Growth of Nano Scale and Optical Properties of Indium Oxide Thin Films

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Abstract - *In the present paper it has been identified that indium oxide nanoparticles (InO-NPs) have different key of interest because of their unique shape and size dependent properties. Various methods have been developed by researchers for synthesis of indium oxide nanoparticles on basis of structural and optical properties. In this present paper deposition of Indium oxide (In_2O_3) thin films was done on glass substrate by variation of temperature in the range of 400⁰C to 600⁰C. Then study of optical properties of indium oxide thin films were done and then at different temperatures nanocrystalline sizes of indium oxide nanoparticles were studied. Characterization of all films was done at room temperature by using X-ray diffraction. To obtain high crystallographic quality of films, observed suitable substrate temperature was noticed which was 575⁰C.*

Keywords: **Indium oxide, nanoparticles, synthesis, optical properties.**

1. INTRODUCTION

Thin films of Indium oxide (In_2O_3) are technologically important transparent conducting oxide (TCO) material. These are used in different fields like: photovoltaic devices [1], transparent windows in LCD [2], gas sensors [3], antireflection coatings [4], electro-chromic devices [5], and solar cells [6]. Preparation of thin films of In_2O_3 can be done by a various techniques like chemical vapors deposition [7], chemical decomposition of a substance by heat [8], vacuum evaporation [9], and magnetron sputtering [10]. Among all the techniques the most commonly used technique for deposition of TCO is chemical decomposition of substance by heat technique is most suitable due to its clearness and non-vacuum deposition system which is not so expansive. This can be modified for large production of quality oxide thin films over large scale. Indium oxide (In_2O_3) thin films are transparent conducting n-type semiconductors having energy band gap of 3.6eV. The structure of Indium oxide (In_2O_3) is body centered cubic (BCC) in crystalline form having lattice constant a= 10:118Å [11].

1.1 EXPERIMENT

In this present work preparation of In_2O_3 thin films were done on glass substrates of soda lime by using chemical decomposition of a substance by heat technique. The apparatus used in this process contain of a substrate holder with heater, a homemade spraying unit, and an enclosure. The glass substrate was placed on a plate of stainless steel. The heater can heat the substrate up to 7000°C temperature. Preparation of indium oxide (In_2O_3) thin films was done by dissolution of $InCl_3$ (0.2 g) with 5 droplets of HCl acid and reflux heating at 900⁰C for 5 min. The solution was sprayed normally on the glass substrate which was heated at different substrate temperatures. Air compressor was used for supplying the carrier gas (air). Filtration of air produced by compressor was done then passed through spray gun using an own meter for controlled flow of air.

Deposition Parameters includes: separation between the substrates and spray nozzle was 25cm, filtered compressed air used as the carrier gas, and the spray rate was 19lper min, and solution taken was 40 ml. All parameters except temperature were kept constant. And temperature variation was (4000°C–6000°C). UV-visible spectrophotometer was used for measurement of Optical transmission of the samples. Optical transmission to near (infrared region) was performed the PL (photoluminescence) measurements were done at room temperature. The source of excitation was 320nm lines of He- Cd laser, and a 320nm filter.

2. RESULT AND DISCUSSIONS

The XRD patterns as a function of substrate temperature for indium oxide thin films were shown in figure 1 (a-f).From results it can be observed that the nature of film deposited was amorphous at 400⁰C and polycrystalline nature of films can be observed by increasing the temperature of the substrate and preferred orientations of (400), (222) overcome. The cubic box byte structure [12] was confirmed by the peaks of in XRD pattern.

