Comparative study for seed layer solvent effects on structural and optical properties of MgZnO thin films deposited by chemical bath deposition technique

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Abstract

C-axis oriented Magnesium doped Zinc Oxide (MgZnO) thin films are promising candidates for variety of applications especially optoelectronic devices. In this work, the effects of seeding solvents on structural and optical properties of MgZnO films were analyzed. The comparison was performed by varying the seed layer solvent i.e. 2-Methoxyethanol, 2-Propanol, Ethanol and Methanol. MgZnO thin films were synthesized on different seed layered glass substrates using Chemical Bath Deposition (CBD) method. The XRD results revealed the hexagonal wurtzite structure for all samples. However, the film with seed layer 2-Methoxyethanol solvent had preferred c-axis orientation and better crystallinity. For 2-Methoxyethanol solvent based seed layer: the morphological study showed wrinkled free, unfractured and highly aligned MgZnO nanorods grown perpendicular to the substrate. Energy dispersive x-ray (EDS) spectroscopy confirmed the presence of magnesium in ZnO film. Highest average transmittance of 80% and band gap value of 3.3 eV was recorded through UV–vis spectroscopy. The optical constants (refractive index and extinction coefficient) were determined by reflectance and absorbance data. Furthermore complex dielectric constant and energy loss functions were estimated.

Introduction

Zinc Oxide (ZnO) is a semiconductor material of group II-IV. It has a wide band gap of 3.3 eV. ZnO has numerous applications in many fields like solar cells, optoelectronic devices, gas sensors, field effect transistors, nano-generators etc [1, 2]. Zinc Oxide thin films gained great attention for optical properties by using different coating techniques [3–5]. In many cases, well-aligned ZnO nanorods showed better performance in terms of high visible transmittance [6, 7]. Therefore high quality c-axis growth of ZnO thin films are considered essential for potential applications like optoelectronic devices. The optical and structural properties of ZnO films can be altered by doping them with transition, rare earth and alkaline elements. It has been reported that optical properties of ZnO can significantly be improved by magnesium doping while keeping the distortion in the host lattice to a minimum due to comparable ionic radii of Mg (57 pm) and Zn (60 pm) [8]. The researcher recently reported magnesium compound with oxygen (MgO thin film) application as super capacitor for space applications [9].

There exist a number of different methods to synthesize the MgZnO films to improve the optical properties [10, 11]. In order to achieve controlled ZnO morphological growth, methods like chemical vapor deposition (CVD) [12], pulse laser deposition (PLD) [13], spray pyrolysis [14], sol-gel method [15] and chemical bath deposition (CBD) [16, 17] are already in use by researchers. Among these, CBD method is a cost effective and largely used because of its minimal thermal budget requirement. Recently, report on possibility of ZnO thin films synthesis at a temperature of 50 °C has been appeared in literature [18]. Synthesis of Zinc Oxide thin films through CBD method can result into different morphological structures. There are many control parameters, such as precursor, solvent, substrate, bath temperature, bath time and seed layer, the combined effects of which determine the properties of Zinc Oxide nanostructures.
Seed layers are used to reduce the lattice mismatch between film and substrate. It has been established that seed layer morphology directly affects the structural properties of Zinc Oxide nanowires and nanorods [19, 20] thus making it the most important control parameter before CBD process. Many aspects of the seed layer growth process and its effects on ZnO thin films have been well explored. The wrinkled seed layer structure produces roughness in the ZnO thin films and affects the optical properties [21]. Boiling temperature of solvent directly affects the morphology of ZnO thin film. For smooth ZnO layers, the solvent having higher boiling temperature are favorable [22]. The drying temperature introduces residual stresses in seed layer which ultimately affects the optical properties and controlled growth of doped ZnO nanorods. However, the influence of solvents, used in preparation of seed layer, on ZnO thin films has rarely been published. The seed layer solvent remarkably affects the structural and optical properties of ZnO nanorods grown on ZnO seed layers [23]. Mingsong wang et al synthesized ZnO nanorods by using mixture of different solvents in the reaction bath solution. They also explained the smooth seed layer plays a key role on controlled growth of nanostructure [24]. Kai Loong Foo et al have grown ZnO nano rods by hydrothermal method using different solvent for seed layer [23].

