# Zinc Emission Lines for Temperature Measurements of the Plasma Produced by Nano-Second Laser

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**Abstract:** ***The main goal of the present work is to study plasma produced by nano-second laser at different laser pulse energies on Brass sample in air. Laser produced plasmas considered a versatile wide important technique in different applications, such as in elemental analysis, and few other related technologies such as in material processing technology, and thin film deposition. In the present work, nsNd: YAG laser is used in the present study for producing plasma at different laser energies and for two different laser wavelengths 1064nm and 532nm. Calculation of plasma temperature for the produced plasma at different energies is performed using optical emission Zn spectral lines at the wavelengths 472.26, 481.08, and 636.23nm.***

**Keywords:** Laser-Induced Plasma Spectroscopy, LIBS, Nd: YAG Laser, Plasma Temperature, and Optical Emission Spectroscopy

## 1. Introduction

Plasma is an ionized gas, in which the gas atoms absorb a sufficient energy to cause the electron to become free and the atom is ionized. When this done the plasma is no longer acts like a gas. So plasma is an electrically quasi-neutral medium contains positive and negative particles. It is important to note that although these particles are unbound, and are not free. With the motion of charged particles, electrical currents with magnetic fields are produced and they are affected by each other's fields. Ionization can be induced heating, strong electromagnetic field applied with a strong electric current, laser or microwave power, and the process is always accompanied by the dissociation of molecular and atomic bonds.

High power Lasers is considered one of the important technique for producing plasma state in laboratory. The idea is based on the ablation of tin amount of the target material by interaction of intense laser beam with solid target. The sufficient energy of the laser is able to excite atoms and ionizes them to produce the plasma. Laser induced plasmas (LIPs) advance and progress as they represent an important plasma technique in different applications, such as in elemental analysis, and few other related technologies such as in material processing technology, and thin film deposition. [1-2].

Laser interaction with solid materials is a difficult process in understanding; however, it contains different stages such as the material ablation, plasma initiation, plasma laser interaction, plasma expansion and shockwave interaction with the solid material [3].

The plasma induced by nanosecond lasers is recently used in thin film deposition of traditional and new materials [4] and in elemental analysis [5-6]. Pulsed laser deposition (PLD) has proofed as an ease and efficient technique in the production of good quality thin films [7-9], however it can be produced in a reactive gas environment. The flux of sputtered material reacts with the environment gas molecules before its deposition [10-12]. The plasma produced by short duration laser pulses is an efficient technique for the production of nano-scale particles [13-15].

Figure 1 shows a schematic contain the description of the main processes: the material ablation, plasma initiation, plasma laser interaction, plasma expansion and shockwave interaction with the solid material [16].

The characterization or diagnostics of the generated plasmas by interaction of strong laser with solid samples is important in understanding the main plasma process which plays a role in the above mentioned applications [17-19].

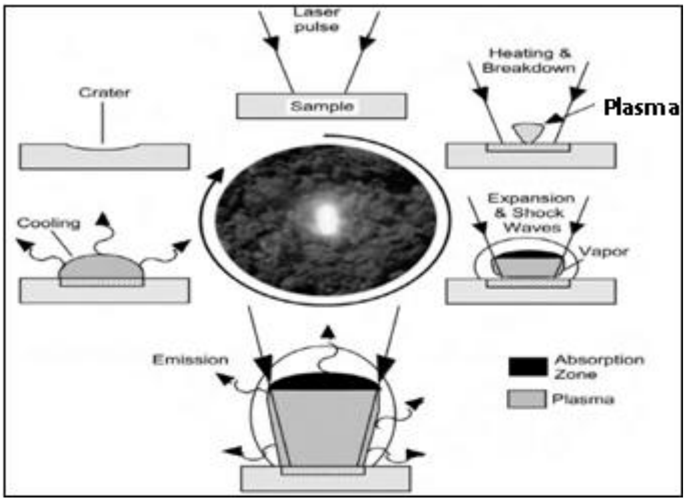


**Figure 1:** Schematic diagram of the main processes involved in laser produced plasma [16].

Suitable Zn spectral lines are used in the present work for characterization of plasmas generated by the interaction of both the fundamental laser at 1064 nm and the second harmonic laser at 532 nm from a nanosecond Nd: YAG laser in air employing the time resolved optical emission spectroscopy.

