

## Original Research Article

# STUDIES ON THE OPTICAL DISPERSION PARAMETERS AND ELECTRONIC POLARIZABILITY OF CADMIUM SULPHIDE THIN FILM.

### ABSTRACT

Thin film of Cadmium Sulphide (CdS) was deposited onto transparent glass substrate by chemical bath deposition technique. CdS thin film was characterized by UV-Visible spectrophotometer within the wavelength range of 280 nm – 920 nm using Single – Beam Helios Omega UV – VIS spectrophotometer. The optical parameters; extinction coefficient, refractive index and dielectric constant of CdS thin film were analyzed from absorption spectra. The optical band gap energy was obtained by Tauc's equation. The Dispersion parameters (dispersion energy, oscillation energy, moment of optical dispersion spectra, static dielectric constant and static refractive index) were calculated using theoretical Wemple-DiDomenico model. The oscillation strength, oscillator wavelength, high frequency dielectric constant and high frequency refractive index were calculated by single Sellmeier oscillator model. Also, Lattice dielectric constant,  $N/m^*$  and plasma resonance frequency were obtained. The electronic polarizability of CdS thin film was estimated by Lorenz - Lorentz equation and Clausius Mossotti local field polarizability model.

Comment [MOU1]: Please explain a bit of the method that used in abstract

Comment [MOU2]: Please the present your valuable finding with your data

*Keywords: Dispersion parameter; Wemple-DiDomenico model; single Sellmeier oscillator model; Clausius-Mossotti local field polarizability; CdS thin film.*

### 1. INTRODUCTION

The properties of Semiconductor materials are very important for determining their applicability in various fields. Moreover, in nanoscale some of the properties have been affected that made it differ from the bulk material especially the bandgap [1 – 4]. Since it is possible to adjust or tailor their electrical and optical properties especially when physical dimensions are reduced to a few nanometres which these properties depend upon, that makes them useful for application in optoelectronics, nonlinear optics and photoelectrochemical solar cell devices [1,4,5,6]. Dispersion parameters can be determined by parameterization of data. This is because these parameters depend on the dielectric functions of films and other corresponding function such as the bandgap, optical dispersion energies ( $E_o, E_d$ ), dielectric constant ( $\epsilon$ ), ratio between the number of charge carriers and effective mass ( $\frac{N}{M^*}$ ) wavelength of the single oscillator  $\lambda$ , and plasma frequency  $\omega_p$ . These

Comment [MOU3]: nanometers

parameters, especially the optical constants provide information about the microscopic characteristics of the material [7].

Chalcogenide semiconductors such as Cadmium Sulphide (CdS) have shown great usefulness and applicability in solar cells and optoelectronics such as linear and nonlinear optics, visible light diodes, and lasers [8,9]. This is because CdS has wide bandgap, low absorption loss, compact crystallographic cell structure and electronic affinity [10]. Moreso, CdS, is most widely used as a window layer in CdTe thin film solar cells and is a buffer layer in Copper Indium and Gallium Selenide (CIGS) thin film solar cells [11 – 15].

Several deposition techniques have been studied and employed in the fabrication of CdS thin films such as spin coating[16], Electro deposition (ED) [17], physical vapour deposition PVD[18], spray pyrolysis [19, 20, 21], Successive ionic layer adsorption and reaction SILAR [22], chemical precipitation [23], Sol - gel deposition [24, 25], Thermal evaporation[26, 27], and Chemical bath deposition (CBD) [2, 28, 29,30 31].

Among all these techniques for synthesizing CdS, CBD has been adjudged to be the simplest, does not require sophisticated and complex machine, does not require high temperature and it is very cheap. Chemical bath deposition of CdS consists of a chemical bath of a salt which contains Cadmium cations and anions of either sulphates, nitrates, chlorides or acetates [32]. The properties of CdS thin films obtained by CBD depends on the preparative parameters, hence several studies have been carried out to optimize such parameters such as; bath temperature, PH of bath content, concentration of different precursors and deposition time [33,34].

