

2021

## Characterization of CdS/ZnS and CdS/CoS Multilayer Thin Films Synthesized by Chemical Bath Deposition

Tizazu Abza

*College of Natural and Computational Science, Hawassa University, Ethiopia, zabishwork2@gmail.com*

SisayTadesse

*College of Natural and Computational Science, Hawassa University, Ethiopia, zabishwork2@gmail.com*

Dinsefa Menseure Andoshe

*Department of Materials Science and Engineering, Adama Science and Technology University, Ethiopia, zabishwork2@gmail.com*

Follow this and additional works at: <https://digitalcommons.aaru.edu.jo/ijtfst>

---

### Recommended Citation

Abza, Tizazu; SisayTadesse; and Menseure Andoshe, Dinsefa (2021) "Characterization of CdS/ZnS and CdS/CoS Multilayer Thin Films Synthesized by Chemical Bath Deposition," *International Journal of Thin Film Science and Technology*. Vol. 10 : Iss. 1 , Article 1.

Available at: <https://digitalcommons.aaru.edu.jo/ijtfst/vol10/iss1/1>

This Article is brought to you for free and open access by Arab Journals Platform. It has been accepted for inclusion in International Journal of Thin Film Science and Technology by an authorized editor. The journal is hosted on [Digital Commons](#), an Elsevier platform. For more information, please contact [rakan@aar.edu.jo](mailto:rakan@aar.edu.jo), [marah@aar.edu.jo](mailto:marah@aar.edu.jo), [u.murad@aar.edu.jo](mailto:u.murad@aar.edu.jo).

# Characterization of CdS/ZnS and CdS/CoS Multilayer Thin Films Synthesized by Chemical Bath Deposition

Tizazu Abza<sup>1,\*</sup>, SisayTadesse<sup>1</sup> and Dinsefa Mensure Andoshe<sup>2</sup>

<sup>1</sup>College of Natural and Computational Science, Hawassa University, Ethiopia

<sup>2</sup>Department of Materials Science and Engineering, Adama Science and Technology University, Ethiopia

Received: 20 Apr. 2020, Revised: 17 Oct. 2020, Accepted: 24 Nov. 2020

Published online: 1 Jan. 2021

**Abstract:** In this work multilayer films of CdS/ZnS and CdS/CoS were prepared using the chemical bath deposition technique. The influence of substrate materials on structural, morphological, compositional and optical properties of the films was investigated. The powder X-ray diffraction (XRD) pattern of CdS/ZnS thin film showed nearly similar structure to that of the cubic ZnS structure. The XRD pattern of CdS/CoS thin films confirmed the co-existence of hexagonal and orthorhombic CdS phases. A cubic CdS structure is observed for CdS/glass thin film. The scanning electron microscopy (SEM) micrograph of CdS/glass film revealed spherical grains of size 125 nm covering the substrate uniformly without voids and cracks. The as large grain size as 800 nm with distinct grain boundaries was observed for CdS/ZnS multilayer film with some voids on the surface. The SEM micrograph of CdS/CoS thin film showed spherical surface grains of size 450 nm on flat and compact background. The energy dispersive X-ray spectra of single and multilayer CdS films confirmed the presence of Cd and S. The optical analysis of the CdS/glass, CdS/ZnS and CdS/CoS thin films confirmed band gaps of 2.5, 2.3 and 2.27 eV respectively.