**Laser Produced Plasma Set-Up**

In the present work a Q-switched 10nsNd: YAG laser beam focused onto the Brass target using a 10cm focusing lens. The incident laser energy on the Brass target was measured using a NovaII energy meter. The emission spectrum recorded using HR4000 spectrometer from Ocean Optics. The spectrum acquired at different laser energy and for two laser wavelengths 1064nm, and 532 nm. Measurements of laser energy using calibrated power meter is performed at various places of the experimental setup.

## 2. Results and Discussions

**1) Measurements of Laser Energy**

NOVA II energy meter is used to measure the laser energy incident to the target against the laser flash lamp voltage. The measurements performed for two different laser wavelengths available in the lab. Figure2 shows the results of these measurements. However, each point is an average of five values with its error bars.

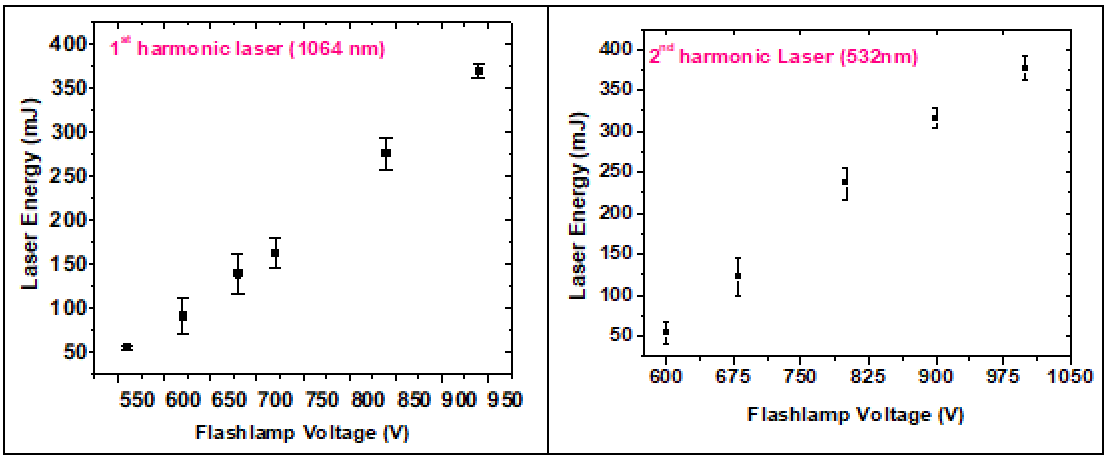


**Figure 2:** Laser Energy vs flash-lamp voltage

**2) Evaluation of Plasma Temperature using Boltzmann Plots**

The plasma temperature can be measured using the intensity spectral lines emitted from the plasma based on the assumption of the atomic states populated according to Boltzmann distribution. The intensity of the spectral line is given by:

$$I_{ij} = \frac{h\upsilon}{4\pi} L\, d\Omega\ g_i A_{ij} \frac{N_o}{U(T)} \exp\left\{-\frac{E_i}{kT}\right\} \quad \textbf{(1-a)}$$

Or

$$\ln\left(\frac{I_{ij}\lambda}{g_i A_{ij}}\right) = \ln\left(\frac{hc}{4\pi} L\, d\Omega \frac{N_o}{U(T)}\right) - \frac{E_i}{kT} \quad \textbf{(1-b)}$$

Selection of group of spectral lines and plotting ln (Iλ/gA) versus $E_i$, will give a straight line of a slope = (-1/kT). This is the so called Boltzmann plot. In the present work plasma temperature are determined using Zn I lines emitted from Brass target. Figure 3 present the spectral lines used in the present work. The necessary atomic data for developing Boltzmann plot are taken from NIST atomic data tables [20] and seen in table (1).

