An Investigation of the Effect of Time Exposure of Nonthermal Plasma on the Optical Properties of CdO Thin Film Prepared by Pulsed Laser Deposition.

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Abstract. The optical properties of pure (CdO) films have been studied through the measuring of the absorbance spectrum and transmittance spectrum using (UV-VIS) spectrometer within the range of wavelengths (310-1100) nm, and the results showed that the electronic transitions of pure (CdO) films prepared have allowed direct transition type, and the optical energy gap type was identified and was direct energy gap and it was found that the value of the energy gap decreases when the deposition time increases by using (Nd:YAG) laser, and it was also found that the energy gap decreases by the increase of the exposure time to non-thermal plasma. It was observed that the increase of laser deposition time leads to the decrease of the absorbance before the exposure to non-thermal plasma, but the absorbance increases by the increase of the exposure to non-thermal plasma. Absorption Coefficient was also calculated and its value was higher than ($\alpha > 10^4$ cm$^{-1}$) in the high absorption region.

1. Introduction

Cadmium Oxide (CdO) is a chemical inorganic compound [1], energy gap (2.21-2.95) eV made it be used as transparent conducting materials in the form of thin films in many practical applications and different technological industries [2]. The (CdO) is used as thin films in the manufacturing of the photic transistors, thin films transistors, anti-reflection coatings and the reflection coatings as well [3]. And because it has high transmittance of the wavelengths range within the visible area and (NIR) region so it was classified within the groups of the transparent conducting oxides, and so it is used as a thermal transparent material in the windows of the cars and planes [3-5]. CdO is classified as a semiconductor of n-type [6]. In this research, we prepared thin films of CdO by PLD with different deposition times and studied the effect of exposure time of non-thermal plasma on the films.

2. Experimental Procedure.

In this study, CdO powder supplied by Aldrich Chemical Company, Inc. - Germany with purity 99.9% has been used as a material for preparing CdO film by PLD. The powder of CdO has been compressed to make pellets using hydraulic compressor manufactured in China with 8 tons. The pellets diameter was (2 cm), and its thickness (3 mm). Borosilicate glass used as substrate with dimensions (7.6 × 2.5) cm$^2$ and their thickness 1mm supplied by China National Machinery. The glass substrates have been cleaned according to conditions of standard cleaning. Thin films of CdO were prepared using PLD method on the glass substrate. The glass substrates were placed on substrate holder in front of the target surface so the target surface becomes parallel to the base substrate.
permanently. The target CdO pellet is placed on a rotary target holder. The distance between the glass substrate and the target was (5.5 cm), and it is fixes for all films. Then, the (Nd-YAG) laser beam, with laser energy (100 mJ), wavelength (1064 nm), frequency (5 Hz), at pressure (0.5x10^{-1} mbar), at room temperature and through the vacuum chamber, has been focused on the rotary target surface inside the deposition chamber and the angle was 45°. Then, all the valves of this system were closed as well as the vacuum chamber, the system was evacuated from the air to get vacuum pressure (0.5x10^{-1} mbar) at different deposition times (5,10,15) sec. The vacuum chamber with cylindrical form of Pyrex glass with diameter (20 cm), height (30 cm) an thickness (5 mm) the chamber has closed top and opened bottom. Absorbance spectrum have been made in the range of the wavelengths (310-1100) nm of all the CdO films prepared using (UV-Visible – Mega-2010) spectra photometer

3. The exposure of deposited (CdO) to non-thermal plasma.
The plasma system was initialized and the preparation process included the preparation and cleaning of the electrodes. These electrodes are made from Aluminum and the distance between the electrodes was 4 cm, these distance constant for all the samples, until the (5x10^{-1} mbar) pressure was gained, and after the samples were exposed to non-thermal plasma at two different times, (30) minutes and (60) minutes. The voltage and current were both constant for all the samples exposed to the non-thermal plasma. (I = 14mA, V= 375 V).

4. The results and discussion.
Optical properties which involve transmittance and absorbance spectra as a function of incident wavelength, absorption coefficient and optical energy gap for ZnO thin films were measured. The formula that connects the absorption and the transmittance according law of energy conservation [7] is:

\[ R + T + A = 1 \]

where A: absorbance, T: transmittance, R: reflectance.

The absorption coefficient \( \alpha \) of CdO films was calculated from the following formula [8]:

\[ \alpha = 2.303 \left( \frac{A}{t} \right) \]

where \( \alpha \) : absorption coefficient, \( t \) : the film thickness.

Thickness of the films was measured by optical method, it has been calculated using the following formula [9]:

\[ t = \frac{\Delta \times \lambda}{2} \]

where \( \lambda \) : is the wavelength of incident laser beam (nm), \( x \) : is the shining fringe width (nm), \( \Delta x \) : is the opaque fringe width (nm).

