American Journal of Materials Science and Engineering, 2014, Vol. 2, No. 2, 18-23
Available online at http://pubs.sciepub.com/ajmse/2/2/2

DOI:10.12691/ajmse-2-2-2

Electrodeposition of Nanostructured ZnO Thin Film: A Review

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Received April 08, 2014; Revised April 25, 2014; Accepted May 27, 2014

Abstract In this review paper, a critical analysis was carried out to investigate the effect of cathodic potential, bath temperature, time and nature of substrates on the ZnO thin films synthesized by electrodeposition technique. XRD patterns of the various deposited films were studied to examine the structural characteristics of the Nanostructured ZnO thin films. From the XRD patterns of the different ZnO thin films, it is found that the nanostructured ZnO film had hexagonal wurtzite crystal structure and the crystals were preferably grown along the (002) or (101) planes. The optical properties: Band gaps, transmittance of films, deposited on ITO/FTO coated glass substrates, were also studied by the various optical transmittance spectra. The band gap energy of the deposited ZnO thin films found varying from 3.18 to 3.85eV. Annealing of electrodeposited films decreased the bandgap considerably. Depending on the crystal size, the transmittance of the nanostructured ZnO thin film was found to be about 70 to 90%.

Keywords: *ZnO thin film, electrodeposition, nanostructures, band gap energy, preferred orientation*

Cite This Article: Manish Kumar, and C. Sasikumar, "Electrodeposition of Nanostructured ZnO Thin Film: A Review." *American Journal of Materials Science and Engineering*, vol. 2, no. 2 (2014): 18-23. doi: 10.12691/ajmse-2-2-2.

1. Introduction

Zinc oxide is a technologically important inorganic compound with the formula ZnO. Zinc and oxygen are the elements of group II and VI with atomic numbers 30 and 8 and atomic weights 65.382 and 15.999 respectively. In the stable form, zinc oxide takes a hexagonal wurtzite crystal structure with lattice parameters a = 3.2458Å and c = 5.2006Å (c/a = 1.6022) [1]. The other two forms of ZnO are zincblende and rock-salt structure. The zincblende structure can be stabilized only by the growth of ZnO on the cubic lattice substrates and the rock salt structure may be obtained under very high pressure about 10GPa and return to the former state of hexagonal wurtzite structure on decompression [2]. ZnO has wide direct bandgap energy of 3.40 eV at room temperature and large exciton binding energy (~60meV) [2]. This high binding energy (~60meV) assures efficient exciton emission at room temperature under very low excitation energy [3]. ZnO materials show an n-type electrical conductivity due to its native or intrinsic defects such as oxygen vacancies and interstitial zinc atoms [4]. Intrinsic zinc oxide thin films are highly resistive in nature, but when commonly doped with Group III elements such as Ga, In or Al, they become conducting [5]. ZnO is an important semiconducting material which is widely used in the field of solar cell application because of its suitability as both as intrinsic n-type buffer layer (i-ZnO) and Al-doped top contact layer for copper indium gallium diselenide (CIGS) solar cells. CIGS solar cells usually consist of glass/Mo/CIGS/CdS/i-ZnO/ZnO:Al structure. The addition of a highly resistive intrinsic n-type buffer layer (i-ZnO) in CIGS solar cell significantly improves the device efficiency because it prevents the leakage current and also work as an anti-reflection coating which absorbs the ultraviolet part of the solar spectrum and permits the lower energy photons to move to the absorber layer [6]. The various properties of ZnO are presented in Table 1.

Table 1. The various properties of ZnO

Property	Value
Density	5.606 g/cm^3
Lattice Parameters	a=b=3.2458 Å, c=5.2006Å
Stable Phase at 300 K	Hexagonal, Wurtzite
Melting Point	1975°C
Dielectric Constant	8.656
Refractive Index	2.008
Band Gap Energy	3.40 eV
Solubility in water	0.16 mg/100 ml (30°C)

Zinc oxide has several favourable properties such as good transparency in the visible and high infrared spectrum, high electron mobility, wide and the direct band gap, large exciton binding energy, high thermal conductivity and strong room temperature luminescence. These properties are used in many applications such as transparent electrodes of thin film solar cells for light transmission and the extraction of photocurrent, heat-protecting windows, transparent oxide thin-film transistors, light-emitting diodes, Varistors, piezoelectric devices, etc.