Comment [MOU4]: pH

This paper reports the dispersion parameters of CdS thin films evaluated from the absorption spectra as a result of variation in deposition time in a chemical bath deposition technique. The accurate determination of these parameters is important not only to know the basic mechanisms but also the underlying phenomena and exploit and develop their interesting technological applications. The dispersion parameters considered are; dispersion energies ( $E_o, E_d$ ), dielectric constant ( $\epsilon_s$ ), the average values of oscillator strength ( $S$ ), wavelength of single oscillator  $\lambda$ , and plasma frequency  $\omega_p$ . Also considered was the electronic polarizability using the Lorenz - Lorentz equation and Clausius Mossotti local field model.

## 2. EXPERIMENTAL DETAILS

CdS thin film was prepared according to our previous work [5] by using ultrasonically cleaned glass substrate of size (25.0x75.0x1.0) mm. The major precursors for CdS are aqueous solutions from Cadmium acetate for Cadmium source and Thiourea for Sulphide source while Ammonium acetate was used as the complexing agent. All the chemicals used were of analytical grades. The bath consists of 30 ml of 0.264gdm<sup>-3</sup> of Cadmium acetate,

Comment [MOU5]: please mention all materials that used in this work and the purity/specification. For example Cadmium acetate(Aldrich, 99%)

15ml of  $0.158\text{gdm}^{-3}$  of ammonium hydroxide, 30 ml of  $0.153\text{gdm}^{-3}$  of Thiourea and 20ml of  $1.542\text{gdm}^{-3}$  of ammonium acetate which brought the volume of the content of the bath to 95ml. The temperature of the bath was maintained at  $90^{\circ}\text{C}$  using 78HW-1 constant magnetic stirrer. The substrates were inserted vertically with the aid of a stand and clips. The deposition was allowed to take place at time intervals of (10, 30, and 50) minutes respectively after which the substrates were removed from the bath simultaneously and rinsed with de-ionized water and then annealed in an oven at a temperature of  $400^{\circ}\text{C}$  for 60 minutes. we used the gravimetric method in calculating the thickness of the film grown in this work. This method is based on the direct determination of the mass deposited onto the glass substrate. The substrate was weighed before deposition and reweighed after deposition; the thickness was determined using relevant equation. The samples were characterized for optical properties using a single - beam UV-VIS Helios omega spectrophotometer by measuring the absorption of the samples within the wavelength range of (280 – 920) nm.

### 3. RESULTS AND DISCUSSION

#### 3.1 Optical Characterization

Optical measurements of transmittance and absorbance of the films deposited at different deposition times are shown in figure 1 and 2. These measurements have been taken in the wavelength range of (280 – 920) nm. The transmittance was calculated using equation (2) [35,36]

$$T = \frac{1}{10^A} \quad 1,$$

Comment [MOU6]:

where A is absorbance as recorded from the spectrophotometer.

From equation (1) it can be understood that

$$A = \log_{10} \frac{1}{T} \quad 2$$

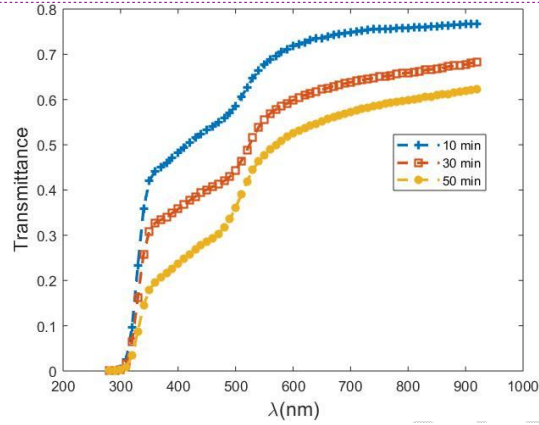
where A is absorbance

The coefficient of absorption ( $\alpha$ ) was calculated from the absorbance data using Beer Lamberts law [37] which relates the transmittance (T), absorbance (A) and thickness (d) of the film as shown in equation (3a, b)

