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DETERMINE EMISSIONS PLASMA IRON BY LASER-INDUCED BREAKDOWN SPECTROSCOPY IN ATMOSPHERIC ENVIRONMENT

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Abstract

The plasma spectroscopy analysis for Iron induced plasma was carried out using a Q-switched Nd: YAG pulsed laser system. The Laser wavelength was (1064) nm, Emission spectra were obtained using different energies in the range (600-900) mJ. Electron temperatures are evaluated at different laser peak powers from Boltzmann (-1/KBT) and Suha equation, also, the electron densities are deduced using stark broadening. A limited number of suitable Fe lines are detected and the plasma parameters are discussed. The Electron temperatures of (Fe) are measured and were found to be in the range of (1.8–1.88) eV. It is observed in the case of iron the electron temperature is proportional with laser energy and the highest peak in (Fe) arrive at (55396.52).

Keywords: Iron Plasma, Laser-Induced Plasma Spectroscopy, Plasma Parameters.

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1. Introduction

The important topic that studies the emissions spectral is plasma. It's a very effective method to study and fabricate and treatments of materials, plasma is a partially ionized gas-forming from neutral atoms, electron, and positive ions. Glow-discharge plasma can be generated easily by hitting pulse laser at low pressure and a high voltage electrical discharge [1,2].
Information of plasma parameters can be calculated from a spectrum emission plasma electrons, where Laser-induced Breakdown Spectroscopy (LIBS) using to measures different plasma parameters, such as electron density (ne), electron temperature (Te), and plasma frequency (f_p). Optical emission is a practical technique and an easy method to determine the parameters. [3]
Iron is a metal of importance for use in device applications, is also common in many different tools, surgical types of equipment, and appliances. Stainless steel is a common type of steel used in a host of different products. automobiles. The spread and development of intense lasers have allowed the creation of easy tools and good techniques for the control of electronic motions. This technique gives the pieces of information at the same time about spectral lines of the electron.[4].
The simplest method to determine the electron temperature of thermodynamic equilibrium in plasma is a Boltzmann plot. Saha–Boltzmann distribution is the best method to evaluate the atomic transitions for upper levels. Where suppose the excitation and electron temperatures are the same. [5-7]
Optical emission spectroscopy (OES), is an important method for analytical plasma characterization depends on several parameters. Spectroscopy has high resolution and wide wavelength coverage from 100 to 1025nm to detect several elements, so has high sensitivity leading to the elements in the sample like (a) a high resolution to resolve more lines of interest and avoid overlapping, (b) wide wavelength coverage, typically from 200nm to 800 nm to be able to detect simultaneously.[8,9] The important parameters that determined by spectroscopy, frequency (f_p), temperature (Te), and electron density (ne). Boltzmann and Saha equations to calculated temperature of electron plasma, [10,11]

$$T_e = \frac{E_1 - E_2}{k_B \ln\left(\frac{\lambda_2 I_2 g_1 A_1}{\lambda_1 I_1 g_2 A_2}\right)} \quad \text{………. (1)}$$

Expresses eq. (1) the is the Boltzmann constant k_B, the intensity I, statistical weight g, absorption strength A, wavelength λ, and E is the excitation energy of one state in eV. The per unit volume of a free electron can depict by Electron density. So, the equation used in this case Suha- Boltzmann equation is given as, [12]

$$n_e = \frac{I_1}{I_2^*} 6.04 \times 10^{21} (T)^{3/2} e^{\left(\frac{-E_k - E_i - x_z}{KT}\right) \times T_e^{3/2}} \quad \text{………. (2)}$$

The energies for the first and second levels are (E_k, E_i), gets a straight line with slope=1. We can determine the plasma temperature from the graph slope. Ionization energy gives in eq.3

$$I_2^* = \frac{I_2 \lambda_2}{g_2 A_2} \quad \text{………. (3)}$$

g_2 is the statistical weight of transition between levels. and A_2 is the probability of transition from level two to level one. So the plasma frequency is, [13]

$$f_p = \frac{n_e e^2}{m_e \varepsilon_0} \quad \text{………. (4)}$$

the fundamental importance characteristic in plasma is the Debye length λD, this parameter proportional inversely with electron density and with the square root of the electron temperature. [14,15]

$$\lambda_D = \sqrt{\frac{\varepsilon_0 K_B T_e}{n_e e^2}} = 7430 \left(\frac{T_e}{n_e}\right)^{1/2} \quad \text{………. (5)}$$