In this work, the effects of seed layers grown using different solvents on MgZnO thin films are presented. Sol-gel method was used to deposit seed layer of constant molar concentration by using four different solvents [25, 26]. In order to achieve better optical results, the molar concentration was fixed at 0.5 M for all the solvents as suggested in literature [25, 27]. The mechanism of quality seed layer produced by the solvent to grow well aligned MgZnO grains was discussed. The magnesium doping percentage was fixed at 5% for all samples in order to: (i) get better optical result [28] (ii) avoid phase segregation (MgO) at higher doping level [29] and (iii) eliminate the effects of doping variations. The best solvent for the synthesis of quality seed layer for MgZnO thin films and optical properties by CBD method was revealed. The seed layer effects on structural, morphological and optical properties of MgZnO thin films prepared by CBD method was studied by XRD, SEM and UV–vis. Additionally EDS was used for elemental analysis. The optical constants were explored by optical data.

**Experimental procedure**

**Preparation of seed layer**

The procedure adopted to grow seed layer was the sol-gel spin coating technique [21, 30]. Soda lime glass slides were used as a substrate. All the substrates were washed with DI water followed by ultrasonic cleaning using acetone. Zinc Acetate dihydrate (Zn(CH3COO)2.2H2O) was used as a host precursor to prepare ZnO seed layer. 2-Methoxyethanol, 2-propanol, Ethanol and Methanol were used as solvents and Monoethanolamine (MEA) as a stabilizing agent. The ZnO solution concentration for seeding was fixed at 0.5 M. Same procedure was adopted to prepare solution for all solvents. First, required quantity of precursor salt was dissolved in each solvent in a separate beaker and stirred for ten minutes by using magnetic stirrer at 300 rpm. After that, MEA poured drop wise in this milky solution to get a clear homogeneous solution with a constant stirring of one hour. The MEA and Zn molar ratio was kept constant at 1:1. The final prepared solution was stored for aging of 24 hours at room temperature. The seed layer was then spin coated on the substrates at the speed of 2000 rpm for thirty seconds. After each coating all wet substrates were dried at 200 °C for thirty minutes in oven. This procedure was repeated seven times.

**Preparation of magnesium doped zinc oxide thin films by CBD**

In CBD, same precursor (Zinc Acetate dihydrate) was used for solution preparation. Magnesium acetate tetra-hydrate (Mg(CH3COO)2.4H2O) was used as a dopant reagent. The doping percentage was fixed at 5 at%. The precursor and dopant with required quantity was dissolved in 125 ml DI water to make 25 mM solution. At the same time another solution of hexamine was made at 20 mM concentration in DI water. Both solutions were separately stirred for fifteen minutes. The prepared solutions were added in CBD double wall beaker, placed on the hot plate magnetic stirrer, to grow MgZnO thin film. When temperature of CBD equipment reached at 85 °C, the seeded glass substrates were immersed vertically in the double wall beaker and kept in this solution for three hours. At the end, films were washed with DI water, dried in air and annealed at 450 °C for two hours. Assigned names for samples were: 2ME for 2-methoxyethanol ZnO seed layer and MgZnO by CBD; 2 P for 2-Propanol ZnO seed layer and MgZnO by CBD; E for ethanol ZnO seed layer and MgZnO by CBD; M for Methanol ZnO seed layer and MgZnO by CBD.

Orientation and crystallinity of all the films were studied by x-ray diffraction spectroscopy (XRD; PANalytical X’pert Pro) using CuKα source (λ = 1.54056 Å). The morphology of thin films was observed by SEM (JEOL, JSM-6480LV) with 10 K magnification. The energy dispersive x-ray spectroscopy (EDS, JEE-420) attached with SEM was used for elemental analysis. UV–vis spectrophotometer (Model: USB4000 oceanoptic) was used for optical measurements with the wavelength range of 300–800 nm.
Results and discussions

XRD analysis

The XRD spectra of MgZnO thin films by CBD using different seed layer solvents along with ZnO seed layer spectra showed in figures 1(a)–(d). The crystal structure had been observed between 25° to 50° diffraction angles. The major peaks detected were at (100), (002) and (101) plane which showed a good agreement with JCPDS card (no. 36-1451) [10]. The MgZnO Films synthesized by CBD possessed hexagonal wurtzite structure and polycrystalline nature. The ZnO seed layer spectra by different solvents showed low intensity peaks of (100), (002) and (101) plane. 2ME seed layer showed sharp peaks with low intensity and (002) plane dominance which exhibited good crystal structure. 2P seed layer showed minor intensity peaks. E seed layer did not showed any peak even with low intensity. M seed layer showed broader peaks due to low crystal quality appeared at pre-heating (drying) state.