Crystalline zinc oxide is thermochromic in nature i.e. changing from white to yellow colour when heated and return to the earlier state on cooling.

ZnO thin films are deposited by the several conventional growth techniques such as DC or RF magnetron sputtering ([7,8,9]), Metalorganic chemical vapor deposition ([10,11]), pulsed laser deposition, spray pyrolysis ([12,13,14,15]), chemical bath deposition ([16,17,18]), molecular beam epitaxy and cathodic electrodeposition method. The cathodic electrodeposition method is emerging as an efficient nanotechnology for the production of ZnO thin films and nanostructures because of its simplicity, low cost equipments, and suitable for large area substrate [3].

2. ZnO Thin Film by Electrodeposition Methods

The cathodic electrodeposition technique has been recognized as the effective method for the production of ZnO thin films due to its simplicity, low temperature process, high deposition rate, low cost technique and suitability for large area substrate. This technique used a very low cathode voltage or current to produce the ZnO thin film on any conductive substrate such as a transparent conducting oxide ([3,19,20]) or any other metal plate ([1,21]). In this deposition technique, the film thickness, morphology and optical properties can be controlled by the various operating parameters: current density, applied potential, deposition time and the concentration of the electrolytic bath. Generally, in this deposition method, zinc nitrate solutions ([19,20,22,23]) or zinc chloride solutions ([1,3,24,25]) are used as a precursor.

2.1. ZnO Thin Film Deposition from Zinc Chloride Solutions

The two main mechanisms that take place in the solutions are the precipitation and the electrochemical reactions at the cathode surface or the working electrode. The fundamental reaction that leads to the formation of ZnO is the electro generation of a base and the electro-precipitation takes place in the presence of zinc ions in the solution [26]. The reaction that takes place with the molecular oxygen can be summarized as

$$\frac{1}{2}O_2 + H_2O + 2e^- \rightarrow 2OH^- \quad (1)$$

$$Zn^{2+} + 2OH^- \rightarrow Zn(OH)_2 \quad (2)$$

A. Goux et al. [26] studied the effect of bath temperature on the ZnO deposition and observed that the continuous film growth and surface passivation would not occur below the 34ºC temperature. They have reported that the oxide nucleation and thin film growth started above the 34°C temperature, whereas the optimum film transparency and crystallinity was obtained above the 40°C temperature. When the temperature of the bath reaches above the 40°C, the zinc hydroxide layer dehydrates by the reaction 3 to form ZnO thin film.

$$Zn(OH)_2 \rightarrow ZnO + H_2O \quad (3)$$

2.2. ZnO Thin Film Deposition from Zinc Nitrate Solutions

When the zinc nitrate as a precursor is dissolved in the water, two anionic groups such as NO_2^- and OH^- are formed in the solution. After that Zn^{2+} ions combined with the OH^- ions to form the zinc hydroxide. In the end, zinc hydroxide is finally oxidized into ZnO and water [27].

$$Zn(NO_3)_2 \rightarrow Zn^{2+} + 2NO_3^- \quad (4)$$

$$NO_3^- + H_2O + 2e^- \rightarrow NO_2^- + 2OH^- \quad (5)$$

$$Zn^{2+} + 2OH^- \rightarrow Zn(OH)_2 \rightarrow ZnO + H_2O \quad (6)$$

The $Zn(OH)_2$ can be decomposed into ZnO and water during the deposition or by the post annealing process. The one of the major advantages of using the zinc nitrate is to be the highly soluble in the aqueous solution.

