Study the Effect of Indium on the Urbach Energy and Dispersion Parameters of CdO Thin Films

Tahseen H. Mubarak\(^1\infty\) Sami Salman Chiad\(^2^*\) Mahmood M. Kareem\(^3\) Nadir Fadhil Habubi\(^2^#\) Mohamed Odda Dawod\(^4^~\) Ehssan S. Hassan\(^4^\)

\(^1\)Department of Physics, College of Science, University of Diyala, Diyala, Iraq \(^2\)Department of Physics, College of Education, Mustansiriyah University, Baghdad, Iraq
\(^*\) Email: dr.sami@uomustansiriyah.edu.iq
\(^#\) Email: nadirfadhil@uomustansiriyah.edu.iq
\(^3\)Department of Physics, College of Education, University of Garmian, Kalar, Iraq
\(^~\) Email: mahmood.mohammed@garmian.edu.krd
\(^4\)Department of Physics, College of Science, Mustansiriyah University, Baghdad, Iraq
\(^\sim\) Email: mohammedodda2017@uomustansiriyah.edu.iq
\(^\allowbreak^\sim\) Email: ehsanphysicyan@uomustansiriyah.edu.iq
\(^\infty\) Corresponding author. Email: dean@sciences.uodiyala.edu.iq

Abstract
CdO thin films have been deposited onto glass substrate by chemical spray pyrolysis. Transmittance and reflectance spectra in the range 300-900 nm were recorded via UV-Visible spectrophotometer for various In-content in the CdO:In thin films. Transmittance decreased with increasing In-content in the CdO:In thin films, while the reflectance slightly increased in the wavelength more than 480 nm. Urbach energy decreased with increasing In-content in the CdO:In thin films. Dispersion parameters are calculated, and find that \(E_d\), \(E_o\), \(\varepsilon_\infty\), \(n(0)\), \(S_o\), \(M_1\) and \(M_3\) are increased with increasing In-content in the CdO:In thin films.

Keywords: Thin films, CdO:In, Spray pyrolysis, reflectance, Dispersion,

Introduction
Transparent conducting oxide (TCO) thin films have great importance in electronic device applications and among these TCOs, cadmium oxide (CdO), an n-type semiconductor with band gap of 2.5 eV [1]. In the thin film form, it finds applications in sensor devices, photodiodes, transparent electrodes, phototransistors and solar cells[2].
Various techniques have been employed to prepare CdO thin films such as spray pyrolysis [3], sputtering [4,5], solution growth [6], activated reactive evaporation [7], pulsed laser deposition [8] and sol-gel method [9]. Urbach energy and dispersion parameters of CuO thin films were calculated and study the effect of In content on these films.

**Experimental Part**

0.1M of Cd(CooCH₃)₂(supplied from Sigma-Aldrich Chemicals) dissolve in re-distilled water and an aqueous solution of 0.1M of InCl₃( 2% and 4% volume) (supplied from Sigma-Aldrich Chemicals) were used as precursor materials to obtain the deposited films by chemical spray pyrolysis on glass substrate. The optimum conditions were arrived at the following parameters: Substrate temperature was kept at 350 °C during deposition process, the distance between nozzle and substrate was 28 cm, compressed air was used as a carrier gas, and rate of deposition was 2 ml/min. Thickness was obtained by gravimetric method was about 350 nm. Double beam UV-Visible spectrophotometer was used in order to record the absorbance spectra and calculate the optical parameters.

**Results and Discussion:**

The obtained results measured that recorded from UV-Visible spectrophotometer is plotted in Fig.1 for In-doped CdO thin films prepared by chemical spray pyrolysis. From this figure, it can notice the decreases of transmittance with increasing In-doping in the CdO thin films, and also decreased with decreasing wavelength (at high photon energy, the absorbance of films increases leads to decreasing transmittance).
Fig. 1: Transmittance spectra of CdO:In thin films with various In-doping.

The reflectance (R) has been found by using the relationship:

\[ R + T + A = 1 \quad \ldots \quad (1) \]

where T and A is the transmittance and absorbance respectively. The reflectance spectra versus wavelength was plotted in Fig. 2. The reflectance increased slightly with increasing In-doping at wavelength more than 480 nm.
The optical conductivity was calculated using the relation [10]:

$$Q = \frac{\alpha \cdot n \cdot c}{4\pi} \quad \ldots \quad (2)$$

where $\alpha$ is absorption coefficient, $n$ is refractive index, and $c$ is speed of light. The optical conductivity as a function of wavelength was plotted in Fig. 3. From this figure, it can notice the slight decreases with increasing In-doping at wavelength more than 480 nm for pure and In-doped CdO thin films.