The MgZnO film pattern for 2ME sample revealed (002) plane dominance which indicated the alignment of nanorods along c-axis perpendicular to the substrate. 2ME sample seed layer and MgZnO film both have (002) plane dominance (c-axis) which indicated better optical results. The MgZnO pattern for 2P sample showed (100) plane dominance. However E and M sample presented (101) plane dominance. In all the MgZnO samples there was no peak related to impurity phase of MgO which indicated that Mg ion successfully occupied the lattice site. Scherrer’s formula was used to calculate average crystallite size for preferred crystal plane [31].

\[ D = \frac{k\lambda}{\beta \cos \theta} \]  

Where \( k \) (0.9) is the constant, \( \lambda \) is the x-ray wavelength \( \theta \) is the Bragg’s angle and \( \beta \) is the full width half maximum for dominating plane peak.

The dislocation density (\( \delta \)) and lattice strain (\( \varepsilon \)) were calculated by using the following relations [32, 33].

\[ \delta = \frac{1}{D^2} \]  
\[ \varepsilon = \frac{\beta}{4 \tan \theta} \]

The lattice constants were calculated by the relations given below [25].

\[ a = \frac{\lambda}{\sqrt{3} \sin \theta} \]  
\[ c = \frac{\lambda}{\sin \theta} \]

Furthermore Cell volume (\( V \)), atomic packing fraction (APF), positional parameter (\( u \)) and bond length (\( L \)) were estimated by the following mathematical equations taken from [34].

\[ V = \frac{\sqrt{3} \ a^2 \ c}{2} \]  
\[ APF = \frac{2\pi a}{3 \sqrt{3} \ c} \]  
\[ u = \left( \frac{a^2}{3c^2} \right) + 0.25 \]  
\[ L = \sqrt{\frac{a^2}{3} + c^2(0.5 - u)^2} \]

The tabular comparison for all values showed in tables 1 and 2.

SEM and EDS analysis

Figure 2 depicted the SEM micro-graphs for MgZnO thin films, ZnO seed layers prepared by different solvents and corresponding EDS table of MgZnO films. Figures 2(a1) and (a2) showed the vertically aligned MgZnO nano-rods, perpendicular to the substrate and wrinkled free (unstressed) ZnO seed layer surface, using 2-Methoxyethanol solvent respectively (sample 2ME). Figures 2(b1) and (b2) showed the randomly oriented MgZnO nano-rods and minor wrinkled crack free ZnO seed layer surface using 2-Propanol solvent respectively (sample 2P). Figures 2(c1) and (c2) showed MgZnO flower like nano-structure and dense wrinkled ZnO seed layer structure using Ethanol solvent respectively (sample E). Similarly figures 2(d1) and (d2) part showed nano-
Figure 1. XRD spectra for ZnO seed layers and MgZnO thin films (a) 2-Methoxyethanol seed layer and MgZnO film (sample 2ME), (b) 2-Propanol seed layer and MgZnO film (sample 2P), (c) Ethanol seed layer and MgZnO film (sample E), (d) Methanol seed layer and MgZnO film (sample M).
network (fiber) type structure and wrinkled ZnO seed layer using Methanol solvent respectively (sample M). This clarified that the morphology of MgZnO films changed with the seed layer surface morphology. The wrinkles produced in seed layer may be attributed to the solvent boiling temperature, as Ethanol and Methanol have low boiling temperatures i.e. 78 °C and 64.7 °C respectively. Since drying temperature was 200 °C, therefore solvent with lower boiling temperature abruptly evaporates which produce stresses (wrinkles) in seed layer [22]. Also, the substrate temperature increases during drying process which forces the solvent to evaporate more rapidly and produce stresses between seed layer and substrate. The wrinkled surface was formed by the evaporation rate and solvent with higher boiling temperature has slower evaporation rate than the solvents with lower boiling temperature. For smooth ZnO surface, slower evaporation rate favors the relaxation of mechanical stress. Low drying temperature [21] or close to the evaporation temperature can produce transparent films. This process directly influences the growth and alignment of upper nanorods. The seed layer morphology greatly affects the growth morphology of nanorods [19, 20].

