber at 10^{-7} mbar. The optimum focalization distance (50 cm) was determined minimizing the spot dimension observed on the target. The spot size is 0.5 mm^2 and the incidence angle is 45°. This angle can be changed by the operator moving a vacuum feedthrough at which the target holder is fixed. The target consists of a pure titanium sheet, with a polished 2 cm^2 surface and 1 mm thickness. The target can be moved vertically with the vacuum feedthrough, so that each laser shot can hit a fresh titanium surface.

An optical spectrometer system (OSS) (Lynear-Horiba Jobin Yvon) detects the visible light plasma emitted in the wavelength region from 250 to 800 nm with 2 nm resolution. It operates by analyzing the light detected with a small convergent lens focused on the plasma region, at 5 mm distance from the target surface. The small lens is placed in the input of an optical fibre which transports the plasma light signal to the spectrometer input. The OSS spectra were acquired using the laser repetition rate hitting the target at 30 Hz frequency.

In order to measure accurately the ion energy and the ion charge state a special ion energy analyzer (IEA), based on the electrostatic ion deflection, was used to measure the time-of-flight (TOF) of the ions travelling for a distance of 1.55 m from the target to the detector along the normal direction to the target surface. By varying the bias of the electrostatic deflection plates, it is possible to filter different energy-to-charge, E/z, ratio values and to plot the experimental ion energy distributions as a function of the ion charge state. IEA contains also an input ring ion collector (ICR) placed at 60 cm distance from the target, in order to detect the ion yield directed towards the IEA. More details about the used ICR and IEA detectors are given in literature [7].

Fig. 1 shows a photo of the experimental set-up (a), a scheme of the IEA detector (b) and of the OSS assembly (c).

Images of the plasma due to the visible emitted component were obtained by using a fast CCD camera (Pixefly CCD-double shutter camera) with high resolution (1360 × 1024 pixel) triggered with the laser pulse. The camera was collimated and focused on the plasma region and an exposition time of only 5 μs was used. Moreover, it was mounted at 90° with respect to the normal to the target surface direction and at 40 cm distance from the target.

3. Results

Fig. 2 (top) shows a typical IEA spectrum obtained irradiating at 270 mJ laser pulse energy and detecting with 35 V plate bias, corresponding to a filtering $E/z = 35$ eV/charge state. The negative peaks indicate that five charge states are produced and that the TOF time decreases with the charge state, i.e. the ion velocity increases with the charge z. On the bottom of Fig. 2 is shown the ICR spectrum relative to the ion yield detected along the IEA direction. This spectrum represents the

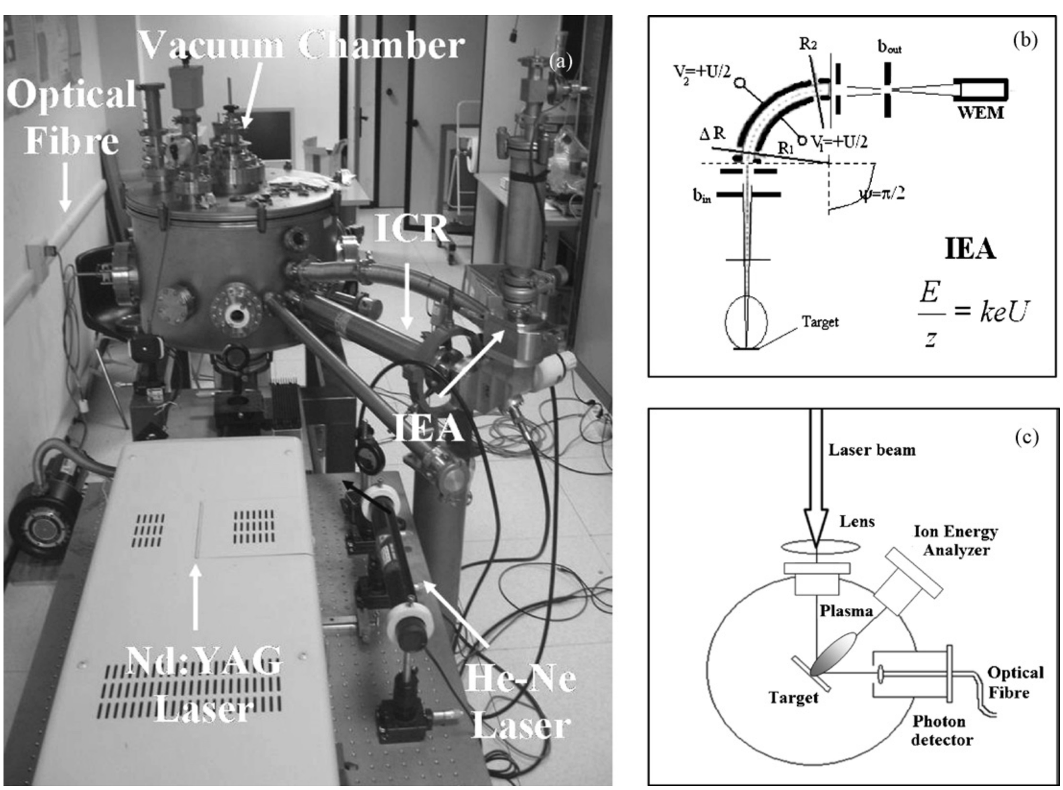

Fig. 1. Photo of the experimental set-up (a), scheme of the IEA detector (b) and scheme of the OSS apparatus (c).

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