**Table 1:** Zn I spectral lines and its atomic data [20]

| $\lambda_{ij}$ (nm) | $E_i$ (eV) | $g_i$ | $A_{ij}$ ($10^7 s^{-1}$) |
|---|---|---|---|
| 472.26 | 6.65 | 3 | 4.58 |
| 481.08 | 6.65 | 3 | 7.0 |
| 636.23 | 7.74 | 5 | 4.65 |

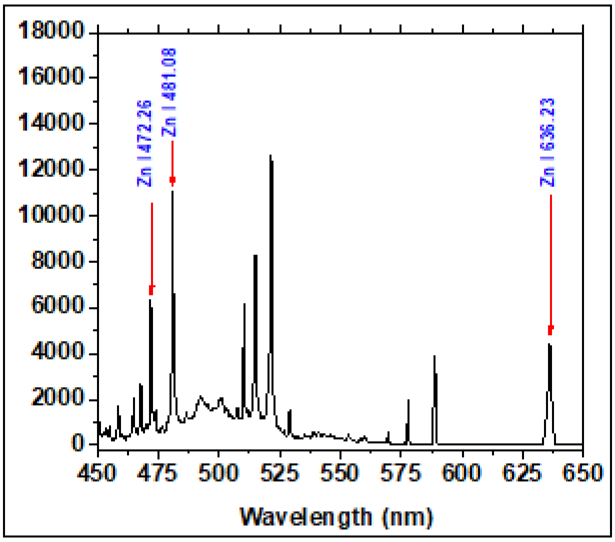


**Figure 3:** Sample of Zn I spectral lines

Sample of Boltzmann plot is shown in Figure 4 and the resulted temperature for the plasma produced by first and second harmonic lasers are seen in Figure 5. However, each data point is an average of five measurements with its statistical error bars.

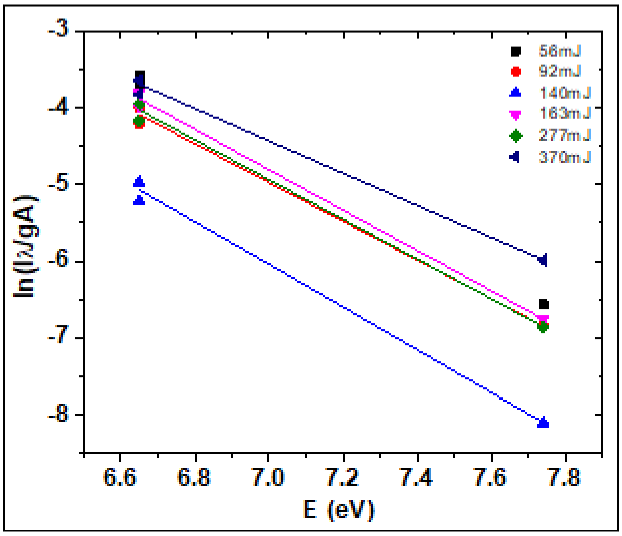


**Figure 4:** Sample of Boltzmann plot at different laser energies

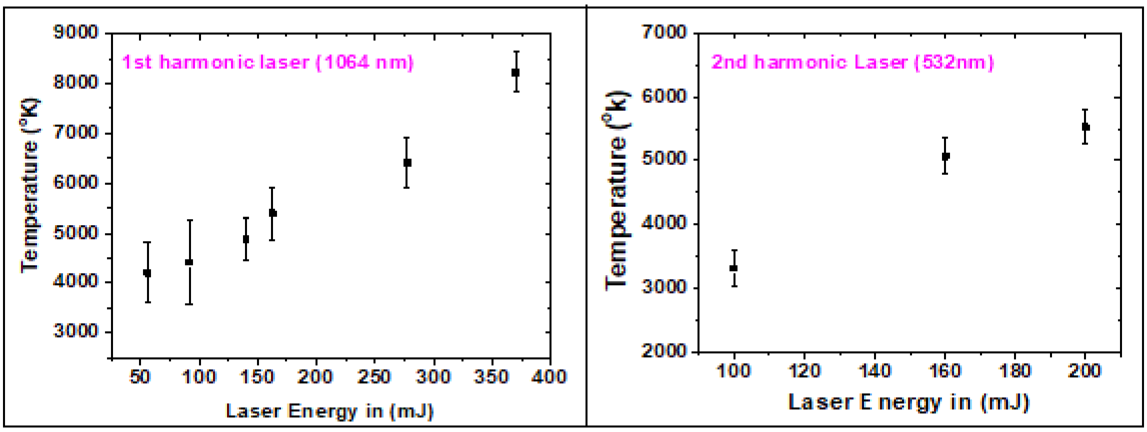


**Figure 5:** Temperature evaluations versus the laser energies for first and second harmonic laser.

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