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Spectroscopic study performance of laser produced $CdTe_{(x)}:S_{(1-x)}$ plasma

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Abstract

In this work, the plasma parameters (electron temperature (T_e), electron density(n_e), plasma frequency (f_p) and Debye length (λ_D)) have been studied using the spectrometer that collect the spectrum of Laser produce $CdTe_{(X)}:S_{(1-X)}$ plasma at X=0.5 with different energies. The results of electron temperature for CdTe range 0.758-0.768 eV also the electron density 3.648×10^{18} – 4.560×10^{18} cm^{-3} have been measured under vacuum reaching 2.5×10^{-2} mbar. Optical properties of CdTe:S were determined through the optical transmission method using ultraviolet visible spectrophotometer within the range 190–1100 nm.

Key words

Laser Induced Plasma Spectroscopic (LIPS), Optical Emission Spectroscopic (OES), Spectroscopy diagnostic, Cadmium telluride (CdTe:S).

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دراسة طيفية لاداء بلازما $CdTe_{(x)}:S_{(1-x)}$ المنتجة بالليزر

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الخلاصة

تم دراسة معلمات البلازما درجة حرارة الالكترون (T_e) وكثافة الالكترون (n_e) و تردد البلازما (f_p) وكذلك طول كرة ديباي (λ_D) في هذا البحث بأستخدام مطياف الانبعاث والذي يعمل على التقاط الطيف الناتج من بلازما كبريتيد كادميوم تيللورايد. عند طاقات مختلفة حيث تمت دراسة الطيف الناتج تحت ظروف الفراغ اي بضغط يصل بحدود $2.5x10^{-2}$ mbar حيث حساب درجة حرارة الالكترون وكانت قيم درجة حرارة الالكترون هي 0.758-0.768 eV وكذلك كثافة الالكترونيات 3.648×10^{18} – 4.560×10^{18} cm^{-3}.

Introduction

A new analytical method recognized as the Laser-Induced Breakdown Spectroscopy (LIBS) use the optical emission of the plasma plume to analysis the elemental composition of the examined material. The plasma plume is induced on the test surface by the focused laser pulse. This type of the atomic emission spectroscopy technique, where the excitation energy is in the form of a laser pulse, cause number of significant advantages to the particle of material analysis. LIBS is able to determine a wide spectrum of chemical elements admit those with low atomic numbers. There is no necessity for any specific sample preparation and all states of matter can be analyzed. Final results of the analysis are useable in a few seconds and one measure may contain spectroscopic traces of all chemical elements present in the sample [1].

Laser induced breakdown spectroscopy, too named laser induced plasma spectroscopy (LIPS) or laser ablation spectroscopy (LAS), is a method based the spectral analysis of the radiation give out by a plasma cause by focusing an intense laser pulse on the sample surface. The intense laser pulse concenter on the sample surface causes evaporation, atomization and ionization of the material and produces a plasma, which expands and cools very rapidly. In typical LIBS conditions, the ablation process is stoichiometric: analyze the atomic and ionic lines given out by the plasma provides the identification of the species current in the sample and their quantification [2].

The cadmium telluride (CdTe) is a II-VI composite semiconductor and found most right candidate for the fabrication of thin film solar cells proper to its optimum energy band gap (1.44 eV) at room temperature and high absorption coefficient (>10^5 cm^{-1}) in the visible range [3].

Well known that the plasma induced by laser ablation is characterized by its main parameters such as the temperature, the electron density and the number densities of the different type current in the plasma determination of such parameters is a main task in order to achieve a best understanding as a way to improve their application. Electronic temperature as the most chief parameter is normally determined by spectroscopic methods. The strong electron density of this kind of plasmas at atmospheric pressure allows in general the assumption of the local thermodynamic equilibrium (LTE) and then the use of the Boltzmann plot.Normalized ionic to atomic lines intensities versus surface hardness. Saha–Boltzmann equations for the plasma temperature calculation. The plasma electronic temperatures $T_e$was deduced using Boltzmann Eq.(1):

$$\mathrm{Ln}(I\lambda/gA) = -E_k/kT - \mathrm{Ln}(4\pi Z/hcN_0) \quad (1)$$

where I is the line intensity, is the line wavelength, E_k is the energy of the upper state, Z is the partition function usually taken as the statistical weight of the ground state, h is the Planck constant, c is the light speed, and N_0 is the population of the ground state. When the left hand of Eq. (1) is plotted versus E_k, the plasma temperature is deduced from the slope of straight line, which is equal to $-1/kT_e$ [4].