**Keywords:** heterostructure, Crystal structure, Cadmium sulfide, Cobalt sulfide, Zinc sulfide, Chemical bath,

## 1 Introduction

Cadmium sulfide (CdS) is an important II-VI group semiconductor material owing to its optical properties, photoconductivity, high electron affinity and stability [1]. It exhibits n-type conductivity because of native defects such as sulfur vacancies and interstitial cadmium [2]. CdS is widely used in optical detectors, optoelectronic devices and as a window material in various heterojunction solar cells [3]. CdS thin films can be prepared by different techniques such as closed space sublimation [4], RF magnetron sputtering [5], chemical bath deposition (CBD) [1, 3], vacuum evaporation [6], and spray pyrolysis [2]. CBD of CdS is a common practice since 1960s [7]. The CBD has many benefits like low cost for equipment and operation, simplicity in operation, low deposition temperature, low energy consumption, and large area deposition in a single procedure [8, 9]. The nature of chemical bath deposited thin film depends on the preparation parameters such as nature of precursors [10-12], the deposition temperature [13, 14], pH [15-17], duration [18-20] and the substrate type [21-23]. Any solid material that does not dissolve in the chemical bath can be used as a substrate. However, type of substrate has

substantial impact on the structural, optical, morphological and other properties of a film [24]. Glass is commonly used substrate for the deposition of CdS films by CBD technique. Other materials like polycarbonate, polyethylene terephthalate, Si wafer and indium-tin-oxide were also used as a substrate to deposit CdS. The substrate surface treatment either by heat or by chemicals also modifies the film properties [3, 25-28]. A semiconductor multilayers film, heterojunction, is formed when a semiconductor substrate is used to deposit another semiconductor of dissimilar bandgap and lattice constants. Semiconductor multilayer thin films are the basics of heterostructure devices that exploits the interface properties of these structures. Such structures inject nonequilibrium charge carriers, control the type of conductivity and other fundamental parameters: band gaps, effective mass of the charge carriers and the mobilities, refractive indices, the electron energy spectrum etc. inside the semiconductor crystals and devices [29]. The operation of semiconductor lasers, light-emitting diodes, photodetectors, highest-performance optical sources and detectors, and high-speed and high-frequency digital and analog devices exploit the heterostructure of semiconductors [30, 31].

In this work, we report on the structural, optical and

\*Corresponding author E-mail: zabishwork2@gmail.com

morphological properties of chemical bath deposited CdS thin films and its heterojunctions with ZnS and CoS. The heterojunction of the CdS with ZnS and several types of their mixtures can be used as an n-type buffer layer to form thin film heterojunction solar cells [32, 33], quantum wells [34], light emitting devices [35] etc. Similarly, heterostructure of CdS and various phases of cobalt sulfide, like Co<sub>9</sub>S<sub>8</sub> and Co<sub>4</sub>S<sub>3</sub>, are currently used for improving photocatalytic hydrogen production [36-38]. There are very few reports on chemical bath deposited heterojunctions of the CdS with ZnS [9, 32]. However, to the best of our knowledge there are no reports on chemical bath deposited heterostructure of CdS with CoS.

## 2 Experimental Section

### 2.1 Synthesis of the Thin Films

In the deposition of CdS/ZnS and CdS/CoS multilayers, the ZnS and CoS layers were first prepared on soda lime glass substrates. Before the deposition of the ZnS and CoS, the soda lime glass slides were immersed in nitric acid for 12 h and in ethanol for 30 min, consecutively. Then the substrates were cleaned by distilled water ultrasonically and dried under ambient conditions. Analytical grade cadmium acetate (BDH), Zinc acetate (CARLO ERBA), cobalt acetate (Loba Chemie), thioacetamide (Titan), and Na<sub>2</sub>EDTA (Fine Chemicals) were used as starting reagents. The CoS substrate was prepared on the cleaned soda lime glass substrate from a solution of 1 M (10 ml) cobalt acetate, 0.2 M (9 ml) Na<sub>2</sub>EDTA, 1 M (10 ml) thioacetamide and 61 ml distilled water at pH of 6 for 90 min. Similarly, the ZnS substrate was prepared on soda lime glass substrate from a solution containing 0.1 M (15 ml) zinc acetate, 0.2 M (2 ml) Na<sub>2</sub>EDTA, 1 M (7 ml) thioacetamide and 36 ml distilled water at pH of 2.5 for 100 min. After their corresponding deposition period, the ZnS and the CoS thin films were taken out of the chemical baths, washed with distilled water thoroughly and dried in ambient conditions before used for the preparation of the CdS films. The CdS thin films were deposited on soda lime glass (CdS/glass), ZnS coated soda lime glass (CdS/ZnS) and CoS coated soda lime glass (CdS/CoS) substrates from a solution of 0.1 M (15 ml) cadmium acetate, 0.2 M (2 ml) Na<sub>2</sub>EDTA, 1 M (7 ml) thioacetamide and 36 ml distilled water at pH of 2.5 for 100 min. The bath temperature of all the depositions carried out in the present work was adjusted to 80 °C. The optical, morphological, compositional and structural properties of the single and multilayer films were characterized by UV-Vis spectrometer, scanning electron microscope (SEM), energy dispersive X-ray analyzer (EDX) and X-ray diffractometer respectively.

