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Study the Impact of the Substrate Temperature on the Optical Properties of Thin Film

Saja Eabd Alamir Chkuer
Technology of Laser Branch/University of Technology

Tabark Talib Hamadi
College of Science for Women/ University of Babylon/ Department: Physics laser

Daha Fareer Fouad Habib
University of Technology/Department of Applied Sciences/Branch: Laser Technology

Yaqeen Ali Zeboon
Applied Science Department/ Technology of Laser Branch /University of Technology

Noor Hameed Kazim
Applied Science Department /Technology of Laser Branch/University of Technology

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Abstract: In the existing work, the optical properties of CdZnO thin films deposited on glass substrates by using pulsed laser deposition (PLD) technique at different substrate temperature RT, 100, 200 and 300C° were measured by UV-VIS spectrophotometer at room temperature in the range from 300 to 1100nm for the potential applications in the new optoelectronic devices.

The optical transmission results shows that the transparency of CdZnO films deposited at room temperature is greater than 40%, which increases with increasing substrate temperature to reach to 60% at 300C°.

The optical band gap energy was found to be decreased from 3.2 eV to 2.7 eV with increasing substrate temperature. The variation of absorption coefficient and extinction coefficient with wavelength also studied in this work.

Introduction

Transparent conducting oxide (TCO) thin films possess an important amount of consideration due to their broad applications in optoelectronic devices [1]. ZnO is one of the most favorable TCOs currently available. It has heavy potential in research for its singular optical and electrical properties, and multilateral applications in ultraviolet light emitters, chemical sensors, transparent electronics, spin electronics, piezoelectric devices, and thin film transistors [1, 2].

Due to its remarkable properties such as transparency in VIS and NIR spectral regions, low resistivity, biocompatibility, and long-term stability, ZnO gains increasing scientific interest. Additionally, ZnO is inexpensive and nontoxic and finds diverse applications in the fields of optoelectronics bio and gas sensing and integrated optical devices and for optically transparent electrodes in flat panel displays or solar cells for self-cleaning coatings.

The optoelectric properties of ZnO thin films rely on the situation of deposition as these properties revisited significantly with the selected doping element nature, the oxygen absorption that occurs through deposition of film and the temperature of film deposition [3].

The combination or mixture of two or more of TCOs such as ZnO and CdO were tested in order to get CdZnO interesting results because of the individual properties that each one of them possessed [4]. In search of semiconductor device, band gap engineering is necessary and an important subject. The variation of energy band gap in the same device can form hetrostructure or quantum well, which raise the efficiencies in Light-emitting diode (LED) and lasers greatly [5]. This means that the energy bandgap is a key point in the evolvement of optoelectronic devices [6].

Pure ZnO is characterized by a wide direct energy bandgap (~3.37 eV) [7]. On the other hand, CdO has low direct bandgap (~2.2 eV) [8]. It is probably the oxide that exhibits the highest conductivity [9]. The low bandgap of CdO could be modulated by doping and growth provisions. There are several methods used to deposit CdZnO thin films such as molecular beam epitaxy [10], pulse laser deposition (PLD) [11], DC reactive magnetron sputtering [12], spray pyrolysis method [13], and sol-gel [14].

Pulsed laser deposition (PLD) is confirmed to be a suitable mechanism for the deposition of ZnO based alloys at various technological cases on unlike substrates. That assumed to outcome in the several structural and micro structural properties, various morphology of the nanostructures surface to be acquired. [13,15-18].

Mechanisms of PLD

The principle of pulsed laser deposition, in contrast to the simplicity of the system set-up, is a very complex physical phenomenon. It involves all the physical processes of laser-material interaction during the impact of the high-power pulsed radiation on a solid target. It also includes the formation of the plasma plume with high energetic species, the subsequent transfer of the ablated material through the plasma plume onto the heated substrate surface and the final film growth process. Thus, PLD generally can be divided into the following four stages as shown schematically in figure (1-1):

1. Laser radiation interaction with the target.
2. Dynamic of the ablation materials.
3. Decomposition of the ablation materials onto the substrate.
4. Nucleation and growth of a thin film on the substrate surface.

In the first stage, the laser beam is focused onto the surface of the target. At sufficiently high energy density and short pulse duration, all elements in the target surface are rapidly heated up to their evaporation temperature. Materials are dissociated from the target and ablated out with stoichiometry as in the target. The instantaneous ablation rate is highly dependent on the fluences of the laser irradiating on the target. The ablation mechanisms involve many complex physical phenomena such as collisional, thermal and electronic excitation, exfoliation and hydrodynamics. [19,20]

During the second stage the emitted materials tend to move towards the substrate according to the laws of gas-dynamic and show the forward peaking phenomenon. R.K. Singh reported that the spatial thickness varied as a function of cosnphi, where n>>1. The laser spot size and the plasma temperature have significant effects on the deposited film uniformity. The target-to-substrate distance is another parameter that governs the angular spread of the ablated materials. Hanabusa also found that a mask placed close to the substrate could reduce the spreading.

