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DIAMOND DETECTORS FOR CHARACTERIZATION OF LASER-GENERATED PLASMA

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Abstract - *CVD mono-crystalline diamond films were employed as detectors of the radiation emitted from the laser-generated plasma obtained with a Nd:Yag laser at the INFN-LNS in Catania (10^{10} W/cm^2) and a high-power iodine PALS laser in Prague (10^{15} W/cm^2). Plasmas were obtained using different targets: Al, Ta, Au, and CF_2. The plasma characterization was carried out by the use of diamond detectors and ion collectors placed at different distances and angles with respect to the position of the ablated target. Diamond detectors measure UV, X-rays, electrons and ions. Time-of-flight technique was exploited to separate photon, electron and particle contributions. The TOF diamond spectra were compared with traditional ion collector spectra. The results indicate that the ion energy resolution of diamond detector is high and that the mean energy of soft X-rays could be obtained by analyzing the spectra acquired for different absorber films.*

Introduction – Laser-generated plasma is characterized by high temperature and density, which can reach values of the order of 10 keV and 10^{20}/cm^3, respectively. These plasmas emit high intensity photons, from IR to visible, to UV and X-ray regions, and high energetic electrons and ions, which energy is of the order of tens of keV and MeV, respectively [1]. Generally, the characterization of the plasma properties uses different detectors, such as fast semiconductors for photons, ion collectors for ions and electrons and ion energy analyzer for energy distribution measurements. Often, detectors are employed in time-of-flight (TOF) configuration and are placed at different angles and distances from the laser irradiated targets.
The main properties of CVD-based diamonds are radiation hardness, low electric constant, low leakage current, fast signal collection time, room temperature operation and high gap energy (5.48 eV). Photons, electrons and ions hitting the sensible volume of the detector

generate electron-hole pairs, (loosing 13 eV for a pair) that results in arising a voltage signal at the device electrodes which is proportional to the deposited energy. The high efficiency charge collection permits to use the diamond to detect soft X-rays, electrons and ion beams. Due to these properties, diamond detector can be employed with success to monitor laser-generated plasmas in TOF configuration.

In this work a CVD diamond is employed to monitor the photons and particles emission ejected from a plasma obtained at INFN-LNS in Catania and at PALS laboratory in Prague, using a laser pulse intensity of about 10^{10} W/cm^2 and 10^{16} W/cm^2, respectively. Results are compared with traditional TOF ion collector measurements.

Experimental section – The Nd:Yag laser of INFN-LNS (Catania) used 1064 nm wavelength and a pulse energy of about 400 mJ with 9 ns duration. The Asterix laser of PALS (Prague) was employed at fundamental (1315 nm) and 3rd harmonics (348 nm wavelength) and pulse energy ranging from 50 J up to 200 J with 400 ps duration. Thick Al, Ta, Au and Teflon (CF_2) were employed as targets. The incidence angle was 30°, an anular ion collector (ICR) was employed as ion collector at 179 cm from the target along the normal direction. The CVD diamond detector was employed, without an with different mylar absorbers, at different known distances from the target and at different angles with respect to the normal direction. The used mono-crystal detector has 25 μm thickness, growth on high B-doped diamond, and 5 mm x 5 mm surface, which is glued on an thick Al backing and covered by a thin Al film (100 nm). Typically operates at 100 V polarization at which the electric field is 40 kV/cm [2].

Results and discussion - Two typical TOF spectra obtained at INFN-LNS (400 mJ laser energy, Ta and Al target, 25 cm target-detector distance) are reported in Fig. 1. Three different regions are observable vs. time: the first is the photo-peak region, representing a peak intensity proportional to the UV and soft X-ray intensity and energy, which duration generally is below 10-20 ns; the second is represented by a continuum region, from about 30 ns to about 300 ns, due to fast electrons detection; the third, is an intense region due to energetic ion detection occurring for times higher than 1 μs, as reported in Fig. 1a. The photo-peak yield, which details for Al ablation are reported in Fig. 1b, decreases exponentially with the mylar thickness absorber, as shown in Fig. 2a. The mylar absorption coefficient of detected photons can be measured from this exponential decay. Thus, by knowing the absorption dependence on the photon energy, as reported in Fig. 2b, it is possible to know, as a first approximation, the mean X-ray energy, according to literature [3].