In the CBD process there are two main steps, nucleation and growth. The seeding process creates the ZnO layer which serves as a ZnO nuclei and it directly influence the MgZnO nanorods formation. The orientation of nanorods is determined by the orientation of seed layer. The seed layer shown in figure 2(a2) for sample 2ME was relatively unstressed compared to other wrinkled seed layer surface samples and had c-axis (002) orientation dominance as revealed by XRD study. Therefore the MgZnO nanorods for sample 2ME also had c-axis orientation due to homogeneous nucleation growth. The MgZnO films for other samples had random orientations of nanorods due to the stressed structure of seed layer and random alignment of ZnO seed nuclei [35].

Figures 2(a3), (b3), (c3) and (d3) showed the EDS results for all corresponding MgZnO films and revealed the presence of Zn, O and Mg in all samples. Moreover this verified the successful incorporation of magnesium in Zinc Oxide. Furthermore the weight percentage for each sample was revealed.

**UV Analysis**

Figure 3 represented the optical absorbance, transmittance, reflectance and tauc's relation for all MgZnO films. The results revealed that the lowest absorbance was achieved by 2ME sample. The average transmittance of nearly 80% had been observed in visible region. The reason was wrinkled free seed layer surface with c-axis preferred orientation, better optical quality and c-axis orientation of MgZnO nanorods as revealed by XRD and SEM study. The c-axis orientation is useful for optical properties [11, 21]. The transmittance for 2ME sample attained maximum value of 90% near IR region indicated that this sample film is useful for many optoelectronic applications. However reflectance rapidly reduced near UV and in visible region. The lowest transmittance value mentioned in table 3 produced by sample M was due to dense, stressed seed layer opaque surface and optical loss by upper fiber type nanostructure as revealed by SEM analysis.

The band gap values were calculated by the relation given below [32, 36] and it ranged from 3.15 eV to 3.3 eV. The maximum band gap value among all samples had been achieved by sample 2ME.

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**Table 1.** The comparison of interplaner distance, grain size, lattice constants, lattice strain, dislocation density and lattice ratio among MgZnO films by CBD using different seed layer solvent.

| Sample | d(002) (Å) | D (nm) | a (nm) | c (nm) | ε | δ | ε/δ |
|--------|------------|--------|--------|--------|----|----|------|
| 2ME    | 2.6168     | 29.23  | 0.3269 | 0.5196 | 0.004001 | 0.0011704 | 1.589476 |
| 2P     | 2.6178     | 32.79  | 0.3281 | 0.5241 | 0.003900 | 0.0009301 | 1.597378 |
| E      | 2.5690     | 38.05  | 0.3241 | 0.5196 | 0.002923 | 0.0006907 | 1.603208 |
| M      | 2.6235     | 20.06  | 0.3287 | 0.5249 | 0.005592 | 0.0024851 | 1.596896 |

**Table 2.** The comparison of cell volume, atomic packing fraction, positional parameter and bond length among MgZnO films by CBD using different seed layer solvent.

| Sample | V (Å³) | APF | a | l (nm) |
|--------|--------|-----|---|--------|
| 2ME    | 48.09  | 0.7604 | 0.381938 | 0.198455 |
| 2P     | 48.86  | 0.7566 | 0.380636 | 0.199491 |
| E      | 47.27  | 0.7539 | 0.379688 | 0.197286 |
| M      | 49.11  | 0.7568 | 0.380715 | 0.199837 |
Here \( (h\nu) \) is the photon energy, \( \alpha \) is the absorption coefficient, \( B \) is a constant and \( E_g \) is the optical energy gap. The Zinc oxide relates to the direct band gap system and the plot between \( (\alpha h\nu)^2 \) and \( (h\nu) \) is supposed to have linear behavior. This corresponds to the strong absorption presence close to absorption edge. Hence extrapolating the linear portion also gives optical energy gap of the films.
Optical constants analysis

The optical parameters like refractive index ($n$) and extinction coefficient ($k$) for MgZnO films by CBD were calculated by the relations taken from [10, 37, 38] and are given below.

| Element | Weight % |
|---------|----------|
| OK      | 36.13    |
| MgK     | 2.98     |
| SiK     | 12.11    |
| ZnK     | 48.78    |

| Element | Weight % |
|---------|----------|
| OK      | 37.2     |
| MgK     | 3.01     |
| SiK     | 14.14    |
| ZnK     | 45.65    |
Here $R$ is the reflectance and $\lambda$ is the incident beam wavelength. Figure 4(a) explained that the refractive index continuously decreased in visible region and lowest value found for sample 2ME as mentioned in table 3. This verified the transparency of the film. Figure 4(b) showed the extinction coefficient values for all samples and revealed that 2ME sample had lowest value compared to others due to little optical loss.