The third stage is important to determine the quality of thin film. The ejected high-energy species impinge onto the substrate surface and may induce various type of damage to the substrate. The mechanism of the interaction is illustrated in the following figure. These energetic species sputter some of the surface atoms and a collision region is established between the incident flow and the sputtered atoms. Film grows immediately after this thermalized region (collision region) is formed. The region serves as a source for condensation of particles. When the condensation rate is higher than the rate of particles supplied by the sputtering, thermal equilibrium condition can be reached quickly and film grows on the substrate surface at the expense of the direct flow of the ablation particles [21,22].

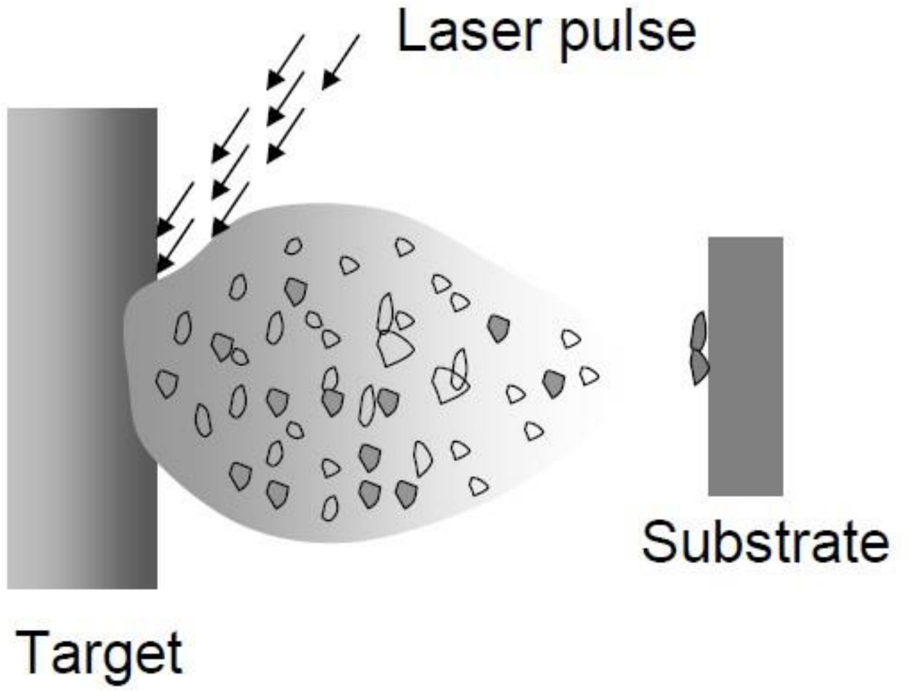


Figure (1): Schematic presentation of the pulsed laser deposition process [20].

Advantages of PLD

1. It is easy to obtain multi- component film that is of the desired stoichiometric ratio by PLD.
2. It has high deposition rate, short test period and low substrate temperature requirements. Films prepared by PLD are uniform.
3. The process is simple and flexible with great development potential and great compatibility.
4. Process parameters can be arbitrarily adjusted, and there is no limit to the type of PLD targets. Multi-target components are flexible, and it is easy to prepare multilayer films and heterojunctions.
5. It is easy to clean and can prepare a variety of thin film materials.

6. PLD uses UV pulsed laser of high photon capability and high energy density as the energy source for plasma generation, so it is non-polluting and easy to control [23, 24].

Disadvantages of PLD

1. For quite a number of materials, there are molten small particles or target fragments in the deposited film, which are sputtered during the laser-induced explosion. The presence of these particles greatly reduces the quality of the film.
2. The feasibility of laser method for large area deposition has not been proved yet.
3. Average deposition rate of PLD is slow.
4. In view of the cost and deposition scale of laser film preparation equipment, it seems that PLD is only suitable for the development of high-tech fields such as microelectronics, sensor technology, optical technology and new material films. [25]

Zinc Oxide

Zinc oxide (ZnO) has attracted much interest within the scientific society as a ‘future material’. However, this is comparatively of a misnomer, as ZnO has been vastly elaborated since 1935, with much of our present industry and day-to-day lives critically depending on this compound**.**

The modern attention in this material has arisen out of growth technologies evolution of high-quality single crystals and epitaxial layers production, allowing for ZnO-based electronic and optoelectronic devices realization**.**

A general view of the ZnO basic properties, inclusive the structure of the crystal, energy band structure and thermal properties are offered, in addition to a preface to the optical properties, basic electronic and potential applications of ZnO. Most binary II-VI compound semiconductors crystallize in the cubic zincblende or hexagonal wurtzite structure. At ambient pressure and temperature (normal conditions), ZnO crystallises in the hexagonal wurtzite (B4 type) structure**.**

ZnO has attracted attention as a transparent conducting oxide (TCO) film because of the following features [26, 27]:

1. Large band gap (3.37eV).
2. High conductivity.
3. Ease in doping.
4. Thermal stability when doped with group III elements.
5. Abundance in nature and non-toxicity.
6. Low cost, relatively low deposition temperature, stability in hydrogen plasma and environmental friendliness.
7. High excitation binding energy.

