

Spectroscopic studying of plasma parameters for SnO₂ doped ZnO prepared by pulse Nd:YAG laser deposition

Muna A. Essa and Kadhim A. Aadim

Department of Physics, College of Sciences, University of Baghdad

E-mail: kadhim_adem@scbaghdad.edu.iq

Abstract

In this work, plasma parameters such as (electron temperature (Te), electron density (ne), plasma frequency and Debye length (λ_D)) were studied by using spectral analysis techniques. The spectrum of the plasma was recorded with different energy values, SnO₂ and ZnO anesthetized at a different ratio (X = 0.2, 0.4 and 0.6). Spectral study of this mixing in the air. The results showed electron density and electron temperature increase in zinc oxide: tin oxide alloy targets. It was located that the intensity of the lines increases in different laser peak powers when the laser peak power increases and then decreases when the force continues to increase.

Key words

Laser-Induced
Breakdown
Spectroscopy (LIBS),
Optical Emission
Spectroscopy (OES),
Zinc oxide (ZnO), Tin
dioxide (SnO₂).

Article info.

Received: May. 2019

Accepted: Jun. 2019

Published: Sep. 2019

دراسة طيفية لمعاملات البلازما لأوكسيد الزنك المشوبة بأوكسيد القصدير المحضرة بواسطة

الترسيب بالليزر النبضي Nd:YAG

منى احمد عيسى و كاظم عبد الواحد عادم

قسم الفيزياء، كلية العلوم، جامعة بغداد

الخلاصة

في هذا العمل ، تمت دراسة معاملات البلازما مثل (درجة حرارة الإلكترون (Te)، كثافة الإلكترون (ne)، تردد البلازما وقطر كرة ديبي (λ_D)) باستخدام تقنيات التحليل للطيف الناتج من البلازما باستخدام مزيج من اوكسيد الزنك المشوب بأوكسيد القصدير وبنسب مختلفة (X=0.2, 0.4, 0.6). تمت دراسة الطيف الناتج في الهواء. لوحظ من النتائج ان درجة حرارة الالكترون وكثافة الالكترون تزداد في المزيج بين اوكسيد الزنك وأوكسيد القصدير، لوحظ ان خطوط الطيف تزداد بزيادة طاقة الليزر ثم عندما تستمر الطاقة بالازدياد.

Introduction

LIBS is an atomic emission spectrum analysis technique. It is a high pulsed laser power density and is translated into a small target size that leads to the breakdown of analyzes in ions and free electrons, leading to the determination of plasma by both continuum and atomic emission [1]. The laser-generated plasma parameters progress rapidly and are strongly linked to irradiation conditions such as the duration of the pulse laser, the

intensity of the laser incident on the surface of the target, the wave length of the laser and the surrounding pressure, which are temporary by nature [2,3]. Optical spectroscopy (OES) is used for years to determine plasma parameters such as electron temperature, Debye length, electron density and plasma frequency [4]. Plasma diagnostics can be performed by calculating the density and temperature of the electron in the plasma. Determination of the power of

the distribution functions that determine the temperature of the plasma according to the temperature, and determine the thermal equilibrium state of the plasma according to electron density [5]. The electron temperature of plasma was calculated using Boltzmann plot method [6]:

$$\ln \left[\frac{\lambda_{ji} I_{ji}}{hc A_{ji} g_j} \right] = -\frac{1}{KT} (E_j) + \ln \left[\frac{N}{U(T)} \right] \quad (1)$$

where I_{ji} is relative emission line density between energy levels I and j. g_j is the degeneracy or Statistical weight of the upper level emitted from the transition phase.

λ_{ji} wavelength (in nano metres).

E_j is the excitation energy (in eV) for level i.

A_{ji} is The possibility of automatic transmission of radiation from the level i to the lower level j .

N Densities of the population of the state.

k is the Boltzmann constant.

The measurement of the electron density through Stark broadening effect requires a free line of self-absorption [7]

$$n_e = \left[\frac{\Delta\lambda}{2\omega_s} \right] N_r \quad (2)$$

ω_s is the theoretic line full width Stark broadening parameter, Calculates the same density as the reference electron, $N_r \approx 10^{17} \text{ cm}^{-3}$.

Debye's length can be calculated by the formula [8]:

$$\lambda_D = \left[\frac{\epsilon_0 K_B T_e}{n_e e^2} \right]^{1/2} \cong 7.43 \times 10^2 \left(\frac{T_e(\text{eV})}{n_e} \right)^{1/2} \quad (3)$$

where K_B is Boltzmann's constant

n_e is the electron density.

T_e is the plasma temperature.

e is electron charge.

Plasma frequency can be given as [8]:

$$\omega_{pe} = (n_e e^2 / m_e \epsilon_0)^{1/2} \quad (4)$$

where m_e is the electron mass.

ϵ_0 is the electric constant, e is electron charge and n_e is the electron number density

Experiment part

The spectra of optical emission of zinc oxide-tin oxide plasma are registered using the experimental setup of laser-induced breakdown spectroscopy (LIBS) shown in Fig.1.