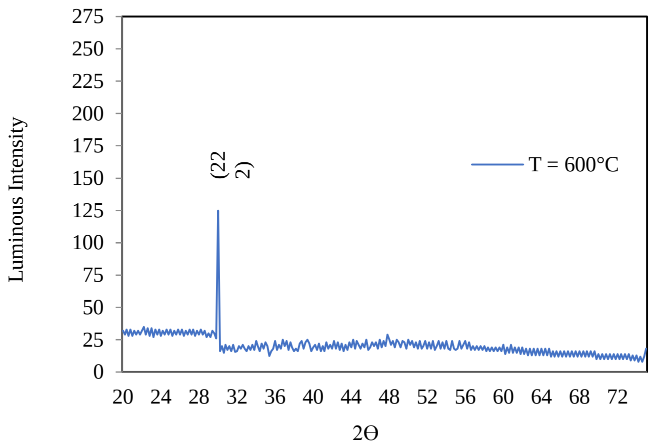

Chart - 1 (a): Graph between 2Θ and luminous intensity at 600^{0}C

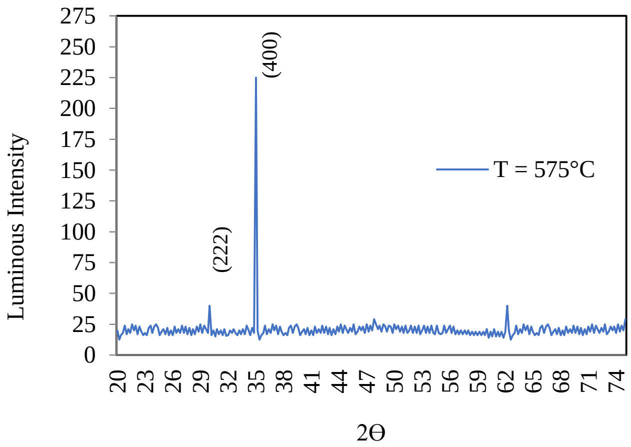

Chart - 1 (b): Graph between 2Θ and luminous intensity at 575^{0}C

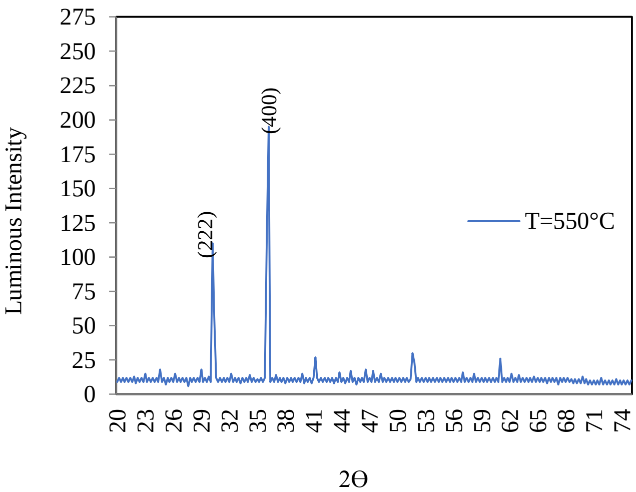

Chart - 1 (c): Graph between 2Θ and luminous intensity at 550^{0}C

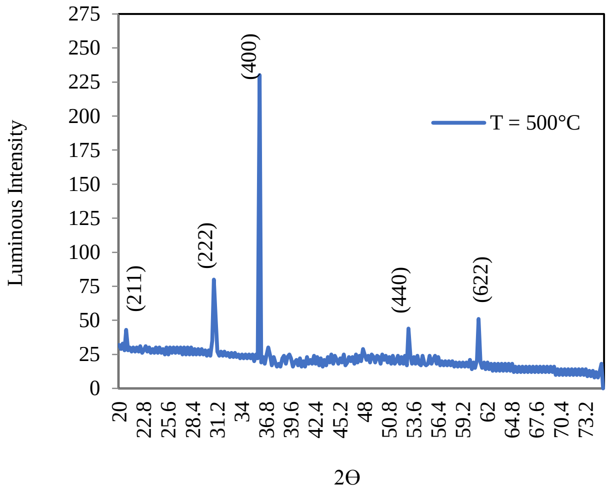

Chart - 1 (d): Graph between 2Θ and luminous intensity at 500^{0}C

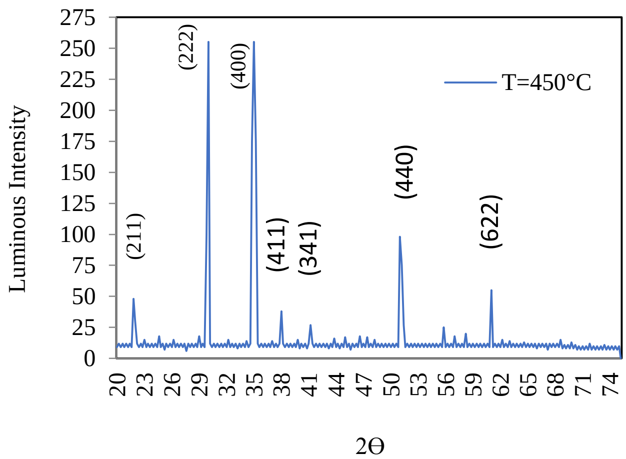

Chart - 1(e): Graph between 2Θ and luminous intensity at 450^{0}C

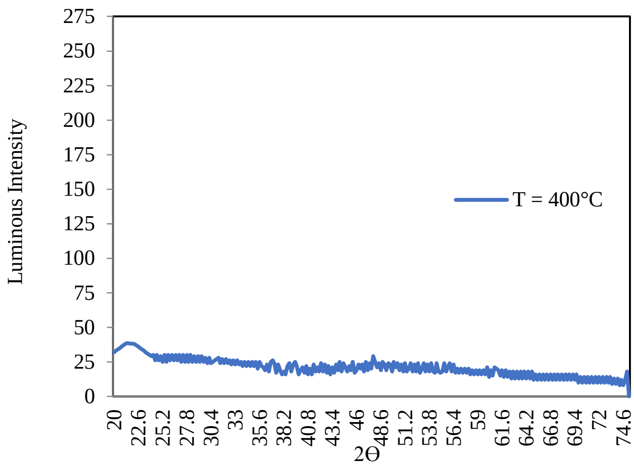

Chart - 1 (f): Graph between 2Θ and luminous intensity at 400^{0}C

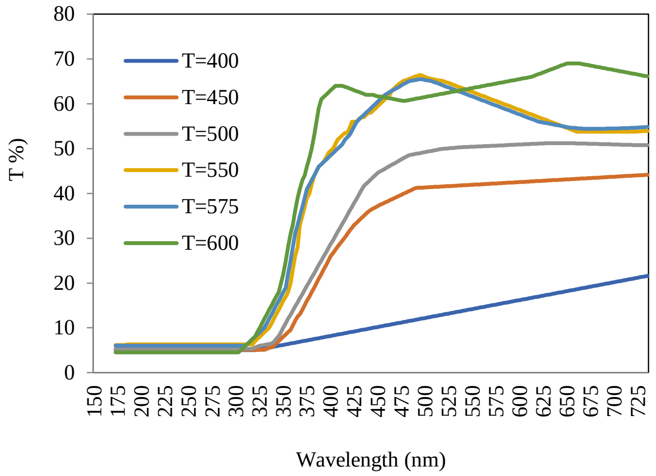

Chart – 2: Optical transmittance curves as a function of the wavelength

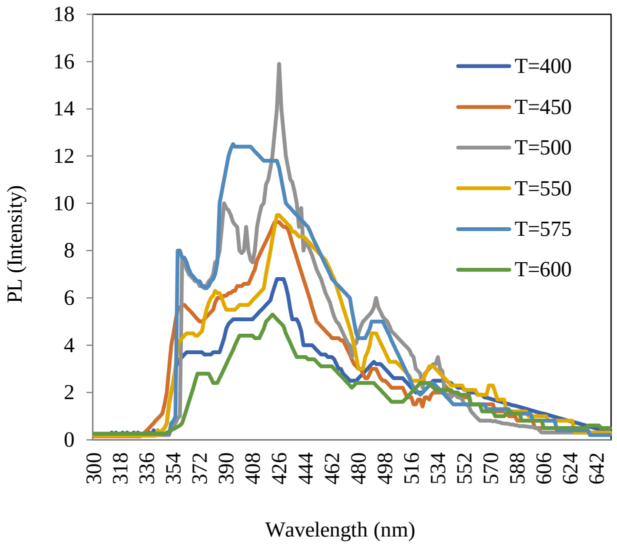

Chart – 3: Optical transmission of In_2O_3 films prepared at different substrate temperature

From figure 1 it can be observed that, the XRD intensity of favored growth orientation was mainly determined by the substrate temperature. The ratio of intensity for the peaks (400) and (222) was comparable at $T_{s=}$ 450^0C. The degree of (400) orientation increases by increasing substrate temperature up to T_s= 575^0C after that there was a measurable decrease in extent of (400) orientation and increase in (222) orientation on increasing substrate temperature up to 600^0C. Scherer's formula [13] was used for calculation of mean crystallite size D for the diffraction peaks:

$$D = (k\lambda)/\beta Cos\theta$$

Where k is constant value,ϴ is angle of scattering andβ is FWHM (full width at half maximum). On raising substrate temperature in range of 575^0C to 600^0C, the size of grain decreases from 36.02 nm to 33.55nm, decrement in the grain size is accompanied with increment of sheet resistance and results in decrement of mobility. The scanning electron microscope (SEM) images of indium oxide (In_2O_3) thin films pre-pared at different substrate temperatures. As indicated by scanning electron microscope (SEM) photographs, films deposited at 400 ^0C have amorphous and non-uniform surface. It is evident from the results that the surface morphology (especially grains dimension) of films were highly affected by increasing the substrate temperature. At lower temperatures the deposited films was not having appropriate surface morphology, while structure improvement and increment in uniformity of films could be observed by increasing substrate temperature. Evident from to the XRD spectra, increment in substrate temperature from400^0C to 550^0C all films results in the polycrystalline structure with (400) and (222) being the leading orientations.