Stark broadening of spectral lines is under probe since the origination of the effect in 1913. With the variegation of the available plasma sources and the increasing attention for plasma diagnostic tools, the theoretical and experimental studies devoted to Stark broadening became favored in the 1960 s. Since that time, several analysis papers have been published to summarize the results get by a big number of research groups all over the world. Count on the moderate worth of Doppler and Stark widths, the line shapes are tell of by Gaussian, Lorentzian or Voigt profiles. The Doppler width is measured as stated by to plasma temperature and atomic mass of the emitting kind. The width Stark is get using

$$\Delta\lambda_{Stark} = w(n_e^{ref}/ne)^m \quad (2)$$

where w is the Stark width at the reference electron density n_e [5].

The electric field that causes Stark effect in laser-induced plasmas results primarily from collisions with electrons, with small contributions due to collisions with ions, Thereforecan be simplified the equation:

$$n_e = \left[\frac{\Delta\lambda}{2\omega_s}\right] N_r \quad (3)$$

$\omega_s$is the theoretical line full width Stark broadening parameter, calculated at the same reference electron density $N_r \approx 10^{17} cm^{-3}$.

The reaction of charged particles to lower the effect of local electric fields is called Debye shielding and the shielding gives the plasma its quasi-neutrality characteristic. a distance λ_D, called the Debye length and defined as [6]:

$$\lambda_D=\left(\frac{\varepsilon_o k T_e}{n_e e^2}\right)^{1/2} = 743 \text{ x } (T_e / n_e)^{½} \quad (4)$$

where:- λ_D : is the Debye length (cm), L: is the system dimension(cm), n_e: is the density of the electron (m^{-3}) ,T_e: is the electron Temperature (K) , e: is the electron charge (C).

Experimental setup

The diameter of laser spot can be changed by exchange the distance between the laser lens and the target. Pulse duration (9 ns) with 6 Hz repetition rate frequency. The completely distance during the measure for system accuracy and precision. In this work a lens of 10 cm focal length has been secondhand. A small focal length lens canful produce a small beam waist, and therefore, stronger breakdown, but it too has a short depth of focus, Fig.1 shows a schematic diagram for the LIBS system (1).