3. Zinc Oxide Thin Film Prepared by Thermal Oxidation of Zinc Metal

Another method for the production of ZnO thin film is by the thermal oxidation of zinc thin films electrodeposited onto the conducting substrate. G. Zou et al. [28] reported that the ZnO thin film was prepared by the thermal oxidation of the zinc thin film. In this method, Zinc thin film was electrodeposited on to the indium tin oxide coated conductive glass slides from the zinc acetate dehydrate and ethylene glycol as a precursor. After that, the deposited Zn thin films were thermally oxidized in a muffle furnace at around 500°C to form the ZnO thin films.

4. Results & Discussion

4.1. Structural Characteristics of ZnO Thin Films

Various researchers up to date have used X-ray diffraction technique to examine the structural characteristics of the ZnO thin film electrodeposited on the several conducting substrates. M. Fahoume et al. [1] studied the structure of ZnO thin films by using the X-ray diffractometry (XRD) and transmission electron microscopy (TEM). They have reported that the ZnO thin films deposited on the ITO coated glass substrate were polycrystalline in nature with a hexagonal crystal structure (zincite) at pH = 4. At a temperature of 70ºC, the film had no preferred orientation and the most intense peak of XRD pattern was along the (101) plane. When the temperature of the bath was increased to 80ºC, the most intense peak of XRD pattern was changed and along the (002) plane. They have also reported that when the ZnO thin films were deposited on the copper substrate then it exhibits only one peak along the (002) plane and the degree of orientation along the (002) direction was increased with increasing the bath temperature. The grain size of the film deposited on the copper substrate was larger than the film deposited on the ITO coated glass substrate. Overall, they found that the preferred orientation of the grains was dependent on the type of substrates and bath temperature.

N. H. Al-Hardan et al. [3] studied the XRD pattern of deposit ZnO thin film on the ITO coated glass substrate and reported that the film exhibited the polycrystalline nature and the resulted XRD pattern showed that ZnO thin film had hexagonal wurtzite crystal structure. They have reported that the most intense peak in the XRD pattern was along the (002) plane and the ZnO thin film was growing parallel to the c-axis of the hexagonal crystal structure. J.S. Wellings et al. [6] studied the various XRD patterns of the as deposited ZnO thin film on the FTO coated glass substrates at different potential from -0.9V to -1.025V. They have reported that ZnO thin films were polycrystalline in nature with hexagonal wurtzite crystal structure and (002) preferred orientation except a sample which was deposited at -0.925V vs. Ag/AgCl. They have also reported that improved crystallinity was observed at -0.975V as compared to the other potentials. They have also observed the effect of annealing on the XRD pattern of the ZnO thin film deposited at -0.975V and concluded that the XRD spectra of both the as deposited and annealed samples had no detectable or noticeable changes. The grain/crystallite sizes of the various ZnO films deposited at the different conditions are presented in the Table 2.

Table 2. The grain/crystallite size of the various ZnO films deposited at the different conditions

S No.	Grain/ Crystallite Size	Conditions	Characterization techniques	Ref.
1	1-3µm	As deposited film on ITO substrate	TEM	[1]
2	7-10µm	As deposited film on copper substrate	TEM	[1]
3	33nm	As deposited film on ITO substrate	XRD	[3]
4	42.7nm	As deposited film on FTO substrate	XRD	[6]
5	55nm	Annealed film on FTO substrate at 550°C	XRD	[6]
6	10nm	As deposited film on ITO substrate	SEM	[19]
7	31nm	As deposited film on ITO substrate	XRD	[20]
8	63nm	Annealed film on ITO substrate at 300°C	XRD	[20]
9	10–15nm	As deposited film on FTO substrate	SEM	[23]
10	17nm	As deposited film on FTO substrate	XRD	[24]
11	38.8nm	As deposited film on ITO substrate with surfactant op-10	XRD	[29]
12	54.5nm	As deposited film on ITO substrate without surfactant op-10	XRD	[29]
13	42nm	As deposited film on FTO substrate by cyclic voltamperometry technique	XRD	[30]
14	54nm	As deposited film on FTO substrate by chronoamperometry technique	XRD	[30]
15	34.8nm	As deposited film by 0.04 M $Zn(NO_3)_2$	XRD	[31]
16	29.0nm	As deposited film by 0.07 M $Zn(NO_3)_2$	XRD	[31]
17	19.8nm	As deposited film by 0.1 M $Zn(NO_3)_2$	XRD	[31]