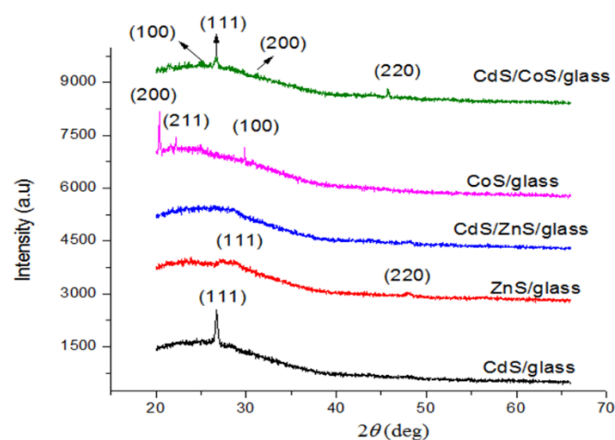
### 2.2 Characterization of the Thin Films

Structural characterization of the films was carried by Bruker D8 X-ray diffractometer (XRD) with CuK $\alpha$  ( $\lambda = 1.5406 \text{ \AA}$ ) radiation working at 40 mA and 40 kV at a scan rate of 0.03°/s. The XRD patterns were analyzed by matching the observed peaks with the standard JCPDS files. The surface morphology and composition of single and multilayer thin films were studied by ZEISS sigma field effect scanning electron microscopy (FE-SEM) attached with ZEISS Analysis Station energy dispersive X-ray (EDX) devices. The optical properties of the thin films were determined from the absorption spectrum using Shimadzu UV-3600 plus UV-Vis Spectrophotometer within the wavelength range of 300 nm-1000 nm for ZnS, CdS and CdS/ZnS, 500- 2000 nm for CoS and 300 – 2000 nm for CdS/CoS films.

## 3 Results and Discussion

### 3.1 Structural Studies

The XRD patterns of different substrates and the CdS thin films deposited on these substrates are shown in Figure 1. As it can be observed from this figure, the CdS thin film deposited on soda lime glass substrate has a single peak at  $2\theta = 26.69^\circ$  which is indexed to (111) plane of cubic structure (JCPDS # 00-010-0454). The XRD pattern of ZnS thin film deposited on glass substrate has two very weak peaks at  $2\theta = 28.63^\circ$  and  $47.97^\circ$  which were indexed to (111) and (220) planes of cubic phase (JCPDS # 00-005-0566). The CdS/ZnS multilayer has similar diffraction pattern to that of ZnS thin films deposited on the glass substrate. This implies that new CdS phase has not been grown on the ZnS structure. Three peaks were observed at  $2\theta = 20, 29, 22.32$  and  $29.95^\circ$  on XRD pattern of CoS thin film deposited on soda lime glass substrate. Comparison of this pattern with the PDF files indicates that the CoS film consists of the mixtures of phases.



**Fig.1:** XRD patterns of CdS, CoS and ZnS thin films deposited on glass and CdS thin films deposited on CoS and ZnS coated glass substrates.