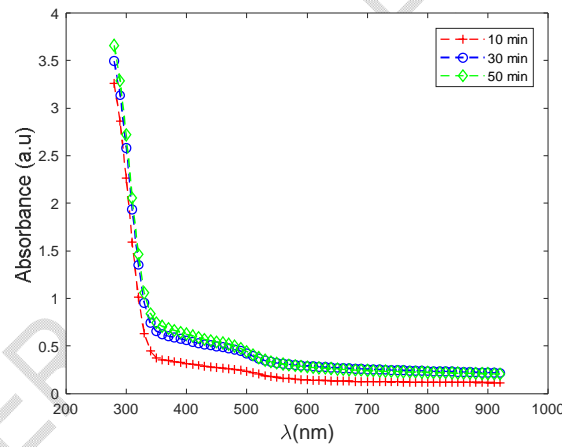
$$T = e^{-\alpha d} \quad 3a$$

So that

$$\alpha = 2.303 \frac{A}{d} \quad 3b$$



Comment [MOU7]: please mention the unit of y axis



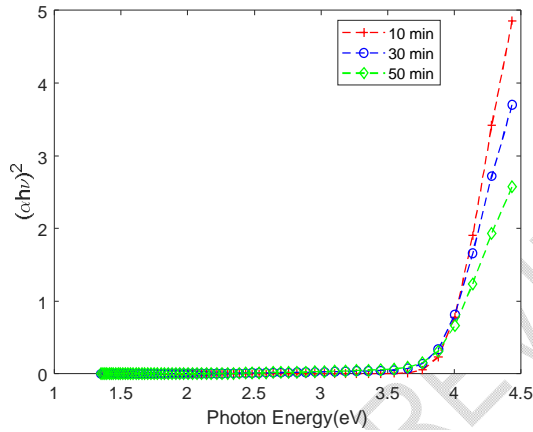
### 3.2.1 Optical energy gap.

The optical bandgap of CdS was obtained from the Absorbance data using the Tauc's relation [38] as shown in equation (4).

$$(\alpha h\nu) = A(h\nu - E_g)^m \quad 4$$

Where  $A$  is a constant called the band tailing parameter,  $E_g$  is the bandgap corresponding to a particular transition occurring in the film,  $\nu$  is the transition frequency,  $h$  is the planks constant given by  $6.63 \times 10^{-34} \text{ m}^2 \text{ kg s}^{-1}$ , The value of  $m$  which is the characteristic nature of the band could be  $\frac{1}{2}$ ,  $\frac{3}{2}$ , 2, or 3 depending on the nature of the electronics transition

responsible for absorption,  $m = \frac{1}{2}$  for direct band gap semiconductors. An extrapolation of the linear region of the plot of  $(\alpha h\nu)^2$  vs  $h\nu$  gives the value of optical band gap  $E_g$ . [39]



Fig

Figure 3 shows the bandgap energy values of the CdS thin films with different deposition times of 10, 30, and 50 minutes and is listed in table 1.

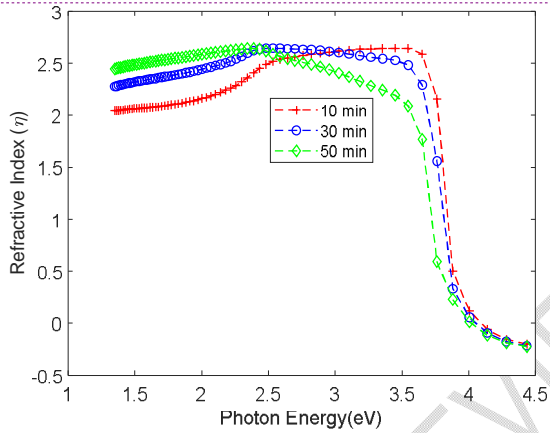
### 3.2.2. Refractive index analysis;

One of the distinctive and essential property of an optical material is its refractive index  $n$ . This is because it is one of the major factors to be considered in selecting materials used for fabricating optical devices or for optical applications. Therefore, it is essential to understand the refractive index of a material since many optical phenomena are dependent on its value. The refractive index  $n$  is closely related to both electronic polarization of ions and the local field inside the optical materials [40]. The refractive index  $n$  was determined using equation (5) [41, 42]

$$\eta = \frac{1+\sqrt{R}}{1-\sqrt{R}} \quad 5$$

where  $R$  is the reflectance of the film.

