IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 3 Issue 2, February 2016.
www.ijiset.com
ISSN 2348 – 7968

Spectral Analysis of the Emissions of Carbon Element in the Laser Induced Plasma System

Dr. Mohammed S.Mahdi
Laser and Opto-Electronic Engineering Department ,University of Technology/Baghdad

Dr. Alaa H. Ali
Materials Research Department ,Ministry of Science and Technology/Baghdad

Esraa M .Abdulhady
University of Technology/Baghdad
Email:aso.ma86@yahoo.com.

Abstract:

In this work, Laser-induced plasma technique (LIPS) has employed to generate plasma in air at atmospheric pressure from a carbon sample by using a passively Q-switched Nd:YAG laser (334.7mJ, 1064 nm with 9 ns pulse duration, 37MW peak power ,the area of the laser spot was $5.72*10^{-6}$ cm^2 and $6.4*10^6$ Mw/cm^2 the power intensity). optical spectrum analyzer with 150 pm optical resolution for spectrum range (320 nm - 740 nm), was used to detect and analyze plasma emission lines of the carbon element and study the plasma properties . The line emission spectra of carbon plasma that have been detected by using a spectrum analyzer (Thorlabs GmbH), have been used to extract the excited plasma temperature via the Boltzmann equation, and measure the electron number density by McWhirter criterion ,where the plasma temperature measured is (6955.001 k) and the electron density $N_e= 2.259*10^{15}$ cm^{-3} at the fundamental wavelength**.**

Keywords: Laser-induced plasma, Plasma temperature, Electron density.

Introduction:

Laser induced plasma system(LIPS) or Laser-induced breakdown spectroscopy (LIBS) is an emerging technique for determining elemental composition in real-time. With the ability to analyze and identify chemical and biological materials by focusing a laser pulse with enough energy onto solids, liquids, and gaseous forms with little or no sample preparation, to produce a plasma useful for spectral analysis, it is more versatile than conventional methods and is ideal for onsite analysis[1]. LIBS has unique advantages such as the capability of rapid, in-situ, multielement measurements with few or no sample preparation. These features allow LIBS to perform measurements under conditions not feasible with conventional analytical techniques (e.g.: ETA-AAS, ICP-AES and ICP-MS) that supported by the actual technology development in the components, make it a very promising technique to be integrated to the established atomic spectroscopic methods[2] .LIPS uses a low energy pulsed laser (typically tens to hundreds of millijoules per pulse) to generate a plasma, which vaporizes a small amount of the sample. Spectral features emitted by the excited species, mostly atoms (but more recently molecules as well)[3]. It has become a powerful sensor technology for both laboratory and field use. In order to obtain a reliable elemental analysis of a sample using LIPS, one needs to control several parameters that can strongly affect the measurements. Some of these parameters are the laser wavelength, its irradiance, the morphology of the sample surface, the amount of ablated and vaporized sample, and the ability of the resulting plasma to absorb the optical energy. If these and related parameters are properly optimized, the spectral line intensities will be proportional to the elemental concentration[4]. This technique is very simple as compared to many other types of elemental analysis methods because of its straight for-ward experimental set-up[5]. Plasma is ionized gas, considered to be a cloud of electrons and ions that results from the breakdown of the sample, and can be formed when a high power pulsed laser sent onto the sample, the sample absorbs the energy from the laser; heated up, melts and evaporates [6] , Plasma was successfully generated In air by focusing laser on to the target surface, due to the interaction of the laser beam with the target material, In nanosecond laser heating of metals, the absorbed laser energy first heats up the target to the melting point and subsequently vaporize that melted portion. In this case evaporation occurs from the liquid metal [7].and it gives a detailed picture of the basic structure elements In the present work, we have used LIPS technique to study the carbon plasma generated by the fundamental (1064 nm) of a Q-switched Nd: YAG laser. The carbon element has important in many industrial application, and in dating organic objects[8]. The spectral analysis of the radiation emitted by laser induced plasmas may be used to obtain its characteristic parameters such as the temperature and the electron density[9].

