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SPECTROSCOPIC STUDY OF THE PLASMAS GENERATED BY NANOSECOND LASER ABLATION OF AL AND CU TARGETS

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În această lucrare este prezentat un studiu spectroscopic experimental privind plasmele generate în aerul atmosferic în urma focalizării pulsurilor laser foarte scurte (~ns) din domeniul vizibil pe ținte de Al şi Cu. Spectrul din domeniul vizibil a fost utilizat pentru evaluarea variației spațiale a temperaturii în interiorul plasmei produsă cu Al şi pentru estimarea maximului temperaturii în cazul celei de Cu. Rezultatele obținute sunt în bună concordanță cu altele publicate în literatura de specialitate.

This paper presents an experimental spectroscopic study of the plasmas generated by focusing visible nanosecond laser pulses on Al and Cu targets in atmospheric air. We used the visible spectrum in order to evaluate the spatial variation of the temperature within the Al plasma plume and to estimate the peak temperature of the Cu plasma plume. The obtained results are in good agreement with other published in the literature.

Keywords: Pulsed laser ablation plasma, Laser-induced plasma spectrometry, Cu and Al emission spectra**.**

1. Introduction

The generation of high-density and high-temperature plasmas by focusing high peak power laser radiation onto a solid target is still a growing field in basic science, engineering and material processing technology. In the last years several experimental and theoretical studies concerned the laser processing, thermal and optical properties which are strongly modified by temperature but also by the change of surface morphology due to melting, recristalisation, and soft or hard

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ablation [1]-[5]. The key parameters of laser-ablated plasmas are the electron (or excitation) temperature and the electron density.

Several methods (mass spectrometry, reflectron and quadrupole mass spectrometry etc. [1]) were used for the characterization of the pulsed laser ablation plasmas. The optical methods are precise and powerful because in many cases they are nondestructive, simple, very fast and sensitive and have high spectral/spatial resolution. Here we use a spectroscopic method in order to characterize the spatial variation of the temperature within the Al plasma plume and to determine the peak temperature of the Cu plume.

The structure of the paper is the following. The Section 2 presents the experimental arrangement for spectroscopic study, the Section 3 presents the experimental results, and the Section 4 outlines the conclusions to this work.

2. Experimental set up

The experimental set up used for the spectroscopic characterization of the pulsed laser ablation plasmas for Cu and Al targets is presented in Fig. 1.

The second harmonic (λ=0.532 μm, 180 mJ energy), of a Q-switched Nd:YAG laser (λ=1.064 μm, 360 mJ energy for the fundamental), 4.5 ns pulse duration, $0.1 \div 10$ Hz repetition frequency was used for plasma production. The laser beam was focused on the target surface with a convergent lens ($f/10$, f=10 cm). The experiment was realized in air, at atmospheric pressure.

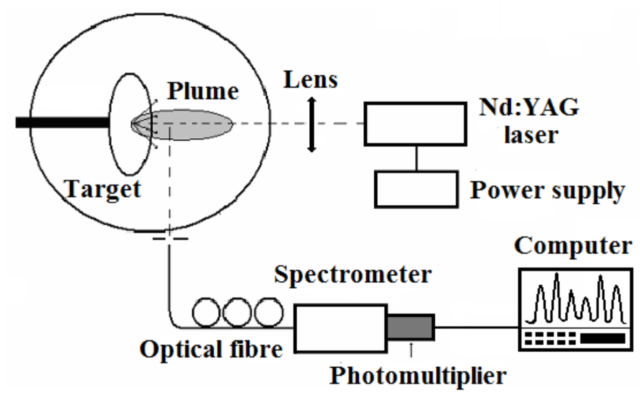

Fig. 1. The scheme of the experimental setup for plasma spectroscopy

A plasma plume containing electrons, atoms and ions from the target and from the air was obtained. The plume dimensions are about 5 mm. The light emitted by the plasma at different positions along the plume axis was collected by an optical fiber and carried at the entrance slit of an Acton Research spectrometer. It has two gratings, at 600 grooves/mm blazed at 1000 nm and 1200 grooves/mm blazed at 750 nm. Its best spectral resolution is about 0.5 nm. The spectrometer is used in the monochromator mode. Behind its exit slit, the light is detected by a Hamamatsu photomultiplier. For each wavelenght, the light intensity is integrated during at least a time equal with the inverse of repetition frequency of the laser shots. Then the light intensity is recorded by a computer. The computer controls also the grating rotation.

Some UV, visible and IR spectra of the Al (for several distances between the target surface and optical fibre) and Cu plasmas obtained by pulsed laser ablation (10 Hz repetition frequency) are presented in Figs. 2 and 3, respectively.

In the case of the laser ablation plasma in Cu, an expanded spectrum including the main lines in visible is presented in Fig. 4. It includes four atomic copper lines, separated by less than 12 nm (two being very closed near 521,9 nm). The profiles of the four Cu lines were fitted with Gauss profiles. Due to the very limited spectral resolution, the line profiles are given mainly by the apparatus function of measurements chain, which is Gaussian. For the spectral region of these four lines the spectral response is considered as constant. An energy calibration was not realized.