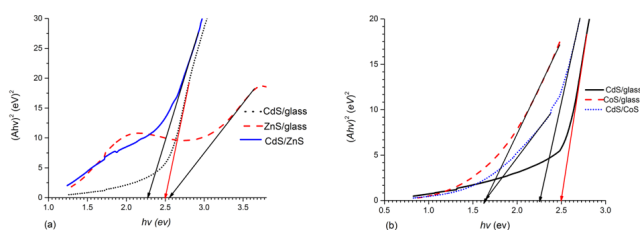


of light. However, the reverse is true in the infrared region.

The energy band gaps of the thin films were obtained using Stern relationship (Eqn. 1) at the near-fundamental absorption edge [41].

$$A = \frac{[k(h\nu - E_g)]^{\frac{n}{2}}}{h\nu} \quad (1)$$

where  $A$  is absorbance,  $k$  is a constant,  $h$  is the Planck's constant,  $\nu$  is the frequency of the radiation, and  $n$  is 1 for the direct transition which is true for almost all compound semiconductors and 4 for the indirect transition. In the case of direct transition  $(Ah\nu)^2$  and the photon energy ( $h\nu$ ) (Eqn.1) has linear relation in the region next to the onset of fundamental absorption [42].



**Fig. 4:** Optical band gap of different substrates and the CdS thin films deposited on these substrates.

The band gap energy ( $E_g$ ) was obtained by extrapolating the linear portion of the  $(Ah\nu)^2$  vs  $(h\nu)$  curve towards  $h\nu$  axis. The band gaps of the CdS/glass, ZnS/glass, CdS/ZnS and CoS/glass thin films are equal to 2.5, 2.6, 2.3 and 1.6 eV respectively (Figure 4). The CdS/CoS multilayer has two band gaps of 1.6 and 2.27 eV corresponding to CoS and CdS phases, respectively. The presence of a single bandgap in CdS/ZnS confirms the homogenization of ZnS and CdS layers instead of forming their own phases. The decrease in band gap when CdS deposited on ZnS and CoS could be due to strain and increase in the grain size as shown in SEM micrograph of CdS/ZnS and CdS/CoS films (Figure 2) [43, 44]. In the case of CdS/CoS, the band gap decrease can also be resulted from the substitution of some of the Cd ions specially at the interface region by relatively larger atomic radius Co ions [45].

## 4 Conclusions

The CdS thin films were synthesized on different substrates by solution growth technique from a solution of cadmium acetate, thioacetamide and  $Na_2EDTA$  in acidic condition. The XRD investigation confirmed that the type of substrate has significant influence on the growth and crystal structure of the CdS thin films. The CdS thin film deposited on soda lime glass substrate was grown in cubic structure and the one grown on ZnS substrate forms a homogenized phase with cubic ZnS structure. The XRD pattern of CdS/CoS

multilayer shows a mixture of hexagonal and orthorhombic CdS structures. The single and multilayered CdS thin films deposited on different substrates possessed different morphology in terms of shape and size of grains, voids and cracks. A stoichiometric CdS thin film was deposited on a glass substrate, however, films deposited on ZnS and CoS substrate are dominated by sulfur. The optical bandgaps of the CdS films on ZnS and CoS substrates decreased as compared to that of deposited on a glass substrate. The structural, morphological and optical results confirmed that CdS thin film deposited on ZnS substrate forms homogenized phase with cubic ZnS structure and that deposited on CoS substrate forms a mixture of hexagonal and orthorhombic CdS phases. The present investigations showed that substrate has significant influence on structural, morphological, compositional and optical properties of the CdS thin films.

## Acknowledgement

The authors thankfully acknowledge Hawassa University for funding this research work.

