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Spectroscopic studies of laser induced aluminium and copper plasmas in air

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Abstract. This work presents recent results from spectroscopic investigations on aluminium and copper plasmas in air, produced by the second (532nm) harmonic of a Q-switched pulsed Nd-YAG laser. The experimentally observed line intensities of neutral copper have been used to extract the excitation temperature using the Boltzmann plot method.

1. Introduction

Plasma formation by intense laser irradiation of solids is the subject of investigations in many fields of applied and fundamental research, from laser-plasma sources to X-ray lasers, from inertial confinement fusion to laboratory astrophysics. Aluminium is a common target in laser-plasma experiments. Plasmas are usually characterized using standard laser-plasma diagnostic techniques [1,2]. The emission spectroscopy has been used in studying plasma generated during incipient laser ablation of aluminium in air [3]. Temporal evolution of the laser-induced breakdown spectroscopy spectrum (LIBS) of aluminium target in different bath gases, has been reported [4]. The effect of self-absorption of aluminium emission lines in LIBS measurements has been evaluated [5]. The work by Glenzer *et al* [6] gives a useful résumé on the theoretical and experimental efforts to describe the expansion of laser-induced plasma plume. This paper will be particularly devoted to the studies by emission spectroscopy on aluminium and copper plasmas in air created by the second harmonic of a Q-switched pulsed Nd-YAG laser irradiation of solid targets.

2. Experimental set-up

The second harmonic (λ=0.532 μm, 180 mJ energy), of a Q-switched Nd-YAG laser (λ=1,064 μm, 360 mJ energy in the first harmonic), 4.5 pulse duration, 0.1$\div$10 Hz repetition frequency was used for excitation. The laser beam was focused through a 25 cm focal length convergent lens on a plane metal target in air, at atmospheric pressure. The target was rotated, in order to have fresh areas under the laser incidence. 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 produced by the ablated plasma was collected by an optical fibre, and then carried on the entrance slit of an Acton Research spectrometer. It has a focal length of 15 cm and two gratings, the first one at 600 grooves/mm blazed at 1000 nm and the second one at 1200 grooves/mm blazed at 750 nm. Its best spectral resolution is about 0.5 nm. This spectrometer is used in the monochromator mode. Behind its exit slit, the light is detected by a Hamamatsu photomultiplier. For each wavelength the light intensity is integrated during a time at least equal with the inverse of repetition frequency of the laser shots. Then the spectral (relative) light intensity is recorded by a computer. The computer controls also the grating rotation. Another spectrometer, an Ocean Optics HR4000CG-UV-NIR spectrometer in the spectral range 200 - 1100 nm with 3648 pixels was also used.

3. Emission spectra and main results

The emission spectrum of the ablation plasma on an aluminium target is presented in Fig. 1. It contains atomic and ionic lines coming from aluminium and atomic lines coming from oxygen and nitrogen, superposed on a strong continuum emission. Because no energy calibration was made, only a qualitative analysis was made for the aluminium plasma.

The emission spectrum of the copper plasma in air is presented in Fig. 2. It contains mainly atomic lines coming from copper, oxygen and nitrogen. An expanded region of this spectrum including the main lines in visible is presented in Fig. 3. It includes four atomic copper lines, separated by less than 12 nm (two being very closed near 521,9 nm); their profiles were fitted with Gauss profiles. Due to the very limited spectral resolution, the line profiles are given mainly by the apparatus function, which is Gaussian. For the spectral region of these four lines the spectral response is considered as constant. No energy calibration was realized.