Cadmium Oxide (CdO)

Cadmium Oxide (CdO) is a II-VI n-type semiconductor has interesting properties like low band gap, low electrical resistivity and high transmission in the visible region. The CdO is insoluble in water and absorbs CO_2 from air and can be reduced to the conducting oxides.

CdO has 2.2 eV direct band gap and 1.98 eV indirect band gaps. CdO has rapidly increased since 2005, with the growth of higher quality films and nanomaterials opening up new fundamental studies and application possibilities. It has been suggested that CdO is potentially an ideal TCO for use in solar cells [28] as it allows optical transmission extending into the infrared (> 1500 nm) combined with extremely low resistivity.

Optical Properties of CdZnO

Both intrinsic and extrinsic effects are related with the optical properties of a semiconductor. Because of the Coulomb interaction, intrinsic optical transitions happen between the electrons in the conduction band and holes in the valence band, including excitonic effects. The essential provision for exciton formulation is that the group velocity of the electron and hole is equal.

Excitons are categorized into free and bound excitons, in samples of high quality with low concentrations of impurity, the free exciton can show also excited states, extra to their ground-state transitions. Extrinsic characteristics are regarded to dopant or defects, which generally make in the band gap discrete electronic states, and thus impact both opticalabsorption and emission processes [29].

The optical properties of $Cd_xZn_{1-x}O$ thin film is heavily influenced by the energy band structure and lattice dynamics. It has been studied by a variety of experimental techniques such as optical absorption, transmission, reflection, photoluminescence, cathode luminescence, etc.

The optical absorption coefficient (α) of thin films can be calculated from the transmittance data at different wavelengths by using the following relation [30].

$$\alpha = \frac{1}{t}\ln\left(\frac{1}{T}\right) \qquad \text{……….} \ (1\text{-}1)$$

Where t: is the thickness of the film and T: is the film transmittance.

The extinction coefficient (K) is defined as the amount of loss in energy that electromagnetic wave suffers it when passing through material, which is related to the wavelength λ (nm) and absorption coefficient α (cm^{-1}) by the equation [31]:

$$K = \frac{\lambda\alpha}{4\pi} \qquad \text{……….} \ (1\text{-}2)$$

Tauc relation is used to evaluate the films optical direct band gap Eg by extrapolation of the linear portion of $(\alpha h\nu)^2$ vs. hν plots as [32].

$$\alpha h\upsilon \approx A\left(h\upsilon - E_g\right)^{\frac{1}{2}} \qquad \text{……….} \ (1\text{-}3)$$

Where hv: is the photon energy and A: is constant.

Methods:

Deposition Equipment

Set-up schematic diagram of laser deposition chamber is shown in figure (2-1), demonstrating the target and substrate holder arrangement inside the chamber with respect to the laser beam.

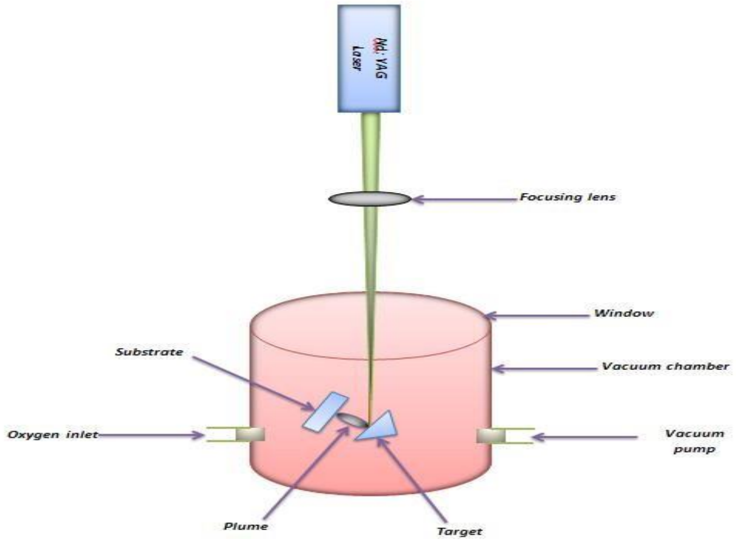


Figure (2): Setup of PLD for preparation CdZnO films.

Deposition Chamber

Deposition chamber shape is cylindrical with 15 cm diameter made from stainless steel. A glass window put on the top of the deposition chamber to allow the laser beam to reach the target. For vacuum sealing, it is settled on Stainless Steel flange including a groove with O-ring. Rotary pump is used to evacuate the chamber connecting directly to it by stainless steel flexible tube is which used to connect to the deposition chamber to obtain a vacuum up to10^{-3} mbar and (Leybold - Heraeus) Pirani gauge is used to controlling the pressure inside the chamber.

Target Preparation

To prepare the composite targets of Cd:Zn, the powders need to be mixed uniformly before pressing. Cadmium (Cd) and Zinc (Zn) powders from Fluka Company with high purity (99.999%) are first weighted and mixed in a tube. The resultant powder is pressed 5 ton to form a target with 2.5 cm diameter and 0.4 cm thickness. The target should be dense and homogenous as possible to ensure a good quality deposition.