To evaluate the number of particles in the Debye sphere (N_D), dependent eq. (6), this equation represents by density and temperature of the electron, and the Debye sphere parameter is the second condition to take place the plasma $N_D \gg 1$. the equation of Debye sphere is, [16]

$$N_D = \frac{4}{3} \pi {\lambda_D}_D^3 n_e \quad \text{………. (6)}$$

Experimental
The optical emission spectra of iron plasma are registered using the experimental setup of laser-induced breakdown spectroscopy (LIBS) shown in Fig.1. at (600-900)mJ. Clear from this figure the system consist of (computer, spectroscopy, fiber, laser, and targets).

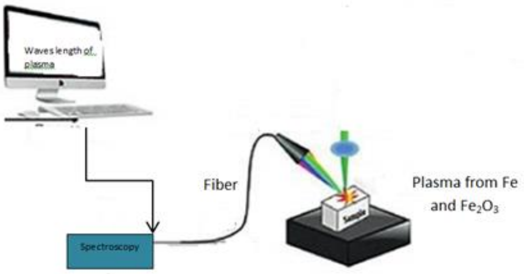

Fig.1: Schematic diagram experimental of spectroscopy optics and optical fiber.

To generate plasma using a Q-switched Nd: YAG pulsed laser on the iron metal at 1064nm wavelength. In this experience use a very accurate lens (200-2000) nm to focusing (f=10cm) of the laser beam on the iron. Using optical fiber (QP600-2-SR-BX, 600um premium fiber solarization resistant, 2m, BX Jacket) and put the fiber in 45º to collecting and transfer plasma emission. Spectroscopy optics use to study the plasma emission (200-1025) nm and (6 Hz) pulse repetition frequency.

Highly pure (99.9 %) iron powder as shown in fig.2(a and b) before and after pressed per tablet. We take (3g) weight from iron powder and press per tablet by hydraulic piston a compressive strength of approximately 6tons. The experience with a thickness of disk (5 mm) and diameter of (10) mm. To estimate the parameters of plasma at 1064 nm and evaluated as ne, λ_D, N_D and f_p. to study the effect same wavelength on the metal (Fe) in different energy.

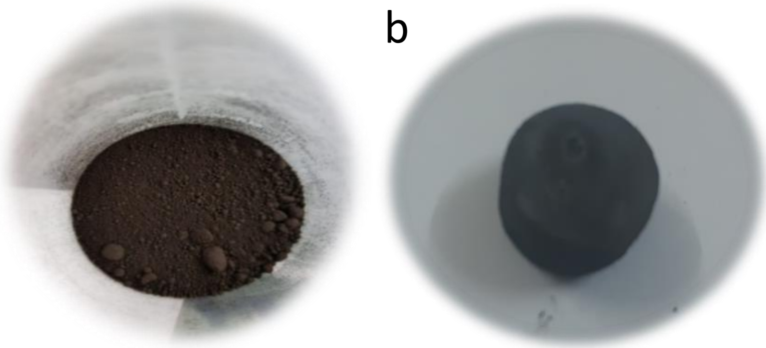

Figure 2: Represent (a) Iron powder (Fe) material with a purity of 99.99% before pressing. (b) (Fe) material after pressing

Results And Discussion

The optical emission spectrum of laser-produced iron plasma in the range of 350 nm to 650 nm is shown in Fig.3. The notable Fe spectral lines in air surrounding, are FeI (321,8), FI(357.38), FI(373.53235), FI(382.04249), FI(396.74204), FI(406.53809), FI(414.18630), FI(438.27677), FI(452.33984), FII(527.2413),FII (558.7114) and FII (591.37639) and FII(649.16651). The transitions are determined by using the spectral database of the National Institute of Standards and Technology (NIST) [18]. Figure (3) appear the emission of spectral laser on Fe target we fined the highest peak of intensity lie at (FII), wavelength 591.37639 at peak 55396.52, and the transitions 3d6(3F2)4p - 3d6(5D)5s.