C. Gu et al. [19] studied the effect of different cathodic potentials and deposition time on the XRD patterns of the ZnO thin films electrodeposited on the ITO coated glass substrates. They have reported that the preferred orientation was changed with the cathodic potential and deposition time. At the potential of -1.3V for 300s, only the (002) preferred orientation was recognized. As the cathodic potentials were decreased from -1.3V to -2.0V, the (002) preferred orientation was weakened and at the -2.0V, the ZnO thin films had random orientations. They were also reported that the (002) preferred orientation of ZnO thin film was also retained at -1.3V after a long deposition time of 1200s. They have also reported that the initial deposited ZnO film on ITO coated glass substrate had (002) preferred orientation and it was independent of the applied cathodic potential. They have also studied the various XRD patterns of ZnO thin films electrodeposited on ITO coated glass substrates at -1.7V for different deposition times. As the deposition time was increased from 120s to 1200s, the (002) preferred orientation was weakened and after 1200s, the deposited films also had random orientation. C. Coskun et al. [20] studied the XRD patterns of annealed and non annealed ZnO thin films deposited on the ITO coated glass substrate. They have reported that the preferred orientation of the grains was along the (101) direction for both the annealed and non annealed ZnO thin films. They have also reported that the crystallite sizes of around 31nm and 63nm were obtained from the Scherrer equation for non annealed and annealed ZnO thin films respectively. Q. Wang et al. [21] also studied the effect of different deposition potentials and annealing on the XRD pattern of ZnO thin films deposited on the Zn substrate and reported that the films had hexagonal wurtzite crystal structure and the most intense peaks in all the patterns were corresponding to the (002) plane. They have also studied the annealing effect on the XRD pattern of ZnO thin film deposited at -1.0V and observed that the peak corresponding to (002) plane becomes broadened and debased after annealing at 380ºC in the horizontal tube furnace. LI Junwei et al. [22] studied the effect of potential and temperature on the XRD patterns of porous ZnO thin films. They have reported that the porous ZnO thin film prepared at the potential of -0.7V had a preferred orientation along the (002) direction, but at the lower potential of -0.9V, the (002) preferred orientation was weakened and the most intense peak corresponding to (101) plane was observed. At the potential of -1.1V and -1.4V, the other peaks corresponding to (100) plane also became stronger and films had random orientations. From the XRD patterns of the ZnO thin films, they have reported that the ZnO films showed the hexagonal wurtzite crystal structure. L. Zhang et al. [23] studied the XRD spectra of as prepared ZnO thin film deposited on the fluorine-doped SnO2 coated glass substrate. The XRD pattern of the prepared film revealed that the ZnO film had a hexagonal wurtzite crystal structure with preferred orientation along the (002) direction. J. Cembrero et al. [25] studied the XRD pattern of ZnO film deposited on the FTO coated substrate and reported that the film had a hexagonal wurtzite crystal structure with the preferred orientation along the (002) direction. The Lattice parameters and the band gap energy of the hexagonal wurtzite crystal structured ZnO thin films are presented in the Table 3.

Table 3. Lattice parameters of the hexagonal wurtzite crystal structure of ZnO thin films

S No.	a (nm)	c (nm)	c/a ratio	Band Gap Energy (eV)	Ref.
1	0.32458	0.52006	1.6022	3.26	[1]
2	0.3250	0.5206	1.6018	3.37	[23]
3	0.3246	0.5207	1.6041	3.32	[27]
4	0.3249	0.5206	1.6023	3.37	[32]

Table 4. The preferred orientation and thickness of various deposited ZnO thin films

