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A Study of the Spectroscopic Performance of Laser Produced CdTe Plasma

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Abstract

In this work, the parameters of plasma (electron temperature (T_e), electron density n_e, plasma frequency (f_p) , Debye length (λ_D) and Debye number (N_D)) have been studied by using the spectrometer that collect the spectrum of Laser produce Cadmium telluride plasma at different energies. The results of electron temperature for CdTe range 0.93-1.18 eV also the electron density $5 \times 10^{10} – 3.8 \times 10^{11}$ cm^{-3} have been measured under vacuum reaching 2.5×10^{-2} mbar .Optical properties of CdTe 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).

1-Introduction

Laser-produced plasmas from interactions with solid targets are a promising subject for much fundamental and applied research. The characteristics of these plasmas depend upon many parameters characterizing the features of the target: properties of the ambient medium, laser wavelength, pulse duration etc.[1]. The ablation process using long pulse duration lasers (> 1 ns) is divided into three stages. In the first stage, the laser light interacts with the solid resulting in rapid ionization of the target surface into plasma on a time scale short compared with the pulse duration. In the second stage, the laser light is efficiently absorbed by the plasma which expands isothermally. In the third stage, after the end of the laser pulse, the resultant plasma plume expands quasi-adiabatically in a medium, which can include vacuum or a background gas, with or without applied fields[2], Sample types can be wide ranging because optical absorption processes initiate

LIBS sampling, thus, allowing analysis of solids, liquids, and gases[3]. Once the energy from the laser pulse heats, ablates, atomizes, and ionizes the sample material, a plasma is formed.

CdTe is a prototypical material in the zinc blende II–VI semiconductor family. It is widely used in various devices including γ - and x-ray spectrometers, solar cells, optoelectronic and optoacoustic modulators, and infrared windows [4]. Experimental measurements of the bulk band structure of CdTe have been reported in previous studies [5], but only for the (100) and (110) surfaces. High-resolution band mapping of CdTe(111) is thus far lacking for this important technological face.

The light of the plasma is then spectrally resolved and detected by a spectrograph and a detector. Both quantitative and qualitative information, such as elemental composition, can be deduced from the resulting plasma spectrum. Emission line properties such as widths, shapes, and shifts can provide information on plasma temperature and electron density[6], Plasma temperature is an important thermodynamic property due to its ability to describe and predict other plasma characteristics such as the relative populations of energy levels and the speed distribution of particles. The method used in this laboratory experiment is the ratio method using two lines of Hydrogen, which assumes that local thermodynamic equilibrium (LTE) is met within the plasma. Under Vacuum with pressure tell to 2.5 $\times 10^{-2}$ mbar, it has been shown through approximations that LTE is usually met after a couple hundred nanoseconds after plasma formation using LIBS with irradiances greater than 10^8 W/cm^2. The ratio method is a common way of reporting plasma temperature can be calculated through the intensity ratio of a pair of spectral lines of atom or ion of same ionization stage [7]. In LTE, The plasma temperature is calculated from the equation[7]:

$$T = \frac{(E_2 - E_1)}{k\, ln\left(\frac{I_1 \lambda_1 A_2 g_2}{I_2 \lambda_2 A_1 g_1}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Electron density (n_e) describes the number of free electrons per unit volume. There are several credible techniques used to determine electron density, including plasma spectroscopy, microwave and laser inter ferometry, and Thomson scattering. The determination of electron density by linear Stark broadening of spectral lines, as used in this lab, is a well established technique. Line broadening in LIBS plasmas is caused primarily by Doppler width and the Stark effect. Doppler width is dependent only on the temperature and atomic mass of the emitting species; this type of broadening is disregarded in this experiment as the Doppler width of the hydrogen line used is usually between 0.04 nm and 0.07 nm. The Stark effect is considered a type of pressure broadening that involves interactions of radiators and neighboring particles. In plasmas, these interactions are caused by collisions of ions and to lesser extent electrons. The Stark effect is mainly responsible for the line broadening of the hydrogen line used in this experiment.[6,8]

Saha-Boltzmann equation utilizes spectral lines of the same element and successive ionization stages. the Saha- Boltzmann equation is given as[7]:

$$n_e = \frac{I_1}{I_2^*} 6.04 \times 10^{21} (T)^{3/2} e^{\frac{(E_1 - E_2 - X_Z)}{kT}} \quad (cm^{-3}) \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where

$$I_2^* = \frac{I_2 \lambda_2}{g_2 A_2} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