Procedure of Thin Film Deposition

CdZnO thin films are synthesized by PLD technique. The focused Nd:YAG (Huafei Tongda Technology-DIAMOND-288 pattern EPLS) SHG Qswitching laser beam at 532 nm (pulse width 7 nsec, repetition frequency 1 Hz) for 300 laser pulse is incident on the target surface making an angle of 45° with it. The substrate is placed parallel to the target surface which is kept a sufficient space (3cm) between them. The films are deposited at room temperature, 100, 200 and 300 C° substrate temperature which raises by a halogen lamp mounted adjacent to the substrate, 500 mJ laser energy, with an oxygen background pressure 7×10^{-2} mbar.

Thickness Measurement

Film thickness measurements by optical interferometer method have been obtained. The method based on interference of the light beam reflection from thin film surface and substrate bottom. This method is known as Fizeau method. He-Ne laser (632.8 nm) is used and the thickness (d) is determined using the formula:

$$d = \frac{\Delta x}{x} \times \frac{\lambda}{2} \qquad \text{………. (2-1)}$$

Where x: is the width of fringe, Δx: is the space between two fringes and λ: is laser light wavelength, as display in figure (2-2). The measured thickness is about 250nm.

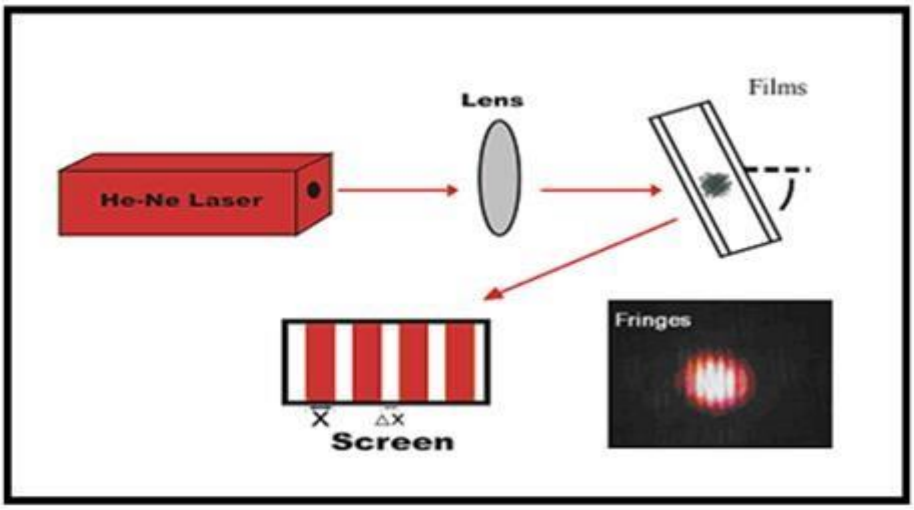


Figure (3): Experimental arranging for thickness measurements [112].

Optical Measurement:

Transmission Measurement

A double –beam 1800 Shimadzu spectrophotometer is used to measure the transmittance of $Cd_{0.2}Zn_{0.8}O$ thin films deposited under different conditions in the range (300-1100) nm. For every scan the background correction is possessed. The transmittance data can be utilized to calculate absorption coefficient, extinction coefficient of the films at various wavelength, and the band gap E_g.

Results and Discussion

The results and discussion of the optical properties of CdZnO thin films deposited on glass substrates by pulsed laser deposition technique at different substrate temperature (RT, 100, 200 and 300) C° have been shown in this chapter. For all CdZnO films the thickness of the film is about 250 nm.

Optical properties:

Transmission

The effect of substrate temperature on optical properties of CdZnO thin films has been determined from the data of transmittance vs. wavelength plot. Figure (3-1) shows the optical transmission spectra recorded for the range over (300-1100) nm at room temperature in air for the CdZnO thin films deposited on glass substrate at various substrate temperatures. The transmission spectra of the films indicated that for all films, the transmission is increases with wavelength increasing, and the optical average transmission increases (from 40% to 60%) with substrate temperature increasing from RT to 300 C°. The increase in transmission at higher temperature may be ascribed to the decreased photons scattering by crystal defects formed by temperature.