## References

- [1] Pandya, S.G., Preparation and characterization of cadmium sulphide nanocrystalline thin film grown by chemical method. *International Journal of Recent Scientific Research.*, **7**, 14887-14890(2016).
- [2] Anbarasi, M., V. Nagarethinam, and A. Balu, Studies on the physical properties of undoped AND Zn-doped CdS thin films prepared by spray pyrolysis technique using perfume atomizer. *Indian J. Sci.*, **13(38)**, 48-52(2015).
- [3] Lim, D., J. Lee, and W. Song, Improvement of the characteristics of chemical bath deposition-cadmium sulfide films deposited on an O<sub>2</sub> plasma-treated polyethylene terephthalate substrate. *Thin Solid Films.*, **546**, 317-320(2013).
- [4] Han, J.-f., G.-h. Fu, V. Krishnakumar, H.-J. Schimper, C. Liao, W. Jaegermann, and M. Besland, Studies of CdS/CdTe interface: Comparison of CdS films deposited by close space sublimation and chemical bath deposition techniques. *Thin Solid Films.*, **582**, 290-294 (2015).
- [5] Feldmeier, E., A. Fuchs, J. Schaffner, H.-J. Schimper, A. Klein, and W. Jaegermann, Comparison between the structural, morphological and optical properties of CdS layers prepared by Close Space Sublimation and RF magnetron sputtering for CdTe solar cells. *Thin Solid Films.*, **519(21)**, 7596-7599(2011).
- [6] Tomakin, M., M. Altunbaş, E. Bacaksiz, and Ş. Çelik, Current transport mechanism in CdS thin films prepared by vacuum evaporation method at substrate temperatures below room temperature. *Thin Solid Films.*, **520(7)**, 2532-2536(2012).
- [7] Hodes, G., Chemical solution deposition of semiconductor films. 2002: CRC press.
- [8] Barote, M., A. Yadav, and E. Masumdar, Synthesis,

