SPIN COATING METHOD FABRICATED OF In$_2$O$_3$ THIN FILMS

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**Keywords:** In$_2$O$_3$, Thin films, Spain coater method, Crystalline structure, Transmission

**Abstract**

In this work, the In$_2$O$_3$ thin films have been fabricated using a spin coating technique; this technique was prepared in our laboratory. The effect of the layer times (3, 5, 7 and 9 times) on optical and structural properties was investigated. In$_2$O$_3$ thin films were fabricated by dissolving 0.2 M of the indium chloride dehydrate InCl$_3$.2H$_2$O in the absolute H$2$O. The In$_2$O$_3$ thin films were crystallized at a temperature of 600 $^\circ$C with pending time of 1 hour. The optical property shows that the prepared In$_2$O$_3$ thin films for 3 and 5 times have a transmission of about 85%. The maximum bandgap energy was 3.69 eV for 5 times and the lowest Urbach energy was 0.47 eV for 9 times. From XDR all fabricated In$_2$O$_3$ thin films having one diffraction crystal plan is (222) peak intensity, this attribution have good crystalline structure with minimum crystallite size of the (222) plan is 59.69 nm. The prepared In$_2$O$_3$ thin films can be used in photovoltaic applications due to the existing phase and higher transmission.

**1. Introduction**

In previous researches, in the field of materials science, several excellent classes have investigated that lead to the synthesis and characterization of thin films as metal oxides (semiconductors) [1]. In$_2$O$_3$ has one of the most important applications in the detection of bacteria in nature, the presence of bacteria in the environment due to the increase in peoples and industries. So it becomes important to investigate In$_2$O$_3$ as a thin film and improve its physical properties. These materials can be developed as photovoltaic applications due to show high transmission overcoming 90% [2], which was located in the visible region. However, the In$_2$O$_3$ thin films can be used in several fields in sciences and technology due to their physical and chemical properties such as highly transparent, good crystalline structure, best electrical conductivity and the ease of chemical mixing in any solution [3]. As well as the In$_2$O$_3$ thin films are requirements of the general environment to protect it can be focused
In$_2$O$_3$ thin films can be fabricated by several techniques such as electrochemical deposition, pulsed laser deposition (PLD), magnetron sputtering technique, molecular beam epitaxy (MBE), reactive evaporation, sol-gel process, chemical vapor deposition, and spray pyrolysis [1‒5].

The aim of this work is to fabricate In$_2$O$_3$ thin films with good transmission and good crystalline structure. The films were fabricated with 0.2 M at a crystallization temperature of 600 °C. We have studied the influence of several layer times on optical transmission, bandgap energy, Urbach energy, crystalline structure and crystallite size of In$_2$O$_3$ thin films.

2. Experiments

The prepared solution of In$_2$O$_3$ was investigated by dissolving the 0.2 M of the indium chloride dehydrates InCl$_3$.2H$_2$O in the absolute H$_2$O. HCl was used as stabilization of In$_2$O$_3$ solution. This solution has been stirred a heated at 50 °C for one hour to have a solution with high transparent. The film coating was deposited two days after the preparation.

The In$_2$O$_3$ thin films were deposited by dropping the In$_2$O$_3$ solution on the microscopic glass substrate, which are prepared at room temperature by a spin coating method. The experimental conditions were applied to obtain a good quality of In$_2$O$_3$ thin films, which was rotated between 2000 to 2500 rpm for the 20s. The In$_2$O$_3$ thin films have been deposited at different coating times are 3, 5, 7 and 9 times. The In$_2$O$_3$ thin films were pre-heated at a temperature of 100 °C, and then crystallized at 600 °C with a pending time of 1 hour.

The In$_2$O$_3$ thin films were characterized to obtain the optical transmission, bandgap energy, Urbach energy, crystalline structure and crystallite size of In$_2$O$_3$ thin films. The optical transmission of the In$_2$O$_3$ thin films was obtained using an ultraviolet-visible spectrophotometer (LAMBDA 25) in the range of 300–1000 nm. However, the crystalline structure was carried by X-ray diffraction (XRD Bruker AXS-8D, CuK$\alpha$, $\lambda = 0.15406$ nm) in the scanning range of (2θ = 30° to 40°).