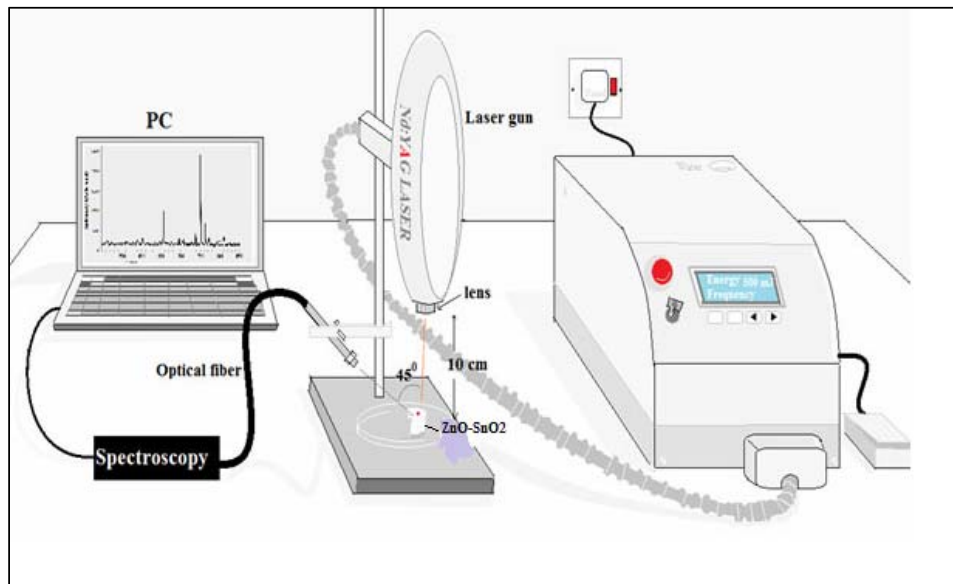


Fig.1: Configure the traditional LIBS system used in this work.

It consists of (pulsed Nd: YAG laser of 1064 nm wavelength, 6 Hz pulse repetition frequency, 9 ns duration and peak power differ from 6 mW to 36 mW). The laser beam focuses on the surface of the irradiated sample located in the focal length of a Converging lens ($f = 10$ cm). The optical fiber image detector is set at 45° with the beam direction at a distance of 5 cm from the plasma sample. Spectrum analyzer in the spectral range of (300 nm–800 nm).

Results and discussions

The optical emission spectrum of laser-produced zinc oxide-tin oxide plasma with ($x=0.2, 0.4$ and 0.6) in air in the range of 300 nm to 800 nm is shown in Fig.2 (a, b and c) clearly this Figure explain the intensity of the spectral lines increases with the increase of laser peak power. This can be explained as follows: Increased laser energy increases the overall ablation rate of the target, which means increasing the excited atoms and thus increasing with higher spectral intensity.

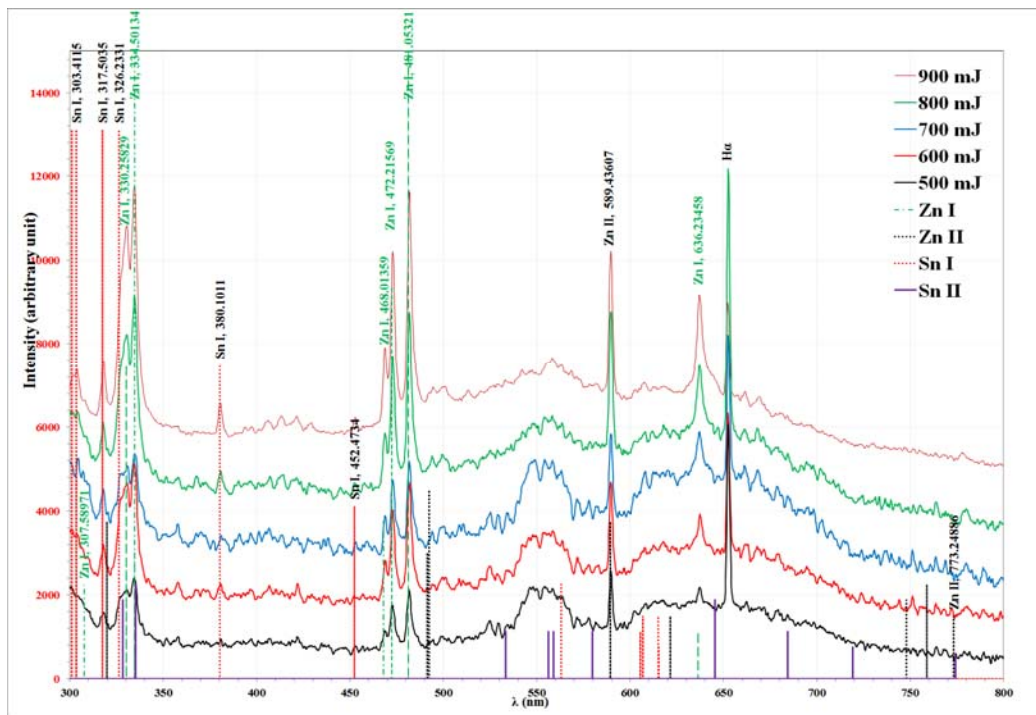


Fig.2 (a): Spectroscopic patterns for plasma emission from $X=0.2$ SnO_2 : ZnO target at different laser energy.

