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Spectroscopic Diagnostics of Plasma parameter in Laser Induced Plasma using PbO Lines

Anas A. Abdullah[1], Sabre J. Mohammed[1] , Ghuson H. Mohammed[2]
[1] *Department of Physics, College of Education for pure science, University of Tikrit , Tikrit , Iraq*
[2] *Department of Physics, College of Science, University of Baghdad, Baghdad , Iraq*
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Corresponding Author:
Name: Anas A. Abdullah
E-mail:
anasabdabdullah@gmail.com
Tel:

ABSTRACT

The optical emission spectrum of produced plasma was studied using pulse laser, where the effect of laser energy at a wavelength of 1064nm was studied on lead oxide that produced by optical emission spectroscopy at different laser energy from 500 to 900 mJ. It was found that the intensity for Pb I and Pb II lines increase with increasing laser energy, but with different ratio, as a result increasing the excitation rate with increasing the number of falling photons. The wave length was recorded at highest laser Energy produced from Pb II which was equal to 666.02 nm. It can be seen that The height of peaks increase with increasing laser energy due to the effect of increasing the Electrical field induced by increasing Electrons density and the temperature of electron (T_e) and electron density (n_e) increase from 1.222×10^{18} cm^{-3} to 1.444×10^{18} cm^{-3} with increasing laser energy from 500 to 900 mJ respectively as a result of increasing number of falling photons which lead to increase in the electron density.

Introduction

The objective of plasma diagnostics is to obtain the information about the state of plasma by means of experimental analysis of the physical processes occurring in it. The knowledge of plasma parameters is required to fully understand the effects of the physical processes taking place in the plasma and to deduce from them its properties [1,2]. Optical emission spectroscopy is widely used, due to its simplicity, to measure plasma parameters such as electron temperature (T_e) and electron density (n_e). Wavelength of emitted light depends on energy difference between levels. While the intensity, depending on Boltzmann distribution for local thermal equilibrium and the intensity can be described as[3].

$$I_{ij} = \frac{n\, g_j A_{ij}\, h\, c}{U(T)\, \lambda_{ij}}\, e^{-E_j/k_B T} \quad ....(1)$$

I_{ij}, λ_{ij} and A_{ij} represent the intensity, wavelength and transition probability corresponds to transition from i to j, g_j is a statistical weight, h is the Planck's constant, n number density of emitting species, c is the speed of light, $U(T)$ partition function[4].

Also, the electron temperature T_e is evaluated from Boltzmann equation, Assuming a Boltzmann distribution of the population of the atomic levels [5].

$$ln\left(\frac{I_{ki}\lambda_{ki}}{A_{ki}g_k}\right) = -\frac{E_k}{k_B T_e} + constant \quad .....(2)$$

The electron temperature (T_e) is evaluated from the inverse of the slope of the Boltzmann plot (ln $\left(\frac{I_{ki}\lambda_{ki}}{A_{ki}g_k}\right)$ versus E_k) for the same upper level[6]. The Stark broadening effect formula can be written in form

$$n_e = \frac{\Delta\lambda}{2\omega}\, N_r \quad ...(3)$$

n_e is the electron density , ω the impact electron constant, N_r is the reference electron density and $\Delta\lambda$ is the FWHM of Stark broadened spectral peak [7].

The plasma its quasi-neutrality characteristic over a distance λ_D is called the Debye length which is a function of the electron temperature (T_e), and the plasma density[8].

$$\lambda_D = \left(\frac{\varepsilon_0\, k_B\, T_e}{n_e e^2}\right)^{1/2} \quad ...(4)$$

ε_o Represent the permittivity of free space, k_B the Boltzmann constant and e the electron charge.

The number of particles in a Debye sphere (N_D) [9].

$$N_D = \frac{4\pi}{3} n_e \lambda_D^3 \quad ...(5)$$

These oscillations occur at frequency called the plasma frequency of electron (ω_p) can be calculated by[8].

$\omega_p = \left(\frac{n_e e^2}{\varepsilon_0 m_e}\right)^{1/2}$ ......(6)

and in frequency units, given approximately by:

$f_p = \frac{\omega_p}{2\pi} \approx 8.98\sqrt{n_e(m^{-3})}$ (Hz) .....(7)

In a partially ionized gas collisions of electrons with gas molecules can dampen these plasma oscillations. Therefore, plasma oscillations can only develop if the mean free time (τ) between collisions is long enough compared with the oscillation period[6].

