Investigation of laser generated plasmas expanding in vacuum and in a background gas by means of Time-Of-Flight measurements

N. Gambino[1,2], D. Mascali[1,3], S. Tudisco[1,2], A. Anzalone[1], S. Gammino[1], R. Grasso[2], R. Miracoli[1,4], F. Musumeci[1,2], L. Neri[1,4], S. Privitera[1,2], A. Spitaleri[1,3]

[1] *INFN - Laboratori Nazionali del Sud, via S. Sofia 62, 95123 Catania, Italy.*
[2] *Università degli Studi di Catania, DMFCI - Dipartimento di Metodologie Fisiche e Chimiche per l'Ingegneria, Viale A. Doria 6, 95125 Catania, Italy.*
[3] *Centro Siciliano di Fisica Nucleare e Struttura della Materia, Viale A. Doria 6, 95125 Catania, Italy.*
[4] *Università degli Studi di Catania, Dip.to Fisica, via S. Sofia 64, 95123 Catania, Italy.*

Abstract

The interest of scientific community in laser generated plasmas is constantly growing; these plasmas allow to investigate a variety of phenomena, from material science to astrophysics issues, that are the subject of our investigation; on this purpose we measured properties of an Al plasma produced with a ND:YAG laser (1064 nm, 600 mJ, 6 ns FWHM) installed at DMFCI of Catania by means of time of flight measurements obtained by using a Faraday Cup and a Langmuir Probe; the plasma expands at different background pressures. The peculiarity of our experimental set-up was that the detected voltage versus time signals were characterized at different positions away from the target surface, covering a wide range of distances; the Langmuir Probe tip was even placed just few mm from the target. This configuration permitted, other than time resolved measurements of temperature and density, to reveal some inner plasma structures that can be interpreted as ion multi-shells following fast electron layers.

1. Introduction

Laser generated plasmas can be useful to study crucial astrophysical phenomena, such as shock wave formation and electron screening contribution in nuclear fusion, that is particularly interesting at the still unexplored low energy domains. Colliding plasma plumes can be employed for the production of jets and shock [1], as shown by some preliminary calculations [2, 3]. They featured that formation of shocks and jets, and also the onset of the Rayleigh Taylor instability, which appears quite soon during the plumes overlapping. Although we appositely designed our experiment for the production of two colliding plasmas (obtained from a single beam splitted laser) but the first measurements were carried out on a single Al plasma plume just to characterize the main features of our system.

2. Experimental Set-Up and First measurements

The core of the experimental set-up consists in a cylindrical vacuum chamber (see fig.1) with a diameter of 250mm and 240mm of height. The laser beam is focalized inside the chamber with a 25mm focal length lens, obtaining a spot size on the order of 400µm. A bulky pure aluminium target was employed during the experimental measurements.

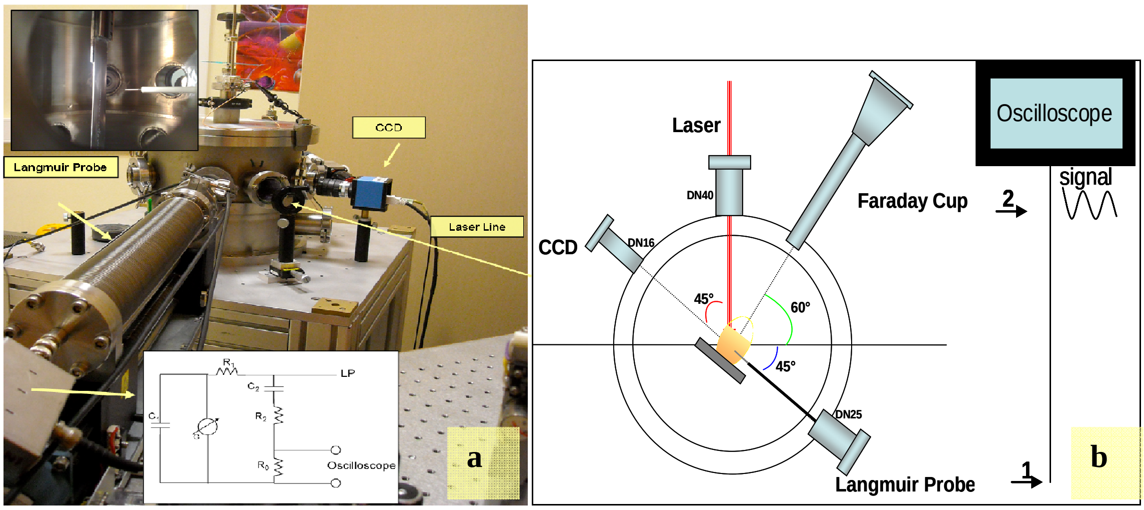

Figure 1: Vacuum Chamber (a), Geometrical configuration of the experimental set-up (b).