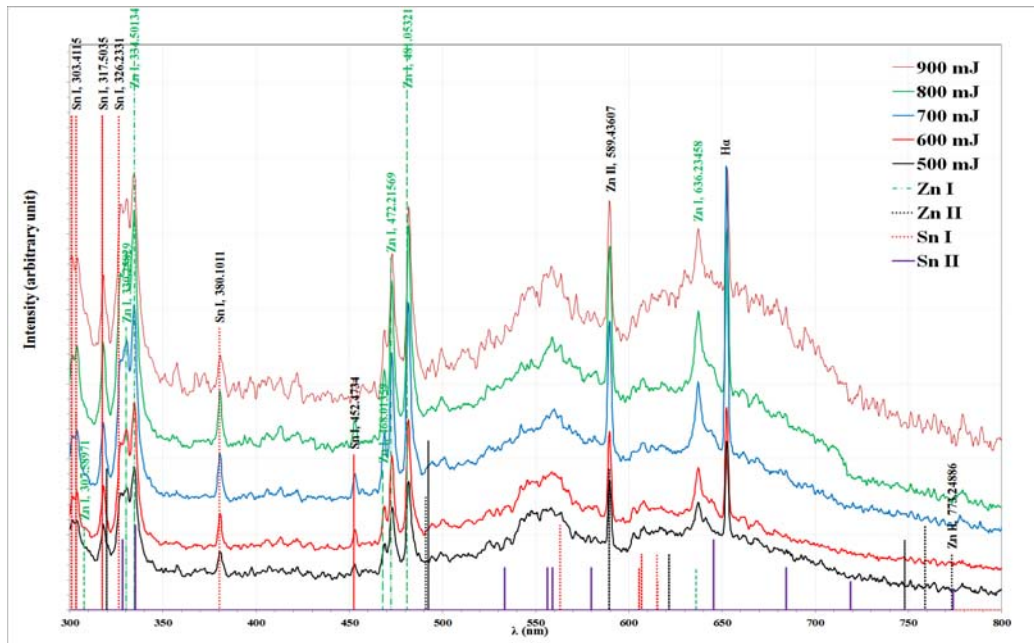


Fig.2 (b): Spectroscopic patterns for plasma emission from $X= 0.4 \text{ SnO}_2: \text{ZnO}$ target at different laser energy.

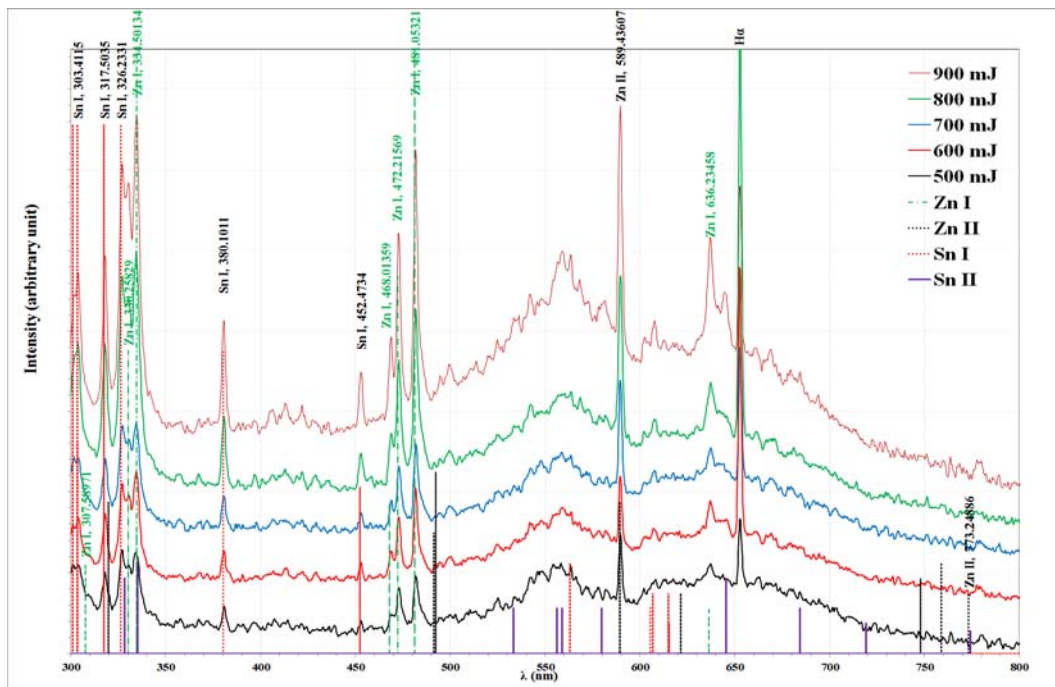


Fig.2 (c): Spectroscopic patterns for plasma emission from $X= 0.6 \text{ SnO}_2: \text{ZnO}$ target at different laser energy.