Experimental part

Bulk samples of PbO have been prepared by solid state reaction process. The powder of Lead Oxide with a purity of 99% are manufactured by BDH chemical Ltd (England).After that it is pressed into pellets with (1.2 cm) diameter and (0.2 cm) thick, using hydraulic piston type (SPECAC), under the pressure of 6 tons/cm2 for 10 minutes .The pellets are in air to temperature (600 ̊C) for 1 hours then cooled to room temperature. Spectral diagnostics is a control tool during the process by spatial monitoring of the plasma, which used emission intensity of the spectral lines to determine plasma parameters. Spectrometer model (Spectra Pro S3000) used in our experiment, has a USB connection with computer and optical fiber with quartz lens at its end, which reserve the light emitted from plasma, as shown in Fig. (1).

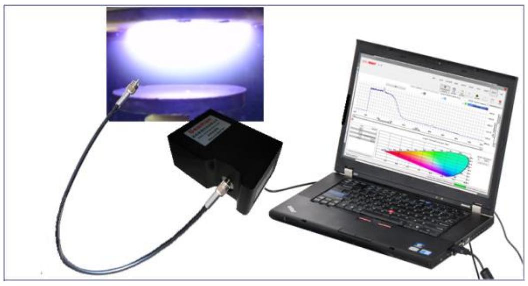

Fig. 1: spectroscopy measurement setup

Results and discussion

The optical emission spectra from laser induced plasma using PbO were recorded by optical emission spectrometer at different laser energy 500 to 900 mJ. Fig. (2) shows the spectroscopic patterns for emission from PbO target at different laser energy and the dominant standard atomic and ionic lead and oxygen standard lines (Pb I, Pb II, O I and O II) [10]. There are many atomic and ionic lead peaks with high intensity and some of weak atomic and ionic oxygen lines. The intensity of emitted lines depends on the transition probability between two levels and the number of excited atoms in the upper level which depend on temperature. It can be noticed that the intensity for Pb I and Pb II lines increase with increasing laser energy, but with different ratio, as a result increasing the excitation rate with increasing the number of falling photons.

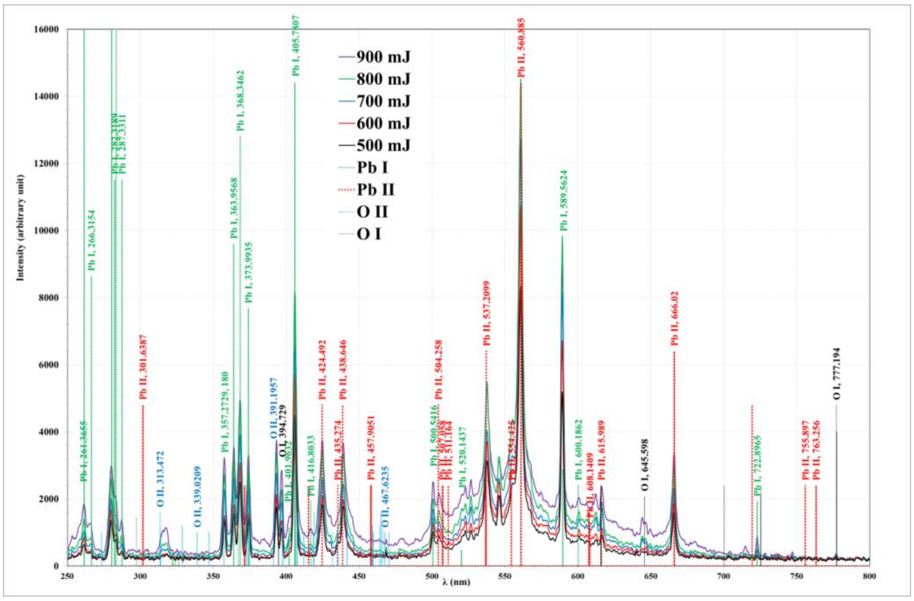

Fig. 2: Light emission spectra induced by for pulse laser plasma from PbO target in vacuum with different laser energy

The value of T_e is calculated by Boltzmann plot (the relation between $\mathrm{Ln}(\lambda_{ji} I_{ji}/hcA_{ji}.g_j)$ versus the upper level energy) for different laser energy as shown in Fig.3. The selection of lines due to isolated and presence in all curves. Also the big difference in their upper energy levels calls for more measurements accuracy[11]. Electron temperature equal the inverse of the slope of best fitting line.