S No.	Preferred Orientation	Thickness of ZnO films	Conditions	Ref.
1	–	500nm	As deposited film on ITO substrate	[1]
2	(002)	–	As deposited film on copper substrate	[1]
3	(002)	0.4µm	As deposited film on FTO substrate	[6]
4	(002)	–	As deposited film on ITO substrate at -1.3V for 1200s	[19]
5	(101)	–	As deposited film on ITO substrate	[20]
6	(101)	–	Annealed film at 300°C	[20]
7	(002)	0.2-30 µm	As deposited films on Zinc substrates	[21]
8	(002)	1µm	As deposited film on ITO substrate at -0.7V	[22]
9	(002)	0.20µm	As deposited film on FTO substrate at -1.3V for 1hr.	[23]
10	–	350nm	As deposited film on FTO substrate	[24]
11	(002)	–	As deposited on FTO substrate	[25]
12	(002)	1.4 µm	As deposited on FTO substrate at -1.1V	[27]
13	(002)	–	Zn film oxidized film at 500°C	[28]
14	–	110nm	As deposited film on ITO substrate with surfactant op-10	[29]
15	–	50nm	As deposited film on ITO substrate without surfactant op-10	[29]
16	(002)	1.339µm	As deposited film on FTO substrate by cyclic voltamperometry technique	[30]
17	(001)	1.248µm	As deposited film on FTO substrate by chronoamperometry technique	[30]

A. Goux et al. [26] studied the effect of different deposition temperature on the XRD patterns of ZnO thin films deposited on FTO coated glass substrate. At the temperature of 22ºC, the XRD pattern of film exhibited the peaks of substrate only and no peak of ZnO was observed. At the temperature of 34ºC, the XRD pattern exhibited the peaks of ZnO {(100) and (101)} along with the peaks of substrate and showed that the ZnO film had hexagonal wurtzite crystal structure. When the temperature was increased, then the peaks become narrower and (002) reflection started to emerge and becomes the preferred orientation at the higher temperature. T. Mahalingam et al. [27] studied the XRD patterns of ZnO thin films deposited at various potentials from -0.8V to -1.2V and reported that the films were polycrystalline in nature and showed the hexagonal wurtzite crystal structure. For all the films deposited at various potentials, the most intense peak in the XRD patterns was along the (002) plane. The intensity of the (002) plane was the maximum for the film deposited at -1.0V vs. SCE whereas the XRD patterns of other films deposited at -0.8V and -1.2V showed that the intensity of (002) plane decreased in comparison to the film deposited at the potential of -1.0V. The preferred orientation and thickness of various deposited ZnO thin films are presented in Table 4.

G. Zou et al. [28] studied the XRD patterns of the as deposited Zn thin film and the Zn thin films annealed at various temperatures from 100 to 500ºC. The XRD pattern of the as deposited Zn thin film revealed that the film had only one strong orientation along the (002) direction. When the Zn thin film was annealed at 300ºC for 6 hours, then the film was completely transformed to ZnO thin film and a weak peak {ZnO (100)} along with the two strong peaks {ZnO (002), (101)} was observed, which showed that the film possessed a hexagonal wurtzite crystal structure. When the Zn film was annealed at 500ºC for 6 hours, then the ZnO thin film exhibited polycrystalline hexagonal crystal structure with (002) preferred orientation. X. Qin et al. [29] studied the XRD patterns of the ZnO thin films deposited on the ITO substrates with 0.5% op-10 surfactant and without surfactant. They have reported that both the ZnO thin films showed the polycrystalline nature with the hexagonal wurtzite structure. The grain size of the ZnO thin film prepared without the surfactant and with the surfactant was calculated as 54.5nm and 38.8nm respectively. B. E. Prasad et al. [31] studied the effect of Zn concentration, deposition temperature, and time on the XRD patterns of the ZnO thin films deposited on the stainless steel flag. They have reported that at high concentrations, the crystals were growing along the (101) direction, but at the high deposition temperatures and at high deposition times, the crystals were growing along the (102) and (103) direction.