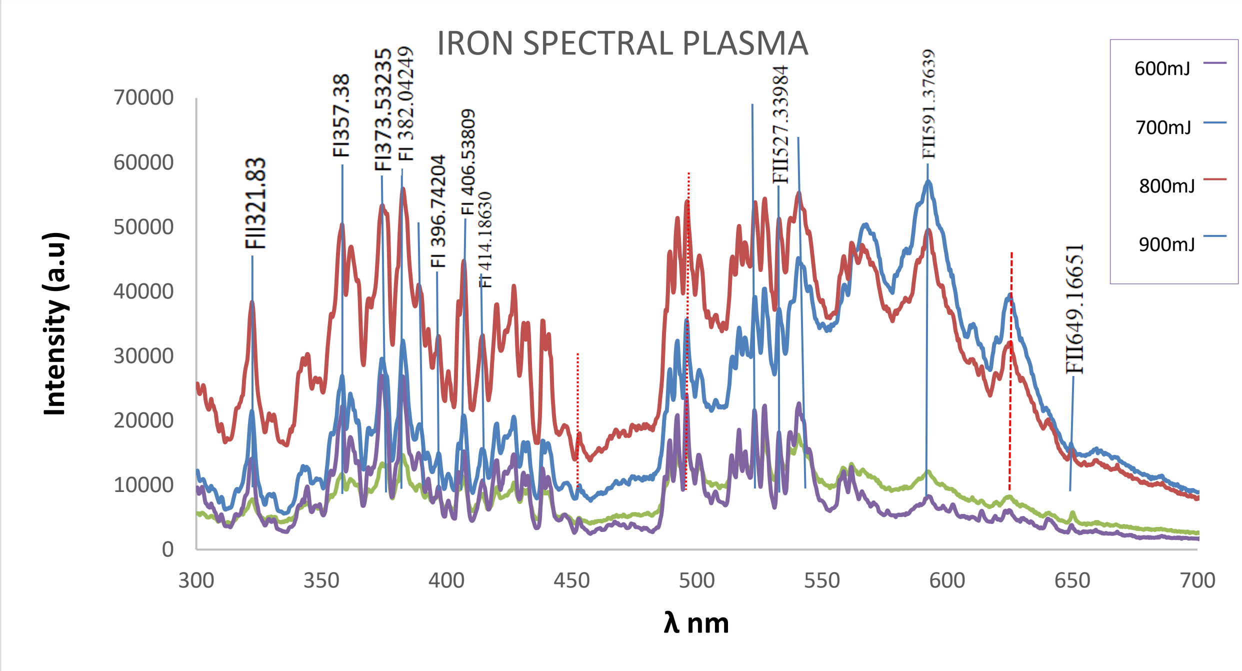

Figure 3: Emission spectra of laser-induced target plasma Fe with different energies.

Tables (1) illustrated the lines emissions and ionization from the Fe plasma target that was produced by the interaction of pulse Nd: YAG laser a wavelength (1064) nm at different laser energies (600-900).

Table 1: Spectroscopic parameters of the (Fe I and FeII) lines [17]

Ions	Wavelength λ (nm)	gkAki (S-1)	Ei(cm-1)	Ek(cm-1)	Transitions	
					Lower level	Upper Level
FeII	321.8	2.4e+06	73 43.346	104 09.618	3d6(1G2)4p	3d6(3H)4d
FeI	357.38	2.41e+06	19 390.168	47 363.376	3d64s2	3d6(3G)4s4p(3P°)
FeI	373.53235	2.70e+07	24338.767	50 475.288	3d6(5D)4s4p(3P°)	3d6(1G2)4s4p(3P°)
FeI	382.04249	6.67e+07	6 928.268	33 095.941	3d7(4F)4s	3d7(4F)4p
FeI	396.74204	1.52e+07	26 627.609	51 825.773	3d7(2H)4s	3d7(2H)4p
FeI	406.53809	1.7e+07	27 666.348	52 257.346	3d6(5D)4s4p(3P°)	3d6(5D)4s (4D)5s
FeI	414.18630	6.57e+05	24 338.767	48 475.686	3d64s2	3d6(3G)4s4p(3P°)
FeI	438.27677	1.54e+06	28 819.954	51 630.178	3d7(2H)4s	3d6(3H)4s4p(3P°)
FeI	452.33984	5.2e+05	29 469.024	51 570.097	3d6(5D)4s4p(3P°)	3d6(5D)4s (6D)4d
FeII	527.2413	3.9e+05	48 039.109	67 000.530	3d7	3d6(3F2)4p
FeII	558.7114	5.4e+05	54 275.649	72 169.004	3d54s2	3d6(3D)4p
FeII	591.37639	4.1e+05	63 272.981	80 178.005	3d6(3F2)4p	3d6(5D)5s
FeI	649.16651	1.78e+07	87 985.667	103 385.785	3d6(5D)4d	3d6(5D3)4f