The grains start to grow on increasing the substrate temperature and the surface roofed fully with fine and large grains. There is decrement in the density of grain boundary with increment in the grain size, as a result crystalline structure was proved (specific sharp peaks) and resulted better optical property (high transmittance) (Chart 1 and Chart 3). Distinctive AFM images of indium oxide (In_2O_3) films deposited at different substrate temperature were shown in Chart 3. As it is evident from the figure that the substrate temperature measurably affects the surface morphology of the deposited films, lower temperature deposited films not have appropriate surface quality. While on increasing the substrate temperature (575^0C to 600^0C) results in better surface quality and crystallographic structure. This was in conformity with XRD and SEM examination. Photoluminescence measurements were performed for investigating the optical properties of indium oxide (In_2O_3) thin films. Chart 3 results the Photoluminescence (PL) emission spectra, the carrier concentration and the conductivity enhancement (Table 1) [14].

Table –1: The Variation Of Electrical Properties Of In2O3 Films As A Function Of Substrate Temperature

T	R_{sh} [kΩ]	ρ [Ω]	η [×10¹⁸ cm⁻³]	μ [cm²/Vs]	T_{MAX} [%]	FOM [10⁻⁷Ω⁻¹cm]
400	16.2	1.040	0.97	5.84	12	8.5×10^{-7}
450	123	6.55	0.06	13.55	52	0.092
500	14	0.426	4.45	4.23	68.8	18.5
550	12	0.124	12.90	3.41	79.9	100
575	5.65	0.139	6.38	6.65	78	126
600	18	0.342	9.82	1.89	78.4	37.6

On further increment in substrate temperature (550^0C to 600^0C) the XRD spectrum showed improvement in films deposited at different substrate temperature with incident beam of about 320 nm. As observed, 320 nm incident wavelengths were in UV range but obtained peaks were in the visible solar spectrum. A well-built near band edge ultraviolet emission peak could be noticed for all samples. It could be understood that photoluminescence (PL) spectra depend on the structure and the stoichiometry of the deposited films [15-16]. So, the photoluminescence (PL) results confirmed that the deposited optimums In_2O_3 are thin films are very close to stoichiometry and have optically high quality. This was remarkable for prepared sample at substrate temperature of 575^0C. Photoluminescence peak of prepared sample at deposition temperature $450^{\circ}C$ also has good width but intensity was smaller than the film deposited at 575^0C. The captivated peak in 425 nm wavelength for deposited sample at deposition temperature 450^0C was companionable with sharp peaks of XRD spectrum.

From photoluminescence (PL) diagram it can be concluded that with increase in the deposition temperature, the crystalline improvement take place and the indium oxide films gets better structure, but for films deposited at 600^0C, the intensity of photoluminescence peak reduced significantly which was in good accord with the XRD results (Chart 1). The optical transmittance curves verses wavelength for the indium oxide (In_2O_3) thin films deposited at different substrate temperatures were shown in figure 2. It could be noticed that the optical transmittance of the films were affected by the deposition temperature. The optical transmittance noticed in the films altered from 13% to 77% with the increment of deposition temperature. The high transmittance noticed in the films was recognized to less scattering effects, better crystalline and structural homogeneity. A shift in the absorption edge was noticed to shorter wavelength for the optimal film, which was in agreement with the Burstein Moss shift [17].

3. CONCLUSION

Thin films of indium oxide (In_2O_3) were deposited by chemical decomposition of a substance by heat vertically onto glass (soda lime) substrates using unheated (room temperature) 0.023 M $InCl_3$solution. Substrate temperature was ranging from 400^0C to 600^0C. Results showed that the substrate temperatures were remarkable parameters and have a remarkable effect on physical properties of the deposited films. Structural, morphological, optical and electrical properties of the films were observed and optimized conditions were achieved. The X-ray diffraction study showed that the films deposited at substrate temperature of 400 ^0C were amorphous while those deposited at temperatures 450^0C were polycrystalline. By using Scherer's formula for two temperatures grain size was calculated and found in connection with SEM. The SEM and AFM analysis showed that at substrate temperature of 575^0C, the deposited films exhibit more smoothness and better crystallographic structure. In photoluminence (PL)analyses, the results confirmed that the deposited optimum indium oxide (In_2O_3) thin films are very close to stoichiometry and are of optically high quality particularly at substrate temperature of 575^0C.The electrical resistivity of deposited films was variable but the best result was regarded to career mobility is at 575^0C in agreement with other analysis for higher conductivity.

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