3. Results and discussion

The optical transmission of deposited In$_2$O$_3$ thin films is shown in Fig. 1, presents with various coating times of deposited films. As seen, the optical transmission of deposited In$_2$O$_3$
thin films was decreased with increasing coating times, we have observed a higher transmission of about 85% in the visible region. However, in the ultraviolet region the optical transmission decreased because of the absorption edge. Fig. 2 shows the absorbance of deposited In$_2$O$_3$ thin films at various coating times, we have concluded that the thin film prepared with 9 coating times has the maximum absorption.

![Graph showing transmission spectra](image1)

**Fig.1.** Variation of transmission spectra (T) with wavelength (λ) of deposited In$_2$O$_3$ thin films at different coating times.

![Graph showing absorbance spectra](image2)

**Fig.2.** Variation of absorbance spectra (A) with wavelength (λ) of deposited In$_2$O$_3$ thin films at different coating times.

The optical bandgap energy of deposited In$_2$O$_3$ thin films were estimated from visible region, it was determined by following equation [6]:

\[
(Ah\nu)^2 = B(h\nu - E_g)
\]

where $A$, $h\nu$, $C$ and $E_g$ are the absorbance, the photon energy, a constant and the bandgap energy of deposited In$_2$O$_3$ thin films.
energy of deposited In$_2$O$_3$ thin films, respectively. The variation bandgap was calculated using the Fig. 3, which is determined by the extrapolation. However, the tail width can be calculated using the Urbach energy of deposited In$_2$O$_3$ thin films also was determined by the following equation [6]:

$$A = A_0 \exp \left( \frac{h \nu}{E_u} \right)$$  \hspace{1cm} (2)

where $A$, $h \nu$, $A_0$ and $E_u$ are the absorbance, the photon energy, a constant and the Urbach energy, respectively. The Urbach energy of fabricated In$_2$O$_3$ thin films was determined by deducting the curves of $\ln A$ with the variation of the photon energy $h \nu$ (see Fig. 4) to obtain of the variation Urbach energy of In$_2$O$_3$ thin films.

Fig.3. The graph of $(Ah \nu)^2$ versus $h \nu$ plots of In$_2$O$_3$ thin films for the bandgap energy.

Fig.4. The graph of $\ln A$ versus $h \nu$ plots of prepared In$_2$O$_3$ thin films for Urbach energy $E_u$. 

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Table 1. Optical characterization of In$_2$O$_3$ thin films at several layer times.

<table>
<thead>
<tr>
<th>Layer times</th>
<th>$E_g^a$ (eV)</th>
<th>$E_u^b$ (meV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3.03</td>
<td>0.62</td>
</tr>
<tr>
<td>5</td>
<td>3.69</td>
<td>0.53</td>
</tr>
<tr>
<td>7</td>
<td>3.18</td>
<td>0.58</td>
</tr>
<tr>
<td>9</td>
<td>3.30</td>
<td>0.47</td>
</tr>
</tbody>
</table>

$^a$ Optical bandgap energy
$^b$ Urbach energy

Reported in Fig. 5 and Table 1 with the variation of the layers times’ the bandgap energy $E_g$ and the Urbach energy $E_u$ of fabricated In$_2$O$_3$ thin films, we have seen that the change in the optical bandgap energy is opposite to the change in the Urbach energy. As can be seen, the optical bandgap energy of prepared In$_2$O$_3$ thin a film has the high value was obtained for the thin film fabricated with 5 times, it is 3.69 eV. After this point it is has a minimum value was 3.18 eV for 7 times. However, the Urbach energy has the lowest value was 0.53 eV for 5 times and the highest at 7 times is 0.58 eV. The decrease of bandgap energy with increasing layer times caused by the oxygen diffusion with the deposition. However, the increase of the Urbach energy of prepared In$_2$O$_3$ thin films can be explained by increasing of the defects in the films with increasing film thickness.