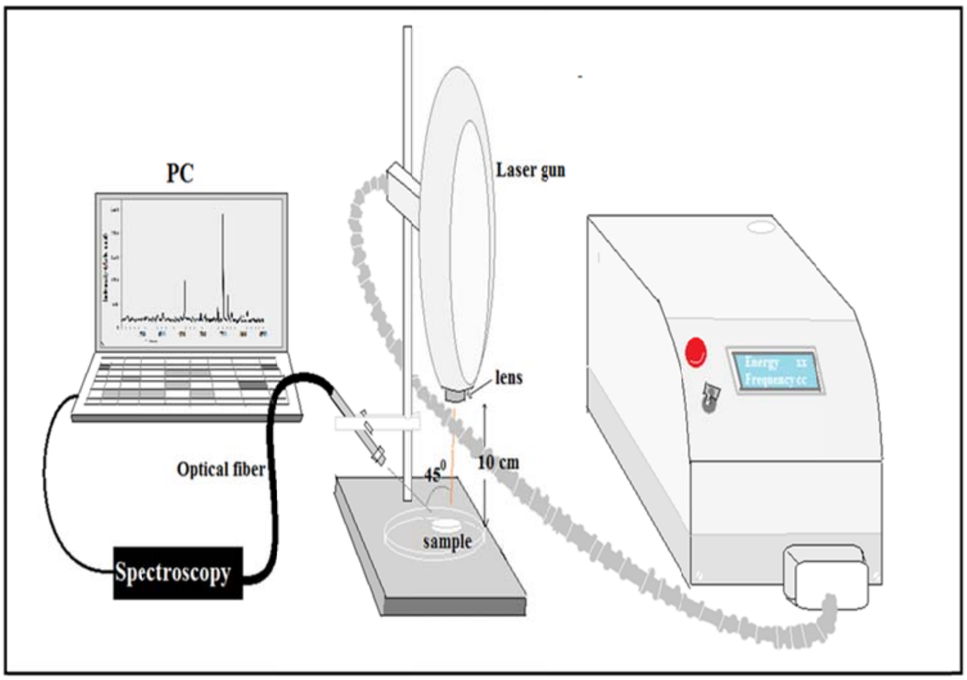

Fig.1: Laser Induced Plasma Spectroscopy (LIPS) system configuration.

The spectrometer study was done using the light give out from sample bombarded by the pulse laser. The spectrometer with short reply time from Ocean Optics (HR 4000 CG-UV-NIR) was used in the system to analyze emitted light.

The light make by the ablated plasma was collected by the optical fiber which was located at angle of about 45 degree to axes of the laser beam to keep off splashing and next guided to the entering slit of the spectrometer. The spectrometer has a strong resolve depending on grating used in it, and answer to a wavelength between 200-900 nm with 3648 pixels. Nd: YAG laser at 1064 nm is tightly concentrate on the target to produced plasma plume.

In order to provide insurance for display a fresh surface after every train of shots the target surface was circle manually. The spectrum of plasma with different value of energies from 500 mJ to 1000 mJ collect the Spectra of S, each spectrum was get over a 300-800 nm wavelength range.

Finally the results were analyzed and compared with National Institute of Standards and Technology data (NIST) [7] and evaluate the plasma parameters.

Results and discussion

Fig. 2 shows the emission spectrum of $CdTe_{(X)}$:$S_{(1-X)}$ target plasma at X=0.5 which is produced by the interaction of Q-switched Nd: YAG laser pulses with CdTe:S target plate at a laser peak power under vacuum. A spectrum consists of a number of characteristic spectral lines of particular atoms in the spectral range (500-800) nm with different pulsed laser energy E= (500, 600, 700, 800, 900, 1000) mJ.

The optical emission spectra of S target plasma which limited were recorded using (OES) technique.

