Diagnosis of copper plasma by laser induced breakdown spectroscopy

N.M. Saadoon1, N.M. Hadi2, S. H. Sabeeh1

1Applied science department, University of technology, Iraq
2Laser optoelectronic center, Ministry of sciences and technology, Iraq

Abstract. In this paper influence of laser energy on the emission spectrum of laser copper-interaction and plasma parameter for plasma Copper by used a first harmonic generated wavelength of Nd:YAG excitation source. The metal plasma that had detection by HR4000 detection system (Ocean optics) was used to different excited plasma temperature via the Boltzmann plot diagram with measuring the electron density number by McWhirter CRITERION. Values of measuring Ne (1.77*1015, 2.01*1015 cm−3) at 1064nm.

Keywords: LIBS; Copper plasma; plasma parameter, electron number density, self-absorption

1. Introduction

Laser induced breakdown spectroscopy (LIBS) is a technique, which was first reported in early 1960s and then reviewed by several researchers. This sensitive technique is based on an optical detection for certain atomic and molecular species by monitoring their emission signals from the laser induced plasma. It provides a useful tool to determine the chemical and physical properties of a wide range of materials including metals, liquids, aerosols, plastics, minerals and biological tissues, etc [1-3]. It is a simple technique as compared with many other types of elemental analysis because of its straightforward experimental set-up. In this technique a pulsed laser is required to generate microplasma on the target surface. Elemental analysis is accomplished by study the emission from plasma plume. The characteristics of laser induced plasma depend upon several parameters characterizing the features of the target, properties of the ambient medium, laser wavelength and pulse duration etc. The first direct spectral analysis made by LIBS can be attributed to Runge et al [4-5]. In 1980s, this technique was increasingly applied as an analytical tool in research [6]. Copper is the most widely used metal for various applications of plasmonic materials due to its high electrical conductivity and optical properties.[7, 8] The emission characteristics and plasma parameters of Copper are of great importance not only in the laboratory plasma diagnostics but also for a number of technological applications, such as for nano-particles, cluster production, contacts of low-voltage switching devices, and as metal films.[9–10] Shuaibov et al. [11] investigated the time-averaged spectra (200–600 nm) of Ag produced by the 1064 nm laser irradiation in vacuum (3–5 torr) at distances of (1–7mm) from the target surface. Chuchmann and Shuaibov [12] reported the temporal dependence of the populations of excited atomic states of silver and copper at the (1–7mm) distance from the target surface. Roberts et al. [13] reported the femtosecond laser (130 fs) ablation of silver foil using the single and double pulse configurations. Rashid et al. [14] reported the comparative study on the effect of the inter-pulse delay and the ratio of the laser pulse energies on the silver emission line intensities, enhancement for collinear and orthogonal pre-ablation dual pulse configurations using the (1064nm) and (532 nm) of Nd:YAG laser. The objective of the present work was to characterize the laser induced Copper plasma in term of spectral line intensities and plasma parameter (Ne and Te) under different laser power energy using LIBS technique.
2. Experimental and method.

1. Nd:YAG (Quantel Brilliant) which use as laser source, with pulse duration of 6 ns, 10 Hz repeated rate and laser energy can deliver until 850 mJ per pulsed at 1064 wavelength.

2. The exaction source energy has changing used flash lamp Q-switch delay through laser controller and measuring in intensity joule meter (Nova-Quantel P/niz01507).

3. The laser pulsed to the point above the surface of copper by convex Lens of 10 cm focal length. The copper foil has moving on 3-D target holder and moved to remove the no uniform pitting of simple surface.

4. The distance between the focusing lens and the sample was kept less than the focal lengths of the lens to forbidding any discharging environments before the target surface. The spectrum was taking in average 10 point of malty pulsed under setup parameters.

5. The spectrum generated from plum have been collect in a fiber optics (High –OH, core diameter: 600,µm) own a collimating lens (45º field of view) put in the 45º angle in direction of the source pulsed. That fiber was joined with (ocean optic spectroscopy HR4000).

6. The emission sign was deal with it by tracing the black single detector through OOH software the data obtained by spectrometer were allowed saved on PC through the HR4000 software for diagnosis method.

3. Result of Emission Spectrum

Plasma produce by a interaction power high with pulsed expand normally on target surface according to the shocks wave [14]. We have produced copper plasma by used Nd: YAG laser with the fundamental wavelength 1.064nm with different energy of laser pulsed between (20-30mj) and 6ns pulsed duration has focusing on the copper foil surface. The spectrum of the plum produce around the Cu surface is recording at fixed distance (5mm) and different laser energy. In this experiment we used a reflected mirror as a focused with angle 45º. The plasma plum emission was recorded as a definition of laser intensity to the Cu surface metal. The ground state configuration of copper is 3d4P^2P_3/2 his yield many state Fig (1) show the spectrum emission cover the window in 300-400 nm, it noted that most strong line belong to the natural copper the line at 324.75 and 327.39nm are the strong line recognized 4S3d4S^2S_{1/2} to 3d4P^2P_{1/2}, consequently.
The Figure (2), show the strong line of emission area in 400-600nm. natural copper emissions dominate line belong to the cuI. The strong line at 521.28nm as $3d^43d^2D_{5/2}$ to $4p^2P_{3/2}$ and 515.32nm identified as $3d^43d^2D_{3/2}$ to $4p^2P_{1/2}$.