Laser-induced plasma (LIP) is used to determine the material properties. It involves laser ablation of material to create a plasma spectroscopy and technology to monitor and analyze the spectrum of light plasma. This allows identification of the atomic components of any liquid, solid, or gaseous materials. The laser beam was focused down to a target. The radiation energy is coupled with the materials locally, the material begins to evaporate , and in this material vapor and the surrounding gas atmosphere a plasma is generated , which leads to the exciting physical components and their spontaneous emission of radiation. The plasma decays and emits element specific radiation. This emission is resolved spectrally and is detected by a spectrometer [1]. During the LIPS experiments some important parameters such as electron density and plasma temperature are required in order to produce reliable spectral features[10]. LIPS can be considered technique suitable for a wide range of different applications , due to its reliability [11], easy, fast, and offer high sensitivity and specificity to all the elements without bias [12] , as is used to identify the coal , metal, and soil analysis, [9], alloy steel [13], and Finally, LIBS instrumentation is generally less expensive and has lower subsequent operating costs than many other techniques[14].

In this work we study the spectral emission lines by a laser induced plasma technique for a carbon material and its stable isotope to build the technological path which can be used in different scientific and research applications.

Experimental Arrangement:

The experimental set-up of the LIBS which built in our laboratory shown in Figure (1).A set-up of experimental was designed by a passively Q-switched Nd: YAG laser, of wavelength 1064 nm and pulse duration 9ns. which delivers pulse energy (334.7 mJ), repetition rate (6 HZ) .the laser beam is focused using the focusing lens . This laser operates at a fundamental wavelength. The (1064 nm) laser output is achieved through the use of a nonlinear crystal. it has proven to be less time consuming and a cheaper option to test element concentrations, was used for LIBS technique used for plasma excitation. The single-shot of laser was focused onto the (C) sample to a spot diameter of ($2.7 * 10^{-3}$ cm) by a lens of focal length(10 cm). the peak power of the laser pulse is (37 MW), and peak-power densities ($6.4* 10^{6}$ MW/ cm^{2}). The optical emission of carbon sample is collected by a lens of focal length 15 mm and is focused onto optical fiber , which deliver the plasma light to the entrance slit of spectrum analyser, model (Thorlabs GmbH- CCS-100) with (1200 Line/mm) grating ,150 pm optical resolution for spectrum range (320-740 nm) and 20-μm slit dimension, which serves to deflect light according to wavelength and then focuses to the detect and convert optical signals to digital, and then transported the digital signal to the application, which shows us the spectral lines for the sample and then analyzed.

