Copper Emission lines for Temperature Measurements of the Plasma Produced by Nano-second Laser

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ABSTRACT

The aim of the present work is to measure the plasma temperature of the plasma generated by focusing an intense laser beam on copper target in air at atmospheric pressure. The plasma is generated using two different laser wavelength (1064 and 532 nm) and for different laser energies. Plasma is generated using a Brilliant Nd YAG pulsed laser from Quantel laser and the emission spectrum is collected using an Echelle spectrometer equipped with ICCD camera Andor type. The temperature is measured by developing a Boltzmann plot from three Cu I spectral lines at 510.55, 515.32, 521.82 nm.

Keywords: Laser-plasma interactions, Laser-produced plasma, laser-plasma interactions of solids.

INTRODUCTION

Laser-induced breakdown spectroscopy (LIBS), or laser-induced plasma spectroscopy (LIPS), is basically an emission spectroscopy technique which uses intense, short pulses of laser radiation to ablate the sample surface [1:3]. Ablation of sample results in plasma generation. Spectral lines of atoms and ions of this radiant plasma are used to develop the plasma parameters and or to develop the quantitative and qualitative analytical information about the sample. Recent applications of LIBS technique for multi-elemental analysis include environmental samples, biological samples, radioactive waste materials etc. [4:6]. The versatility of LIBS technique for multi-element analysis and its applicability to different types of samples (solid, liquid and gas) make it attractive in detecting and quantifying hazardous pollutants using in-situ remote excitation.

LIBS technique can be characterized as a non-destructive one and features high sensitivity, no sample preparation, and rapid on-line multi-elemental analytical capability (1). When a powerful pulsed laser is focused on a surface, a tiny amount of the materials is vaporized and through photon absorption it is heated up until it ionizes and expands from the sample surface as a plasma cloud. This laser-induced plasma is a micro-source of light that can be analyzed spectrally and temporally resolved detection of the characteristic emissions by a spectrometer.

An accurate knowledge of plasma temperature and density reveals a better understanding of the plasma processes taking place such as vaporization, dissociation, ionization and excitation. So the target of this paper is to evaluate the effect of the laser beam energy on the properties of the plasma generated by focusing an intense laser beam on Copper solid target in air at atmospheric pressure. The temperature is measured by Boltzmann plot of Cu I spectral for the plasma generated by both first and second harmonic laser at 1064 nm and 532 nm for different laser energy.
EXPERIMENTAL SET-UP

Figure 1 show the experimental setup used in the present study. A Q-switched Nd-YAG Brilliant laser from Quantel delivering a laser beam in 6 ns FWHM at the fundamental wavelength 1064nm and 5ns at the second harmonic wavelength. The laser was focused onto the target using 10 cm quartz lens. The incident power on the target was monitored using an absolutely calibrated power meter in conjunction with a plane quartz beam splitter reflecting 5% of the incident laser beam. Pure Copper target was used in the present experiment. The target is firstly polished and moved so a fresh. The emission spectrum was recorded using a SE 200 Echelle spectrograph produced by Catalina corp. equipped with an ICCD type Andor model iStar DH734-18F. The gain of the camera was fixed at a value of 250 with binning mode at 1x1. This spectrometer allows for a time resolved spectral acquisition over the whole UV-NIR (200-1000nm). A low pressure Hg lamp was used for wavelength calibration. A quartz fiber cable of diameter 25 μm was employed to conduct the emitted light from the plasma plume to the entrance hole of the Echelle spectrograph. The fiber tip was positioned using a x-y translational stage of a resolution of 100 μm, which enabled us to fix the fiber at 1.25 cm from the laser axis at a distance of 1.5 mm normal to the target. The cross sectional area seen by the fiber was estimated by feeding a laser beam from the backside of the fiber using a small diode laser. The estimated cross sectional area was 2 ± 0.1 mm.

Fig (1): Experimental Set-up.
Moreover the instrumental bandwidth of the system was measured by employing a low pressure Hg pin lamp. The spectra were acquired at different delays after the laser pulse, using constant opening gates of ICCD. The choice of the gate corresponds to a compromise between the need of not having very large variations of the signal during the measurement time, and at the same time having a good signal for calculating line intensities and widths. The experimental results were collected from three single shots from three fresh target positions for checking the reproducibility; this allows us to present an average and a standard deviation of the results.