X_z is the ionization energy of the species in ionization stage z in eV, Tz is the line intensity for transition from upper level-2 to lower level-1, $\lambda_2$is the corresponding wavelength of transition from level-2 to level-1, g_2 is the statistical weight of transition from level-2, $A_2$is the transition probability from level-2 to level-1 and T_e is the electron temperature The subscript *z* denotes the ionization stage of the species for the referred.
While the plasma frequency is calculate from the equation [9]:

$$f_p \approx 8.98 \sqrt{n_e} \ \text{(Hz)} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

This frequency, depending only on the plasma density, is one of the fundamental parameters of plasma. Because of the smallness of *m,* the plasma frequency is usually very high.[9]
The response of charged particles to reduce 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 [10]:

$$\lambda_D = \left(\frac{\varepsilon_o k T_e}{n_e e^2} \right)^{1/2} = 743 * (T_e / n_e)^{1/2} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

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where :- λ_D : is the Debye length (cm) ,L: is the system dimension(cm) ,n_e : is the density of the electron $\left(m^{-3}\right)$,T_e: is the electron Temperature (K) , e : is the electron charge (C) and N_D also known as the number of particles in the Debye sphere which is dependent on electron density and electron temperature this Second condition for plasma existence $N_D >>> 1$ as follows[12]:

$$N_D = \frac{4\pi}{3} n_e \lambda_D^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

2-Experimental Setup

The diameter of laser spot can be changed by changing the distance between the laser lens and the target. Pulse duration (9 ns) with 6 Hz repetition rate frequency. The exactly distance during the measurements for system accuracy and precision. In this work a lens of 10 cm focal length has been used. A shorter focal length lens can produce a small beam waist, and therefore, stronger breakdown, but it also has a smaller depth of focus, Figure 1 shows a schematic diagram for the LIBS setup (1).

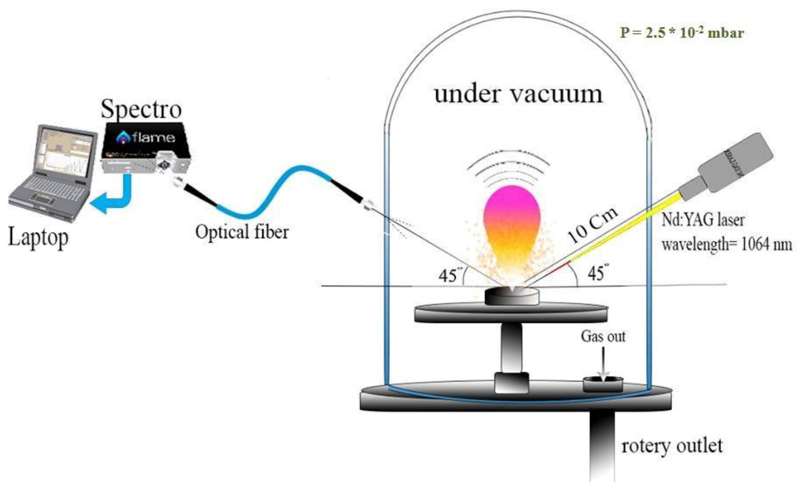

Figure 1: Laser Induced Plasma Spectroscopy (LIPS) System configuration

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

The light produced by the ablated plasma was collected by the optical fiber which was 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 resolution depending on grating used in it, and responds to a wavelength between 200-900 nm with 3648 pixels. Nd: YAG laser at 1064 nm is tightly focused 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 Pb, each spectrum was obtained over a 300-800 nm wavelength range.

Finally the results were analyzed and compared with National Institute of Standards and Technology data (NIST) [13]and evaluate the plasma parameters.

3-Results and Discussion

Figure (2) show the emission spectra of laser induced CdTe target plasma which confined in Vacuum in the spectral range (300-800) nm with different pulsed laser energy E=(400,600,800) mJ

The optical emission spectra of Pb target plasma which confined in vacuum were recorded using (OES) technique.