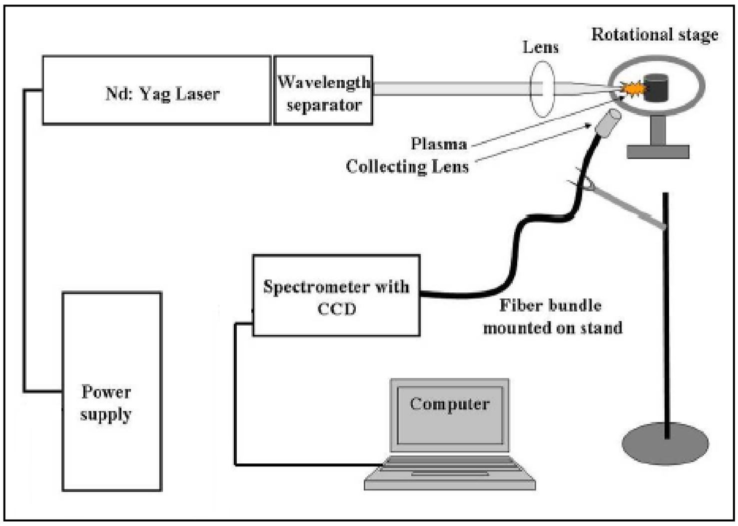


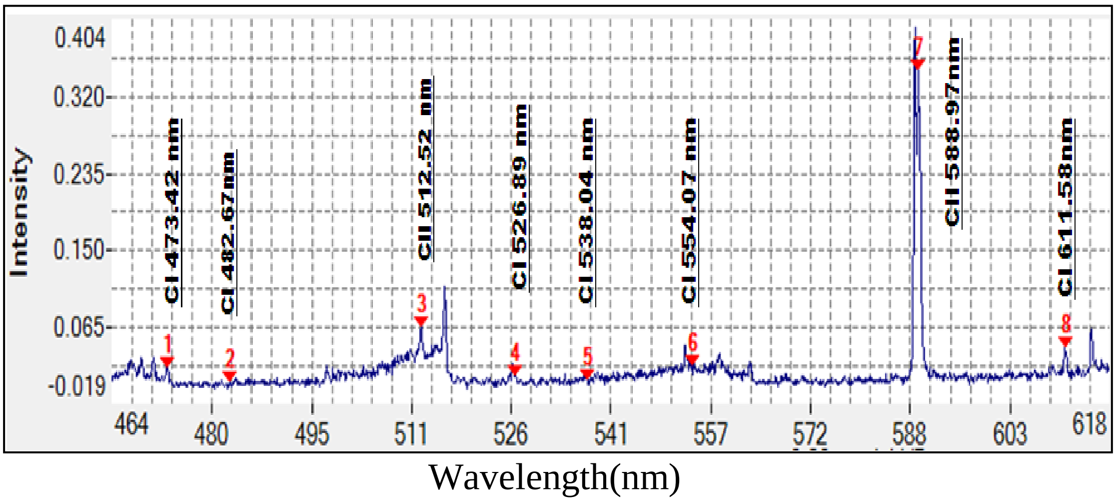
Fig (1) The main components of LIPS

Results and Discussion:

The present work includes the measurement of plasma emission intensity in the near UV-Visible region produced by the interaction of a Q-switched Nd: YAG laser. The spectra of the plasma photons an emitted in the region from [320-740] nm for Carbon with the use of the fundamental wavelength.

Also the plasma temperature and electron density have been calculated assuming the local thermodynamic equilibrium (LTE). The electron temperature Te and density ne were determined using the emission intensity for C at the neutral condition and ionic, and the emission line for the carbon was determined. The emission spectra displayed in the Figure. (2), The wavelengths of all the observed spectral lines along with their relevant spectroscopic data are displayed in Table. 1. Depending on the (National Institute of Standards and Technology Atomic Spectra Database) (NIST)[15].

ISSN 2348 – 7968



Fig(2) The emission spectrum of the produced Carbon (C) graphite plasma in air at normal atmospheric pressure in the region from [464-618] nm for laser energy (334.7 -mJ), and power density ($6.4*10^6$ MW/ cm^2)

In LIBS experiment , the local thermodynamic equilibrium (LTE) condition is assumed, a set of emitted spectrum is given in the range from (464 - 618)nm is shown in Figure 2. Shows the strong lines of Carbon appear under the above spectrum, from the spectral lines from the sample can determine the atomic constants used to evaluate the plasma temperature and the electron density from the (C) lines are given in Table (1).

BY using the lines CI 482.67 nm at the Ak_i = 6.28E+04 S^{-1} , gk=3 ,Ek= 81105.03cm^{-1} and CI 554.07 nm with Ak_i = 1.83E+05 S^{-1} , gk= 5 , Ek= 87753.73 cm^{-1}, used to calculate the plasma parameter by the equation below:

$$\frac{I_1}{I_2} = \frac{g_1 A_1}{g_2 A_2} \cdot \frac{\lambda_2}{\lambda_1} exp\left(-\frac{|E_1 - E_2|}{KT_e}\right) \qquad (1)$$

when, subscripts 1 and 2 refer to the two spectral lines of the same element. The spectroscopic constants *I , λ , g , A and E* represent the line intensity, wavelength, statistical weight, transition probability and the energy of the excited state, respectively. *Te* is the electron temperature and *k* is the Boltzmann constant . The result of temperature is (6955.001 K).

The electron density for Local Thermodynamic Equilibrium (LTE), expressed as the McWhirter criterion, and can be calculated by equation below:

$$ne \geq 1.6 * 10^{12} . T^{1/2} . (\Delta E)^3 \qquad (2)$$

Where ne is the electron density, ΔE (eV) is the highest energy transition for which the condition holds, and T (K) is the plasma temperature[4].The result of the minimum electron density is ($2.259*10^{15}$ cm^{-3}).

Table (1): Spectroscopic parameters of the neutral and ionized carbon in graphite material lines from the NIST.

Element	λ	I	A-Value	J	gk	E_l_lev.	E_u_lev.
(Name)	nm	(Relative)	S^{-1}	Upper	Upper	Cm^{-1}	Cm^{-1}
CI	473.42	0.00423	2.56E+05	2	5	64086.92	85203.64
CI	482.67	0.0047	6.28E+04	1	3	60393.14	81105.03
CII	512.52	0.0482	3.21E+06	1/2	2	162517.89	182023.86
CI	526.89	0.00953	1.27E+06	1	3	68856.33	87830.17
CI	538.04	0.00454	1.86E+06	1	3	61981.82	80562.85
CI	554.07	0.0216	1.83E+05	2	5	69710.66	87753.73
CII	588.97	0.3478	3.15E+07	1 1/2	4	145550.7	162524.57
CI	611.58	0.0415	5.54E+05	0	1	71364.9	87 711.37

Conclusion:

LIP System is a useful spectrochemical technique that can provide analysis in situ without sample preparation, which can be used in a wide range of environments. In this work used the LIP system portable commercial Thorlabs spectrometer equipped with ICCD detector to analysis the emission lines from the carbon element , the spectral lines emitted from the carbon plasma were used to calculate the plasma parameters (temperature and the electron density) in air at atmospheric pressure in LTE condition because of the importance of these parameters (Te, Ne) to characterize the plasma, giving information about the physical state of it.