4.2. Optical Properties of ZnO Thin Films

M. Fahoume et al. [1] studied the effect of film thicknesses on the optical transmission spectra of the electrodeposited ZnO thin films and reported that the films showed the optical transmittance values above the 75% when the thickness of the films were below the 340nm. They have also reported that when the thicknesses of the films were increased, the transmission value was decreased. They also found that the optical band gap energy of the electrodeposited ZnO thin films was 3.26eV which was much closer to the band gap energy of ZnO single crystal (3.40eV). C. Gu et al. [19] studied the optical transmittance spectra of ZnO thin films deposited on the ITO coated glass substrate at different cathodic potentials and at the cathodic potential of -1.7V for different times. They have reported that the ZnO thin films were transparent to the visible light range and the films showed the optical transmittance values to about 80 to 90%. They have also found that the values of band gap energy (E_g) of the ZnO thin films deposited at different cathodic potential and at different deposition times were 3.5eV and it was independent of the applied potential and the deposition times. C. Coskun et al. [20] studied the optical absorption spectra of as-deposited ZnO thin film and annealed ZnO thin film at 300ºC. They have observed

that the band gap energy of the as-deposited ZnO thin film was about 3.23eV corresponding to a wavelength of 385nm and the band gap energy of the annealed ZnO thin film was about 3.37eV corresponding to a wavelength of 368nm. At the wavelength of 600nm, they found that the reflectivity for as deposited ZnO thin film was 32.7% and for annealed ZnO thin film was 24.75%. They have also observed that the reflectivity of films decreased after annealing process which resulted in the improvement of crystal quality. Q. Wang et al. [21] reported that the band gap energy of the as-deposited ZnO thin film was high as 3.56eV but when the film was annealed at 380ºC; the band gap energy was decreased to about 3.29eV. They have also reported that the band gap energy of the as-prepared film was high due to the presence of $Zn(OH)_2$ with the ZnO in the film because $Zn(OH)_2$ is a wider band gap energy material than ZnO. LI Junwei et al. [22] studied the effect of different cathodic potential and deposition temperature on the optical transmittance spectra at 600nm wavelength of porous ZnO thin films of 1μm thickness. They have reported that the highest optical transmittance of about 63.6% was obtained from the film, which was deposited at -1.1V and 70ºC. They have found that the optical band gap energy of the films increases with increasing the absolute deposition potentials. They were also found that the optical transmittance values were increased with increasing the deposition temperatures up to 70ºC after which it was decreased with increasing the temperatures. The highest optical transmittance of about 63% was observed in the film, which was deposited at the temperature of 70ºC and the band gap energy of the films was also increased with increasing the temperature from 3.35 to 3.42eV. Figure 1 shows the variation of the band gap energy of various as-deposited ZnO thin films with the grain/crystallite size and indicates that the band gap energy of the ZnO thin films increases as the grain/crystallite size decreases.

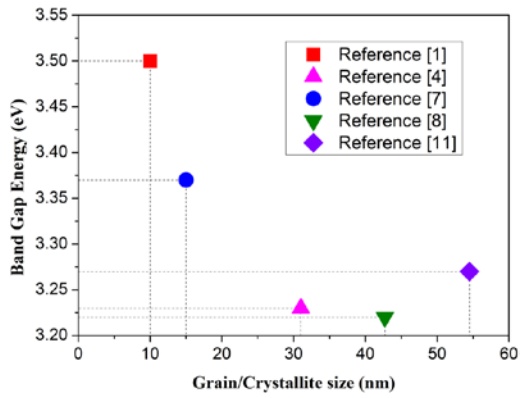

Figure 1. Variations of the band gap energy with the grain/crystallite size of the various as-deposited ZnO thin films

The relation between the crystallite size and band gap was derived using the non-linear curve fitting and is found to be:

$$Bandgap = 3.20 + 0.9\exp\left(\frac{-d}{9.31}\right)$$

Where d is the crystallite size of ZnO nano crystals in nm. The Band gap energy and transmittance values of ZnO thin films deposited at different conditions are presented in Table 5.