We choose three peaks for (Fe) at (357.3, 373.53, and 382.04) nm as shown in fig. (3) in air. Boltzmann's plot requires peaks that originated from the ionization stage. Using parameters of the energies of upper levels, statistical weights and transition probabilities used for the experimental plots for the element (Fe) have been obtained from the (NIST) [18]. Where the electron temperature equals the slope of fitted line $-1/K_B T$ according to equation (1). The fitting lines. R2 is a statistical coefficient indicating the goodness of the linear fit which takes a value between (0.8,0.9).

Electron densities are calculated by using equation (2), where the stark broadening in plasmas results from collisions with charged species.

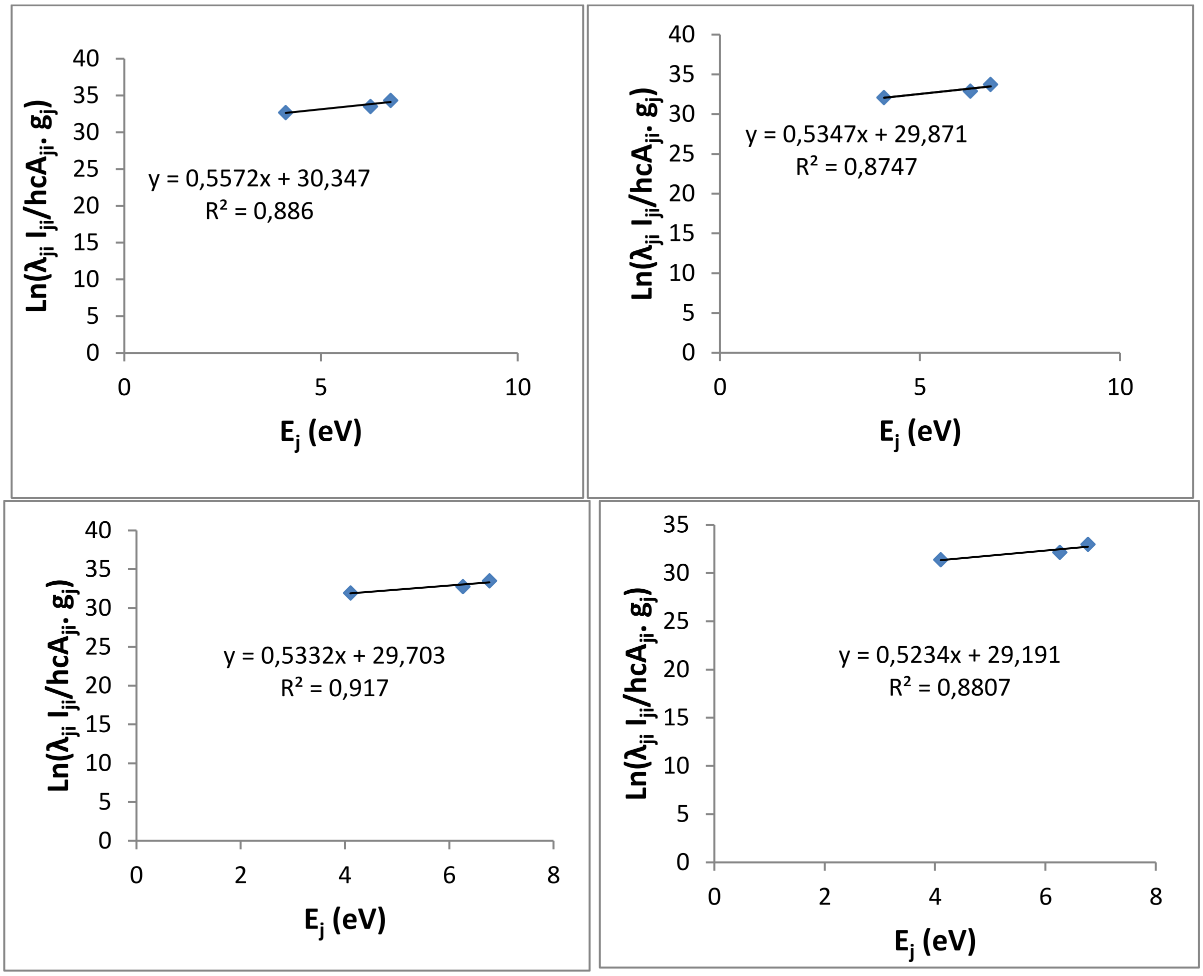

Figure 4: Boltzman plot for the Fe target with different laser energies in the air.