The complex dielectric constant ($\varepsilon$) defines the phonons excitation and optical transition in the material. The real and imaginary parts of $\varepsilon$ can be calculated by the following relations [37, 39].

$$\varepsilon = \varepsilon_r + \varepsilon_i$$  \hspace{1cm} (13)

$$\varepsilon_r = n^2 + k^2$$

$$\varepsilon_i = 2nk$$

$$n = \left(\frac{1 + R}{1 - R}\right) + \sqrt{\frac{4R}{(1 - R)^2} - k^2}$$  \hspace{1cm} (11)

$$k = \frac{\alpha\lambda}{4\pi}$$  \hspace{1cm} (12)

**Table 3.** The comparison of transmittance, band gap, refractive index and extinction coefficient among MgZnO films by CBD using different seed layer solvents.

| Sample | Average transmittance (%) | Band gap (eV) | Refractive index ($n$) lowest value | Extinction coefficient ($k$) lowest value |
|--------|---------------------------|---------------|----------------------------------|----------------------------------------|
| 2ME    | 80                        | 3.3           | 1.6                              | 0.05                                   |
| 2P     | 50                        | 3.25          | 2.1                              | 0.25                                   |
| E      | 40                        | 3.15          | 1.8                              | 0.15                                   |
| M      | 35                        | 3.22          | 2.4                              | 0.3                                    |
These values describe light dispersion in materials and energy absorption by dipole motion. Figure 5 revealed the real and imaginary parts produced enhance optical response than optical constants. Furthermore, the two important parameters that are related to real and imaginary parts i.e. volume energy loss ($VELF$) and surface energy loss ($SELF$) can be estimated by the following relation [37, 40].

\[
VELF = \frac{\varepsilon i}{(\varepsilon r^2 + \varepsilon i^2)}
\]

\[
SELF = \frac{i}{(\varepsilon r + 1)^2 + \varepsilon i^2}
\]

Figure 6 explained that $VELF$ values were higher than $SELF$. The energy loss occurred in sample film interior by electronic transition than surface and found identical results for both $VELF$ and $SELF$. All the results from figures 4–6 verified that the MgZnO film by CBD using 2-Methoxyethanol solvent for seed layer produced better optical response than others. Hence 2-Methoxyethanol solvent is suitable for seed layer synthesis before CBD method for optoelectronic devices.

**Conclusion**

Mg doped ZnO nanostructures were well synthesized by CBD on ZnO seed layers prepared by different solvents using sol-gel spin coating method. The following conclusions were made by this research.
1. The XRD pattern revealed the hexagonal wurtzite structure with c-axis preferred orientation both for MgZnO nanorods and seed layer using 2-Methoxyethanol solvent.

2. Crackless and wrinkled free (unstressed) surface was observed for 2ME seed layer.

3. The SEM analysis revealed the vertically aligned nanorods produced for sample 2ME.

4. Complete incorporation of Mg in ZnO was elucidated by EDS analysis.

5. Lowest absorbance, lowest reflectance, highest 80% average transmittance and 3.3 eV band gap were achieved by sample 2ME.

6. The optical constants ($n$ and $k$) and complex dielectric constant values were found to be decreased for sample 2ME. This verified film transparency.

7. From above all results it has finally concluded that 2-Methoxyethanol solvent is suitable for:

(i) The synthesis of wrinkled free, unstressed, unfractured and better quality seed layers.

(ii) The optical properties of MgZnO nanorods for optoelectronic devices.
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References

[1] Terasako T, Obara S, Sakaya S, Tanaka M, Fukuoka R, Yagi M, Nomoto J and Yamamoto T 2019 Morphology-controlled growth of ZnO nanorods by chemical bath deposition and seed layer dependence on their structural and optical properties Thin Solid Films 669 141–50
[2] Chu D, Hamada T, Kato K and Masuda Y 2009 Growth and electrical properties of ZnO film prepared by chemical bath deposition method Phys. Status Solidi a 206 718–23
[3] Minami T, Yamamoto T and Miyata T 2000 Highly transparent and conductive rare earth-doped ZnO thin film prepared by magnetron sputtering Thin Solid Films 366 63
[4] Pei Z L, Zhang X B, Zhang G P, Gong J, Sun C, Huang R F and Wen L S 2006 Transparent conductive ZnO:Al thin films deposited on flexible substrates prepared by direct current magnetron sputtering Thin Solid Films 20 497
[5] Musta V, Teixeira B, Fortunato E, Monteiro R C C and Vilarinho P 2004 Al-doped ZnO thin films by sol–gel method Surf. Coat. Technol. 180 659

