Study of the Spectroscopic Performance of Laser Produced CdTe, and CdTe:Ag Plasma.

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Abstract. This article, plasma parameters [(Te) electron temperature, (nₑ) electron density, (fp) Plasma frequency, (λD) Debye length , and (ND) Debye number], were studied by using a spectrometer that collects the laser spectrum produces cadmium telluride Plasma in different energies. As well as for CdTe: Ag for different card ratios. The electron temperature results for the CdTe range (0.699 - 0.738) ev also has an electron density of (2.867 - 4.430)*10¹⁸ cm⁻³ was measured under vacuum up to 2.5 x 10⁻² mbar. As well as for CdTe:AgTe range (0.738 - 0.606) and ne range(4.430 - 4.691)*10¹⁸ cm⁻³. The properties of CdTe and CdTe: Ag were determined throughoptical transmission method using the ultraviolet spectral spectrum inside range 190-1100 nm.

Keywords. Optical Emission Spectroscopic (OES), Cadmium telluride (CdTe), Laser-Induced Plasma Spectroscopic (LIPS).

1. Introduction
The characteristics of the plasma that introduced from interactions between Laser with solid targets depends upon numerous parameters describing the solid target has features like: pulse duration, laser wavelength, properties of the ambient medium, etc.[1]. That plasmas are a promising subject for much major and connected research. There are three stages of ablation method using lengthy pulse period lasers (greater than one ns). The first step, ray of the laser interrelates with the solid resultant speedy target surface ionization into a plasma on time scale short associated with the pulse duration. The second step, ray of laser competently absorbance thru the plasma was grows iso-thermally, and after ending of laser pulse, are resulting plasma cloud grows quasiadiabaticall on media, which can contain vacuum or gas, within or without applied fields that is the third stage [2]. A plasma is formed, Whenthe sample materialheats, ablates, atomizes, and ionizes by the energy from the laser pulse. A method based on the analysis of the radiationspectral gives out by plasma cause by focusing an intense laser pulse on the sample surface its known as Laser-induced breakdown spectroscopy (LIBS), also named laser-induced plasma spectroscopy (LIPS) or laser ablation spectroscopy (LAS). The intense laser pulse conceneters on the sample surface causes evaporation, atomization and ionization of the
material and produces a plasma, which expands and cools very rapidly. The ablation process in typical LIBS conditions is stoichiometric: analyze the atomic and ionic lines give out by the plasma provides the ID of the species current in the taster and their quantification.[3]

The composite semiconductor cadmium telluride [CdTe] is a II-VI and originate most right candidate for the production of thin-film solar cells proper to its optimal energy band gap (1.44eV) at room temperature and in the visible range (>105 cm⁻¹) high absorption coefficient.[4]

A main task is to determine of Plasma parameters in order to achieve the best understanding as a way to improve their application. Its main parameters such as the temperature, the electron density and the number densities of the different type current in the plasma. Spectroscopic methods are normally determine electronic temperature as the most chief parameter. In this kind of plasmas at atmospheric pressure the strong electron density allows, in general the assumption of the local thermodynamic equilibrium (LTE) and then use of the Boltzmann. Surface hardness versus normalized ionic to atomic lines intensities. The calculation for the plasma temperature by Saha–Boltzmann equations. The plasma electronic temperatures $T_e$ was conclude by using Boltzmann equation (1):

$$\ln(\frac{I_λ}{gA}) = -\frac{E_k}{kT_e} - \ln(\frac{4\pi Z}{hcN_0})$$ (1)

where the line intensity is $I$, the line wave length is $λ$, $E_k$ is the energy of the upper state, $Z$ is generally taken as the statistical weight of the ground state it is the partition function, $h$ is the Planck constant, $c$ is the speed of light, and $N_0$ is the population of the ground state. When the left hand of Eq. (1) is plotted versus $E_k$, from the slope of straight line we can deduce the plasma temperature, which is equal to $-1/kT_e$.[5]

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 1960s. 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 telling of by Gaussian, Lorentzian or Voigt profiles. The Doppler width is measured as stated by plasma temperature and atomic mass of the emitting kind. The line width Stark is get by using:

$$\Delta \lambda_{\text{Stark}} = w(\frac{n_{e,\text{ref}}}{n_e})^m$$ (2)

where $w$ is the Stark width at the reference electron density $n_{e,\text{ref}}$.[6]