3. Discussion of the results

The Al spectra presented in Fig. 2 give information on the variation of the temperature along the axial direction of the plasma plume. The graph indicates that the intensity of the Al species lines, and consequently the temperature and density of the plasma plume, decreases with the distance from the target surface.

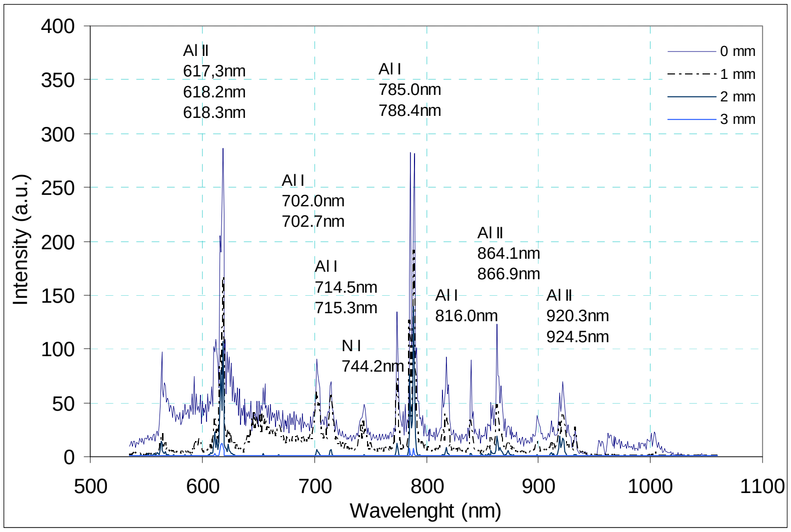

Fig. 2. Al plume spectra in visible and near-infrared regions at different heights above the target surface.

The Cu spectrum presented in Fig. 3 is obtained at the target surface. The relative intensities of the Cu lines presented in figure 4 are used to determine the plasma temperature at the target surface as follows.

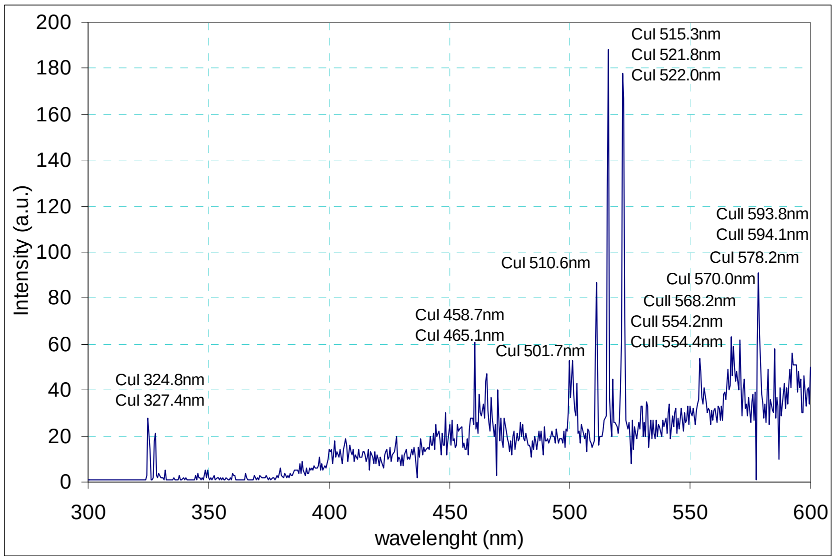

Fig. 3. Cu plume spectrum in near UV and visible range.

Considering the plasma in local thermodynamic equilibrium, the intensity of the lines (in fact the light flux) emitted at the transition between the u and k levels is given by the relation [1], [9]

$$I_k \sim \frac{N_{Cu}}{4\pi} \cdot \frac{g_{u,k}}{Z_{Cu}} e^{-\frac{E_{u,k}}{kT}} \cdot A_{ul,k} \frac{hc}{\lambda_k} \quad (1)$$

where N_{Cu}, g_u, E_u and $Z(T)$ state for the total number of the Cu species in the plume, the statistical weight, the energy of the upper level, and the partition function respectively.