The electron temperatures (T_e) were limited of the best linear fit slope in the Boltzmann plot (1). Boltzmann's plot requires a war of the same atomic type and the ionization phase itself (choose four peaks for SnI specie at

304.101 nm, 317.772 nm, 327.000 nm and 380.656 nm) for $\text{ZnO}:\text{SnO}_2$ at $x=0.2$ as shown in Fig.3, also (choose four peaks for ZnI specie at 307.59 nm, 330.294 nm, 334.501 nm and 636.235 nm) for $\text{ZnO}:\text{SnO}_2$ at $x=0.4$ as

it is shown in Fig.4. for ZnO:SnO₂ at x=0.6 (choose four peaks for SnI specie at (304.101 nm, 317.772 nm, 327.000 nm and 380.656 nm) as shown in Fig.5, and needed higher levels, statistical weights and transfer potentials used in the experimental plots were obtained for each component from the National Institute

of Standard Technology database (NIST) [9], where the electron temperature equal to Inverted slope of fitting line (the slope of fitted line equals $-1/k_B T$). for all fitting lines. R2 is a statistical coefficient indicating the quality of linearity that takes a value between (0, 1). The best one have R2 value nearer to 1.

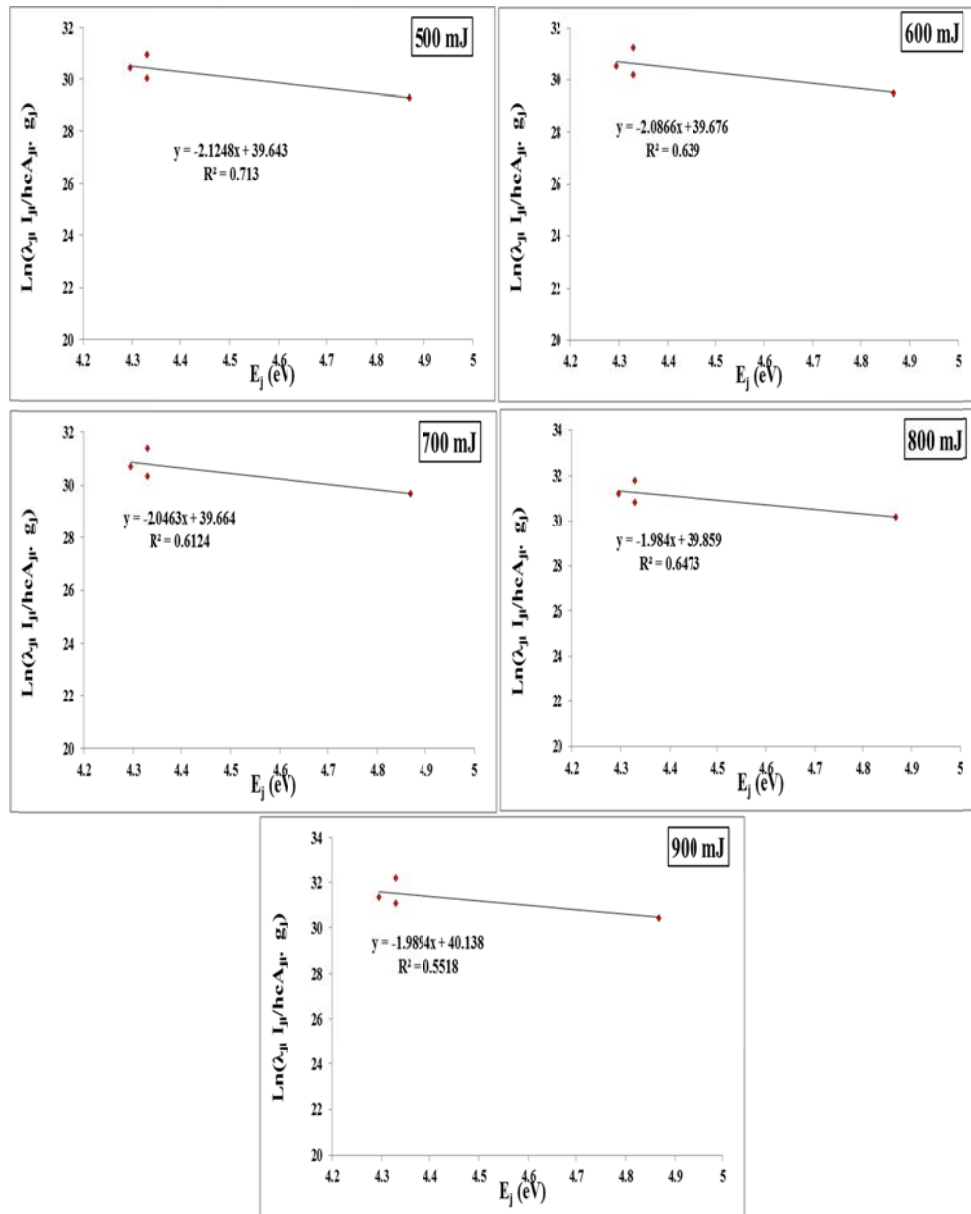


Fig. 3: Boltzmann plot for plasma emission from X= 0.2 SnO₂: ZnO target at different laser energy.

