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Plasma Characteristics of Ag and Cu Metals produced by Pulse Laser Ablation of Nd:YAG Laser in Air

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Abstract

In this work, the spectra for plasma glow produced by pulse Nd:YAG laser (λ=1064nm) on Ag and Cu metals in air were analyzed by studying the atomic lines compared with silver and copper strong standard lines. The effect of laser energies of the range 300 to 500 mJ on spectral lines, produced by laser ablation, was investigated using optical spectroscopy. The electron temperature was found to be increased from 1.180 to 1.374 eV, while the electron density increased from 2.50×10^{17} *to* 3.97×10^{17} cm^{-3} *with increasing laser energy from 300 to 500 mJ for Ag target. Also for Cu target, the electron temperature was found to be increased from 0.853 to 1.121 eV, while the electron density increased from* 0.25×10^{17} *to* 0.26×10^{17} cm^{-3} *with increasing laser energy from 300 to 500 mJ.*

Keywords: Pulse laser, spectroscopy, Boltzmann plot, plasma characteristics.

Introduction

Plasma is a quasi-neutral gas of charged and neutral particles which exhibited collective behavior. Hence, it consists of positive (or negative) ions and electrons, as well as neutral species. Plasma is depicted as an electrically unbiased medium of limitless negative and positive particles, that implies the aggregate charge of a plasma is around zero [1]. Plasma diagnostics are utilized to get data about the idea of plasma, for example, the substance pieces and types of the plasma, thickness of the plasma, electron temperature [2]. Beat laser-incited plasmas of metals and combinations have more enthusiasm as they utilized as a part of a few applications, for example, blend of Nano-particles [3] examination on essential substance [4] spectroscopic investigations [5]. Light radiated in a wide range for spectroscopic examination from the plasma created by high-control laser beats was distinguished and the subsequent range conveyance. A range frequently comprises of various trademark unearthly lines of a specific particle or particle [6].The electron temperature of plasma was figured utilizing Boltzmann relation [7]:

$$Ln\left(\frac{I_{mn}\lambda_{mn}}{g_m A_{mn}}\right) = \left(\frac{E_m}{KT_e}\right) + \left(\frac{N(T)}{U(T)}\right) \quad (1)$$

Where λ_{mn}, I_{mn}, g_m, and A_{mn} are the wavelength, intensity, statistical weight, and transition probability between the transition states of upper level (m) and lower level (n), separately.

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The stark broadening can be induced by both electrons and ions. However, electrons are mainly responsible for the major part of stark broadening induction, and thus are because of the high relative velocities. The width of stark broadening spectral line could depend on the density of electron (n_e). If the electrons are thermally equilibrium, the Boltzmann distribution of density will be adopted [8]. The density of electron in cm^{-3} can be determined from the line width as follows:

$$n_e = \left(\frac{\Delta\lambda_{FWHM}}{2.W}\right).10^{16} \quad (2)$$

where$\Delta\lambda_{FWHM}$ is the fundamental width at half maximum of the measured line. W is theparameter of the electron impact (the value of the stark broadening). The condition above isgenerally used for counts as far as plasma produced from solid targets.The Coulomb interaction extend in plasma is decreased because of the screening impact. The screening scale length, called the Debye length (λ_D) was computed as takes after[9]:

$$\lambda_D = \left(\frac{kBT_e}{4\pi e^2 n_{oe}}\right)^{1/2} \approx 7430\left(\frac{T_e(eV)}{n_{oe}(cm^{-3})}\right)^{1/2} \quad (3)$$

An important criterion for an ionized gas to be a plasma is that it should be dense enough so that $L >> \lambda_D$. While the plasma frequency can be calculated as follows [10]:

$$\omega_p = \sqrt{\frac{N_e q_e^2}{\epsilon_o m_e}} \quad (4)$$

plasma oscillations can only develop if the mean free time τ_n between collisions is long enough compared to the oscillation period. This condition is a criterion for an ionized gas to be considered plasma. The concept of Debye shielding developed if the number of particles in a Debye sphere, $N_D >> 1$. [10]

$$N_D = n_e\left[\frac{4\pi\lambda_D^3}{3}\right] = \frac{1.38\times10^6 T_e^{3/2}}{n_e^{1/2}} \quad (5)$$

Where: T_e in K.