Figure 6. (a) VELF and (b) SELF for MgZnO films by CBD using different seed layer solvents.
[6] Campa A, Krc J, Malmstrom J, Edolf M, Smde F and Topic M 2007 The potential of textured front ZnO and flat TCO/metal back contact to improve optical absorption in thin Cu(In,Ga)Se2 solar cells *Thin Solid Films* 515 5968

[7] Gao Y, Nagai M, Chang T-C and Shyu J-T 2007 Solution-derived ZnO nanowire array film as photoelectrode in dye-sensitized solar cells *Cyst. Growth Des.* 7 2467

[8] Jiang D Y, Shen D Z, Liu K W, Shan C X, Zhao Y M, Yang T, Yao B, Lu Y M and Zhang J Y 2008 Effect of post annealing on the band gap of MgZnSn – xO thin films *Semicond. Sci. Technol.* 23 035002

[9] Kariper I A and Meydami Rezeli T 2019 UV region supercapacitor: Bi-doped natural MgO rock salt thin film *Ceram. Int.* 45 9219–24

[10] Inbaraj P P H and Joseph Prince J 2015 Optical and Structural properties of Mg doped ZnO thin films by chemical bath deposition method *J. Mater. Sci.: Mater. Electron.* 29 935–43

[11] Kurtaran S, Alagd S, Ofogofoglu G, Akyuz L and Atay F 2016 Transparent conductive ZnO thin films grown by chemical spray pyrolysis: the effect of Mg *J. Mater. Sci.: Mater. Electron.* 27 8478–85

[12] Chang P-C, Fan Z, Wang D, Tseng W-Y, Chioi W-A, Hong J and Lu J G 2004 ZnO nanowires synthesized by vapor trapping CVD method *Chem. Mater.* 16 5133–7

[13] Sun Y, Fuge G M and Ashfold M N R 2004 Growth of aligned ZnO arrays by catalyst. Free pulsed laser deposition methods *Chem. Phys. Lett.* 396 21–6

[14] Krunks M, Dedova T and Ack I O 2006 Spray pyrolysis deposition of ZnO. Oxide nanostructured layers *Thin Solid Films* 515 1157–60

[15] Ahn S E, Lee J S, Kim H, Kang B H, Kim K H and Kim G T 2004 Photoresponse of sol-gel synthesized ZnO nanorods *Appl. Phys. Lett.* 84 5022–4

[16] Li Q, Jian B, Sun J, Wang J, Yn K, Sun K and Yu D 2010 Controlled growth of well aligned ZnO nanorod arrays by low-temperature wet chemical bath deposition method *Appl. Surf. Sci.* 256 1698–702

[17] Terasako T, Murakami T, Yagi M and Shirakata S 2013 Shape controllability and photoluminescence properties of ZnO nanorods grown by chemical bath deposition *Thin Solid Films* 549 292–8

[18] Patma meydani Rezeli T and Afsin Kariper 2019 Structural and optical properties of undoped and silver, lithium and cobalt doped ZnO thin films *Surf. Rev. Lett.* 1950138

[19] Guellimin S, Consonni V, Appert E, Rapenne L and Roussel H 2012 Critical nucleation effects on the structural relationship between ZnO seed layer and nanowires *The Journal of Physical Chemistry C* 116 25106–11

[20] Kenanakis G, Vernardou D, Kou doumas E and Katsarakis N 2009 Growth of c-axis oriented ZnO nanowires from aqueous solution, the decisive role of a seed layer for controlling the wires diameter *J. Crystal Growth.* 311 4799–804

[21] Segawa H, Hideaki, Izumi R, Hayashi T, Yano T and Shibata S 2011 Low-temperature crystallization of oriented ZnO film using seed layers prepared by sol-gel method *J. Mater. Sci.* 46 5357–43

[22] Guo D, Yu J, Fu C, Huang Z and Zhang L 2016 (002)-oriented growth and morphologies of ZnO thin films preapred by sol-gel method *Materials Science-poland* 34 555–63