RESULTS AND DISCUSSIONS

Figure (2) shows the typical emission spectrum of the produced plasma in the spectral range 200-900 nm. The data taken was spatially integrated from the surface of the target up to 2 mm normal to the target surface. This confirms that the plasma is homogenous within this short distance in front of the target [7]. However, the continuum emission decreases quickly with increasing delay time because of the expansion of the plasma.

Fig. (2) Typical emission spectrum from Cu produced plasma in the range 200-900 nm.

For extracting quantitative data and evaluating the plasma parameters from the line intensities, it is important to verify that the plasma is not optically thick for the lines being used for this purpose. The ratio of emission intensities of resonant and non-resonant lines should be verified according to a procedure for the “optically thin” limit described by Cremers and Radziemski [8], Simeonsson and Miziolek [9], and Sabsabi and Cielo [10]. A multiplet is very useful in the assessment of self-absorption [11]. However, the intensity ratio of its components is well known for the free atoms and ions, and any deviation will indicate the magnitude of the self-absorption. A convenient possibility to analyze quantitatively the total self-absorption of a line is offered by the measurement of a second line from the same upper level or lower level. If in addition, the absorption oscillator strength is also much weaker, this transition will hardly be influenced by absorption. A comparison of the measured intensity ratio of both lines with their optically thin limit is required. The optically thin limit in this case is simply given by the branching ratio see ref. [12].
The calculated optically thin limit ratio for the spectral lines at 521.82 nm and 515.32 nm is 1.85 and the experimental ratio is within this limit with acceptable error bars for different laser energies see fig.(3).

![Graph showing the intensity ratio of Cu I spectral lines](image)

**Fig. (3)** The measured intensity ratio of Cu I spectral lines [I(521.82)/I(515.32)]

The excitation temperature can be determined from the measurement of the intensity of its spectral lines assuming that the population of the energy levels follows the Boltzmann distribution law. For full LTE the intensity of the spectral line is given by

\[
I_{ij} = \frac{h\nu}{4\pi} L \, d\Omega \, g_j A_{ij} \frac{N_0}{U(T)} \exp \left\{ -\frac{E_i}{kT} \right\}
\]

(1)

Where \( L \) is the thickness of the plasma layer, \( h \) is Planck's constant, \( \nu \) is the frequency=\( c/\lambda \), \( d\Omega \) is the solid angle, \( A_{ij} \) is the transition probability, \( N_0 \) is the total density of atoms or ions, \( g_j \) is the statistical weight, \( U(T) \) is the partition function, \( E_i \) is the excitation energy of the upper level, \( k \) is Boltzmann constant, and \( T \) is the excitation temperature.

![Spectrum of Cu I spectral lines](image)

**Fig. (4)** Sample of Cu I spectral lines
Fig (5). Presents the obtained Boltzmann plots at different laser energies.
The present measurements are done for different laser energies (56 – 370 mJ) for the fundamental laser wavelength (1.064 μm) and (100-200 mJ) for the second harmonic laser wavelength (532nm). The temperature developed from Boltzmann plot using the three Cu I spectral lines shown in fig. (4) at the wavelengths 510.55, 515.32, 521.82 nm. These spectral lines are found very suitable for the temperature measurements of the laser produced plasmas in air. Figure (5) presents the obtained Boltzmann plots at different laser energies with good regression (~0.999). Fig. (5) Summarizes the measured temperature at the laser energy on the target.

![Fig. (6) The measured temperature versus the laser energy on the target.](image)

**CONCLUSION**

Successful measurements of temperature of the plasma generated by focus a Nd-YAG laser of different laser energy for the two laser wavelengths (1064 and 532 nm) on the Copper target are performed. Temperature measurements using three Cu I at 510.55, 515.32, 521.82 nm are very sensitive and recommended for temperature measurements of plasma produced by laser in air at different laser energies. The present study proofs that the temperature are strongly depends on the time and on the laser energy. The measurements in the present study proofs that at the end of laser pulse, the atoms in plasma are excited while leaving the target surface and traveling in the direction of laser source. Moreover, the impact excitation after the end of the laser pulse is the dominant process in the plasma and it is cooling. As well as higher laser irradiance gives rise to more target heating, melting and vaporization, resulting also a higher vapor density, velocity and temperature in the plume, and more charged species as expected.
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REFERENCES