In this work we aim to study the effect of laser energy on the emission spectrum intensity behavior and plasma parameters for metals such as Ag and Cu.

Experimental part

Ag and Cu metals with (diameter= 1.5 mm, thickness = 0.5 mm, 99.99% in purity). The samples were bombarded by Nd:YAG pulse laser (Hua Fei Tong Da Technology –Diamond -288 Pattern EPLS) (6 Hz frequency) with wavelength (1064 nm) and different energies (300, 400, and 500 mJ) in air The emission of light from the surface of samples was collected and transferred to spectroscope (THORLABS CCS200, wavelength range 200−1000nm, Spectral Resolution <0.5nm FWHM @ 633nm) with resolution4 px/nm was used to diagnose plasma jet parameters such as electron temperature T_e and electron density n_e (consists of grating to analyze the light and CCD array to convert the incident light electrical information) by optical fiber, which was set at angle of about 45 degree off the laser beam axis to avoid splashing, and transfer by optical fiber to the entrance slit of the spectrometer.

Results and discussion

Figures (I) and (II) displays the emission spectra for laser induced on silver and copper surface respectively with different laser energies (300, 400, and 500) mJ in air using 1064 nm laser. These figures display that the dominant identified peaks corresponding to silver ionic lines (AgI) and some of atomic lines for silver (AgII) and copper ionic lines (Cu I) and some of atomic lines for copper (Cu II) respectively. The emission spectrum intensities increase with increasing laser energy.

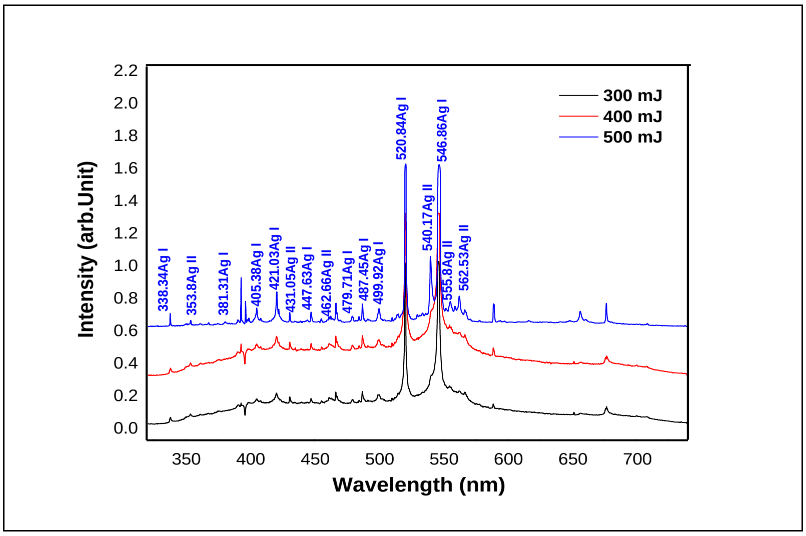

Figure I

The emission spectrum of laser induced silver target plasma in air with different laser energies