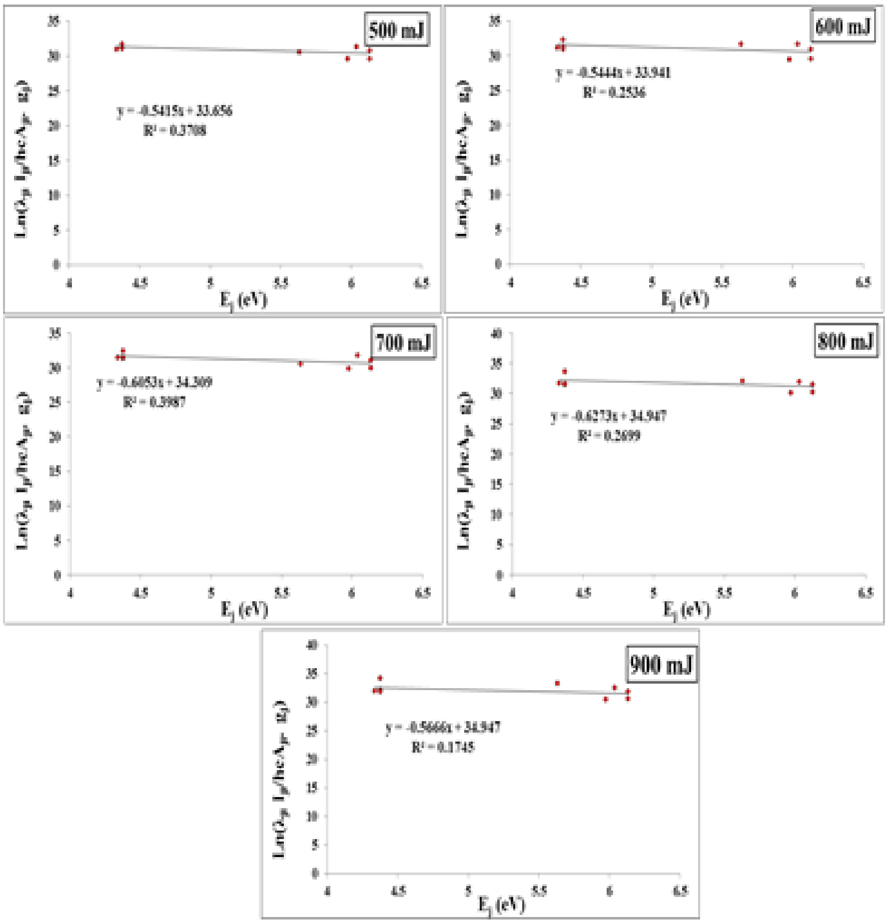

Fig. 3: Boltzmann plot made from the analysis of number of lines PbO II target using 1064nm laser, with different laser energies

Fig. (4) shows the (Pb II 666.02 nm) peak profile where full width at half maximum ($\Delta\lambda$) found by using Lorentzian fitting, which used to calculate electron density at different laser energy using Stark effect, depending on the standard values of broadening for this line [12]. It can be seen that the full width increase with increasing laser energy due to the effect of increasing the electric field caused from increasing the electron density.

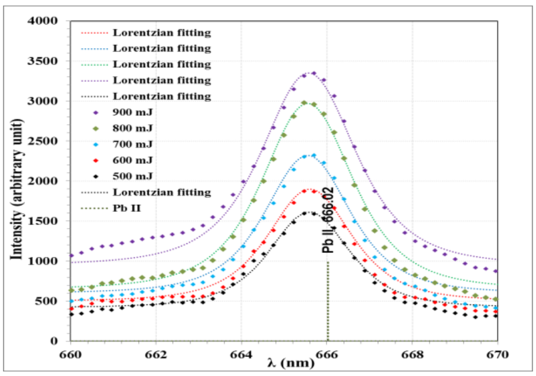

Fig. 4: Pb II 666.02 nm peaks broadening and Lorentzian fitting at different laser energy using Pb target

The variation of electron temperature (T_e) and electron density (n_e) with laser energy from Pb target were shown in Fig. (5). This figure shows that the n_e increase from 1.222×10^{18} cm^{-3} to 1.444×10^{18} cm^{-3} with increasing laser energy from 500 to 900 mJ as a result of increasing number of falling photons which leads to the ejection of more electrons by photo ionization process hence increasing the electron density. This increment cause more electron- neutral collisions which leads to reducing the mean values of electron temperature as a result of losses of electron energies in many ways such as elastic, excitation and ionization collisions [13]. At high laser energy electron temperature becomes almost stable as a result of equilibrium between energy gained by laser and energy lost by collisions. These results match our calculation (2014) [14].