Comment [MOU8]: please explain the data in Fig 3, what the effect of deposition time on the band gap energy



Comment [MOU9]: please explain the result of refractive index, explain more the effect of deposition time on refractive index

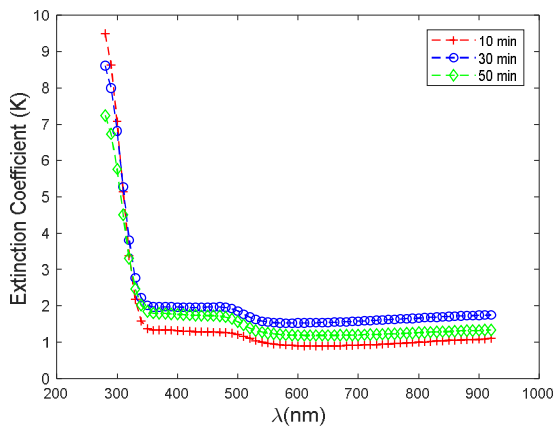
Fig

### 3.2.3 Extinction coefficient

The extinction coefficient  $k$  is determined using equation (6) [41, 42]

$$K = \frac{\alpha \lambda}{4\pi} \quad 6$$

where  $\alpha$  is the absorption coefficient and  $\lambda$  is the wavelength of the incident beam. The extinction coefficient also known as the absorption index is so important in determining several optical measurements that are related to the absorption of light waves in the medium and dielectric constant [43]. The extinction coefficient  $k$  spectra as a function of incident waves is shown in fig 5.

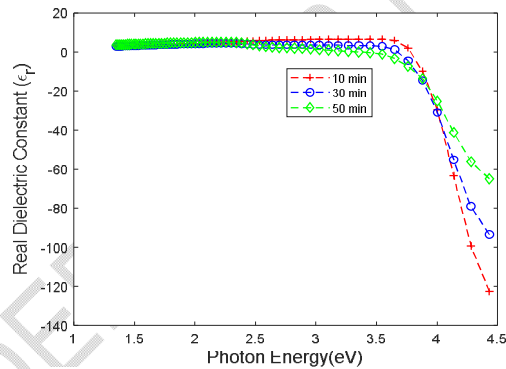


Fig

The figure shows that the extinction coefficient decreases with increase in the incident waves.

### 3.2.4 Dielectric constant analysis

The fundamental electron excitation spectra of CdS thin film are described with complex dielectric constant  $\epsilon^*$ . The real part of dielectric constant  $\epsilon_r$  is related with the property of slowing down the speed of light in materials as well as dispersion of electromagnetic waves that travels within the material whereas the imaginary part of the dielectric constant  $\epsilon_i$  provides a measure of the disruptive rate of the wave in the material, meaning that it is responsible for



Fig

the energy absorption from electric field due to dipole motion [44, 45]. The values of real and imaginary part of the dielectric constant were obtained using equation (7 a, & b) [46] and shown in figure 6 and 7.

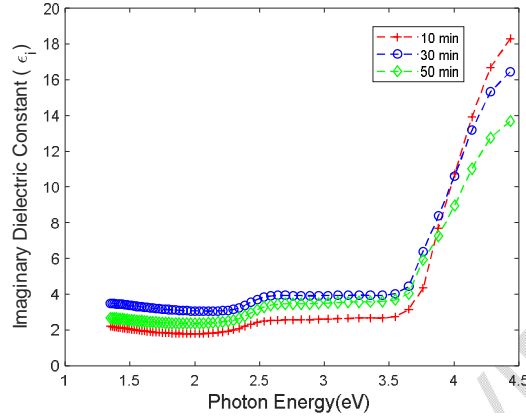
$$\epsilon_r = \eta^2 - k^2 \quad 7a$$

and

$$\epsilon_i = 2\eta k \quad 7b$$

**Comment [MOU10]:** please explain more the data... why the 30 min of deposition have the higher extinction coefficient

**Comment [MOU11]:** please explain the data from your result, explain the trend and the effect of deposition time on dielectric constant. Make explanation more deeply