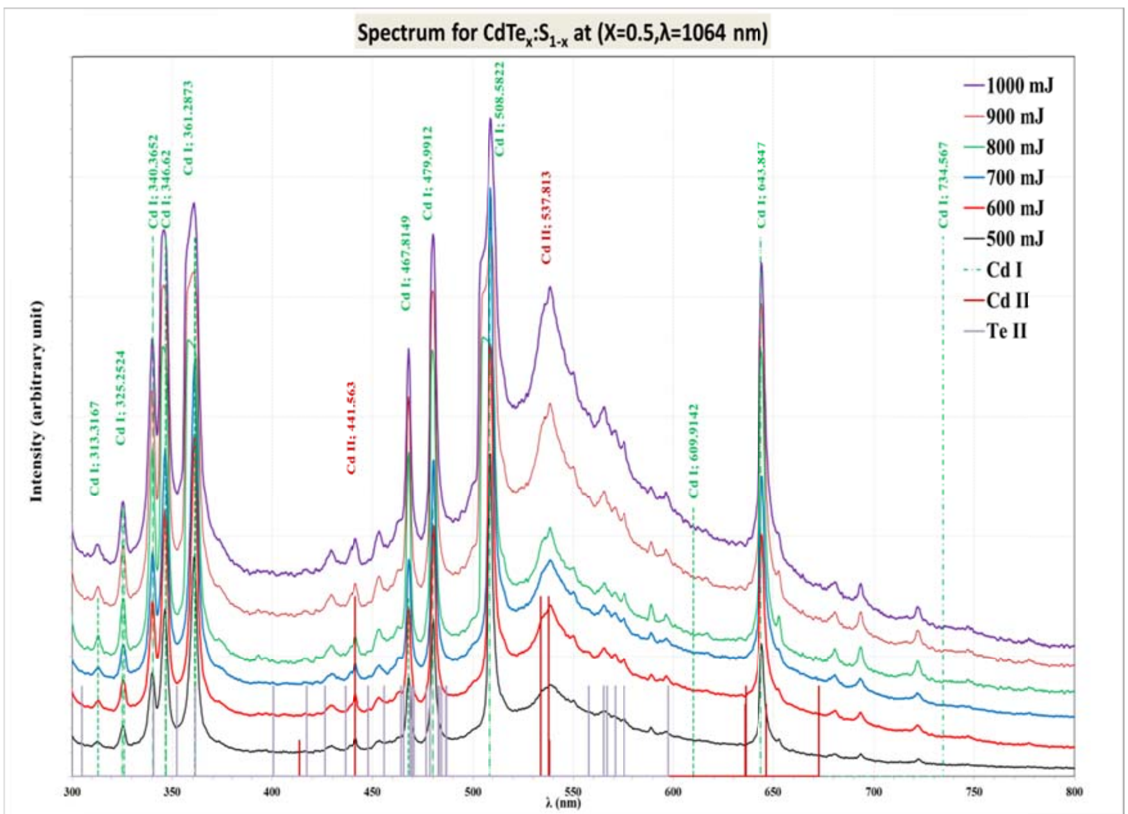

Fig.2: Emission spectra of laser induced CdTe:S target with different laser energies.

Table 1 displays the calculated electron temperature (T_e), fall width half maximum (FWHM), electron density (n_e), plasma frequency (f_p) and Debye length (λ_D) for CdTe:S target at different laser pulse energies. All measured plasma parameters (λ_D, fp and n_e) were satisfied the criteria for the plasma. It shows that fp decrease with decrease laser energy because it is proportional with n_e, while λ_D increasing.

Table 1: Plasma parameters for CdTe:Swith different laser energy.

E(mJ)	T_e (eV)	FWHM (nm)	$n_{e*}10^{18}$ (cm^{-3})	f_p(Hz) $*10^{12}$	λ_D $*10^{-7}$(cm)
500	0.758	1.400	3.648	17.152	3.387
600	0.767	1.500	3.909	17.754	3.291
700	0.772	1.600	4.169	18.337	3.196
800	0.770	1.650	4.300	18.621	3.144
900	0.771	1.700	4.430	18.901	3.099
1000	0.768	1.750	4.560	19.177	3.049

The calculated values of the electron temperatures (T_e) using Boltzmann plot Eq.(1) show that the electron temperature and electron density are increased with increasing the laser pulse energy, as shown in Fig.3. At higher laser peak energy, T_e becomes almost stable, because the plasma becomes opaque to the laser beam which shields the target. Plasma shielding occurs when the plasma itself reduces the transmission of the laser peak power along the beam path.