Figure 1: Spectrum of Cu foil from (300-900nm) generated at 1064nm and 20mj laser energy
Figure 2: Spectrum of Cu of the region (400-600 nm) generated by 1064 nm laser at 20 mj laser energy

Figure 3: Spectrum of Cu foil from (300-900 nm) generated at 1064 nm and 30 mj laser energy

Figure 4: Plum emission of target cover the window (400-600 nm) generated by 1064 nm laser at 30 mj laser energy
4. Result of Determine the plasma parameter

4.1. Plasma temperature

The plot Boltzmann equation with the Thermodynamic Local Equilibrium (LTE) assumption was used for the calculation the Te and Ne, the Boltzmann method use to the determine of that figurative is give in [13,14]:

\[
\ln kkk \lambda gg kkkk kk = \frac{1}{uU} \sum_{TT} \langle TT \rangle - kkkk EE kkkk kk \ldots \ldots \ldots 1
\]

the m, n, I_mn, g_m, and A_mn are an upper state, lower state , the line intensity, level degeneracy, with the transition probability, consequently n(t), u(t), E_m, K, with T are the number of plum, the partition function, the upper energy level, the Boltzmann constant, and the electrons temperature, consequently. The parameters of selection spectrum line in this work had been used from NIST database [15, 16] they listed in table (1). the electrons temperatures can be calculated by using the slope of line which have relation to the selection energy lines driven above the plum species. The spectroscopic parameters like g_m, A_mn, and E_m can be retrieved from the available database.

Typically Boltzmann plot at 1064 nm wavelength and 20mj laser energy is dhow in fig 3 in, a linear fitting with the data are summarized. from the diagram Te is 6113K. The profile of spectral line from LIBS technique has various broadening effects like Doppler broadening, Resonance broadening, and Stark broadening [16]. The Stark broadening was the observed broadening in this methods .

**Table 1.** Spectroscopy parameter of the singly / second ionized and Cu line data take from reference [15].

| Atom/ ion | \( \lambda \) (nm) | \( g_j \) | \( Aji^{(+)} \) | \( E_j \) (ev) | Transition |
|-----------|-----------------|------------|-----------------|-----------------|------------|
| Cu I      | 510.55          | 4          | 2.0*10^6        | 3.82            | 4S^1/2-P4P^2P |
| Cu I      | 515.32          | 4          | 6.6*10^7        | 6.191           | 4P^3-P4d^4D |
| Cu I      | 521.82          | 6          | 7.5*10^7        | 6.192           | 4P^3-P4d^4D |
| CuI       | 578.21          | 4          | 1.65*10^6       | 3.76            | 4S^2-P4P^2P |
| Cu1       | 324.31          | 4          | 1.37*10^8       | 33.78           | 3d4p2p3/2 |

Where \( E_u \)=Upper level energy, \( A \) = Transition probability
The plasma temperature was determined for varying energy laser by Nd:YAG laser with 1064 nm as wavelength. It is noticed with increasing the energy laser the intensity and width of spectrum line increased. The electron temperature increased between 6113 to 7776.4 k also the electron number density was calculated for different energy laser. As shown in result note that END varying between $1.77 \times 10^{15}$ to $2.01 \times 10^{15}$ cm$^{3}$. It was observed increasing in electron temperatures and END with increasing the $E_i$, it is came from absorption, reflection of laser photon by plum. With increase the excitation flounce, more species, ion and electron are generated the laser pulsed interacts with species, resulting in further heat and ionisation and respectively increasing consumption of incoming laser pulsed [17,14].

4.2. Local thermodynamic equilibrium

Emission spectroscopy used to measurement of the Te and Ne necessitates optically thin spectrum line. The self-absorption depend on the oscillator strength, level energy degenerate, broader enviormente and also on the plum parameter. The target plum is dominate to by optical thin in case of the self – absorption a strongest lines appears to a dipping at the fixed frequently [18]. Here we didn’t find any penetration at the central frequency of plume line.

The condition that the atomic state should be populated and depopulated predominantly by
electron collision, rather than by radiation required an electron density is given by McWhirter equation, which is the condition for reached to smallest $N_e$ to ensure the warrant of the LTE [19,20].

$$N_e > 1.6 \times 10^3 \left( \frac{12}{12} \right)^{1/2} \left( \frac{T}{\Delta E} \right)$$

When $T$ (K) as plum temperature and $\Delta E$ (eV) it energy different between levels must been with local thermodynamic equilibrium. In our experiment the electron number density range satisfy the local thermodynamic equilibrium. When the laser focused on the target the ablated Cu surface take a placed with according to the density gradient plasma fasting expansion[11].

5. Conclusion

Nd:YAG lasers in the 1064nm wavelength to diagnosis the copper plasma. ET and END was measured on the axis direction of plum. It observed was noted that the plasma temperature and END increased with increasing laser energy

6. References

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