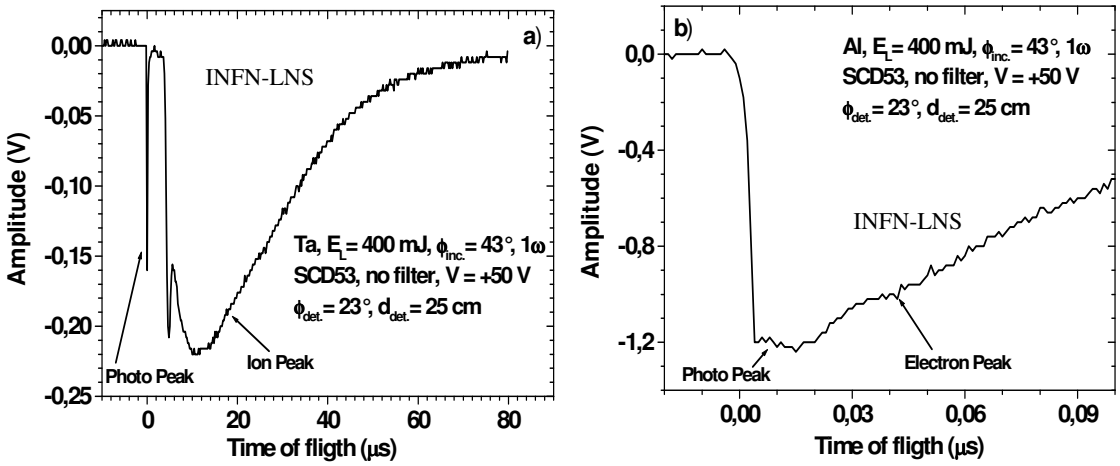

Fig.1: TOF diamond spectra for Ta (a) and Al (b) plasmas obtained at INFN-LNS.

Fig. 2b indicates that the mean energy of the X-ray emission at INFN-LNS was 260 eV at which corresponds an electronic plasma temperature of about 110 eV assuming the electron energy to be due to thermal interactions and to thermal gas expansion in vacuum. Such energy should be about a factor three or four lower with respect to the maximum energy of the electron Bremsstrahlung spectrum in the plasma.

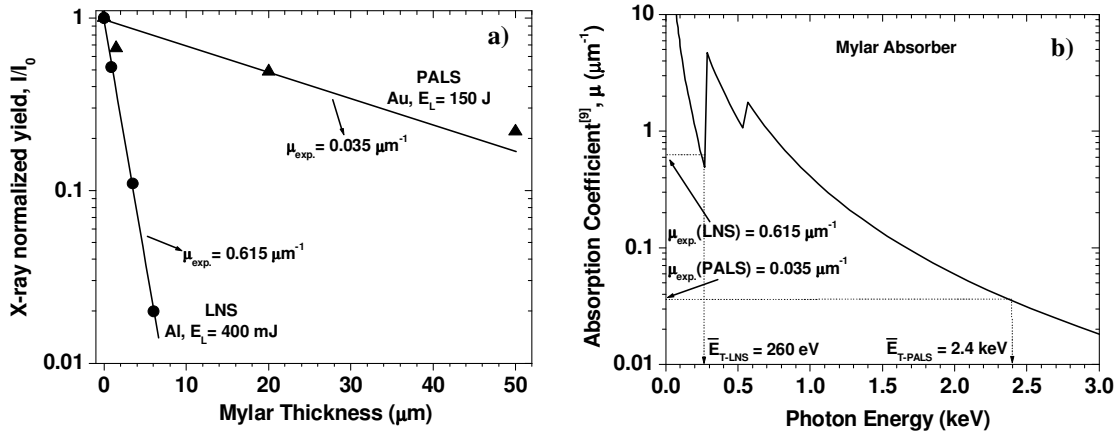

Fig. 2: X-ray yield vs. absorber thickness (a) and absorption coefficient vs. energy (b).