The absorption edge gives a measure of the energy band gap and the exponential dependence of the absorption coefficient, in the exponential edge region, the Urbach rule is expressed as [11]:

$$\alpha = \alpha_o \exp \left( \frac{h\nu}{E_U} \right) \quad \ldots \quad (3)$$

where $\alpha_o$ is a constant, $E_U$ is the Urbach energy, which characterizes the slope of the exponential edge. The values of $E_U$ are obtained from plotting relation between $\ln \alpha$ versus photon energy ($h\nu$) as in Fig. 4, the slope value represent the Urbach energy.
These values are listed in Table 1. The absorption in this region is due to the transitions between the extended states in one band and the localized states in the exponential tail of the other band. From the Table, the Urbach energy decreased with increasing In-content in CdO thin films.

![Graph](image)

Fig. 4: Lna versus hν of CdO:In thin films with various In-doping.

The refractive index dispersion for crystallized and amorphous materials can be expressed as [12]:

\[ n^2 - 1 = \frac{E_o E_d}{E_o^2 - E^2} \quad \text{.....(4)} \]

Where \( n \) is the real part of refractive index, \( h\nu \) is the photon energy, \( E_o \) is the average excitation energy for electronic transitions and \( E_d \) is the dispersion energy, which is a measure of the strength of interband optical transitions. This model describes the dielectric response for transitions below the optical gap.

By plotting \((n^2-1)^{-1}\) vs. \((h\nu)^2\) and fitting a straight line, the values of the parameters \( E_o \) and \( E_d \) were calculated from \((E_o / E_d)\) represents the intercept on the vertical axis and \((E_o E_d)^{-1}\) is the slope of the plot, this shown in Fig. 5.
The refractive index at infinite wavelength ($n_\infty$) can be determined from the following relation [13]:

$$\frac{n_\infty^2 - 1}{n^2 - 1} = 1 - \left(\frac{\lambda_0}{\lambda}\right)^2 \quad (5)$$

The plot of $(n^2-1)^{-1}$ versus $(h\nu)^2$ was plotted to find the values of $(n_\infty)$ of CdO:In thin films. These values are shown in Table 1.
The $M_1$ and $M_3$ moments of the optical spectra have obtained from the following relations [14]:

$$E_d^2 = \frac{M^3_1}{M_3} \quad \text{and} \quad E_o^2 = \frac{M_1}{M_3} \quad \ldots (6)$$

The values of $M_1$ and $M_3$ moments of the optical spectra are increased with increasing In-content in the CdO:In thin films as shown in Table 1.

**Table 1: Some optical parameters of CdO:In thin films.**

<table>
<thead>
<tr>
<th>Sample</th>
<th>$E_d$ (eV)</th>
<th>$E_o$ (eV)</th>
<th>$E_g$ (eV)</th>
<th>$\varepsilon_{\infty}$</th>
<th>$n(o)$</th>
<th>$M_1$</th>
<th>$M_3$ eV$^2$</th>
<th>$S_o \times 10^{13}$ m$^{-2}$</th>
<th>$\lambda_o$ nm</th>
<th>$U_{em}$ eV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure</td>
<td>21.87</td>
<td>4.81</td>
<td>2.406</td>
<td>5.545</td>
<td>2.35</td>
<td>4.54</td>
<td>0.196</td>
<td>1.01</td>
<td>592</td>
<td>769</td>
</tr>
<tr>
<td>2 %</td>
<td>24.25</td>
<td>4.85</td>
<td>2.425</td>
<td>6.000</td>
<td>2.45</td>
<td>5.00</td>
<td>0.212</td>
<td>1.07</td>
<td>599</td>
<td>740</td>
</tr>
<tr>
<td>4 %</td>
<td>27.47</td>
<td>5.03</td>
<td>2.517</td>
<td>6.560</td>
<td>2.56</td>
<td>5.50</td>
<td>0.219</td>
<td>1.10</td>
<td>615</td>
<td>704</td>
</tr>
</tbody>
</table>

**Conclusions**

CdO thin films with various amounts of In-content have been deposited onto glass substrate by chemical spray pyrolysis. Transmittance spectra in the range of 300-900 nm decreased with increasing In-content in the CdO:In thin films. Urbach energy decreased
with increasing In-content in the CdO:In thin films, while the energy gap increased from 2.406 eV to 2.517 eV after additive of 4% In in the CdO:In thin films. Dispersion parameters such as: $E_d$, $E_o$, $\varepsilon_\infty$, $n(0)$, $S_o$, $\lambda_o$, $M_1$ and $M_3$ are decreased with increasing In-contain in the CdO:In thin films.

References