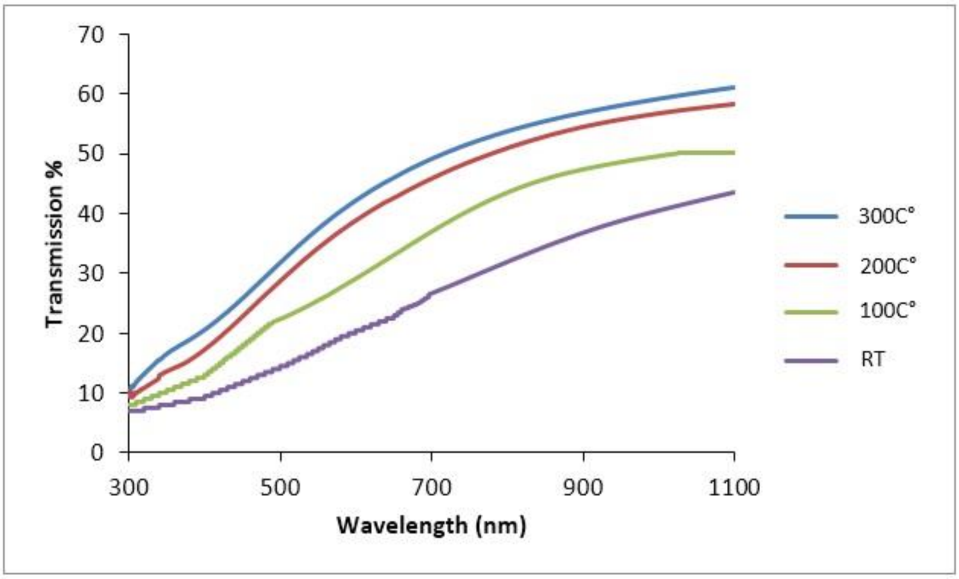


Figure (4): UV-VIS transmission spectra of the CdZnO /glass thin films at different substrate temperature.

Absorption Coefficient (α)

Figure (5) demonstrates the variation of the absorption coefficient against wavelength for CdZnO films at different substrate temperature. It is found from this figure that the highest absorption coefficient is at short wavelength range from 300 to 500 nm. The absorption coefficient of the films is decreased gradually in the range 500 to 800 nm because it is inversely proportional to the transmittance, also the absorption coefficient increased as the substrate temperature increased.

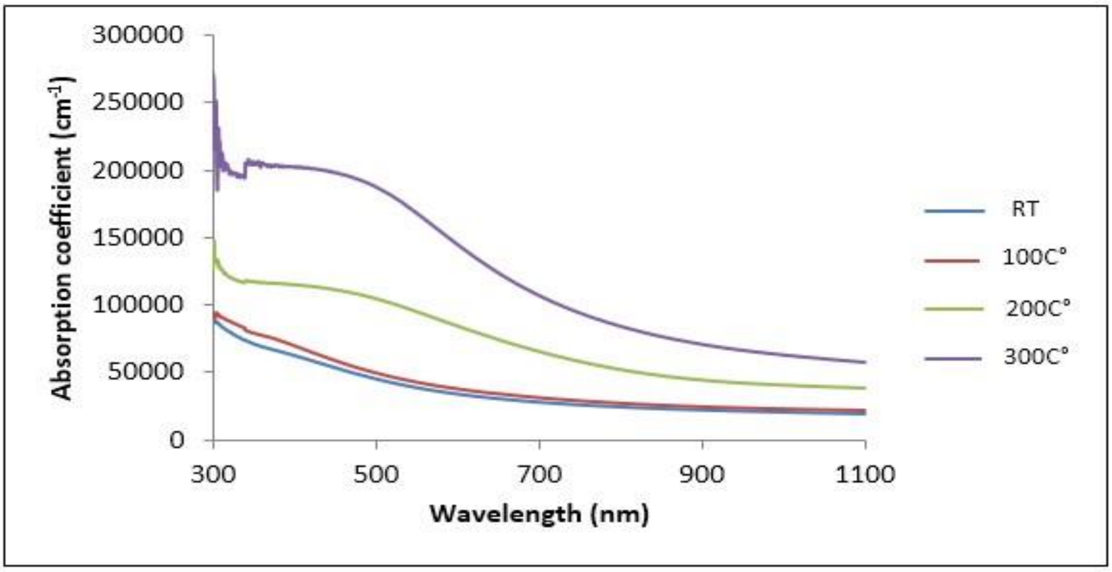


Figure (5): The optical absorption coefficient as a function of wavelength of CdZnO thin films with different substrate temperature.

Extinction Coefficient (K)

Figure (6) exhibits the variation of the extinction coefficient as a function of wavelength for CdZnO films at different substrate temperature. The values of extinction coefficient (k) are calculated from equation (1-2).