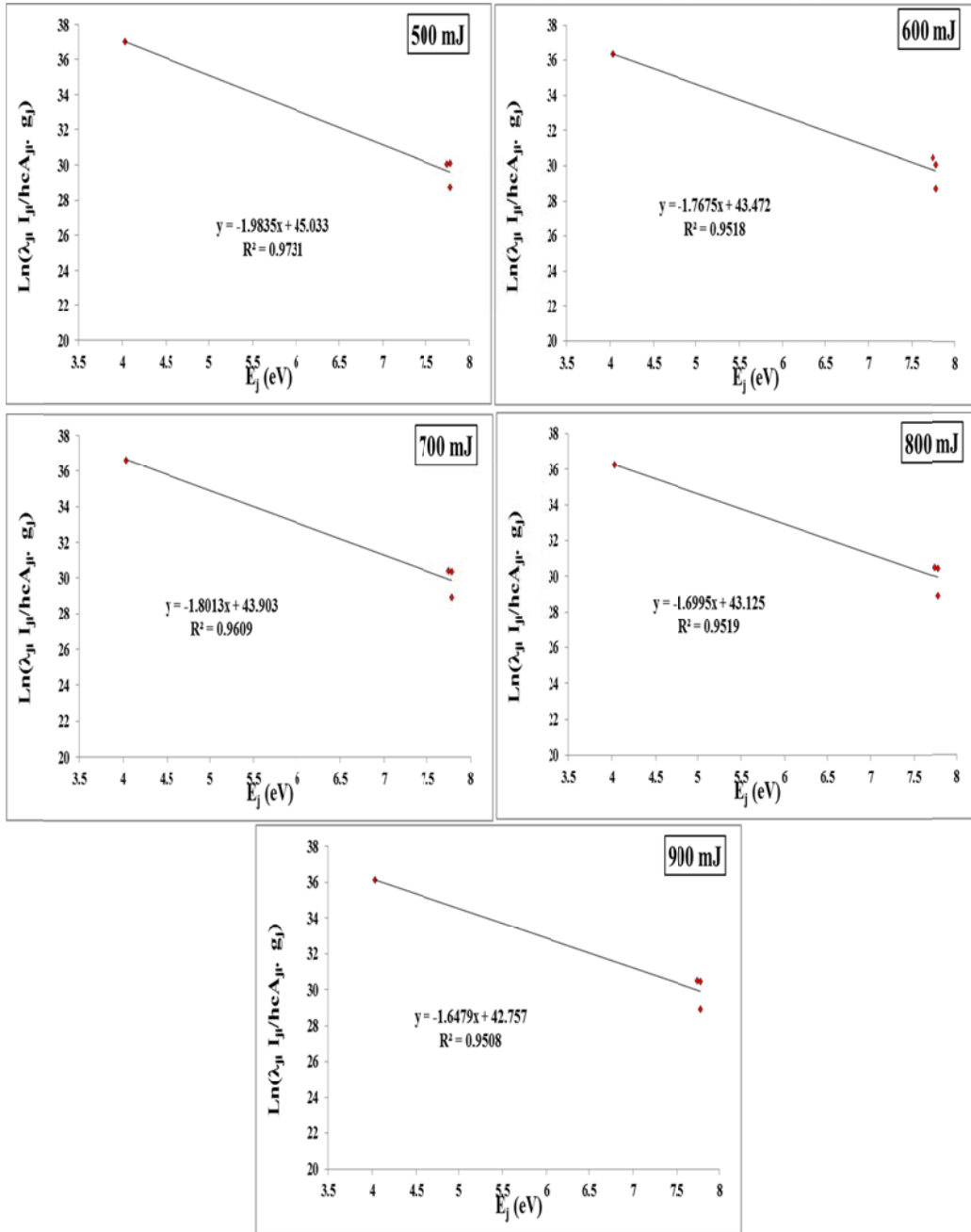


Fig.4: Boltzmann plot for plasma emission from X= 0.4 SnO₂: ZnO target at different laser energy.