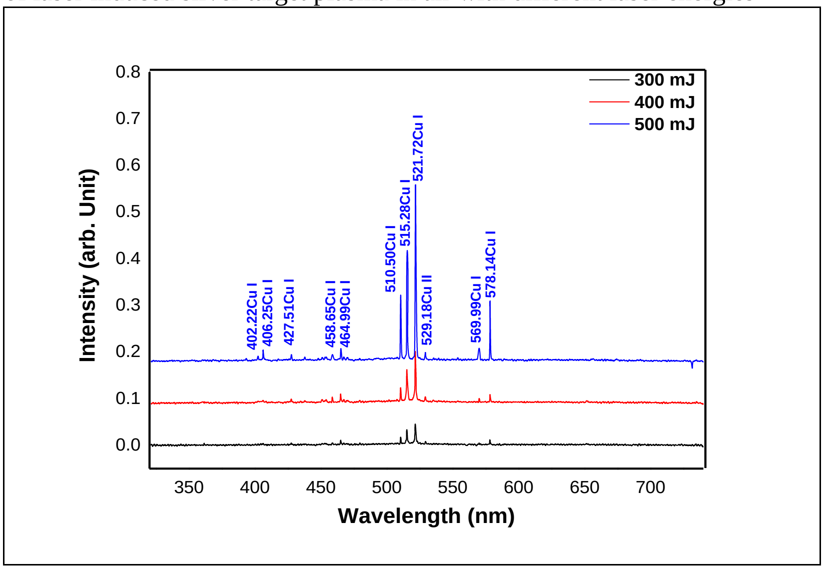

Figure II

The emission spectrum of laser induced copper target plasma in air with different laser energies

Ag and Cu target plasma in air using 1064 nm laser

The value of T_e is obtained from the Boltzmann plot method, as shown in Figures(III) and (IV) from the analysis of the six recorded Ag I lines for plasma induced on silver and Cu I lines for plasma induced on copper respectively, in air using 1064 nm laser, at different laser energies 300, 400, and 500 mJ. The values of T_e were estimated from the inverse of the slope of a linear best fit for the result values. The fitting equations and the R^2 were shown in the figures below for all fitting lines. R^2 is a statistical coefficient indicating the goodness of the linear fit which takes a value between (0, 1). The better one has R^2 value closer to 1 [11].

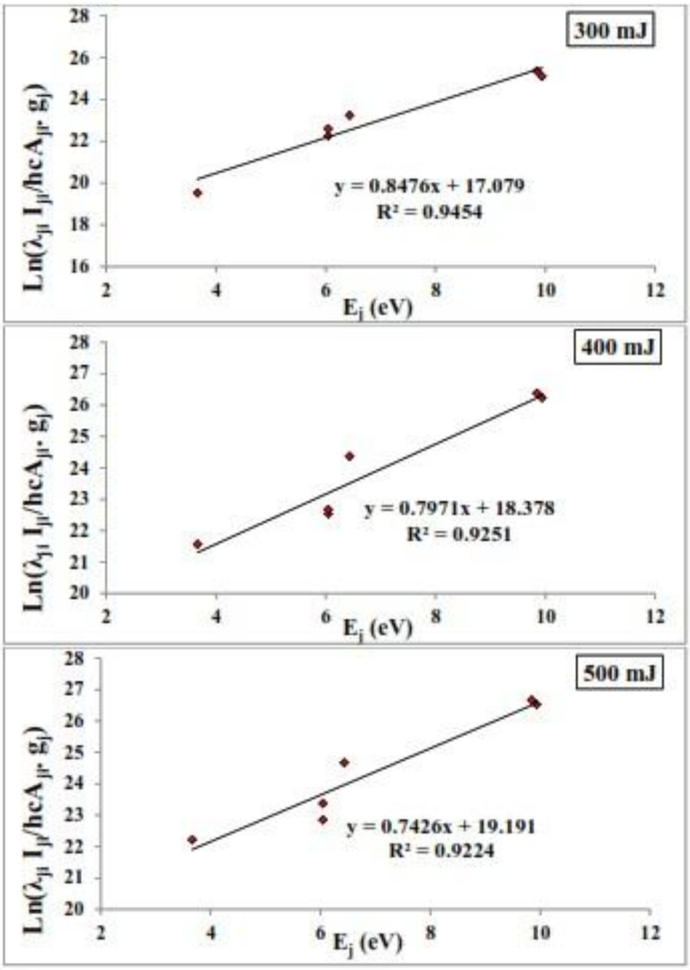

Figure III

Boltzmann plot method from the analysis of six Ag I lines for silver in air using 1064 nm laser, with different laser energies. The best fit straight line, its equation and average relative standard deviation values R^2 are shown