The optical energy gap of the direct allowed transition of the pure (CdO) films has been calculated using the formula [10].

\[ (\alpha \hbar \nu) = B \left( \hbar \nu - E_g \right)^r \]

where \( E_g \) : energy gap, \( B \) : a constant depending on the material quality, \( \hbar \nu \) : photon energy, \( r \) : exponential coefficient depends on the type of transitions (\( r = 1/2 \)), and it called Tauc relation.

4.1. Absorbance Spectrum (A)
All the measurements of absorbance spectrum have been made in the range of the wavelengths (310-1100) nm of all the CdO films prepared using (UV-Visible – Mega-2010) spectra photometer, the following figures (1,2, and 3) show the absorption spectrum as a function of the wavelength of the pure CdO films prepared by (PLD) method and at different deposition times (5,10,15) sec using (Nd:YAG) laser before and after the exposure to non-thermal plasma at (30, 60) min, at room temperature. The highest value of the absorbance was at (UV) region and on this base the CdO film material of high absorbance could be used in the (UV) region of the electromagnetic spectrum in the detective applications. When comparing this result to the
researcher's results it was found that it agrees with the researcher [11]. Figures 1, 2 and 3 showed that the increase of laser deposition time leads to the increase of the thickness of the prepared film and so the increase of the thickness leads to the decrease of the film's ability to absorb the incident photons of the deposited films before the exposure to the plasma, while after the exposure of the deposited films to the non-thermal plasma as shown in the figures, it was clearly observed that the increase of the absorbance of the deposited films after the exposure to non-thermal plasma by the increase of the wavelength, the reason for that is the increase of the exposure to plasma increases the packing factor of the prepared film and so leads to the increase of the possibility of interaction between the falling photons and the film material.

**Figure 1.** (Absorption spectrum of (CdO) films as a function of photon wavelength before and after the exposure to non-thermal plasma, deposition time of (5) sec).

**Figure 2.** (Absorption spectrum of (CdO) films as a function of photon wavelength before and after the exposure to non-thermal plasma deposition time of (10) sec).
4.2-Transmittance Spectrum  ($T$)

The transmittance spectrum behaves contrary to the absorbance spectrum, and the figures (4, 5 and 6) show the transmittance spectrum as a function to the wavelength of the pure (CdO) films prepared by (PLD) method, at different times (5, 10, 15) sec using (Nd:YAG) laser before and after the exposure to non-thermal plasma at (30, 60) min at room temperature, the figures show that the transmittance increases by the increase of the wavelength of the pure (CdO) prepared before the exposure to non-thermal plasma, the pure (CdO) films show high transmittance increases by the increase of the wavelengths in the two regions the (VIS-NIR), the transmittance reaches to approximately (75\%) of the prepared samples, this means that these films can be used as an optical window of the solar cells because this active spectrum region of the solar cells is found in the visible region of the electromagnetic spectrum, and this makes the researchers more interested in using the (CdO) films as optical windows in the solar cells. When comparing this result with the results of the researchers, it was observed that it agrees with the researchers. 

When the prepared the pure (CdO) films prepared to non-thermal plasma, it is observed that by the increase of the exposure time to non-thermal plasma leads to the decrease of the transmittance as shown in the figures.

Figure 3. (Absorption spectrum of (CdO) films as a function of photon wavelength before and after the exposure to non-thermal plasma deposition time of (15) sec).

Figure 4. (Transmittance spectrum of (CdO) films as a function of photon wavelength before and after the exposure to non-thermal plasma deposition time of (5) sec)
Figure 5. (Transmittance spectrum of (CdO) films as a function of photon wavelength before and after the exposure to non-thermal plasma deposition time of (10) sec).

Figure 6. (Transmittance spectrum of (CdO) films as a function of photon wavelength before and after the exposure to non-thermal plasma deposition time of (15) sec).

4.3-Absorption Coefficient (α)
Absorption coefficient of CdO films has been calculated from the formula (2), the figures (7,8 and 9) show the change of absorption coefficient as a function of the energy of the incident photon of CdO films prepared by PLD method and at different deposition times (5,10,15) sec using (Nd:YAG) laser before and after the exposure to non-thermal plasma at (30, 60) min, at room temperature. The value of the absorption coefficient is higher than ($\alpha >10^4 \text{ cm}^{-1}$) in the high absorption region, the value of the absorption coefficient increases continuously of the energy ranges which are higher than the value of the energy gap before the exposure to non-thermal plasma that's to say the absorption coefficient has high values in the range of high energies, and this is an indicator to the great possibility of the occurring of direct electronic transitions between valence band and conduction band. When comparing this results with the results of the researchers, it was observed that it agrees with the researchers [11, 14]. The figures (3,8 and 9) show that the absorption coefficient increases by the
increase of the deposition time using (Nd:YAG) laser, and the reason of the increase of \((\alpha)\) is the absorption of the prepared films increased by the increase of the laser deposition time because the thickness of the prepared films increased and \((\alpha)\) increased when the exposure time to plasma increased because the of the high arrangements of its particles after the exposure to plasma, while in the case of the exposure of pure (CdO) films deposited to non-thermal plasma as it clearly appears in the figures the increase of \((\alpha)\) by the increase of the exposure to non-thermal plasma.