The signal due to electrons detection is less evident than for photons and ions because a large continuum spectrum characterize the electron plasma emission, moreover a soft X-ray signal, due to the late recombination of ions, could be overlapped to the electron peak, as reported in literature [4]. The spectrum of Fig. 1b indicates an electron energy emission from aluminium ranging approximately between 20 eV and 300 eV, while the spectrum of Fig. 1a indicates an ion energy emission from tantalum ranging between 600 eV and 10 eV. In this last spectrum, the peak detected at 4 μs is due to nitrogen and oxygen contaminants ion emission, which energy is about 300 eV. Higher temperature and particle energies can be obtained increasing

the laser pulse intensity. A typical TOF spectrum obtained at PALS (155 J laser energy, CF_2 target, 176 cm target-detector distance) is reported in Fig. 3a. Also in this case three different regions are observable vs. time: the first is the photo-peak region, which duration generally is below 50 ns; the second represents a continuum region due to fast electrons detection, extended from photo-peak to the ion peak position; the third, is the intense region due to energetic ion detection occurring for higher times. In this case the photo-peak yield decreasing with the mylar absorber thickness gives an absorption coefficient of 0.035 μm^{-1}, at which corresponds a mean X-ray energy of 2.4 keV. Thus the electronic plasma temperature in this case becomes 1.02 keV. The signal due to electrons detection is less evident than for photons and ions because a large continuum characterize the plasma emission. The spectrum indicates an electron energy ranging approximately between 1 keV and 11 keV and an ion (carbon) energy ranging between about 90 keV and 10 MeV.

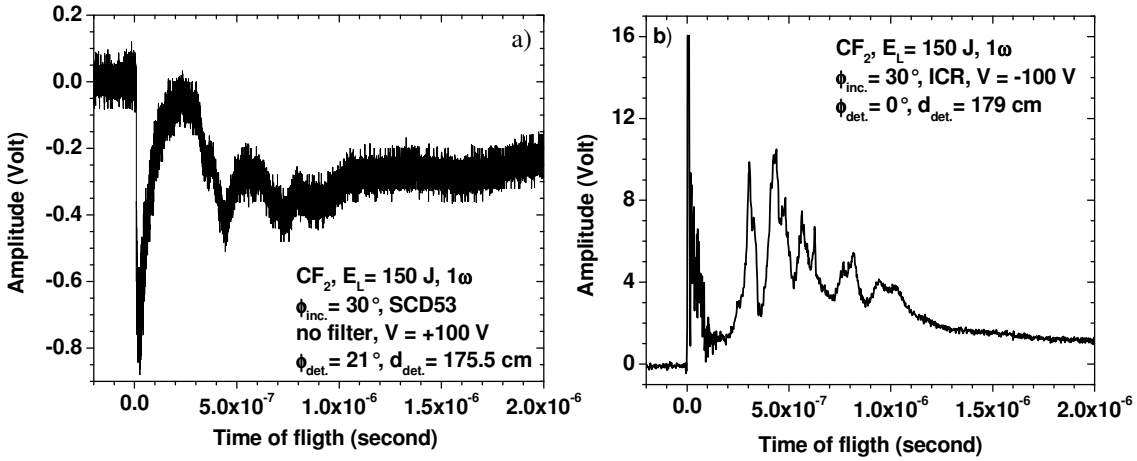

Fig. 3: Typical TOF spectra for diamond (a) and ion collector (b) from PALS experiment.

Fig. 3b reports, for comparison, the ion collector spectrum obtained contemporary to the diamond spectrum of Fig. 3a. The ion energy measurements, due to collection of C and F ions at different charge state and energy, are in good agreement with those obtained by the diamond detector. Obtained results indicate that the diamond is a good detector to characterize the laser-generated plasmas; it shows high efficiency and good energy resolution to be employed in TOF configuration and to detect contemporary energetic photons, electrons and ions ejected from the plasma.

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