Tables (2) appear the values of parameters (Te, FWHM, $ne, f_p, \lambda D$, and N_D). Where f_p and N_D for target surface at different laser pulse energies (600, 700, 800, and 900) are calculated through the FWHM methods, from the table (2) and figure (4) the plasma generated dependent on the plasma conditions. It shows that (ne, f_p) increases with laser energy.

Table 2. Plasma parameters (T, ne, fp, λD, and Nd) for the Iron (Fe) with different laser energies (600-900).

E(mJ)	T (eV)	FWHM	ne*1018 (cm-3)	f_p (Hz)	λD *10-6 (cm)	Nd*103
900	1.8	1.40	1.1	9.2E+12	9.9	4.1
800	1.88	1.400	1.1	9.1E+12	9.9	4.3
700	1.8	1.350	1.0	9.0E+12	9.9	4.1
600	1.8	1.300	9.8	8.9E+12	1.0	4.2

becomes almost stable because the plasma becomes dusky to the laser beam which shields the target. Plasma shielding occurs when it reduces the transmission of the laser peak power along the beam path.

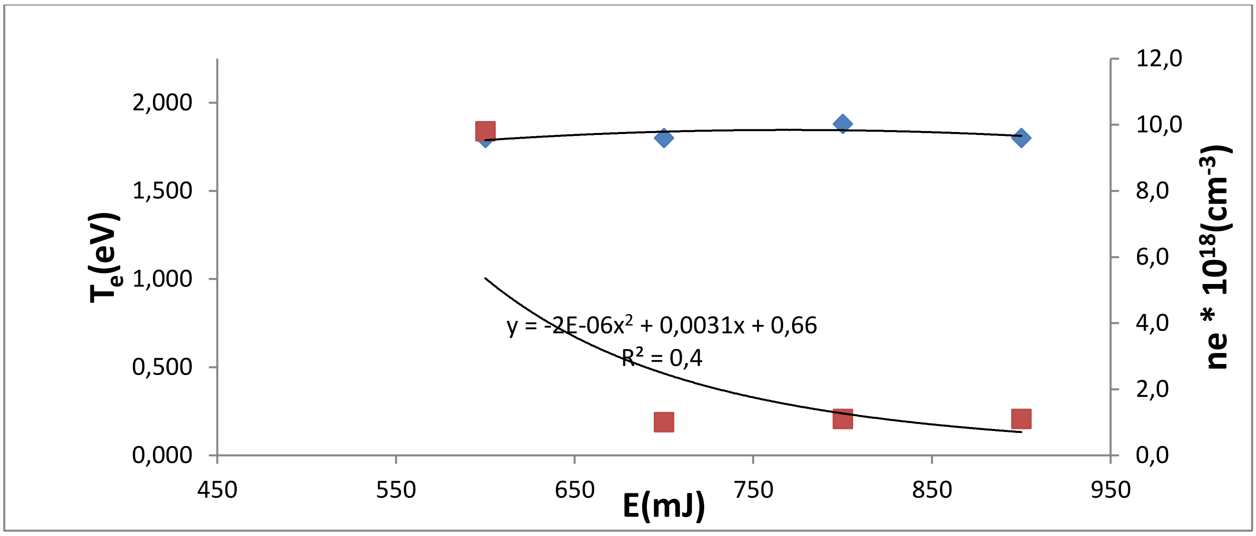

Figure 5: the variation of (Te) and (ne) versus the laser energy (600, 700, 800, and 900) for Fe.

Conclusions

Laser-induced plasma spectroscopy (LIPS) is an effective tool to analyze the emission spectra and study plasma characterization. The intensity of emission increase with increasing the energy of the laser. results show a slight rise in plasma frequency and electron temperature due to the increase of electron density. While A decrease in λD values was observed with increasing electron density. The analytic study of the plasma plume and the calculation of plasma parameters constitute a basic factor in the manufacture of some medical devices and treatment materials.

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