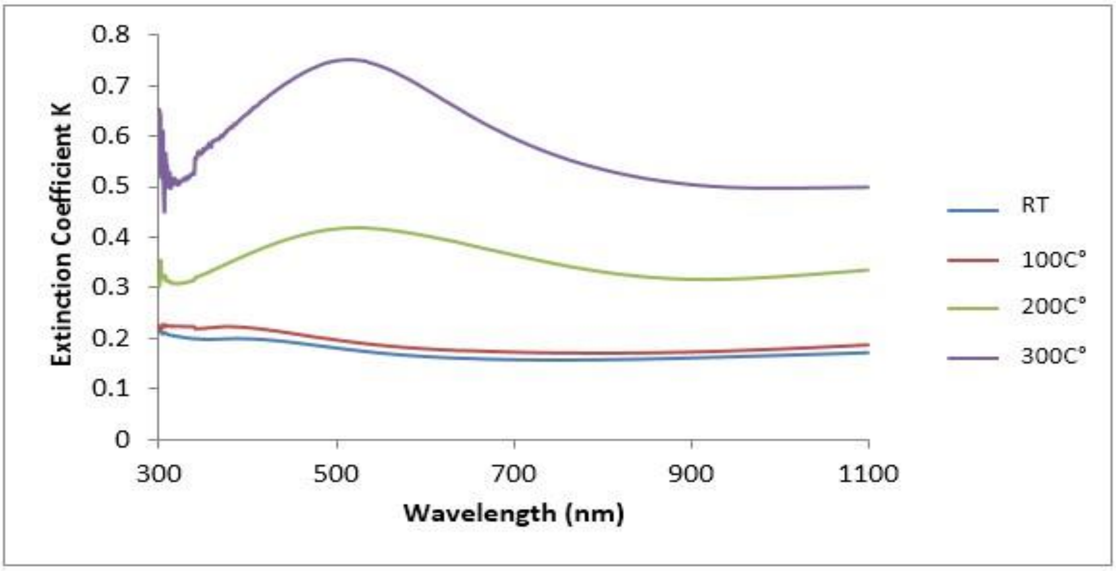
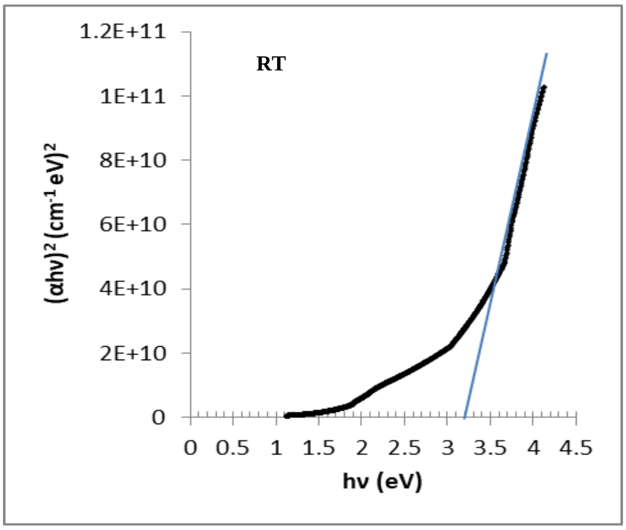
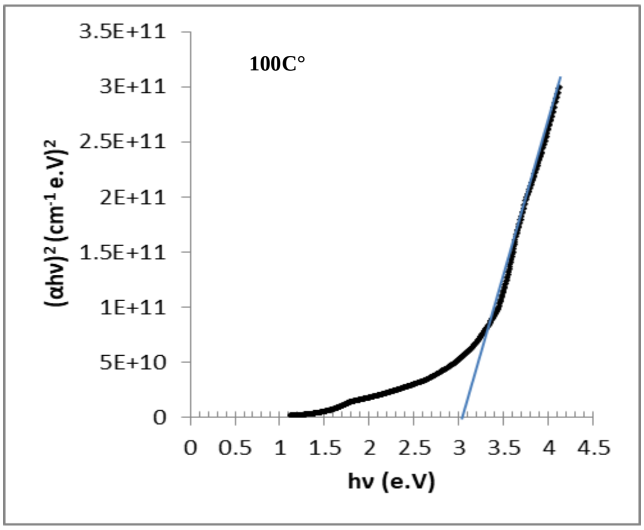


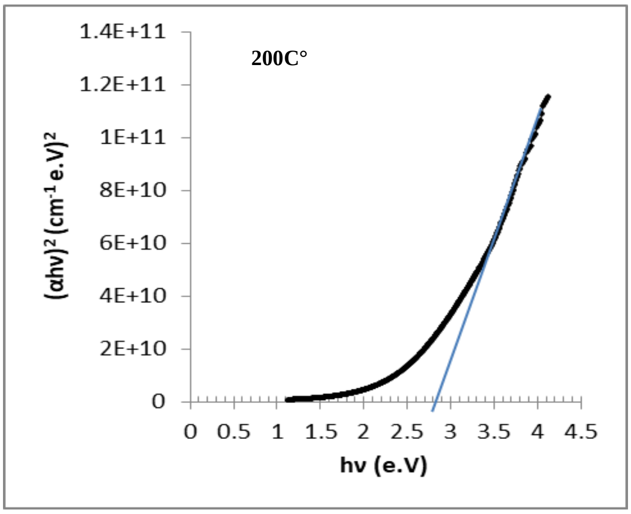
Figure (6): Extinction coefficient as a function of wavelength of CdZnO thin films at different substrate temperature.

Optical energy gap (Eg)

In order to extrapolate the value of the optical band gap energy Eg from the linear portion of (αhν) vs. hν plots. The corresponding plots are shown in figure (7). The direct band gap value of the CdZnO films decreased from 3.2 to 2.7 eV as substrate temperature increased from RT to 300C° as listed in table (3-1). These results are in agreement with other work [33, 34].







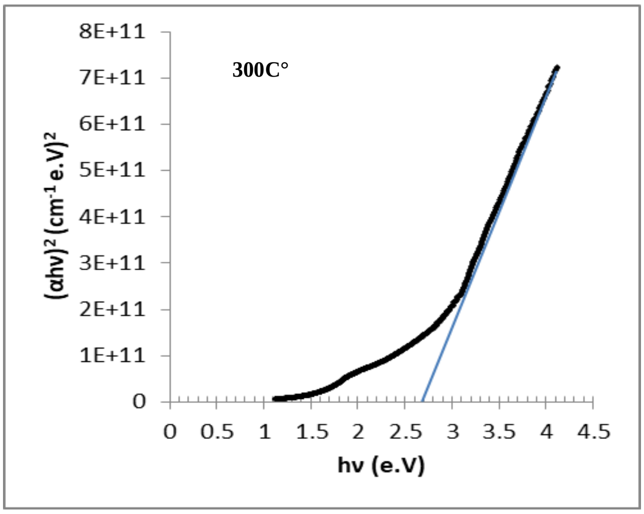


Figure (7): Variation of (αhν) with photon energy (hν) of CdZnO films at different substrate temperature.