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. Therefore, so can be simplified the equation:

$$n_e = \left[\frac{\Delta \lambda}{2\omega_0}\right] N_r$$ (3)

$\omega_0$ is the theoretical line full-width Stark broadening parameter, calculated at the same reference electron density $N_r \approx 10^{17} \text{ cm}^{-3}$

Debye shielding gives the plasma its quasi-neutrality characteristic. The shielding caused by reaction of charged particles to lower the effect of local electric fields is called Debye shielding, a distance $\lambda_D$, called the Debye length and defined as [7]:

$$\frac{1}{\lambda_D^2} = \frac{4\pi N_e}{\varepsilon_0} = \frac{4\pi N_r}{\varepsilon_0}$$
\[ \lambda_D = \left( \frac{\varepsilon_n k T_e}{n_e e^2} \right)^{1/2} = 743 \times \left( \frac{T_e}{n_e} \right)^{1/4} \tag{4} \]

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

2. Experimental setup

In this work a lens has a focal length of 10 cm has been used. A small beam waist can be produce by a shorter focal length lens, and for that reason, tougher breakdown, but it besides has a focus of smaller deepness, a graphic diagram for the LIBS setup shown in figure 1.

![Figure 1. Schematic of the experimental setup for the emission spectroscopy of the laser-induced plasma.](image)

By changing the distance between the target and the laser lens can be changed the diameter of laser spot. (9 ns) pulse duration using (6 Hz) duplication rate frequency. an exactly distance pending the measurements for precision. By using the emitted light from sample bombed by pulse laser the spectrometer was analyzed. To analyze emitted light it has been used the short response time spectrometer from Ocean Optics (HR 4000 CG-UV-NIR) in the setup. The optical fiber has been collected by the light produced by the ablated plasma. The optical fiber has been set at angle of about 45° degree to axes of the laser beam to avoid splashing and then guided to the entrance slit of the spectrometer. The spectrometer has a high accuracy depending on grating used in it, react wavelength from (200 to 900) nm with 3648 pixels. At 1064 nm NEODYMIUM: YAG laser is tightly fixated on the target to produce plasma Plume. In order to insure exposing a fresh surface after every train of shots the target surface was rotated manually. The spectrum of plasma with different value of energies varied from 500 mJ to 1000 mJ collect the Spectra of CdTe, and 1000 mJ collect the Spectra of CdTe:Ag each spectrum was gotten over a 300-800 nm wavelength range. In conclusion the results were studied and compared with Nationality Institute of Standards and Technology data (NIST) [8]. Then calculated parameters of plasma.
3. Results and discussions

Figure 2. show the CdTe target plasma induced by emission spectra of laser, which (CdTe plasma) confined in air in the spectral range (300-800) nm with different pulsed laser energy E=(500, 600, 700, 800, 900 and 1000) mJ. The optical emission spectra of CdTe: Ag target Plasma which confined in air were noted down using (OES) technique with pulse laser energy E=(1000)mJ with different concentrations (0, 0.3, 0.5, and 0.7).

![Emission spectra of laser-induced CdTe target in the air with different laser energies.](image)

**Figure 2.** Emission spectra of laser-induced CdTe target in the air with different laser energies.

Table 1. display the calculated electron temperature ($T_e$), fall width half maximum (FWHM), electron density ($n_e$), plasma frequency ($f_p$) and Debye length ($\lambda_D$) for CdTe target at different laser pulse energies. Measured all plasma parameters ($\lambda_D$, $f_p$ and $n_e$) were contented the criteria for the plasma. It shows that $f_p$ decrease with decrease laser energy because it is proportional with $n_e$, while $\lambda_D$ increasing.
Table 1. Parameters of plasma for CdTe in air with laser of different energy.

| E (mJ) | Te (eV) | FWHM (nm) | \(n_e \times 10^{18} \text{(cm}^{-3}\)) | \(f_p \times 10^{12} \) | \(\lambda_p \times 10^{-7} \text{(cm)}\) |
|-------|---------|-----------|---------------------------------|------------------|-------------------|
| 500   | 0.699   | 1.100     | 2.867                           | 15.204           | 3.669             |
| 600   | 0.716   | 1.200     | 3.127                           | 15.880           | 3.555             |
| 700   | 0.721   | 1.400     | 3.648                           | 17.152           | 3.302             |
| 800   | 0.732   | 1.500     | 3.909                           | 17.754           | 3.216             |
| 900   | 0.734   | 1.700     | 4.430                           | 18.901           | 3.025             |
| 1000  | 0.738   | 1.700     | 4.430                           | 18.901           | 3.034             |

The calculated values of the electron temperatures (Te) by using Boltzmann plot equation show that the electron density and electron temperature are increased through increasing the laser pulse energy, in the ambient air as shown in figure 3. At higher laser peak energy, \(n_e\) 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.