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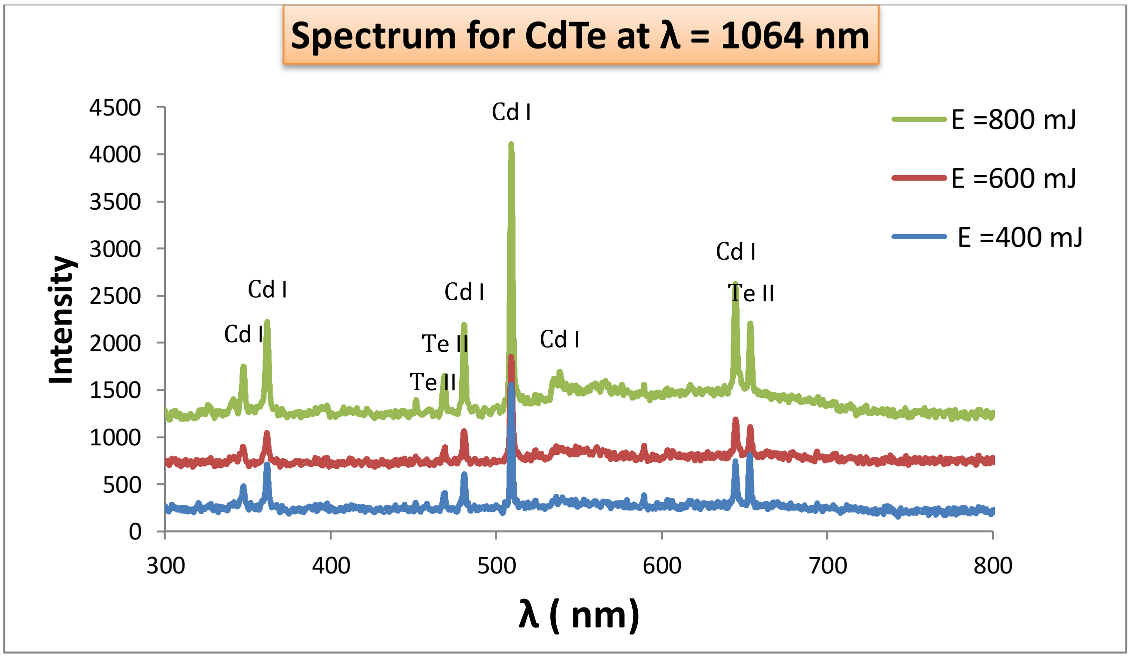

Figure 2: Emission spectra of laser induced CdTe target in Vacuum with different laser energies

Tables (1) display the calculated electron density (n_e), electron temperature (T_e), plasma frequency (f_p), Debye length (λ_D),) and Debye number (N_D) for CdTe target at different laser pulse energies. All calculated plasma parameters (λ_D, fp and N_D) were satisfied the criteria for the plasma. It shows that fp decrease with laser energy because it is proportional with n_e, while λ_D and N_d increasing.

Table 1: plasma parameters for Pb in Vacuum with different laser energy

Laser energy (mJ)	Te (eV)	n_e (cm^{-3})	f_p (Hz)	λ_D (cm)	N_d
800	1.180	3.85E+11	5.6E+09	1.2E-01	2.8E+09
600	1.039	1.36E+11	3.3E+09	1.9E-01	4.0E+09
400	0.930	4.96E+10	2.0E+09	3.0E-01	5.5E+09

The variation of (T_e) and (n_e) was determining the Ratio Method using two lines of CdTe (CdTe(111) in this part) .is shown in Figures (4) for different laser energies.