Table 5. Band gap energy and transmittance values of ZnO thin films deposited at different conditions

S No.	Conditions	Band Gap Energy (eV)	Transmittance (Approximately)	Ref.
1	As deposited ZnO film	3.26	Above 75 %	[1]
2	As deposited film	3.22	–	[6]
3	Annealed film at 550ºC, 15min	3.20	–	[6]
4	As deposited ZnO film	3.5	80– 90%	[19]
5	As deposited ZnO film	3.23	–	[20]
6	Annealed ZnO film at 300ºC	3.37	–	[20]
7	As deposited film	3.56	–	[21]
8	Annealed film at 380°C	3.29	–	[21]
9	As deposited film at 34ºC	3.56	–	[21]
10	As deposited porous ZnO films	3.33 - 3.43	50 – 63.6%	[22]
11	As deposited film	3.37	Above 90%	[23]
12	As deposited film	3.32	70 – 80%	[27]
13	Zn film oxidized at 300ºC, 6hr.	3.18	80 – 90%	[28]
14	Zn film oxidized at 500ºC, 6hr.	3.20	Above 90%	[28]
15	With surfactant op-10	3.21	Above 80%	[29]
16	Without surfactant	3.27	Above 80%	[29]
17	As deposited nanowires	3.37	–	[32]
18	As deposited petal like architectures	3.85	–	[32]

L. Zhang et al. [23] studied the optical transmission spectra of as prepared ZnO thin film and annealed ZnO thin films at 250ºC and 350ºC. They have reported that the as-deposited film and annealed film at 250ºC showed the higher optical transmission of about 90% or above. They have also reported that the ZnO film, which was annealed at 350ºC showed lower transmittance value as compared to other films. A. Goux et al. [26] studied the optical transmission spectra of ZnO thin films deposited at different temperatures from 34ºC to 89ºC and reported that the optical properties were totally dependent on the morphology and the smoothness of the films T. Mahalingam et al. [27] studied the optical transmission spectrum of the 0.3μm thick ZnO thin film deposited at the potential of -1.1V and bath temperature of 80ºC and reported that the optical transmission of the film decreases with decrease in wavelength and was close to 80% at the wavelength of about 600nm.

5. Conclusion

In this review paper, a critical analysis of the nanostructured ZnO thin films, synthesized by the electrodeposition technique was carried to examine the effect of various parameters: cathodic potential, bath temperature, time, etc. on the film deposition. Most of the authors have used the bath temperature above the 60°C to deposit the ZnO thin films and no attempt have been made to deposit the film at room temperature. From the XRD patterns of the different ZnO films, it is found that the ZnO thin films had a hexagonal wurtzite crystal structure with lattice parameters in the range of a = 0.3245 to 0.3250nm and c = 0.5200 to 0.5207nm. The crystal structure of films was independent of the initial conditions and the most of the films showed polycrystalline in nature.

From the XRD patterns, it is concluded that the nanostructured ZnO thin film had hexagonal wurtzite crystal structure and the crystals were preferably grown along the (002) or (101) planes. The grains or crystallites size of different films was varied from 10nm to 10µm and concluded that the electrodeposited ZnO films had nanostructured particles and the grain size of the films increases after annealing process at different temperature. From the optical transmittance spectra of different ZnO thin films, it is concluded that the most of the films had high transmittance value in the range of 70 to 90% and band gap energy in the range of 3.18eV to 3.85V. As the grain/crystallite size increases, the bandgap of the ZnO thin film decreases. In most cases, the band gap energy of the deposited films decreased after the annealing process, due to the decomposition of $Zn(OH)_2$ into ZnO and H_2O. Because the $Zn(OH)_2$ is a wider band gap material as compared to the ZnO and is normally coexisted with the ZnO in the as-deposited films.

Acknowledgements

The authors are thankful to Dr. V. K. Gahlot, HOD, MSME Department, MANIT, Bhopal and Dr. Appu Kuttan K.K., Director, MANIT, Bhopal for their valuable support in this work.

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