Fig

### 3.2.5 Dispersion energy parameters

In optical communication and designing devices, the dispersion of the refractive index is very important. The spectral dispersion is obtained from the Wemple DiDomenico model given in equation (8).[47]

$$\eta^2 - 1 = \frac{E_d E_o}{E_o^2 (h\nu)^2} \quad 8$$

where  $E_d$  is dispersion energy and is related to the strength of the inter band optical transition.  $E_o$  is the oscillator energy which gives the quantitative information on the overall band structure of the CdS thin film. By plotting  $\frac{1}{n^2 - 1}$  against the square of the photon energy  $(h\nu)^2$  as shown in figure 8a. The values of  $E_d$  and  $E_o$  are calculated from the slope  $(E_o E_d)^{-1}$  and intercept  $(E_o/E_d)$  on the vertical axis as extracted from the linear fit of each of the deposited sample is given in table 1. From the values of  $E_d$  and  $E_o$ , the static refractive index ( $\eta_o$ ) and static dielectric constant ( $\epsilon_o$ ) are calculated using equation (9) [47].

$$\epsilon_o = \eta_o^2 = 1 + \frac{E_d}{E_o} \quad 9$$

The moments of optical dispersion spectra  $m_{-1}$  and  $m_{-3}$  are evaluated from equation (10a) and (10b)

$$E_o^2 = \frac{M_{-1}}{M_{-3}} \quad 10a$$

And the values of  $\eta_o$ ,  $\epsilon_o$ ,  $M_{-1}$  and  $M_{-3}$  are listed in table 1.

$$E_d^2 = \frac{M_{-1}^3}{M_{-3}} \quad 10b.$$

The Wemple–Didomenico formula can be modified to find the static optical index of refraction at infinite wavelength [48, 49,50] in the form of

$$\frac{\eta_{\infty}^2 - 1}{\eta^2 - 1} = 1 - \left(\frac{\lambda_0}{\lambda}\right)^2 \quad 11a$$

By plotting  $\frac{1}{\eta^2 - 1}$  against  $\lambda^{-2}$  of CdS as shown in figure 8b, the high frequency refractive index ( $\eta_{\infty}$ ) was calculated from the intercept extracted from the linear fit of each of the deposited sample whereas  $\eta_{\infty}^2 = \epsilon_{\infty}$  and were also listed in table 1.