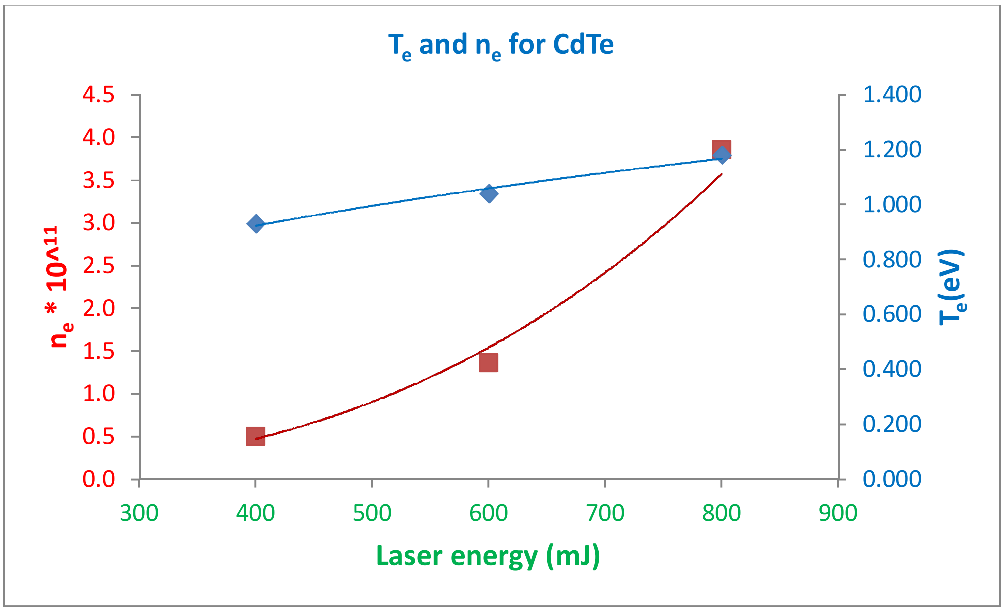

Figure 4: The variation of (T_e) and (n_e) versus the laser energy for CdTe in Vacuum

The higher calculated values of electron temperature T_e (Eq.1) in the vacuum is attributed to the high kinetic energy of free electrons in the plasma comparing with more collisions present in other media caused energy transfer to species by numerous ways and presence of secondary charged particles. It can be seen that the electron temperatures shows in fig.5, a slow linear increase as the laser peak energy increased; which is due to the absorption of laser photon by the plasma, and at the same time the plasma is relatively transparent to the laser beam.

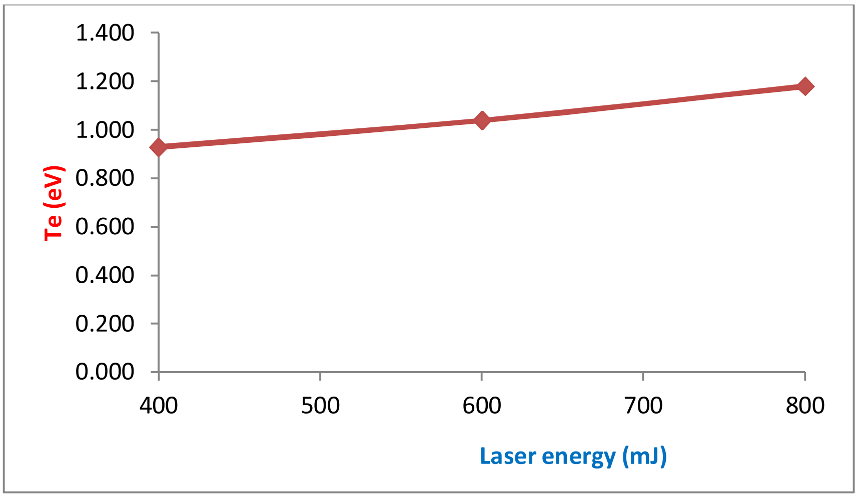

Figure 5: electron temperatures for CdTe in Vacuum different laser energies

Electron density is an important parameter that is used to describe a plasma environment and is also crucial for establishing thermodynamic equilibrium. The electron density (n_e)

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in the plasma can be measured from the emission coefficient and intensity of spectral lines using the Saha- Boltzmann equation.

Figure (6) show electron densities of laser induced plasma for CdTe component target in the vacuum, at different laser peak energies, respectively. It can be seen that the electron density varies directly with varying laser peak energy. It can be noticed at a given laser energy that the value of electron density vacuum is proportional with laser energy. This results agree with (M. HANIF and et-al)[4].