The Langmuir probe consists of a tungsten 5mm long cylindrical thin tip, with a diameter of 0.15mm, connected to a rigid 300mm long coaxial cable, having a thickness of 3mm covered by an alumina sheath. The signal was collected through a RC circuit that is shown in fig.1. The Faraday cup has an active area of 346mm^2. Both time of flight signals were collected by means of a Textronik Oscilloscope and triggered with the laser pulse. Two different experimental set-up were realized: in the first one the Farday cup was located 120cm away from the target surface and parallel to the plasma expansion direction while the Langmuir probe was located 1.5cm away from the target surface and perpendicular to the plume expansion direction. The Farday Cup was biased constantly at -30V, while the Langmuir Probe was biased from -100V to +100V with steps of 5-10V at each laser shot, in order to reconstruct off-line the *I-V* curves (current vs applied voltage) in function of time thus finally obtaining the plasma parameter like Electron Density and Electron Temperature. The data analysis have been carried out by means of a Matlab code [4]. In the second set of measurements the probe was located parallel the expansion direction, (the target was rotated of 15°, see fig.1.a) at 1.5cm from the target (to made a further comparison with the orthogonal configuration) and also from 0.2cm to 0.49cm from the target surface using the probe tip only as time of flight detector without biasing the tungsten tip. All measurements have been done at an operating pressures of $4 \bullet 10^{-6}$mbar and at $1 \bullet 10^{-3}$mbar.

3. Results and Discussion

We report here the plasma parameters (Electron Density and Electron Temperature), obtained when the probe was located 1.5cm from the target surface orthogonal and parallel to the plasma plume expansion direction at an operating pressure of $4{\bullet}10^{-6}$mbar (see fig.2).

The Electron Density was determined with the OML-Orbital Motion Theory, given by the formula [5]:

$$I_{e,i} = \frac{2}{\sqrt{\pi}} A_p e n_e \left(\frac{kT_{e,i}}{2\pi m_{e,i}} \right)^{1/2} \left(\frac{eV}{kT_{e,i}} + 1 \right)^{1/2} \qquad (1)$$

The Electron Temperature was determined by applying the Langmuir Theory, since it is inversely proportional to the slope of the ln$I$ vs. V curve when $V < V_p$, where V_p is the plasma potential.

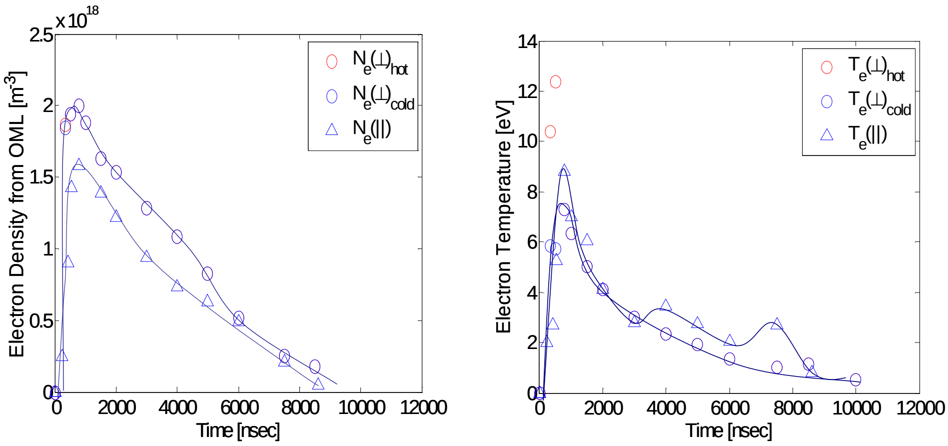

Figure 2: Comparison between the electron densities (a) and the electron temperatures (b) when the probe was located at 1.5cm from the target surface orthogonal and parallel to the plume expansion direction.