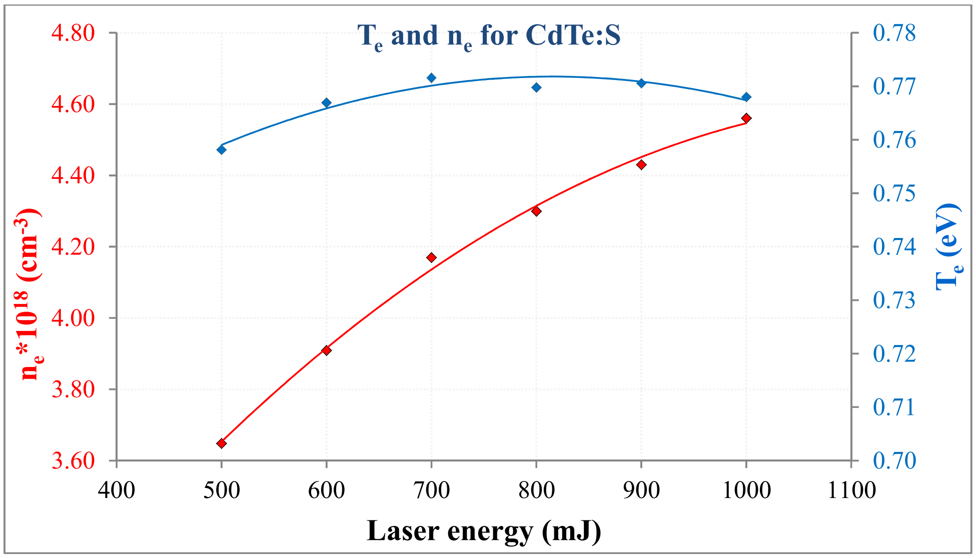

Fig. 3: The variation of (T_e) and (n_e) versus the laser energy for CdTe:S.

Boltzmann plot requires peaks that originate from the same atomic species and the same ionization stage, (peak is used Cd II specie at 441.5) nm for CdTe powder (pellet) as shown in Fig.4 The energies of upper levels, statistical weights, and transition probabilities used for the experimental plots of each element have been obtained from the National Institute of Standard Technology database (NIST) As well, the electron temperature equals to the invert of slope of the fitting line (the slope of the fitted line equals to -1/ T). R^2 is a statistical coefficient indicating the goodness of the linear fit which takes a value between (0, 1). The fitting equations and the R^2 were shown in the figure for all fitting lines. The better one has R^2value closer to 1.