**Figure 7.** The absorption coefficient as a function to the photon energy of the CdO films before and after the exposure to non-thermal plasma at (30, 60) min, deposition time (5) sec

**Figure 8.** The absorption coefficient as a function to the photon energy of the CdO films before and after the exposure to non-thermal plasma at (30, 60) min, deposition time (10) sec
Figure 9. The absorption coefficient as a function to the photon energy of the CdO films before and after the exposure to non-thermal plasma at (30, 60) min, deposition time (15) sec.

4.4-Optical energy gap ($E_g$)

In this study, the type of the energy gap was determined by knowing the absorbance coefficient and it was a direct energy gap because the lowest value of the absorbance coefficient of the pure (CdO) films was $(10^4 \text{cm}^{-1})$. ($E_g$) of the allowed direct transition of the pure (CdO) films prepared has been calculated through formula (4), by the substitution of the value of ($r$) by ($r=1/2$) of the allowed direct transition, and by drawing the figure that shows the relation between ($\alpha h\nu$), the falling photon energy ($h\nu$), the extending of the straight from the drawn curve until it intersects with energy axis ($h\nu$) at the point ($\alpha h\nu)^2 = 0$) to get the value of the optical energy gap of the allowed direct transition of the pure (CdO) prepared films, the figure (10,11 and 12) show the change of the ($\alpha h\nu)^2$ as a function to the falling photon energy of the pure (CdO) films prepared by (PLD) method at different deposition times (5,10,15) sec. using (Nd:YAG) laser before and after the exposure to non-thermal plasma at (30,60) min, at room temperature. The figures showed that the value of the energy gap of the allowed direct transition of the pure (CdO) films decrease by the increase of the laser deposition time before the exposure to plasma as shown in table (1), the value of ($\alpha$) was higher than $(10^4 \text{cm}^{-1})$ and that proves that ($E_g$) of pure (CdO) films is a direct energy gap, when comparing these results with the results the researchers, it was found that they agree with [15]. After the pure (CdO) films have been exposed to non-thermal plasma at (30,60) min, the figures showed that when the exposure time to non-thermal plasma increases, the ($E_g$) decreases as shown in table (1) the reason why the ($E_g$) value decreases by the increase of the plasma exposure time is that the exposure to non-thermal plasma led to the generating and emerging of positioned levels among the energy gap and that the exposure to non-thermal plasma leads to the directing of energy on the deposited films leading to the rearrangement of the particles and so creating positioned levels near the conduction band and valance band. It is necessary to explain that the reason of difference of the values of ($E_g$) is that the difference of the films thickness and their preparation method.
Figure 10. Optical energy gap of the CdO before and after the exposure to plasma at (30,60) min deposition time (5) Sec.

Figure 11. Optical energy gap of the CdO before and after the exposure to plasma at (30,60) min deposition time (10) Sec.

Figure 12. Optical energy gap of the CdO before and after the exposure to plasma at (30,60) min deposition time (15) Sec.
Table 1. Shows the values of \(E_g\) of the pure (CdO) films before and after the exposure to non-thermal plasma.

| Deposition time (Sec.) | \(E_g\) (eV) Before the exposure plasma | \(E_g\) (eV) After the exposure plasma |
|------------------------|----------------------------------------|--------------------------------------|
|                        |                                        | 30 min.                              | 60 min.                              |
| 5                      | 2.4                                    | 2.2                                  | 2.1                                  |
| 10                     | 2.3                                    | 2.25                                 | 2                                    |
| 15                     | 2.2                                    | 2.1                                  | 2                                    |

5. Conclusion

All the measurements of both absorbance spectrum and transmittance spectrum have been made in the range of the wavelengths (310-1100) nm of CdO films which were prepared in this work by the (PLD) method. The highest value of the absorbance was in the (UV) region before the exposure to plasma. It was observed that the absorbance decreases by the increase of the laser deposition time and the increase of the wavelength before the exposure to plasma. It was found that the absorbance of the deposited films increases after the exposure to the plasma by the increase of the wavelength. The transmittance reached to approximately (75\%) in the prepared samples in the (VIS) and (NIR) regions. The (\(\alpha\)) of the pure (CdO) film is \((\alpha>10^4\ cm^{-1})\) in the high absorbance region. It was found that (\(E_g\)) of the pure (CdO) films prepared by (POLD) method is a direct energy gap. These results may be useful for many of optical applications.
6. References

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