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LANGMUIR PROBE DIAGNOSTICS OF PLASMA PRODUCED BY LASER ABLATION

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Abstract – A non-equilibrium plasma has been produced at INFN-LNS of Catania by means of laser ablation of a tantalum target placed in vacuum and by using a 9 ns Nd:YAG laser with 900 mJ maximum pulse energy and 1064 nm wavelength. The plasma plume is emitted mainly along the normal to the irradiated target surface. Plasma characterization has been performed "in situ" with a millimetric Langmuir Probe measuring the probe current vs. the polarization voltage and the time delay from the laser shot. The analysis of the I-V curve has permitted to characterize the plasma plume in terms of electron temperature, electron density, ion current density and plasma potential.

Introduction - Pulsed laser irradiation of solid targets in vacuum generates non-equilibrium plasmas with peculiar properties. Plasma expands at supersonic velocity and it is characterized by high temperature and density values, high fractional ionization and charge states, high plume directivity and energetic particle emission [1]. Plasma temperature, density and expansion velocity assume different values depending on the expansion time (delay from the laser pulse), expansion length (distance from the target surface) and plasma species (ions, electrons, neutrals). Various techniques are usually employed in order to characterize laser-generated plasmas, such as time-of-flight (TOF) technique by means of ion collectors (IC) or ion energy analyzer (IEA) [2], optical spectroscopy measurements [3], X-ray detection [4], etc. In all the above mentioned techniques the detection devices are usually far from the target surface, i.e. in the free flight region where plasma temperature and velocity are frozen [5]. Therefore, the consequent plasma temperature and density calculations give underestimated values because they are performed far from the target surface, i.e. they do not refer to the early beginning of the plasma expansion. Langmuir probe detectors can overcome this disadvantage because they can be put in the region close to the target surface where plasma is hot and dense [6]. The Langmuir Probe diagnostics is a powerful method for the evaluation of the plasma current-voltage curve (I-V curve) and the characterization of the following plasma parameters: electron temperature, electron density, ion density and plasma potential.

Experimental set-up – The laser employed at INFN-LNS of Catania is a Q-switched Nd:YAG operating at 1064 nm wavelength, 9 ns pulse duration and 1–900 mJ energy. The laser beam is focused through a convergent lens on a tantalum target placed inside a vacuum chamber at 10^{-6} mbar. The laser beam direction is normal to the target surface and the spot diameter is 1 mm. The target consists of a pure Ta sheet having a polished surface of 2 cm^2 and a thickness of 1 mm. The target can be moved vertically with the vacuum feedthrough, so that each laser shot can hit a fresh flat surface. A plasma plume is emitted along the normal to the irradiated target. The Langmuir probe used for the plasma plume characterization consists of a 4 mm long tungsten wire, with a diameter of 150 μm (the metallic wire protrudes from a cylindrical alumina sheath). The probe is placed 1.5 cm far from target surface (the wire is positioned on-axis, i.e. along the plume expansion direction) as sketched in Fig. 1. It is not possible to locate the probe closer to the target surface because of tip overheating and damaging. The time resolved measurements have been performed by using an appropriate electric circuit schematically shown in Fig. 1. Such an apparatus allows to maintain the probe tip at a given voltage and to acquire the probe signal as a function of the time, by means of a fast storage oscilloscope. In this way it is possible to characterize the plasma plume expansion with temporal intervals of 0.1 μs, thus describing the plasma plume dynamics in terms of density and temperature changes vs. time.

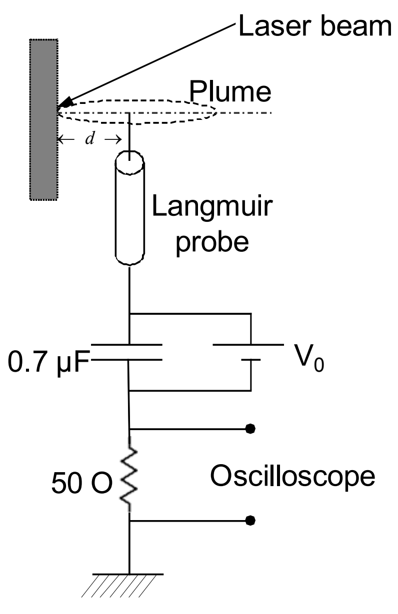

Figure 1 : Scheme of the experimental set-up.

Results and Discussions – Three typical I-V curves, obtained for a laser energy of 400 mJ, are reported in Fig. 2. They refer to the oscilloscope signals acquired at three different times: 400 ns (solid line), 800 ns (dashed line) and 1000 ns (dots). A smoothing process of the probe I-V signal has been performed by using a MATLAB tool for curve smoothing. As shown in Fig. 2 an electron current (positive values) is obtained for positive probe voltages, while an ion current (negative values) is acquired for negative probe voltages (see zoom).