Figure 2.a features that the densities obtained in the two configurations are quite comparable, having at a fixed time a maximum difference of $\Delta N_e = N_e(\|) - N_e(\perp)_{cold} = 0.3 \cdot 10^{18} m^{-3}$. In addition, the curves (except for some oscillations of $N_e(\|)$ at 4000-5000nsec, due probably to large experimental errors) are in agreement with the theoretical adiabatic and isoentropic plasma expansion dynamical model [10]. Electron temperatures are shown in figure 2.b: they reveal that $T_e(\|)_{cold}$ and $T_e(\perp)_{cold}$ are in agreement, especially in the first 3000nsec. But crucial in this case is the existence of a non thermalized hot electrons component it the early stage of the plume expansion. They are more evident when the probe is in the parallel configuration and at 0.5cm far from the target surface: in the first 500nsec cold electrons have 10-15 eV, while the hot ones have 15-20 eV. According to [6], the two electron temperature (TET) plasma may develop some instabilities which violate locally the plasma quasi-neutrality; this mechanism finally produces strong self-generated electric fields which further

accelerate some plasma layers and make the expanding plume as a plurality of electrons and ion bunches, completely decoupled with respect to the plasma core which expands at much lower velocity. This hypothesis is also confirmed by the time of flight signals collected when the probe was located from 0.2cm to 15cm from the target surface (see fig. 3).

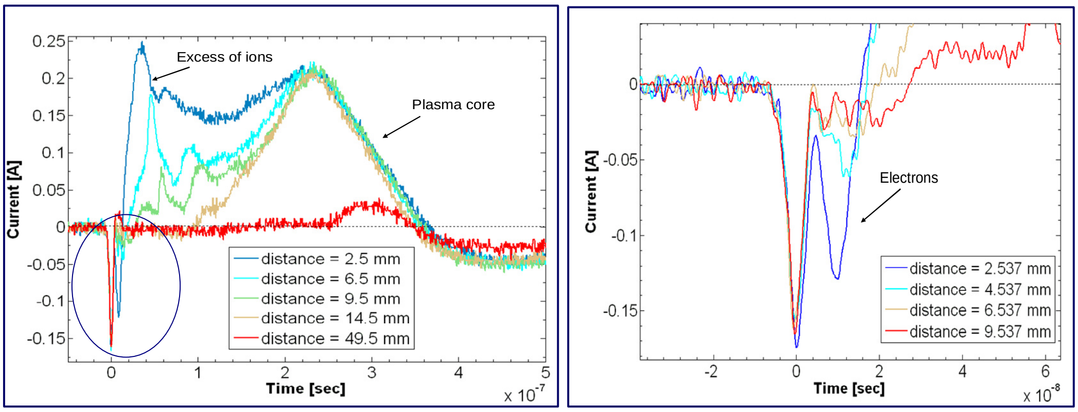

Figure 3: Time of Flight signals obtained when the probe was located parallel to the plasma expansion direction: (a) from 2.5mm to 49.5mm far from the target surface
(b) from 2.57mm to 9.53mm far from the target surface.

When the Langmuir probe was used as TOF measurement tool, since for the fast expanding layers the quasi-neutrality condition no longer applies, the probe particle collection is only governed by its geometrical cross section. This explains why the contribution of multi-layer disappears at large distances from the target surface. Figure 3 shows that the thermalization between the cold and the hot component takes places on a timescale of about 1000nsec . The existence of two electron populations is confirmed also by measurements done in the orthogonal configuration: cold electrons have 6-8 eV, while the hot ones have 11-13 eV.

The data analysis reported here is a preliminary phase. We aim to improve our numerical code (presented in [8]) and to realize further experiments on nuclear astrophysics for studies that up to now have only been carried out by numerical simulations.

4. References

[1] P. Hough et al, J. Phys. D: Appl. Phys. 42, 2009, 05521.

[2] D. Mascali et al, Rad. Eff. & Def. in Solids, in press.

[3] S. Ivanovski et al, Rad. Eff. & Def. in Solids, in press.

[4] D. Mascali, *Acta Technica CSAV*, 2008, 53, 333-345.

[5] V. A. Godyak,et al. J. Appl. Phys. 73, 3657–3663, 1993.

[6] N. M. Bulgakova et al, Phys. Rev. E, 62, 2002, 4.

[7] S. Anisimov et al, Phys. Rev. B, 1993, 98.

[8] N. Gambino et al, Rad. Eff. & Def. in Solids, 165, 6, 2010.