Fig. 5. Variation as a function of the layer times of the bandgap energy and Urbach energy of In$_2$O$_3$ thin films.

The X-ray diffraction was used in this work to determine the crystalline structure of In$_2$O$_3$ thin films, the results are shown in Fig. 6. The XRD was investigated in the range of
$2\theta = 30^\circ$ to $40^\circ$. As seen, some In$_2$O$_3$ thin films detected three diffraction peaks, are (222), (400) and (411) peaks. With the increase of layer times, we have improved in the peak intensity of the (222) peak, this shows that the elaborated In$_2$O$_3$ thin films have a crystalline structure with a preferred orientation to the (222) plan. However, Fig. 6 presents the measured diffraction angle of the (222) peak at several layer times. As seen, the diffraction angle of the (222) peak increased caused by the shifted of (222) peak to the high angle, this attribution can be explained by the decrease in the lattice parameters of the structure of In$_2$O$_3$ thin films with the increase in the layer times of deposition.

![Fig.6. The X-ray diffraction of the crystalline structure of In$_2$O$_3$ thin films at several layer times.](image)

![Fig.7. Variation of diffraction angle of the (222) peak of In$_2$O$_3$ thin films at several layer times.](image)

The crystallite $G$ of (222) crystal plane of fabricated In$_2$O$_3$ thin films at several layer times was measured by the Scherer equation [8]:
where \( G \) is the measured crystallite size at several layer times, \( \lambda \) is the X-ray wavelength (\( \lambda = 0.15406 \) nm), \( \beta \) is the FWHM (full width at half-maximum, and \( \theta \) is the diffraction angle of the (222) plane crystal plane, the variations are shown in Table 2. Fig. 8 shows the measured crystallite size at several layer times 3, 5, 7 and 9 times of the fabricated In\(_2\)O\(_3\) thin films by a spin coating method. We have a decrease of measured crystallite size with increasing layer times from 3 to 9 times, the intensity of (222) peak also increased when the layer times increased, this observation has been indicated to improve the crystallinity and the preferred orientation of prepared In\(_2\)O\(_3\) thin films.

![Variation of measured crystallite size of In\(_2\)O\(_3\) thin films at several layer times.](image)

**Table 2. Structural characterization of In\(_2\)O\(_3\) thin films at several layer times.**

<table>
<thead>
<tr>
<th>Layer times</th>
<th>( G ) (nm)</th>
<th>( \theta ) (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>75.54</td>
<td>30.50</td>
</tr>
<tr>
<td>5</td>
<td>74.19</td>
<td>30.58</td>
</tr>
<tr>
<td>7</td>
<td>60.58</td>
<td>30.80</td>
</tr>
<tr>
<td>9</td>
<td>59.69</td>
<td>30.71</td>
</tr>
</tbody>
</table>

a. Measured crystallite size  
b. Diffraction angle of the (222) peak

4. Conclusions

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In this work, we have investigated the effect of layers times on the optical and structural characterization of the fabricated In$_2$O$_3$ thin films by spin coating technique. In$_2$O$_3$ thin films were fabricated by dissolving the indium chloride dehydrate InCl$_3$.2H$_2$O in the absolute H$_2$O, the solution was deposited on a glass substrate by varying the layer times 3, 5, 7 and 9 times, the thin films were crystallized at 600°C. The obtained In$_2$O$_3$ thin films have a good optical transmission of about 85% for the smaller layer times. The maximum bandgap energy was 3.69 eV for 5 times and the lowest Urbach energy was 0.47 eV for 9 times. From XDR all fabricated In$_2$O$_3$ thin films having one diffraction crystal plan is (222) peak intensity, this attribution have good crystalline structure with minimum crystallite size of the (222) plan is 59.69 nm. The prepared In$_2$O$_3$ thin films can be used in photovoltaic applications due to the existing phase and higher transmission.

Acknowledgments

X-ray diffraction data in this work were acquired with an instrument supported by the University of Biskra. We thank Mr. B. Gasmi (Biskra University) for the assistance in XRD data acquisition.

References