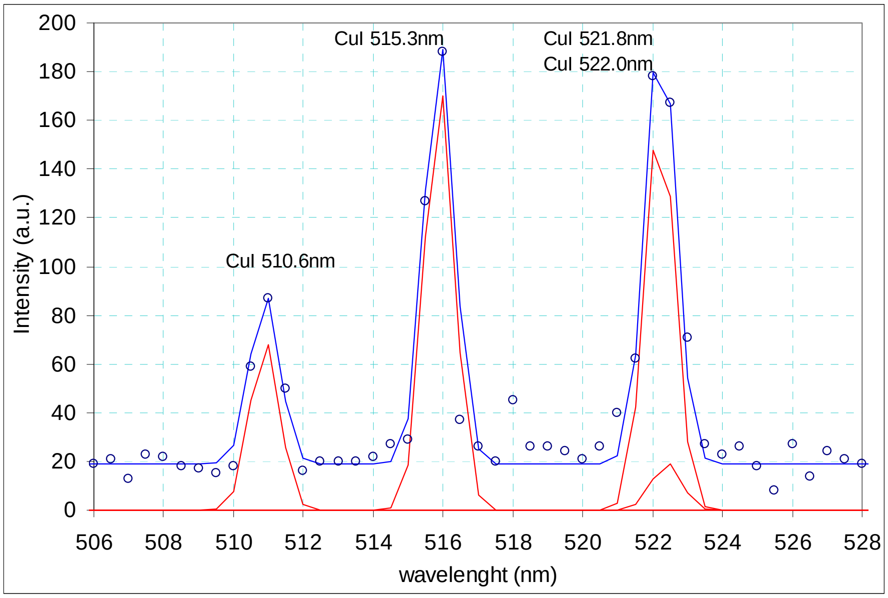

Fig. 4. Cu plume experimental spectrum (small cercles) and its fit using Gauss profiles

The electron (excitation) temperature is obtained from the slope $-\frac{1}{kT}$ of the best fit of the line:

$$\ln\frac{I_k \lambda_k}{g_{u,k} A_{ul,k}} = \ln\frac{hcN_{Cu}}{4\pi Z_{Cu}} - \frac{E_{u,k}}{kT} \tag{2}$$

in the plane with the energy E_u on horizontal axis and $\ln\frac{I\lambda}{g_u A_{ul}}$ on the vertical axis Boltzmann graph), as presented in Fig. 5

Throughout this paper, the atomic data as given by Kurucz Atomic Line Database [7] were used. For the four Cu I lines, this database includes the transition probabilities as given by Bielski [8]. These values can be found also in an exhaustive compilation by Fu *et al* [9]. Table 1 contains the values of these atomic data, used through the calculations.

Considering the Cu plume spectrum presented in Fig. 4 with line intensities the profile surfaces which lead to the Boltzmann's graph presented in Fig. 5, an electron temperature of about 7970 K is obtained for the Cu ablation plasma. This result is in good agreement with other results published in the literature [1], [9].

Table 1.

wavelength (nm)	g_{upper}	$A_{ul}\left(10^8\ \mathrm{s}^{-1}\right)$	$E_{upper}\ \left(\mathrm{cm}^{-1}\right)$
510.554	4	1.95E+06	30783.69
515.323	4	1.03E+08	49935.20
521.820	6	1.22E+08	49942.06
522.007	4	2.18E+07	49935.20

4. Conclusions

In this paper we studied the Al and Cu laser-ablation plasmas under atmospheric air conditions using spectroscopic methods. We obtained the UV, visible and IR laser-ablation plasmas spectra of the above mentioned specimen. The results indicate that the intensity of the Al lines, and consequently the temperature plasma plume, decreases with the distance from the target surface. By using the visible spectrum of the Cu we evaluated the temperature of the Cu plasma near the target surface. Our results are in good agreement with the previous results [1], [9] and may be used for the evaluation of sevaral plasma parameters like: temperature, electron density.

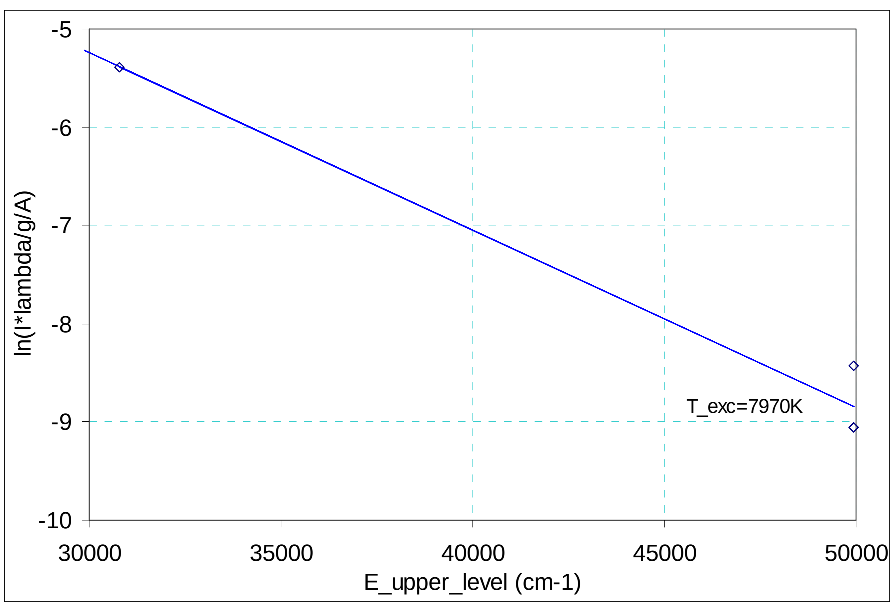

Fig. 5. The Boltzmann's graph.

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