(1): The value of band gap with different substrate temperature.

Substrate Temperature (C°)	Eg (eV)
RT	3.2
100	3.05
200	2.85
300	2.7

Conclusion

1. The optical average transmission increases (from 40% to 60%) with substrate temperature increasing from RT to 300 C°.
2. The influence of substrate temperature on the optical energy band gap of CdZnO thin films is significant and found that the band gap decreased as substrate temperature increases to change from 3.2 to 2.7 eV.
3. The variation of absorption coefficient and extinction coefficient with wavelength show a shift in spectra for CdZnO thin films due to the influence of increasing substrate temperature.

Reference:

1. A. Klein, C. Korber, A. Wachau, F. Sauberlich, Y. Gassenbauer, S. Harvey, D. Proffit, T. Mason "Transparent Conducting Oxides for Photovoltaics: Manipulation of Fermi Level, Work Function and Energy Band Alignment" Materials, 3, 4892-4914, **(2010)**.
2. A. Singh, P. Kumar "structural, morphological and optical properties of sol gel processed CdZnO nanostructured films: effect of precursor solvent" International Nano Letters, **(2013)**.
3. F. A. Ali, "Investigation on the properties of pure and doped Nanocrystalline ZnO films" Ph.D thesis, Department of physics Karunya School of Science and Humanities, Karunya University, India **(2011)**.
4. J. Arbiol, M. D. Male, M. Eickhoof, A. F. Morral, " Bandgap engineering in a nanowire: self-assembled 0, 1 and 2D quantum structures" Mater. Today, Vol. 16, 213-9, **(2013)**.
5. B. Lai, Z. Chen, J. Zhang, SH. Chu, G. Chu, R. Peng," Bandgapengineered $Cd_xZn_{1-x}O$ nanowires as active regions for green-lightemitting diodes" Nanotechnology, 25, 355201, 7pp, **(2014)**.

6. A.G. S. Kumar, L. Obulapathi, M. Maddaiah, T. S. Sarmash, D. J. Rani, J. V. V. N. Kesava Roa, T. Subba Roa and K. Asokan "Oxygen partial pressure on the structural and electrical properties of CdZnO thin films" Solid State Physics, AIP Cnf. Proc. 1665,080002, **(2015)**.
7. V.R. Shinde, T.P. Gujar, C.D. Lokhande, R.S. Mane, S.H. Han " Mn doped and undoped ZnO films: A comparative structural, optical and electrical properties study" Mater. Chem. Phys. 96, 326, **(2006)**.
8. R.J. Deokate, S.M. Pawar, A.V. Moholkar, V.S. Sawant, C.A. Pawar, C.H. Bhosale, K.Y. Rajpure " Spray deposition of highly transparent fluorine doped cadmium oxide thin films" Appl. Surf. Sci. 254, 2187, **(2008)**
9. G. A. Flores, B. V. Perez, A. P. Rodriguez, M. V. Garcia, S. C. Tellez, J. A. L. Guzman, C. Falcony, M. A. Frutis "Electrical and structural characteristics of spray deposited $(ZnO)_x$-$(CdO)_{1-x}$ thin films" Revista Mexicana de Fisica 59, 403-411, **(2013)**.
10. S. Sadovef, S. Blumstengel, J. Cui, J. Puls, S. Rogaschewski, P. Schafer " Visible band-gap ZnCdO heterostructures grown by molecular beam epitaxy" Appl. Phys. Lett. 89, 201907, **(2006)**.
11. V. Kumar, K. Lethy, A. Kumar, R. Krishnan, N. V. Pillai, R. Philip "Effect of cadmium oxide incorporation on the microstructural and optical properties of pulsed laser deposited nano structured zinc oxide thin films" Mater. Chem. Phys. 121, 406, **(2010)**.
12. G. S. Kumar, T. S. Sarmash, L. Obulapathi, D. J. Rani, T. S. Rao, K. Asokan "Structural, optical and electrical properties of heavy ion irradiated CdZnO thin films" Thin Solid Films, Vol. 605, 102-107, **(2016)**.
13. T. Noorunisha , V. S. Nagarethinam , M. Suganya , D. Praba , S. Ilangovan , K. Usharani , A.R. Balu "Doping concentration and annealing temperature effects on the properties of nanostructured ternary CdZnO thin films towards optoelectronic application" OptikInternational Journal for Light and Electron Optics, Vol. 127, Issue 5, 2822-2829, **(2016)**
14. F. Yakuphanoglu, S. Ilican, M. Caglar, Y. Caglar " Microstructure and electro-optical properties of sol–gel derived Cd-doped ZnO films" Superlattice and Microstures, 47, 732-743, **(2010)**
15. H.H. Ahmed, A.E. Al-Samarai, A.M. Ali "structural and optical properties of $Cd_xZn_{1-x}O$ thin film prepared by chemical bath deposition method" Diyala Journal for pure sciences, Vol. 10, No. 1, 65-72, **(2014)**.
16. J. A. Najim, J. M. Razaiq "Effect Cd doping on the structural and optical properties of ZnO thin films" International letters of chemistry, physics and Astronomy, Vol. 15, 137-150, **(2013)**.
17. V. Devi1, B.C. Joshi1, M. Kumar, R. J. Choudhary "structural and optical properties of Cd and Mg doped zinc oxide thin films deposited by pulsed laser deposition " Journal of Physics: Conference Series 534, 012047, **(2014).**
18. Y. Ogawa, SH. Fujihara, "Blue luminescence of MgZnO and CdZnO films deposited at low temperature", Journal of the electrochemical society, 0013-4651, 154(9), J283, 6, **(2007)**.
19. D. Dijkkamp, T. Venkatesan, X. D. Wu, S. A. Shareen, N. Jiswari, Y. H. MinLee, W. L. McLean, M. Croft," Preparation of Y_Ba_Cu oxide superconductor thin films using pulsed laser evaporation from high Tc bulk material", Appl. Phys. Lett. 51, 619, **(1987)**.
20. M. Caidi, A. Amassian, M. chakar, M. Kulishov "Pulsed Laser Deposition of PLZT film: structural and optical characterization"Applied Surface Science 234, 341, **(2004).**