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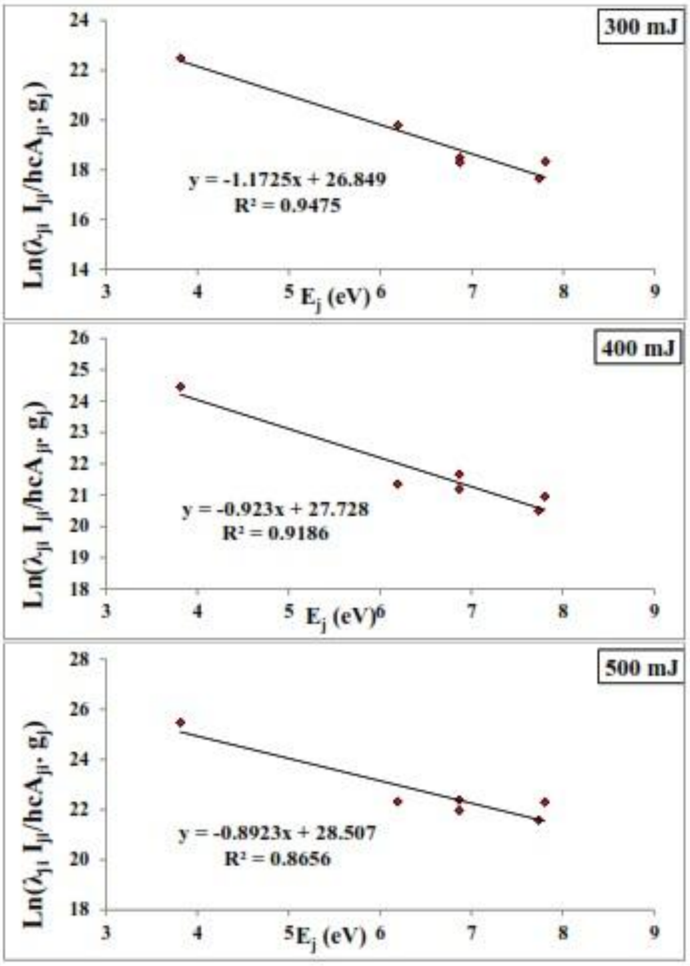

Figure IV

Boltzmann plot method from the analysis of six Cu I lines for copper in air using 1064 nm laser, with different laser energies. The best fit straight line, its equation and average relative standard deviation values R^2 are shown.

Table (I) and (II): shows experimental calculated values of Electron temperature (T_e), electron density (n_e), Debye length (λ_D), plasma frequency (f_p) and Debye number (N_D) for both Ag and Cu metals respectively at different laser energies. All calculated plasma parameters were satisfied the plasma conditions. These tables indicate that the electron temperature increase with increasing laser energy from 300 to 500 mJ as a result of increasing the energy gained to electrons from laser. The increment in mean electron energy cause to increase the probability of ionization collision hence increasing the electron density. Plasma frequency mainly depend on $n_e^{1/2}$, thus it have the same behavior. While λ_D depend on $(T_e/n_e)^{1/2}$ as a result on clearly increasing n_e while slightly increasing in T_e. N_D depends on ($T_e^{3/2}$ / $n_e^{1/2}$) thus it has the same behavior with Debye length (λ_D).