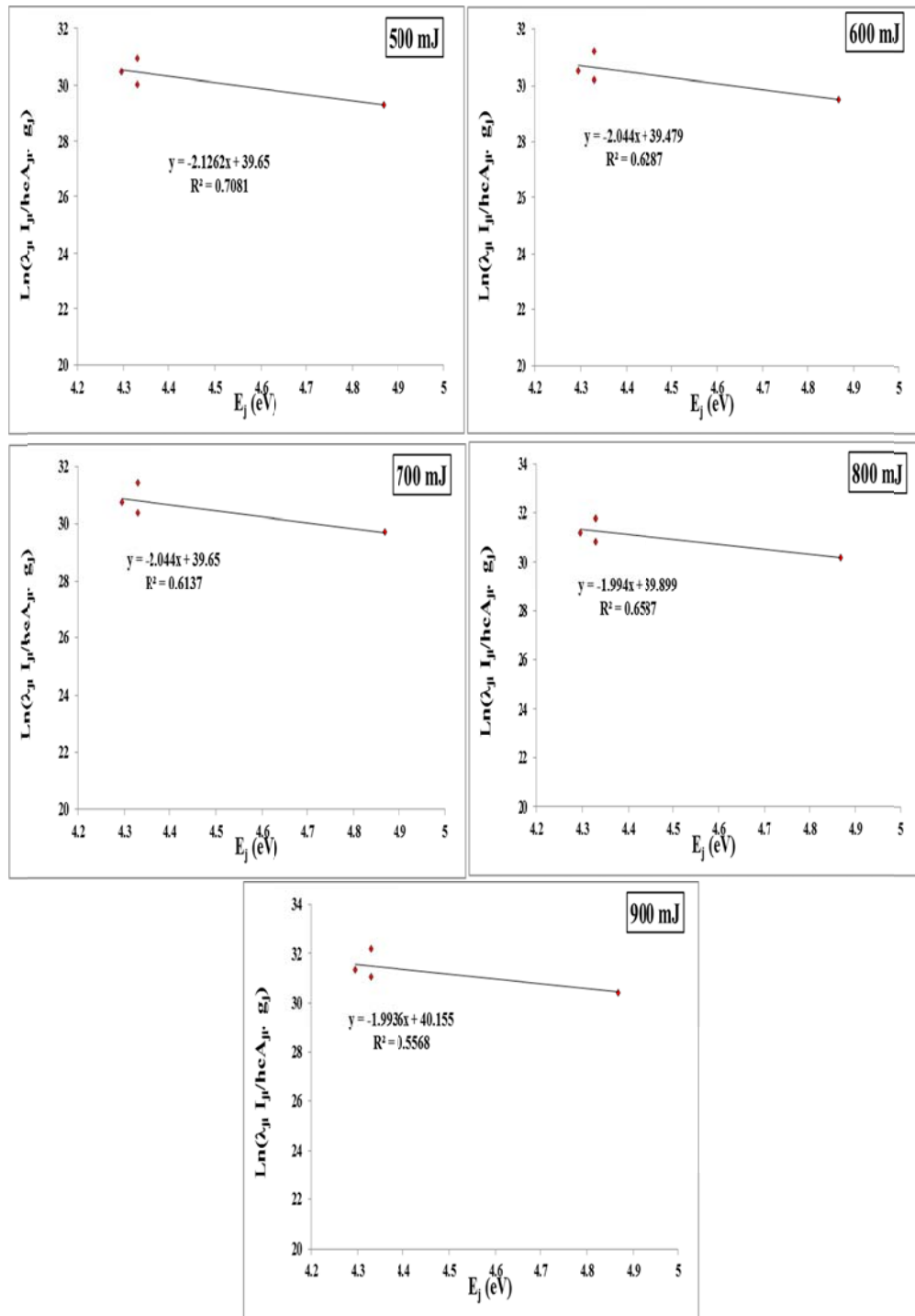


Fig.5: Boltzmann plot for plasma emission from X= 0.6 SnO₂: ZnO target at different laser energy.

The densities of electron were calculated by using stark broadening as shown in Fig.6 from Eq.(2) Stark broadening of of the plasma spectral

lines results from collisions with the charged species, which widens the line and a shift in the peak wavelength.