References:

[1] A.Miziolek, V.Palleschi, I. Schechter **,** ***"Laser-Induced Breakdown Spectroscopy (LIBS) : Fundamentals and Applications"***, Cambridge University Press, New York ,(2006).

[2] J. D. Winefordner, I.B. Gornushkin, T. Correll, E. Gibb,B. W. Smith , N.Omenetto **," *Comparing several atomic spectrometric methods to the super stars: special emphasis on laser induced breakdown spectrometry, LIBS, a future super star*"**, J.Anal .At . Spectrom , 19 , 1061 –1083, (2004).

[3] David A. Cremers, Leon J. Radziemski**, *"Handbook of Laser-Induced Breakdown Spectroscopy"***, Second Edition , Wiley ,(2013).

[4] Jagdish P. Singh, Surya N. Thakur, ***" Laser-Induced Breakdown Spectroscopy "***, First Edition , Elsevier,(2007).

[5] M. Hanif, M. Salik, M. A. Baig, ***" Diagnostic Study of Nickel Plasma Produced by Fundamental (1064 nm) and Second Harmonics (532 nm) of an Nd: YAG Laser"***, Journal of Modern Physics, 3, 1663-1669,(2012).

[6] Dilek Arica Ates**," *Laser Induced Breakdown Spectroscopic Analysis of Metal Aerosols Generated by Pneumatic Nebulization of Aqueous Solutions*"**, İzmir Institute of Technology, (2010).

[7] S. Pandhija , A. K rai, ***"Laser-Induced Breakdown Spectroscopy: A versatile Tool for Monitoring Traces in Materials",*** Pramana Journal of Physics ,Indian Academy of Sciences ,Vol. 70,pp. 553-563,(2008).

[8] P. Bulman , D. McLeod-Henning, ***"Applying Carbon-14 Dating to Recent Human Remains"***, National Institute of Justice Journal, V 269, (2012).

[9] Z. Wang, T. Yuan, Z. Hou, W. Zhou, J. Lu,H.Ding, X.Zeng, ***" Laser-induced breakdown spectroscopy in China",*** Front. Phys, (2014).

[10] D. W. Hahn , N. Omenetto, ***"Laser Induced Breakdown Spectroscopy (LIBS), Part I: Review of Basic Diagnostics and Plasma–Particle Interactions :Still-Challenging Issues Within the Analytical Plasma Community"*** , Applied Spectroscopy, Volume 64, (2010).

[11] R.Gaudiuso , M.Dell'Aglio , O. De Pascale , G.S. Senesi , A.De Giacomo **," *Laser Induced Breakdown Spectroscopy for Elemental Analysis in Environmental, Cultural Heritage and Space Applications: A Review of Methods and Results*",** *Sensors* , *10*, 7434-7468,(2010).

[12] S. J. Rehse, H. Salimnia , A. W. Miziolek, ***"Laser-Induced Breakdown Spectroscopy (LIBS): an Overview of Recent Progress and Future Potential for Biomedical Applications"***, *Journal of Medical Engineering & Technology*; 36(2): 77–89 ,(2012).

ISSN 2348 – 7968

[13] C. Lopez-Moreno, K. Amponsah-Manager, B. W. Smith,I. B. Gornushkin,N. Omenetto,S. Palanco, J. J. Laserna , J. D. Winefordner, ***" Quantitative analysis of low-alloy steel by microchip laser induced breakdown spectroscopy"*** , J.Anal . At . Spectrom . , 20 , 552–556,(2005).

[14] Giorgio S. Senesi, ***" Laser-Induced Breakdown Spectroscopy (LIBS) applied to terrestrial and extraterrestrial analogue geomaterials with emphasis to minerals and rocks"*** , Earth-Science Reviews 139 ,231–267, (2014).

[15] Kramida A., Ralchenko, Yu., Reader, J., and NIST ASD Team "NIST Atomic Spectra Database (ver. 5.1)", in, National Institute of Standards and Technology, Gaithersburg, MD. , [Gaithersburg, Md.], (2013).http://www.nist.gov.