- characterization and photoelectrochemical properties of n-CdS thin films. *Physica B: Condensed Matter.*, **406(10)**, 1865-1871(2011).
- [9] Oladeji, I.O. and L. Chow, Synthesis and processing of CdS/ZnS multilayer films for solar cell application. *Thin Solid Films.*, **474(1-2)**, 77-83(2005).
- [10] Al-Hussam, A.M. and S.A.-J. Jassim, Synthesis, structure, and optical properties of CdS thin films nanoparticles prepared by chemical bath technique. *Journal of the Association of Arab Universities for Basic and Applied Sciences.*, **11(1)**, 27-31(2012).
- [11] Chu, J., Z. Jin, W. Wang, H. Liu, D. Wang, J. Yang, and Z. Hong, Influence of anionic concentration and deposition temperature on formation of wurtzite CdS thin films by in situ chemical reaction method. *Journal of Alloys and Compounds.*, **517**, 54-60(2012).
- [12] Khallaf, H., G. Chai, O. Lupan, L. Chow, S. Park, and A. Schulte, Investigation of aluminium and indium in situ doping of chemical bath deposited CdS thin films. *Journal of Physics D: Applied Physics.*, **41(18)**, 185304(2018).
- [13] Sharkey, J.J., V. Dhanasekaran, C.W. Lee, and A.J. Peter, Microstructural parameters and optical constants of CdS thin films synthesized with various bath temperature. *Chemical Physics Letters.*, **503(1-3)**, 86-90(2011).
- [14] Liu, F., Y. Lai, J. Liu, B. Wang, S. Kuang, Z. Zhang, J. Li, and Y. Liu, Characterization of chemical bath deposited CdS thin films at different deposition temperature. *Journal of Alloys and Compounds.*, **493(1-2)**, 305-308(2010).
- [15] Ochoa-Landín, R., M. Sandoval-Paz, M. Ortuño-López, M. Sotelo-Lerma, and R. Ramírez-Bon, Observations on the influence of pH control on the properties of chemically deposited CdS films in an ammonia-free system. *Journal of Physics and Chemistry of Solids.*, **70(6)**, 1034-1041(2009).
- [16] Prabakar, S. and M. Dhanam, CdS thin films from two different chemical baths—structural and optical analysis. *Journal of Crystal Growth.*, **285(1-2)**, 41-48 (2005).
- [17] Kariper, A., E. Güneri, F. Göde, C. Gümüş, and T. Özpozan, The structural, electrical and optical properties of CdS thin films as a function of pH. *Materials Chemistry and Physics.*, **129(1-2)**, 183-188(2011).
- [18] Guillén, C., M. Martinez, and J. Herrero, Accurate control of thin film CdS growth process by adjusting the chemical bath deposition parameters. *Thin Solid Films.*, **335(1-2)**, 37-42(1998).
- [19] Alexander, J.N., S. Higashiya, D. Caskey Jr, H. Efstathiadis, and P. Haldar, Deposition and characterization of cadmium sulfide (CdS) by chemical bath deposition using an alternative chemistry cadmium precursor. *Solar Energy Materials and Solar Cells.*, **125**, 47-53(2014).
- [20] Çetinörgü, E., C. Gümüş, and R. Esen, Effects of deposition time and temperature on the optical properties of air-annealed chemical bath deposited CdS films. *Thin Solid Films.*, **515(4)**, 1688-1693(2006).
- [21] Cao, M., Y. Sun, J. Wu, X. Chen, and N. Dai, Effects of cadmium salts on the structure, morphology and optical properties of acidic chemical bath deposited CdS thin films. *Journal of Alloys and Compounds.*, **508(2)**, 297-300(2010).
- [22] Lee, J.-H., Influence of substrates on the structural and optical properties of chemically deposited CdS films. *Thin Solid Films.*, **515(15)**, 6089-6093(2007).
- [23] Oliva, A., R. Castro-Rodríguez, O. Ceh, P. Bartolo-Perez, F. Caballero-Briones, and V. Sosa, First stages of growth of CdS films on different substrates. *Applied Surface Science.*, **148(1-2)**, 42-49(1999).
- [24] Martínez, M., C. Guillen, and J. Herrero, Cadmium sulphide growth investigations on different SnO<sub>2</sub> substrates. *Applied Surface Science.*, **140(1-2)**, 182-189(1999).
- [25] Castro-Rodríguez, R., A. Oliva, V. Sosa, F. Caballero-Briones, and J. Pena, Effect of indium tin oxide substrate roughness on the morphology, structural and optical properties of CdS thin films. *Applied Surface Science.*, **161(3-4)**, 340-346(2000).
- [26] Long, F., W.-M. Wang, Z.-k. Cui, L.-Z. Fan, Z.-g. Zou, and T.-k. Jia, An improved method for chemical bath deposition of ZnS thin films. *Chemical Physics Letters.*, **462(1-3)**, 84-87(2008).
- [27] Luque, P., M. Quevedo-Lopez, and A. Olivas, Influence of deposition time on ZnS thin film growth over SiO<sub>2</sub> and glass substrates. *Materials Letters.*, **106**, 49-51(2013).
- [28] O'Brien, P., E. Hill, M. Malik, and M. Toohey, Chemical bath deposition of cadmium sulphide on silicon nitride: Influence of surface treatment on film growth. *Materials Letters.*, **61(1)**, 284-287(2007).
- [29] Chu, S., C. Cohen-Tannoudji, and W. Phillips, Nobel Lectures in Physics: 1996-2000. 2003, World Scientific Pub. Co. Inc.
- [30] Razeghi, M., *Fundamentals of solid state engineering*. 2006: Springer.
- [31] Frensley, W.R., *Heterostructure and quantum well physics*, in VLSI Electronics Microstructure Science. 1994, Elsevier. p. 1-24.
- [32] García-Barrientos, A., H. Gomez-Pozos, E. Villicaña-Ortiz, and L. Cruz-Netro, Comparative Study of CdS and CdS/ZnS Thin Films Deposited by CBD as a Buffer Layer Solar Cell. *Microscopy and Microanalysis.*, **24(S1)**, 1548-1549(2018).
- [33] Echendu, O.K. and I.M. Dharmadasa, Graded-bandgap solar cells using all-electrodeposited ZnS, CdS and CdTe thin-films. *Energies.*, **8(5)**, 4416-4435(2015).
- [34] Szczerbakow, A., M. Godlewski, E. Dynowska, V.Y. Ivanov, K. Swiatek, E. Goldys, and M. Phillips, Structure, surface morphology and optical properties of thin films of ZnS and CdS grown by atomic layer epitaxy. *Acta Physica Polonica-Series A General Physics.*, **94(3)**, 579-582(1998).
- [35] Valkonen, M.P., T. Kannianen, S. Lindroos, M. Leskelä, and E. Rauhala, Growth of ZnS, CdS and multilayer ZnS/CdS thin films by SILAR technique. *Applied surface science.*, **115(4)**, 386-392(1997).
- [36] Kumar, D.P., H. Park, E.H. Kim, S. Hong, M. Gopannagari, D.A. Reddy, and T.K. Kim, Noble metal-free metal-organic framework-derived onion slice-type hollow cobalt sulfide nanostructures: Enhanced activity of CdS for improving