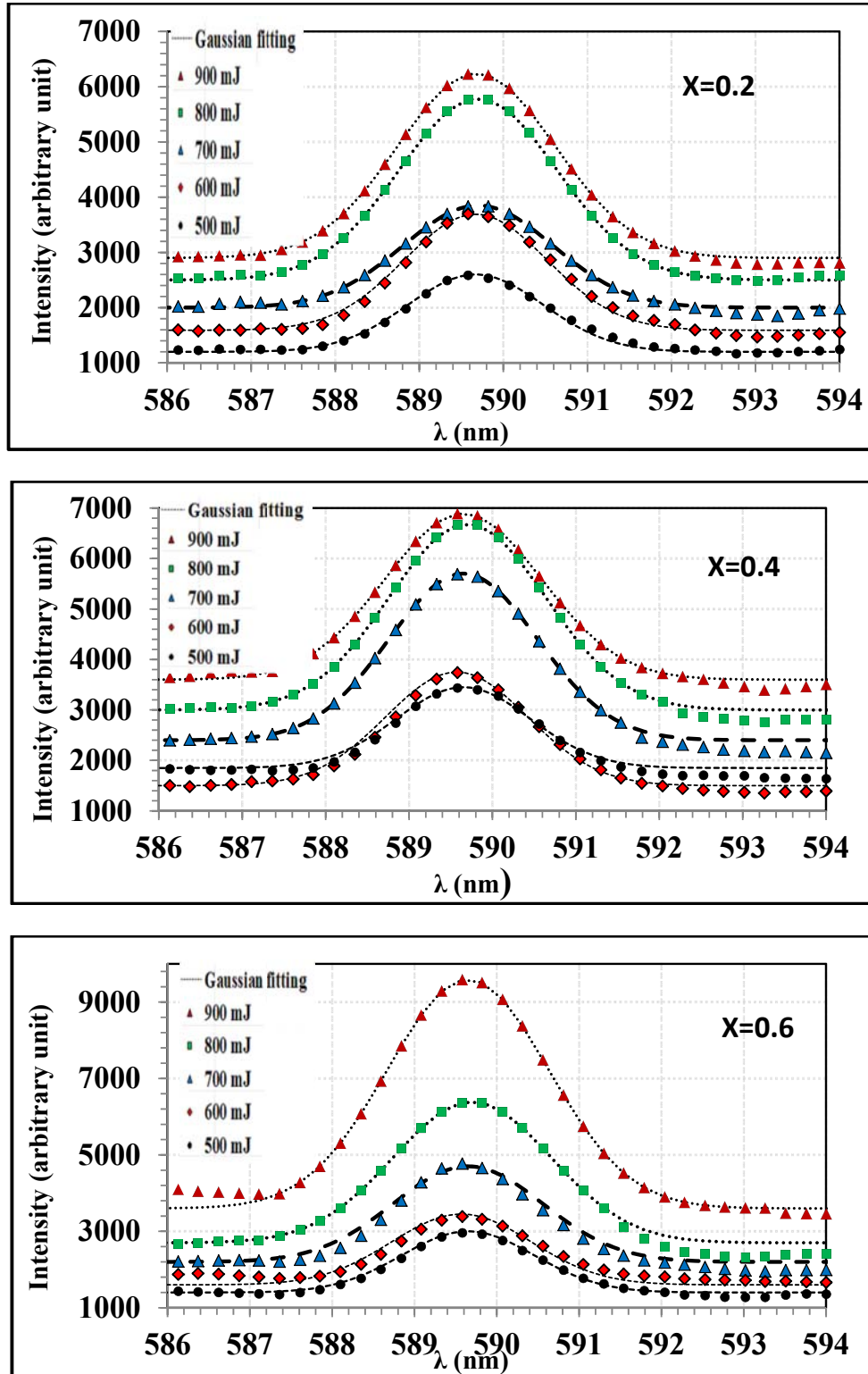


Fig.6: Stark broadening for 498.4 nm ZnII line for mixed samples ($X=0.2$, $X=0.4$ and $X=0.6$) at different laser energy.

The calculated values of the electron temperatures (T_e) by using Boltzmann plot Eq.(1) show that

electron density and the electron temperature are increased with increase the laser pulse energy as it is shown in Fig.7 (a, b and c) At the

highest laser power, the energy is almost stable, because the plasma becomes transparent to the laser beam that protects the target. Plasma

shielding occurs when the plasma itself reduces the transmission of the laser peak power along the beam path.