Table 1

Plasma parameters calculated from spectroscopy lines for silver in air using 1064 nm laser, with different laser energies

Laser energy (mJ)	**T_e (eV)**	**n_e*10^{17} (cm^{-3})**	**f_p (Hz) *10^{12}**	**λ_D *10^{-5}(cm)**	**N_D**
300	1.180	2.50	4.493	1.613	4400
400	1.254	2.63	4.605	1.616	4651
500	1.347	3.97	5.658	1.363	4210

Table 2

Plasma parameters calculated from spectroscopy lines for copper in air using 1064 nm laser, with different laser energies.

Laser energy (mJ)	T_e (eV)	$n_e * 10^{17}$ (cm^{-3})	f_p (Hz) $*10^{12}$	λ_D $*10^{-5}$(cm)	N_D
300	0.853	0.25	1.432	4.304	8489
400	1.083	0.26	1.435	4.819	11975
500	1.121	0.26	1.441	4.882	12549

Figures (V) and (VI) show the variation of T_e and n_e with laser energy for Ag and Cu respectively. This figures shows that the T_e and n_e increase with increasing laser energy when varies from 300 to 500 mJ for both silver and copper respectively.

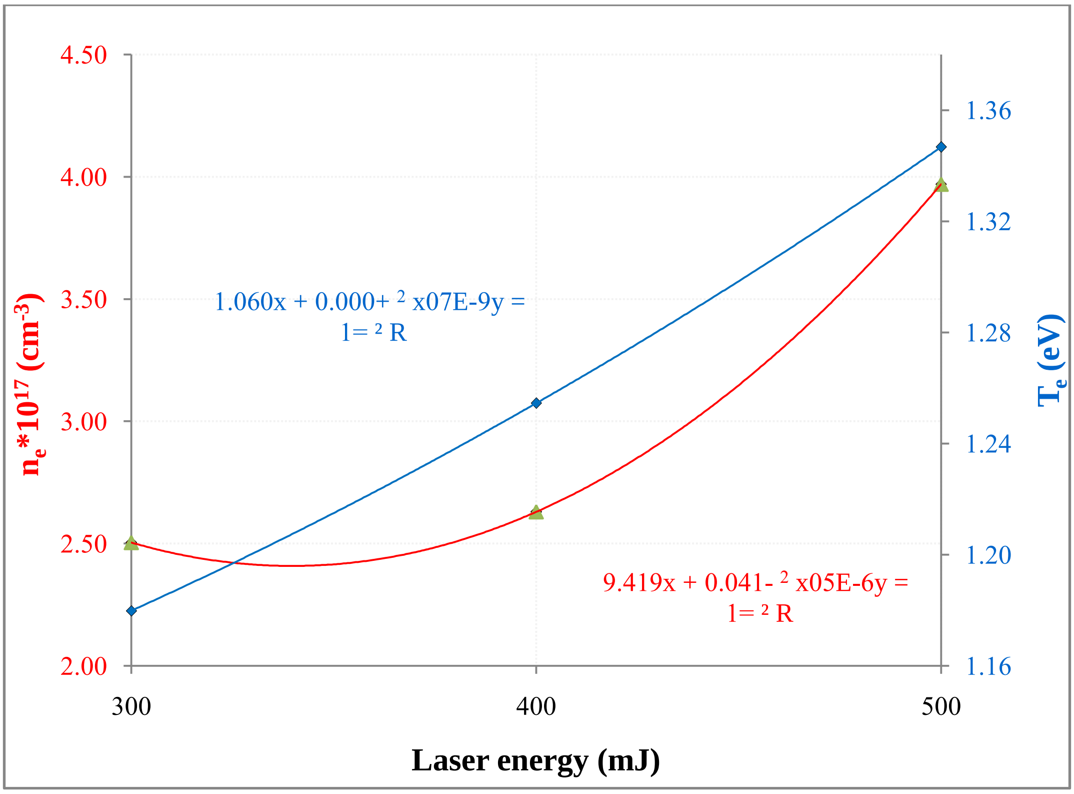

Figure V

The variation of T_e and n_e with laser energy for plasma induced on silver in air using 1064 nm laser

