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

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ABSTRACT

The optical emission spectrum of produced plasma was studied using pulse laser, where the effect of laser energy at a wavelength of 1064 nm 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 (Tₑ) and electron density (nₑ) increase from 1.222×10¹⁸ cm⁻³ to 1.444×10¹⁹ 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.

Keywords: spectroscopy; Boltzmann plot; plasma parameters

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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 (Tₑ) and electron density (nₑ). 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].

\[ I_{ij} = \frac{n g_j h c}{U(T) \lambda_{ij}} e^{-E_j/k_B T} \]  

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

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

\[ \ln \left( \frac{I_{ij} \lambda_{ij}}{A_{ij} \lambda_k} \right) = -\frac{E_k}{k_B T_e} + \text{constant} \]  

The Stark broadening effect formula can be written in form

\[ \lambda_D = \left( \frac{e^2 n_e k_B T_e}{\pi m_e^2} \right)^{1/2} \]  

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where\( \lambda_D \) is the Debye length which is a function of the electron temperature (Tₑ), and the plasma density [8].

These oscillations occur at frequency called the plasma frequency of electron (ωₚ) can be calculated by [8].
\[ \omega_p = \left( \frac{n_e e^2}{\epsilon_0 m_e} \right)^{1/2} \quad \ldots \ldots (6) \]

and in frequency units, given approximately by:

\[ f_p = \frac{\omega_p}{2\pi} \approx 8.98 \sqrt{n_e (m^{-3})} \quad (Hz) \quad \ldots \ldots (7) \]

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 (\( \tau \)) 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).

**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.

The value of \( T_e \) is calculated by Boltzmann plot (the relation between \( \ln(n_{ji} I_{ji}/hcA_{ji} \lambda_i) \) 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 (Δλ) 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.

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].
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_w*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 T_e is calculated by Boltzmann plot (the relation between Ln(λji Iji/hcAj.i. 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.

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التشخيص الطيفي لمعلمات البلازما المنتجة بالليزر باستخدام خطوط أوكسيد الرصاص

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الملخص

تم دراسة طيف الانبعاث البصري من البلازما المنتجة باستخدام ليزر نبضي حيث تم دراسة تأثير طاقة الليزر وبطول موجي 1064nm على PbO أوكسيد الرصاص بواسطة مطياف الانبعاث الضوئي عند طاقات ليزر مختلفة من 500 mJ إلى 900 mJ. وجد أن كثافة خطوط Pb I تزداد مع زيادة طاقة الليزر ولكن بنسبة مختلفة، نتيجة لزيادة معدل الانشطار مع زيادة معدل الالكترونات الساقطة. وقد تم حساب الطول الموجي ل_LINES_ في أعلى شدة لليزر الناتج من Pb II وكان يساوي 666.02 nm عند أعلى طاقة نبضة للليزر. إن ارتفاع القمم يزداد بزيادة طاقة الليزر بسبب تأثير زيادة مجال الكهربائي الناجم عن زيادة كثافة الإلكترونات. وناتج عن زيادة كثافة الفوتونات الساقطة في تدفق على تدفق، ان الضوء السفلي للليزر بدأ تدفق من 1.222×10¹⁸ cm⁻³ إلى 1.444×10¹⁸ cm⁻³ بزيادة طاقة الليزر 900 mJ إلى 500 mJ.

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