[23] Foo K L, Hashim U, Muhammad K and Voon C H 2014 Sol-gel synthesized zinc oxide nanorods and their structural and optical investigation for optoelectronic applications *Nanoscale Res. Lett.* 9 429

[24] Wang M, Kim E J, Han S H, Park C and Koo K-N 2008 Controlled growth of ZnO crystal growth and crystallite orientation in ZnO films/nanorods prepared by chemical bath deposition: effect of solvent *Crystal Growth & Design* 8

[25] Bekkari R, Jaber B, Labrim H, Oua H, Zayyoun N and Lannari I 2019 Effect of solvents and stabilizer molar ratio on the growth orientation of sol-gel derived ZnO thin films *Hindawi International Journal of Photonenergy* 31640437

[26] Foo K L, Kashiw M, Hashim U and Liu W-W 2014 Effect of different solvents on the structural and optical properties of zinc oxide thin films for optoelectronic applications *Ceram. Int.* 40 Part A 733–61

[27] Farooq A and Kamran M 2012 Effect of sol concentration on structural and optical behavior of ZnO thin films prepared by sol-gel spin coating *International Journal of Applied Physics and Mathematics* 2 430–432

[28] Caglar M, Caglar Y and Ilican S 2016 Investigation of the effect of Mg doping for improvement of optical and electrical properties *Physica B* 8 485–9

[29] Huang K, Tanga Z, Zhang L, Yua J, Lv J, Liuc X and Liud X 2012 Preparation and characterization of Mg-doped ZnO thin films by sol–gel method *Appl. Surf. Sci.* 258 426–31

[30] Fuchs P, Hagendorfer H, Romanuk Y E and Tiwari A N 2015 Doping strategies for highly conductive Al-doped ZnO thin films grown from aqueous solution *Phys. Status Solidi a* 212 51–5

[31] Prajapati C S and Sahay P P 2012 Effect of precursor on structure, optical and electrical properties of chemically deposited nanocrystalline ZnO thin films *Appl. Surf. Sci.* 258 2823–8

[32] Kumar K D A, Ganesh V, Shikir M, AlFaicy S and Valanarasu S 2018 Effect of different solvents on the key structural, optical and electronic properties of sol-gel dip coated AZO nanostructured thin films for optoelectronic applications *J. Mater. Sci.: Mater. Electron.* 29 887–97

[33] Makuku O, Mbaifa W and Sathiajat T P 2016 Structural, Optical and electrical properties of low temperature grown undoped and (Al, Ga) co-doped ZnO thin films by spray pyrolysis *Ceram. Int.* 42 14581–6

[34] Khara S and Chand P 2019 Influence of different solvents on the structural, optical, impedance and dielectric properties of ZnO nanoflakes *Chin. J. Phys.* 57 28–46

[35] Yang L, Zhao Q X and Willander M 2009 Size-controlled growth of well-aligned ZnO nanorod arrays with two-step chemical bath deposition method *J. Alloys Compd.* 469 623–9

[36] Shinde V R, Lokhande C D, Mane R S and Han S-H 2005 Hydrophobic and textured ZnO films deposited by chemical bath deposition: annealing effect *Appl. Surf. Sci.* 245 407–13

[37] Shikir M, Arit M, Ganesh V, Manthiram MMA, Singh A, Yahia I S, Maidur S R, Patil P S and AlFaicy S 2018 Investigation on structural, linear, nonlinear and optical limiting properties of sol-gel derived nanocrystalline Mg doped ZnO thin film for optoelectronic applications *J. Mol. Struct.* 1173 375–84

[38] Usha K S, Sivakumar R and Sanjeeviraj G 2013 Optical constants and dispersion energy parameters of NiO thin films prepared by radio frequency magnetron sputtering technique *J. Appl. Phys.* 114 123501

[39] Dhanasekaran V, Mahalingam T, Chandramohan R, Rhee J-koo and Chu J P 2012 Electrochemical deposition and characterization of cupric oxide thin films *Thin Solid Films* 520 6608–13

[40] Al-khanbashi H A, Shiribeen W, Al-Ghamdi A A, Bronstein L M and Mahmoud W E 2014 Spectroscopic ellipsometry of Zn1-xCuxO thin films based on a modified sol-gel dip-coating technique *Spectrochim. Acta, Part A* 118 800–5