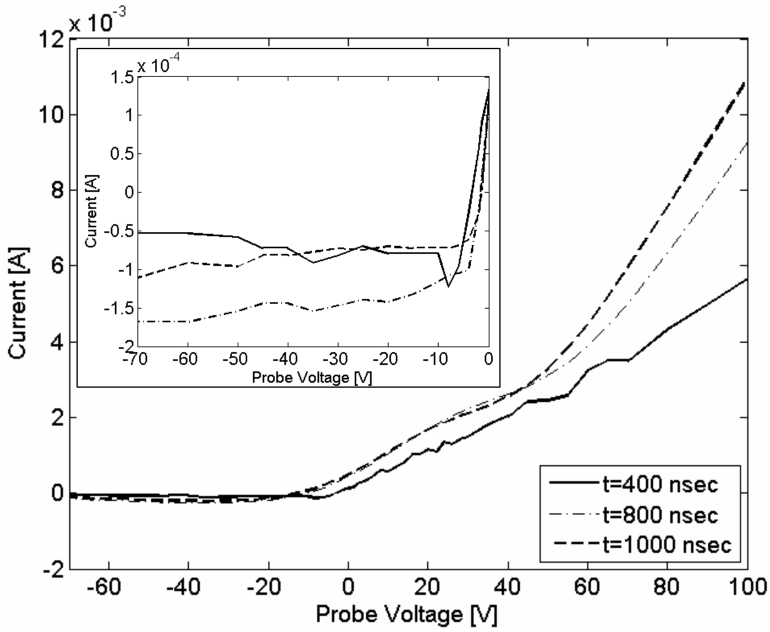

Figure 2 : I-V curves acquired at three different times.

The electrostatic probe methods are based on the sheath formation in quasi-neutral plasmas [7]. The plasma potential V_p plays a key role in the I-V curve analysis, as the values of the other plasma parameters can be extracted from the characteristic curve once known V_p. The current measured at the plasma potential is usually defined as the electron saturation current I_e^S. If $V < V_p$ the electrons feel a negative repelling potential (V_p - V) and only the ones whose energy is higher that the applied tip voltage can reach the probe. Then this part of the I-V curve gives information about the electron energy distribution. The plasma potential can be determined by plotting the logarithm of the probe current versus the applied voltage. By applying the Langmuir theory [7] the electron temperature can be determined, as it is inversely proportional to the slope of the natural logarithm of the I-V curve where $V < V_p$. Moreover, known the electron temperature, the electron density can also be calculated [7]. In particular cases the electron energy distribution function can be formed by two or more electron populations, each one characterized by a specific density and temperature [8]. In our measurements, in fact, we have distinguished two electron populations (warm and cold electrons), as two different slopes of the (ln I-V) curve have been observed. For a time of 400 ns (solid line in Fig. 2) the maximum plasma potential has been observed, and it results to be about 11 eV; the warm and cold electron temperatures are about 37 and 10 eV, respectively, the electron density being about $1\cdot10^{10}$ cm^{-3}.

The dependencies of electron temperature and density on the delay time from the laser pulse are reported in Fig. 3. The warm electrons have a mean temperature value about four times higher than the cold ones. Moreover, both populations reach a maximum temperature at about 400 ns after the laser pulse (corresponding to a plasma expansion front velocity of $3.75\cdot10^4$ m/s) and they are approximately constant after 2 μs.

After about 2 μs the high density plasma front arrives in proximity of the probe tip. Such part of the plasma plume is characterized by lower temperatures but higher densities, up to $9\cdot10^{10}$ cm^{-3}. This density is related to a large volume plasma, but the density at the early stage of plasma plume creation can be calculated by means of a simple geometrical model, which considers the plasma plume expanding as a cone with a basis aperture of 60°. According to this model the plasma density in the first stage of its expansion should be in the order of 10^{18} cm^{-3}.

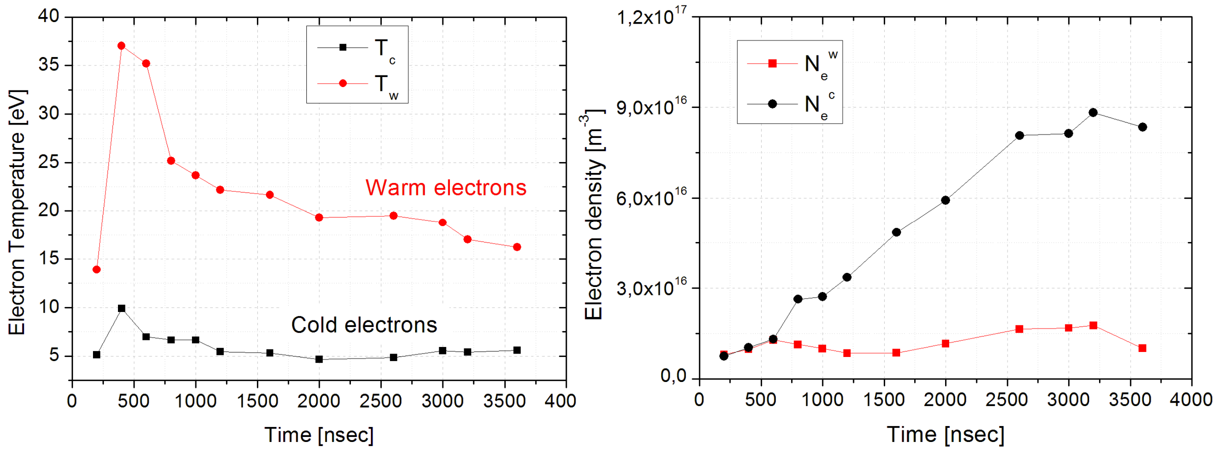

Figure 3 : Electron temperature and density vs. time

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