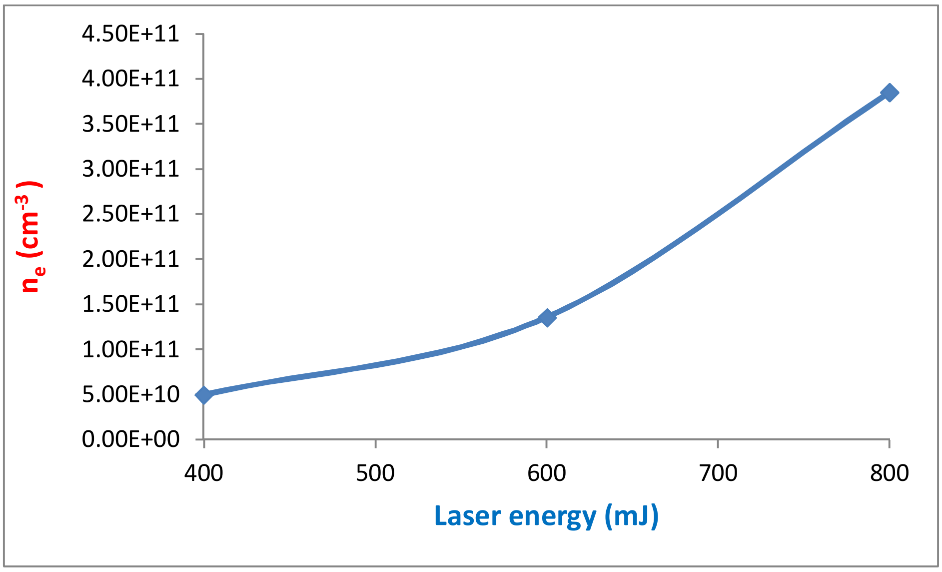

Figure 6: electron densities for CdTe in vacuum different laser energies

Figure (7) show plasma frequency in Vacuum laser induced plasma for CdTe Component target. Form the figure it is seen that the plasma frequency increase with the increase of the laser peak power as shown in Table (1).

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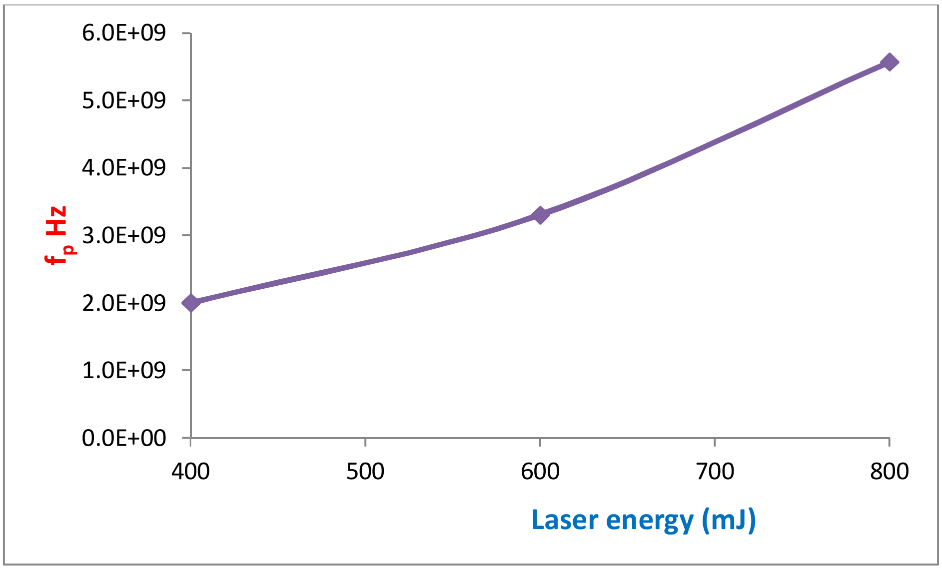

Figure 7: plasma frequency vs. Laser peak energy of laser induced CdTe target plasma

Figure (8) Illustrates Debye shielding length of CdTe component target plasma, induced by Nd:YAG laser irradiation in Vacuum media as a function of laser peak energy.
From this figure, it's appeared that for a given laser energy the Debye length in Vacuum is higher Value at low energy, because Debye length depends on plasma temperature and plasma density (varies directly with $\sqrt{T_e}$ and inversely with $\sqrt{n_e}$). Since the value of electron temperature is larger Vacuum, then the Debye length is greater at low energy.