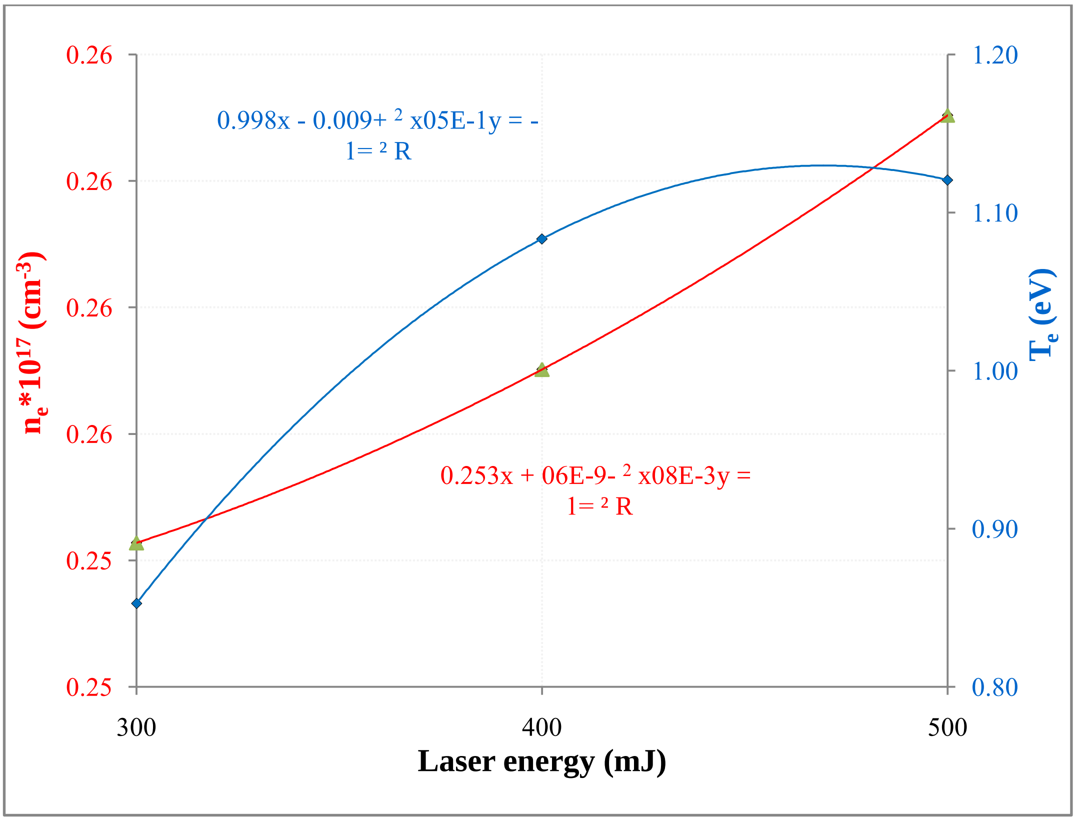

Figure VI
The variation of T_e and n_e with laser energy for plasma induced on copper in air using 1064 nm laser

Conclusions

Study the effect of laser energies on spectra for plasma glow produced by pulse Nd:YAG laser for wavelength (λ=1064nm) on Ag and Cu metals show the electron temperature increase exponentially from 1.180 to 1.347 eV, and the electron density increase from 2.50×10^{17} to 3.97×10^{17} cm^{-3} with, increasing laser energy from 300 to 500 mJ for Ag target. While for Cu target the electron temperature increase exponentially from 0.853 to 1.121eV, and the electron density increase from 0.25×10^{17} to 0.26×10^{17} with increasing laser energy from 300 to 500 mJ. All plasma parameters satisfy plasma conditions. The electron temperature and electron density for Ag target are greater than from Cu target, while the Debye number (N_D) for Ag target is smaller than the Cu target. The result for Cu target is considerable ideal state.

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