**TABLE 1. OPTICAL AND DISPERSION PARAMETERS OF CdS THIN FILMS**

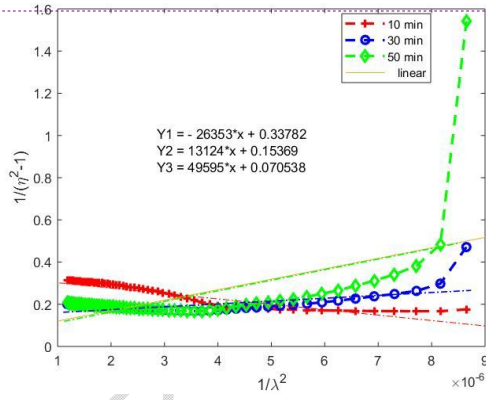
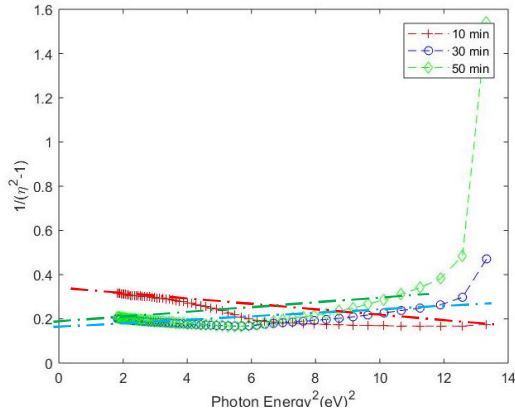
<i>Time</i>	<i>10 min</i>	<i>30 min</i>	<i>50 min</i>
$E_g$	3.78 eV	3.72 eV	3.70 eV
$E_d$	13.16 eV	27.64 eV	20.98 eV
$E_o$	4.44 eV	4.25 eV	1.48 eV
$\eta_o$	1.99	2.75	3.90
$\epsilon_o$	3.96	7.58	15.18
$M_{-1}$	2.96	6.50	14.18
$M_{-3}$	0.1502 eV <sup>2</sup>	0.36 eV <sup>2</sup>	6.47 eV <sup>2</sup>
$S_o$	$3.795 \times 10^{-5}$	$7.62 \times 10^{-5}$	$2.02 \times 10^{-5}$
$\lambda_o$	279.30 nm	292.22 nm	838.50 nm
$\eta_{\infty}$	1.72	2.74	3.90
$\epsilon_{\infty}$	2.96	7.51	15.18
$\epsilon_L$	7.02	5.99	5.30
$\bar{N}$	$1.62 \times 10^{41} kg^{-1}m^{-3}$	$2.31 \times 10^{41} kg^{-1}m^{-3}$	$5.8 \times 10^{41} kg^{-1}m^{-3}$
$\bar{M}^*$			
$\omega_p$	$1.25 \times 10^6 Hz$	$8.18 \times 10^5 Hz$	$1.30 \times 10^6 Hz$
$\alpha_p$	$9.27 \times 10^{-33} Fm^2$	$7.90 \times 10^{-33} Fm^2$	$1.01 \times 10^{-33} Fm^2$

Using the single Sellmeier oscillator model, [43] equation (11b), the oscillator strength and oscillator wavelength of CdS thin film were evaluated and listed in table 1.

$$\eta^2 - 1 = \frac{S_o \lambda_o^2}{1 - \left(\frac{\lambda_o}{\lambda}\right)^2} \quad 11b$$

Where  $\lambda$  is incident wavelength,  $S_o$  is oscillator strength and  $\lambda_o$  is oscillator wavelength. By plotting  $\frac{1}{\eta^2 - 1}$  against  $\lambda^{-2}$  of CdS as shown in figure 8b. The values of  $S_o$  and  $\lambda_o$  are obtained from the slope and intercept extracted from the linear plot of all the deposited samples.

The lattice dielectric constant ( $\epsilon_L$ ) of CdS thin film is also calculated from equation (12) [51].

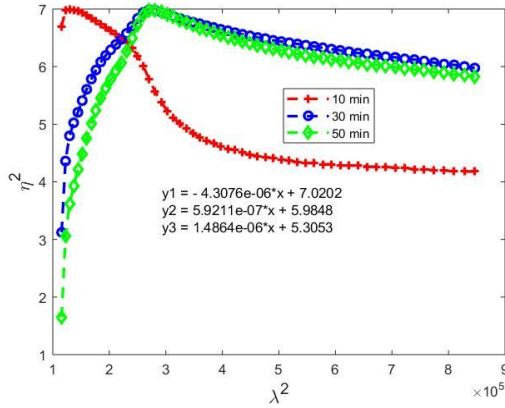


Comment [MOU12]: same comment as above

Fig

$$\eta^2 = \epsilon_L - \left[ \frac{e^2}{4\pi c^2 \epsilon_0 M^*} \right] \lambda^2 \quad 12$$

where  $e$  is the charge of electron,  $c$  is the speed of light,  $\epsilon_0$  is the permittivity of free space,  $\frac{N}{M^*}$  is the ratio of number of free charge carriers and effective mass of electrons. Also, the plasma resonance frequency  $\omega_p$  which is referred to as the material change from metallic to dielectric can be evaluated from the curve  $n^2$  versus  $\lambda^2$  using equation (13) [43]. Using the curve, the values of  $\epsilon_L$ ,  $\frac{N}{M^*}$  and  $\omega_p$  were obtained and listed also in table 1