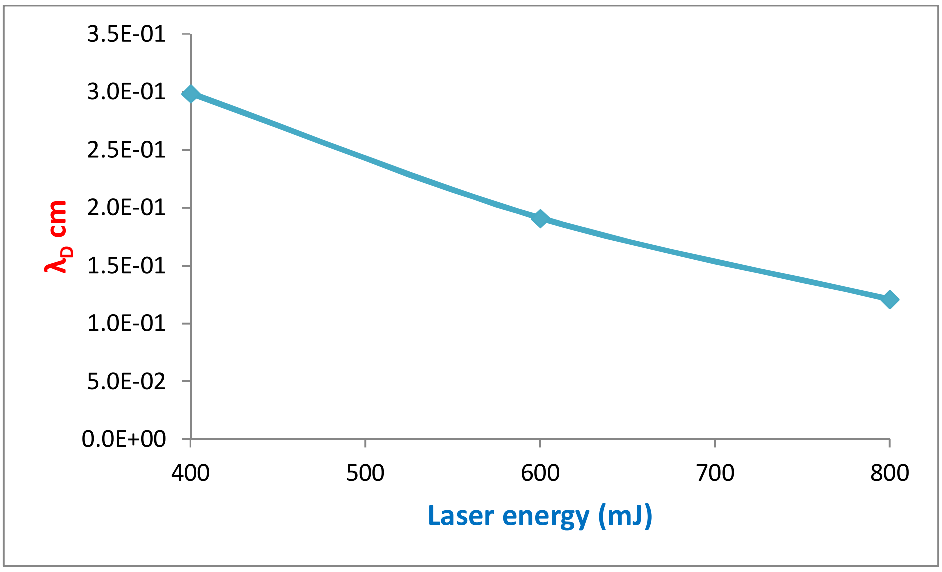

Figure 8: Debye length for CdTe in Vacuum different laser energies

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Number of particles in Debye sphere (N_D) are calculated using Eq.(6). It showed from figure (9) that for a given laser energy the Debye sphere N_D in Vacuum , The higher values of N_D at low energy due to that it's dependent on n_e and T_e, because of the values of T_e in Vacuum is high, and the values of n_e are smaller leads to increase N_D values in Vacuum.

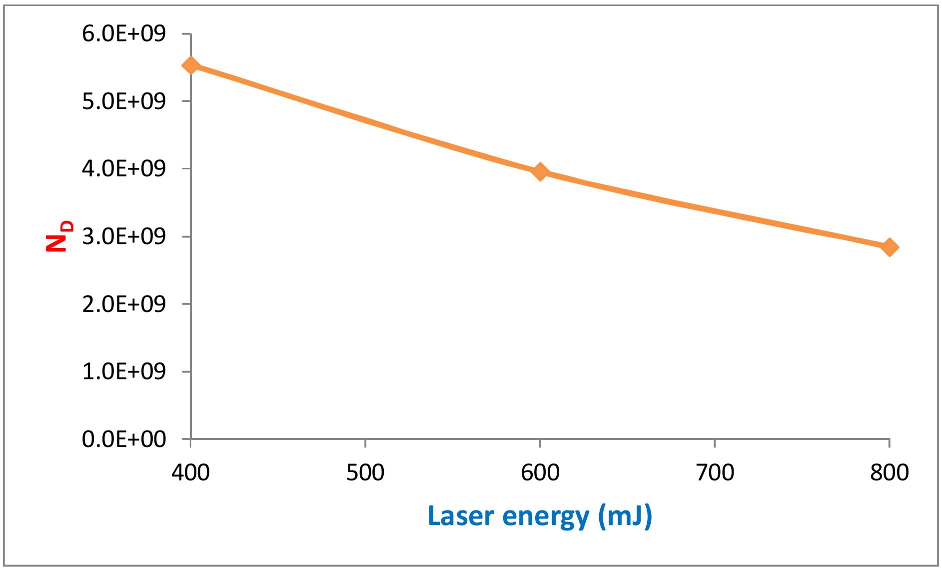

Figure 9: Debye number for CdTe in vacuum different laser energies

4-Conclusions

A Q-switched Nd:YAG laser at its fundamental wavelength (1064 nm) was used to study the laser produced lead plasma. The emission spectrum of the plasma reveals transitions of neutral atoms and singly ionized lead ions. The spectral lines intensities of the laser induced plasma emission exhibited a strong dependence on the ambient conditions. It is found that the intensities at different laser peak powers increase with increasing laser peak power and then decreases when the power continues to increase. Plasma parameters such as electron temperature, electron density, Debye length, number of particles in Debye sphere and plasma frequency are found to be strongly effective by the laser energy. The results showed variations of the electron temperature and the electron number density with the laser energy indicate that both increase with increasing in laser energy. The electron temperature calculated for the 1064 nm that the values of T_e ,n_e and f_p were increased in case of laser induced plasma in vacuum environment while the values of λ_D and N_D were decreased in laser induced plasma vacuum environment.

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