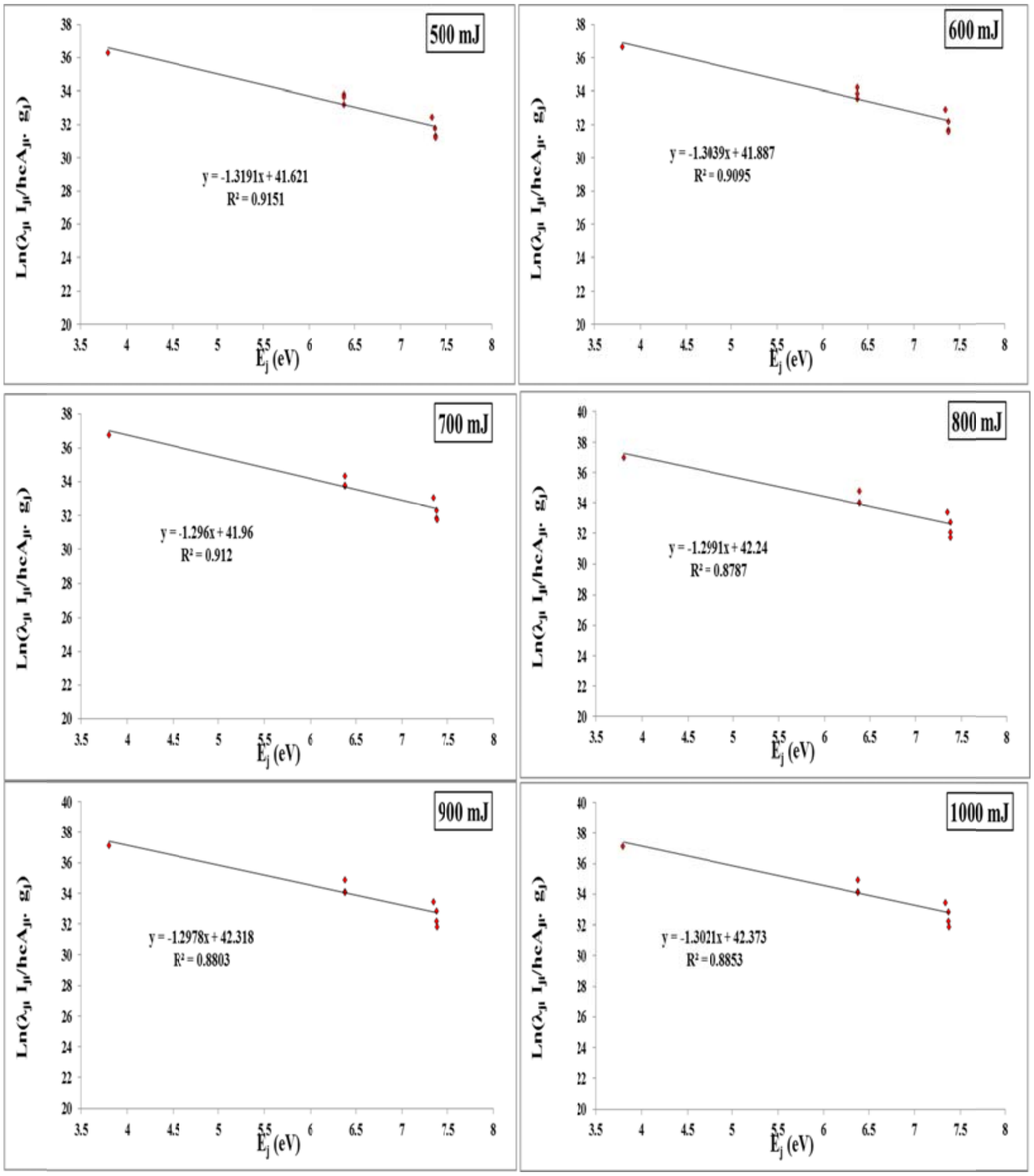

Fig.4: Boltzmann plots of CdTe:S target with different laser energies.

The electron densities are calculated using stark broadening Eq.(3) as display in Fig.5. Stark broadening of spectral lines in plasmas results from the aris from collisions of charged species in the broadening of the line and the shift of the peak wavelength.

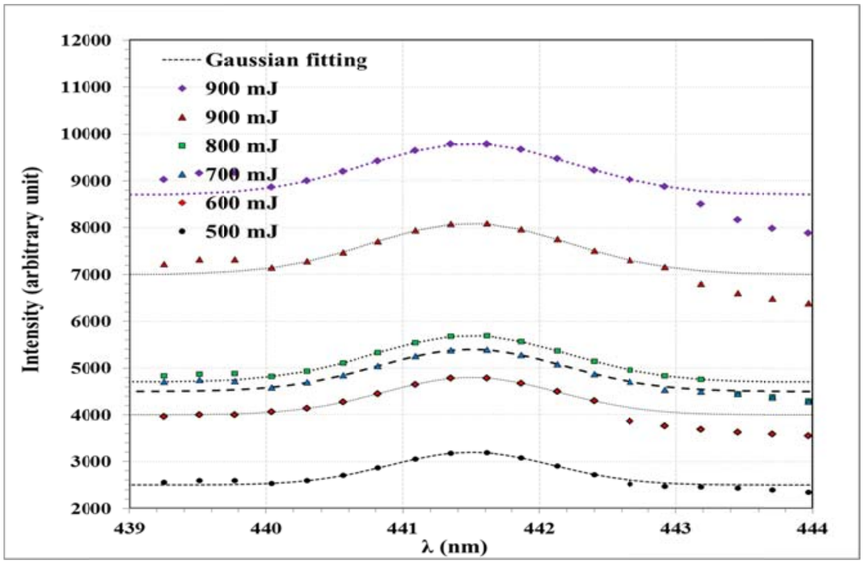

Fig.5: Variation in the signal intensity and width of the Cd(II) lines at 441.5 nm with different values of 1064 nm laser for CdTe:S.

Conclusions

For studying the plasma CdTe:S produced by laser, a Nd: YAG laser with a fundamental-wavelength Q-switched (1064 nm) laser was used. The plasma emission spectrum represents the transfer of neutral atoms and ionised Cd ions. The spectral line from the plasma laser emission intensity shows a strong dependence on environmental conditions. It has been find that the intensity of the power of different laser peaks increases as the peak laser power rises. It has been found that plasma parameters such as electron temperature, electron density, debye length and plasma frequency are very effective with laser energy. The results show that the change in electron temperature and electron density with laser energy shows that both increases with laser energy. An electron temperature of 1064 nm was calculated. In the case of laser-induced plasma, T_e, n_e and f_p increased, while λ_D levels reduced the plasma levels.

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