![Figure 3. The variation of the laser energy versus (Te) and (ne) for CdTe in air](image)

Boltzmann plot needs peaks that originate from the same ionization stage and the same atomic species, (peak is used Cd II species at 441.5 nm) for CdTe powder (pellet) in the ambient air as shown in figure (4). For each element it has been used the National Institute of Standard Technology database (NIST) for the experimental plots. The energies of higher levels, statistical weights, and transition probabilities have been obtained. As well, the electron temperature equals to the inverse of slope of the fitting line (the slope of the fitted line equals to \(-1/T\)). R2 is a statistical coefficient representing the best of the line-fitting which takes a value between (0, 1). The equation of fitting and the R2 were shown in the figure for all fitting lines. The better one has R2 value closer to 1.
Figure 4. Boltzmann plots of CdTe target with different laser energies in the ambient air.
The electron densities are calculated by using stark broadening equation (3) as shown in figures 5. The results collisions of charged species in the broadening of the line and the shift of the top wavelength results or form the Stark broadening of spectral lines in plasmas.

![Figure 5](image_url)

**Figure 5.** Variant of width & intensity of the Cd(II) positions at (441.5) nm with changed values of 1064 nm laser wavelength for CdTe in the ambient air.

The optical emission spectra of CdTe: Ag target plasma is shown on the figure (6)

![Figure 6](image_url)

**Figure 6.** Emission spectra of laser-induced CdTe:Ag target in air with different Ag concentration.
Table 2. shows that fp decrease with decrease of Ag ratio for the reason that the frequency of plasma proportional with n_e, however, $\lambda_{D}$ growing and increasing.

| Ag ratio | Te (eV) | FWHM (nm) | n_e*10^{18} (cm^{-3}) | fp *10^{12} (Hz) | $\lambda_{D} *10^{-7}$ (cm) |
|----------|---------|-----------|------------------------|-----------------|---------------------------|
| 0.0      | 0.738   | 1.700     | 4.430                  | 18.901          | 3.034                     |
| 0.3      | 0.700   | 1.770     | 4.613                  | 19.286          | 2.894                     |
| 0.5      | 0.624   | 1.800     | 4.691                  | 19.449          | 2.709                     |
| 0.7      | 0.606   | 1.800     | 4.691                  | 19.449          | 2.670                     |

Figure 7. (Te) and (ne) variation vs. different Ag concentration used for CdTe :Ag in ambient air.

The calculated values of the electron temperatures (Te) by using Boltzmann plot equation(1) show that the electron temperature is decreasing with increasing of Ag ratio but the electron density is increased with increasing the Ag ratio, in the ambient air as shown in figures (7).
Figure 8. Boltzmann plots of CdTe:Ag target with different Ag ratio in the ambient air.

The electron densities are calculated by using stark broadening for peak 441.5 nm and it be fitting by using lorentzian fitting.
5. Conclusions

For studying the plasma CdTe, and CdTe:Ag produced by the 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 ionized Cd ions. The spectral line from the plasma laser emission intensity shows a strong adaption on environmental circumstances. It has been discovered that the intensity of the power of different laser peaks increases as the peak laser power rises for CdTe Plasma, and its increases as the Ag ratio rises for CdTe:Ag Plasma. It has been found that the electron temperature, electron density, Debye length (plasma parameters), and plasma frequency are very effective with laser energy and with Ag concentration rises. The results show that the change in an electron density, and electron temperature with laser energy displays that both increases per laser energy for CdTe Plasma but for CdTe:Ag Plasma, electron density rises and electron temperature decreases with increasing of Ag Ratio. An electron temperature of 1064 nm was calculated.

5. References

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