- photocatalytic hydrogen production. *Applied Catalysis B: Environmental.*, **224**, 230-238(2018).
- [37] Qiu, B., Q. Zhu, M. Du, L. Fan, M. Xing, and J. Zhang, Efficient solar light harvesting CdS/Co<sub>9</sub>S<sub>8</sub> hollow cubes for Z-scheme photocatalytic water splitting. *Angewandte Chemie International Edition.*, **56(10)**, 2684-2688(2017).
- [38] Reddy, D.A., H. Park, M. Gopannagari, E.H. Kim, S. Lee, D.P. Kumar, and T.K. Kim, Designing CdS Mesoporous Networks on Co-C@ Co<sub>9</sub>S<sub>8</sub> Double-Shelled Nanocages as Redox-Mediator-Free Z-Scheme Photocatalyst. *ChemSusChem.*, **11(1)**, 245-253(2018).
- [39] Abza, T., D.G. Dadi, F.G. Hone, T.C. Meharu, G. Tekle, E.B. Abebe, and K.S. Ahmed, Characterization of Cobalt Sulfide Thin Films Synthesized from Acidic Chemical Baths. *Advances in Materials Science and Engineering.*, 2020.
- [40] Cao, M., L. Li, B. Zhang, J. Huang, K. Tang, H. Cao, Y. Sun, and Y. Shen, Influence of substrates on the structural and optical properties of ammonia-free chemically deposited CdS films. *Journal of alloys and compounds.*, **530**, 81-84(2012).
- [41] Abza, T., F.K. Ampong, F.G. Hone, R.K. Nkum, and F. Boakye, Preparation of cadmium zinc sulfide (Cd<sub>1-x</sub>Zn<sub>x</sub>S) thin films from acidic chemical baths. *Thin Solid Films.*, **666**, 28-33(2018).
- [42] Nasr, T.B., N. Kamoun, M. Kanzari, and R. Bennaceur, Effect of pH on the properties of ZnS thin films grown by chemical bath deposition. *Thin solid films.*, **500(1-2)**, 4-8(2006).
- [43] Das, N., P. Ghosh, M. Mitra, and K. Chattopadhyay, Effect of film thickness on the energy band gap of nanocrystalline CdS thin films analyzed by spectroscopic ellipsometry. *Physica E: Low-Dimensional Systems and Nanostructures.*, **42(8)**, 2097-2102(2010).
- [44] Makhdoumi-Kakhaki, Z., A. Youzbashi, P. Sangpour, N. Naderi, and A. Kazemzadeh, Effects of film thickness and stoichiometric on the electrical, optical and photodetector properties of CdS quantum dots thin films deposited by chemically bath deposition method at different bath temperature. *Journal of Materials Science: Materials in Electronics.*, **27(12)**, 12931-12939(2016).
- [45] Saravanakumar, S., R. Chandramohan, R. Premarani, J.J. Devadasan, and J. Thirumalai, Studies on Dilute Magnetic Semiconducting Co-Doped CdS Thin Films Prepared by Chemical Bath Deposition method. *Journal of Materials Science: Materials in Electronics.*, **28(16)**, 12092-12099 (2017).