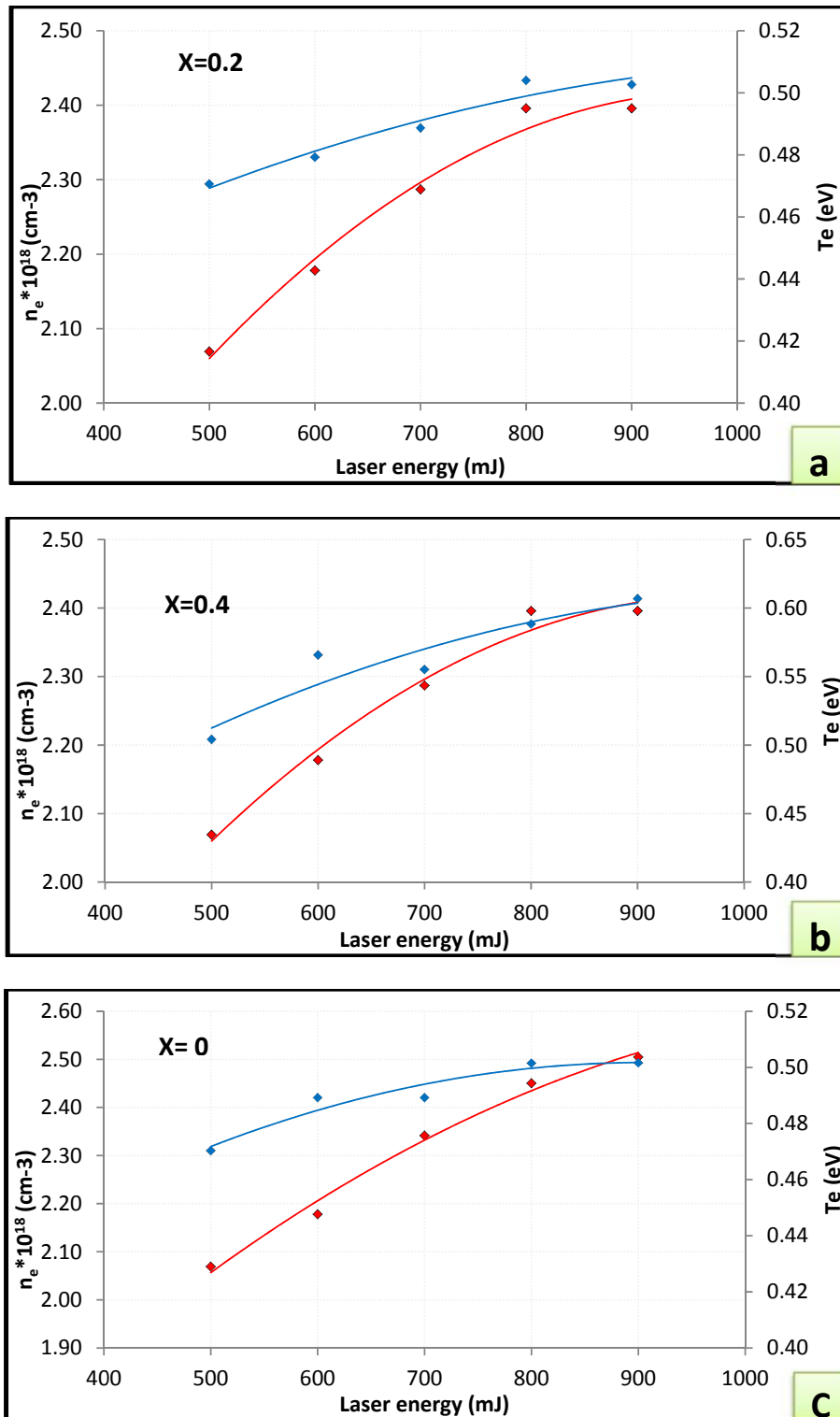


Fig.7 (a, b, c): Variation of n_e and T_e of plasma emitted from SnO₂: ZnO target at different ratio using laser with different energy.

Tables from 1 to 3 shows the calculated (Debye length (λ_D) electron density (n_e) and electron temperature (T_e) by using Eq.(3) and plasma frequency (f_p) by using Eq.(4) for ZnO:SnO₂ at different laser energies).

All calculated plasma parameters (f_{pand} and λ_D). It shows that plasma frequency (f_p) increase with the energy of laser because it's proportional with electron density (n_e).

Table 1: Plasma parameters for ZnO: SnO₂ at X=0.2 with different laser energies.

E(mJ)	Te (eV)	FWHM (nm)	$n_e \cdot 10^{18}$ (cm ⁻³)	f_p (Hz) *10 ¹²	λ_D *10 ⁻⁷ (cm)
500	0.471	1.900	2.069	12.917	3.544
600	0.479	2.000	2.178	13.253	3.485
700	0.489	2.100	2.287	13.580	3.435
800	0.504	2.200	2.396	13.900	3.408
900	0.503	2.200	2.396	13.900	3.403

Table 2: Plasma parameters for ZnO:SnO₂ at X=0.4 with different laser energies.

E(mJ)	FWHM (nm)	Te (eV)	n_e (cm ⁻³)	f_p (Hz)	λ_D (cm)
500	1.90	0.504	2.07E+18	1.3E+13	3.7E-07
600	2.00	0.566	2.18E+18	1.3E+13	3.8E-07
700	2.10	0.555	2.29E+18	1.4E+13	3.7E-07
800	2.20	0.588	2.40E+18	1.4E+13	3.7E-07
900	2.20	0.607	2.40E+18	1.4E+13	3.7E-07

Table 3: Plasma parameters for ZnO: SnO₂ at X=0.6 with different laser energies.

E(mJ)	Te (eV)	FWHM (nm)	$n_e \cdot 10^{18}$ (cm ⁻³)	f_p (Hz) *10 ¹²	λ_D *10 ⁻⁷ (cm)
500	0.470	1.900	2.069	12.917	3.542
600	0.489	2.000	2.178	13.253	3.521
700	0.489	2.150	2.341	13.741	3.396
800	0.502	2.250	2.450	14.057	3.361
900	0.502	2.300	2.505	14.212	3.325

Conclusions

The intensity of the spectral lines of the laser-induced plasma emission showed a strong dependence on the surrounding conditions. It was found that the intensity at different laser peak powers increases with the laser peak energy and then decreases when the power continues to increase. The interaction of laser beams with metal targets is a very useful way to produce plasma columns that consist of highly concentrated electrons, ions and neutral molecules. For the air environment, laser-induced plasma spectra were found to show strong spectral lines and increase their intensity while increasing

the laser energy pulse. Plasma parameters such as (electron density, electron temperature, number of particles in Debye sphere, plasma frequency and Debye length) are found that laser energy is strongly affected. The results showed that the values of (N_D , λ_D and T_e) were increased in case of laser induced plasma in air while the values of (f_p and n_e) were decreased in laser induced plasma air

References

- [1] J. Feng, Z. Wang, Z. Li, W. Ni, Spectrochim. Acta-Part B at Spectrosc., 65, 7 (2010) 549-556.

- [2] V. N. Rai, H. Zhang, F. Y. Yueh, J. P. Singh, A. Kumar, *Appl. Opt.*, 42, 18 (2003) 3662-3669.
- [3] S. S. Harilal, C. V. Bindhu, M. S. Tillack, F. Najmabadi, A. C. Gaeris, *J. Appl. Phys.*, 93, 5 (2003) 2380-2388.
- [4] Ulf Saalmann and Jan-Michael Rost, *Phys. Rev. Lett.*, 89, 14 (2002) 143401-1-143404.
- [5] A. M. El Sherbini, *World J. Nano Sci. Eng.*, 2, December (2012) 206-212.
- [6] S.A.M. Mansour, *Opt. Photonics J.*, 5, 3 (2015) 79-90.
- [7] E. Oks, *J. Phys. B At. Mol. Opt. Phys.*, 49, 6 (2016) 065701-1_065701-5.
- [8] R.K. Yagi, R.S. Pandey, A. Kumar, K.K. Srivastava, *Int. J. Eng. Sci. Technol.*, 3, 8 (2011) 168-176.
- [9] "NIST National Institute of Standards and Technology USA, electronic database."