21. G. Ausanio, A. C. Barone, V. Iannotti, L. Lanotte, S. Amoruso, R. Bruzzese, M. Vitiello, “Magnetic and Morphological Characteristics of Nickel Nano Particles Films Produced by Femtosecond Laser Ablation”, Appl. Phys. Lett. 85, 18, P. 4103,**(2004)**.

22. J. Ylänen, P. Vuoristo, “Use of Pulsed Laser Deposition in the Production of Thin Films – a Literature Review”, Tampere University of Technology, Institute of Materials Science Report March, **(2006)**.

23. *23+ R. Eason, “pulsed laser Deposition of thin films Applications-led growth of functional materials”, John Wiley & Sons, **(2007)**.

24. *24+ C. Phipps “Laser Ablation and its Application”, New Maxico Springer **(2007)**.

25. K. Kinoshita, H. Ishibasi, T. Kobayashi," Improved surface smoothness of YBaCuO films and related multilayers by ArF Excimer laser deposition with shadow mask eclipse method", Jpn. J. Appl. Phys., 33, L417, **(1994)**.

26. S. Cho, J. Ma, Y. Kim, Y. Sun, G. K. L. Wong, J. B. Ketterson, " Oxamflation in a novel antitumor compound that inhibits mammalian histone deacetylase", Appl. Phys. Lett., 75, 18, P. 2761, **(1999)**.

27. S. Singh, P. Thiyagarajan, K. M. Kant," structure, microstructure and physical properties of ZnO based material in various forms: bulk, thin film and nano", J. Phys. D: Appl. Phys., 40, 6312, **(2007)**.

28. K. M. Yu, M. A. Mayer, D. T. Speaks, H. He, R. Zhao, L. Hsu, S. S. Mao, E. E. Haller, W. Walukiewicz," Ideal transparent conductors for full spectrum photovoltaics", J. Appl. Phys. 111, 123505, **(2012)**.

29. J. E. Jaffe, J. A. Snyder, Z. Lin, A. C. Hess," LDA and GGA calculation for high-pressure phase transitions in ZnO and MgO", Phys. Rev. B62, 3, 1660, **(2000).**

30. A. J. Haidar, J.A. Saimon, A. J. Addie, "Effect of Mg Concentration $MgxZn_1XO$ nanostructure thin films by PLD on optical and topographical properties", Eng. & Tech.Journal, vol. 31, part (B), No.7, **(2013)**.

31. C.M. Muiva, Y. S. Sathiaraj, K. Maabong, "Effect of doping concentration on the properties of aluminium doped zinc oxide thin films prepared by spray pyrolysis for transparent electrode applications" Ceramic International 37, 555-560 , **(2011)**.

32. A. I. Hassan, K. S. Khashan, J. A. Saimon "Preparation and Characterization of NiO Thin Films by PLD" Eng. And Technology Journal, Vol.33, Part (B), No.1, 52-60, **(2015)**.

33. A. G. Kumara, T. S. Sarmash, L. Obulapathi, D. J. Rani, T. S. Rao, K. Asokan, "Effect of substrate temperature on structural and optical properties of reactive dc magnetron sputtered CdZnO thin films" Materials Today: Proceedings 3, 1604–1608 **(2016).**

34. N. J. Mohammed, H. A. Mahdi, S. F. Madlul, A. K. Hasan, "Effect of Substrate Temperature on Structural and Optical Properties of Cadmium Sulfide Thin Films Prepared by Evaporation Thermal Deposition" Al-Mustansiriyah Journal of Science, Volume 30, Issue 1, 205-209 (2019).