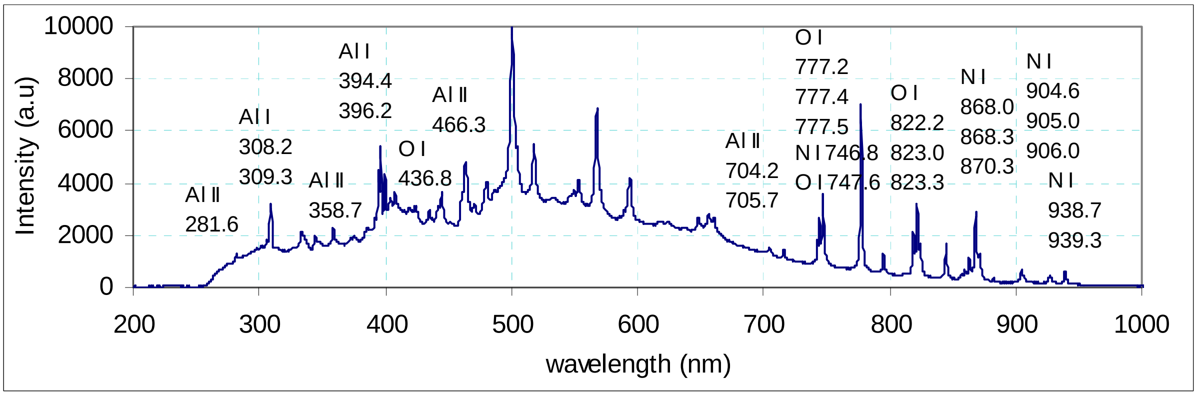

Fig. 1. Emission spectrum of the aluminium ablation plasma in air

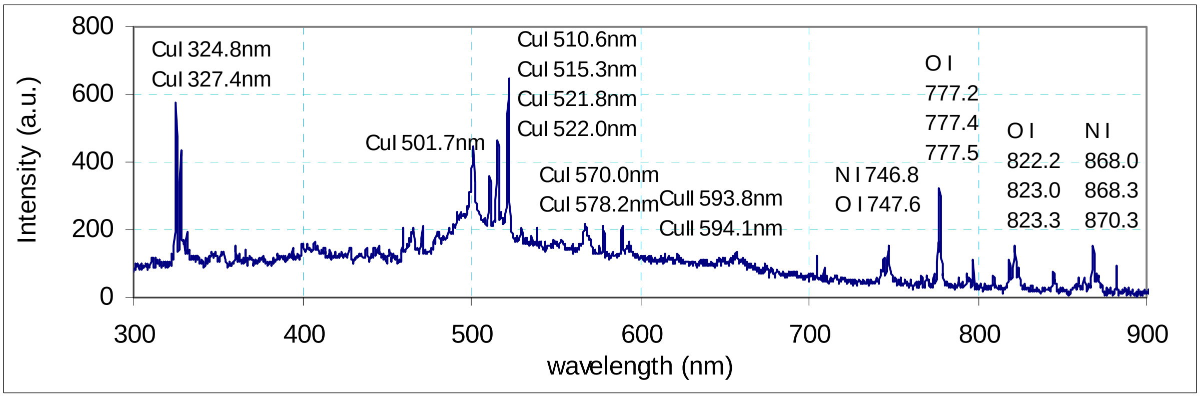

Fig. 2. Emission spectrum of the copper ablation plasma in air

The emission coefficient is given by:

$$\varepsilon = \frac{1}{4\pi} n_u A_{ul} h\nu_0 \tag{1}$$

where ν_0 is the line frequency, n_u is the particle density in the upper level, A_{ul} is the emission rate for the spontaneous emission, and h is the Planck constant. Considering the plasma in local thermodynamic equilibrium (LTE), the Boltzmann distribution can be used to obtain the population in different excited levels, the expression of the emission coefficient is:

$$\varepsilon = \frac{n}{4\pi} \frac{g_u e^{-\frac{E_u}{kT}}}{Z(T)} A_{ul} h\nu_0 \tag{2}$$

where n is the total density of the considered species, g_u and E_u are the statistical weight and the energy of the upper level, and $Z(T)$ is the partition function.

The last expression is used in the following form:

$$I_k = \frac{N_{Cu}}{4\pi} \cdot \frac{g_{u,k}}{Z_{Cu}} e^{-\frac{E_{u,k}}{kT}} \cdot A_{ul,k} \frac{hc}{\lambda_k} \tag{3}$$

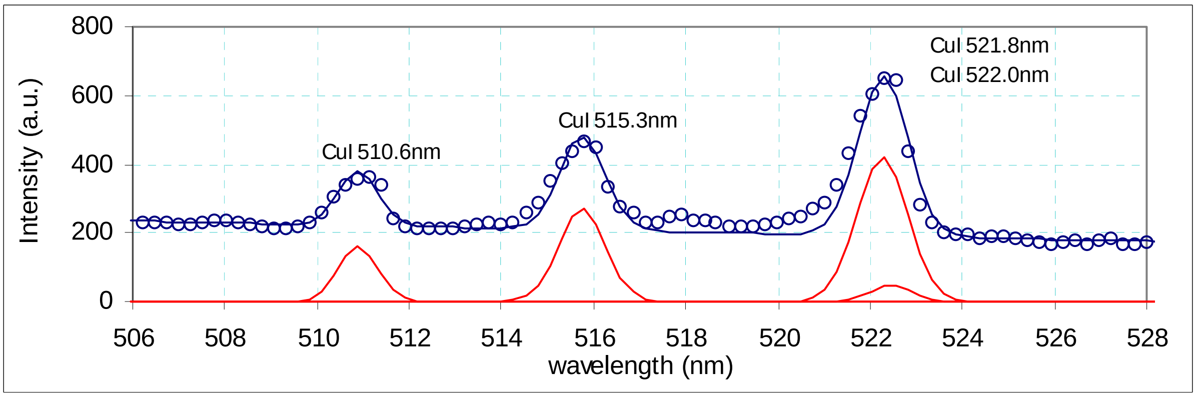

Fig. 3. CuI emission spectrum used for the determination of the electron temperature

where the line intensity (in fact the light flux) was used instead the emission coefficient. In fact, for optical thin plasmas, as we supposed implicitly, the two quantities are strictly proportional. In Eq. (3) N_{Cu} represents the total number of the Cu species in the plume.

The electron temperature is obtained from the slope $-1/kT$ of the best fit of the line:

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

in the plane with the energy E_u on horizontal axis and $\ln\frac{I\lambda}{g_u A_{ul}}$ on the vertical axis.

For the copper plasma, an excitation temperature of 8210±370 K was obtained. These values are near to those reported by Barthélemy *et al* [7], for ablation plasma containing aluminium.

4. Conclusions

In this paper we studied by emission spectroscopy aluminium and copper plasmas obtained by laser ablation in air. Emission lines from atomic and ionic species were measured. The electron temperature was obtained for the copper plasma from the CuI lines intensities. The results (T_e=8210±370 K)are in good agreement with those published by other authors.

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