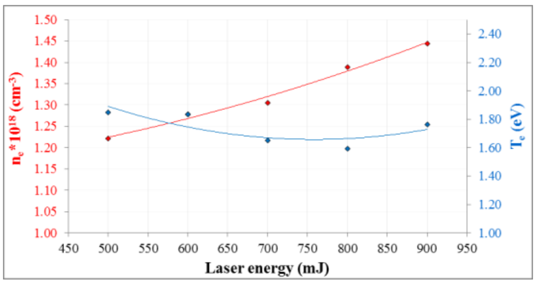

Fig. 5: The variation of T_e and ne with laser energy for plasma induced on PbO target using 1064 nm laser

Table (1) : plasma parameter calculated from spectroscopic lines for PbO target using 1064nm, with different laser energy

	Laser energy	T_e (eV)	n_e*10^{18} (cm^{-3})	w_p*10^{12}(Hz)	λ_D *10^{-6}(cm)
PbO	**500**	1.847	1.222	9.928	0.913
	600	1.837	1.278	10.151	0.891
	700	1.652	1.306	10.261	0.836
	800	1.594	1.389	10.583	0.796
	900	1.765	1.444	10.793	0.821

Conclusions

The value of Te is calculated by Boltzmann plot (the relation between Ln(λji Iji/hcAji. gj versus the upper level energy) for different laser energy, the (Pb II 666.02 nm) peak profile where full width at half maximum (Δλ) found by using Lorentzian fitting.

It can be seen that the full width increase with increasing laser energy due to the effect of increasing the electric field caused from increasing the electron density.

The variation of electron temperature (T_e) and electron density (n_e) with laser energy from Pb target, were the increase from 1.222×1018 cm^{-3} to 1.444×1018 cm^{-3} with increasing laser energy from 500 to 900 mJ as a result of increasing number of falling photons which leads to the ejection of more electrons by photo ionization process hence increasing the electron density.

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التشخيص الطيفي لمعلمات البلازما المنتجة بالليزر باستخدام خطوط اوكسيد الرصاص

أنس عبد عبدالله[1] ، صبري جاسم محمد[1] ، غصون حميد محمد[2]

[1] قسم الفيزياء ، كلية التربية للعلوم الصرفة ، جامعة تكريت ، تكريت ، العراق

[2] قسم الفيزياء ، كلية العلوم ، جامعة بغداد ، بغداد ، العراق

الملخص

تم دراسة طيف الانبعاث البصري من البلازما المنتجة باستخدام ليزر نبضي حيث تم دراسة تأثير طاقة الليزر وبطول موجي 1064nm على اوكسيد الرصاص PbO بواسطة مطياف الانبعاث الضوئي عند طاقات ليزر مختلفة من 500 mJ إلى 900 mJ. وجد أن كثافة خطوط Pb I و Pb II تزداد مع زيادة طاقة الليزر ولكن بنسب مختلفة، نتيجة لزيادة معدل الاثارة مع زيادة معدل الفوتونات الساقطة. وقد تم حساب الطول الموجي عند أعلى شدة لليزر الناتج من Pb II فكان يساوي 666.02 nm. ان ارتفاع القمم يزداد بزيادة طاقة الليزر بسبب تأثير زيادة المجال الكهربائي الناجم عن زيادة كثافة الالكترونات وان درجة حرارة الالكترون T_e وكثافة الالكترون n_e تزداد من 1.222×10^{18} cm^{-3} إلى 1.444×10^{18} cm^{-3} بزيادة طاقة الليزر 500 mJ إلى 900 mJ على الترتيب كنتيجة لزيادة عدد الفوتونات الساقطة التي تؤدي الى زيادة كثافة الالكترونات.