Fig

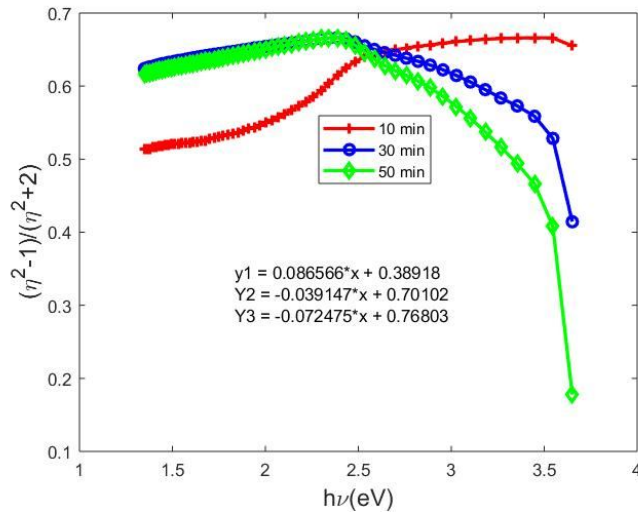
### 3.2.6 Electronic polarizability

The electronic polarizability ( $\alpha_p$ ) gives the degree of the electronic response to the application of an electromagnetic field on the electron clouds [44]. The polarizability ( $\alpha_p$ ) of CdS thin film can be evaluated using Lorenz - Lorentz equation and Clausius Mossotti local field model [51, 52] as shown in equation (14).

$$\left(\frac{\eta^2-1}{\eta^2+2}\right) = \frac{N_A \rho}{3\epsilon_0 M} \alpha_p \quad 14$$

where  $\eta$  is the refractive index,  $N_A$  is the Avogadro's number  $M$  is the molar mass of bulk CdS and  $\rho$  is the density of bulk CdS. Therefore, the plot of  $\frac{\eta^2-1}{\eta^2+2}$  against  $h\nu$  of CdS thin film is shown in figure 8(d). The intercept of plot on the vertical axis gives the value of  $\alpha_p$  and listed in table 1, as extracted from the linear plot of the deposited samples.

Comment [MOU13]: same comment as above



Fig

#### 4.0 Conclusion

Cadmium Sulphide (CdS) thin film was deposited by chemical bath deposition technique on a transparent glass substrate. The CdS thin film has a very high transmittance through the entire electromagnetic spectral range which justify it as a good material for optoelectronic devices and solar cells. The dielectric constant was evaluated from the linear refractive index and extinction coefficient. The dispersion parameters ( $E_d$ ,  $E_0$ , moment of optical spectra  $S_0$ ,  $\lambda_0$ ,  $\frac{N}{M^*}$ ,  $\omega_p$ , and  $\alpha_p$ ), dielectric constants ( $\eta_0$ ,  $\eta_\infty$ , and  $E_L$ ) have been evaluated using Wemple DiDomenico model and single Sellmeier oscillator model. The electronic polarizability of CdS thin film was evaluated using Clausius - Mossotti local field polarizability model.

#### References

1. K. Suresh Babu; C. Vijayan; PrathapHaridoss (2006). Synthesis of size-tunable and stable CdS nanocrystals in DMF. 60(1), 124–128. doi:10.1016/j.matlet.2005.07.084
2. O. Okorie A. D. A. Buba, A. M. Ramalan "Optical and Dielectric Properties of Cadmium Sulphide Thin Film Grown Using Chemical Bath Deposition Technique." IOSR Journal of Applied Physics (IOSR-JAP), vol. 9, no. 5, 2017, pp. 82–89. DOI: 10.9790/4861-0905018289
3. P. A. Nwofe, and P. E. Agbo, Effect of Deposition Time on the Optical Properties of Cadmium Sulphide Thin Films, Int. J. Thin.Fil. Sci. Tec. 4(2),2005, 63-67, 63http://dx.doi.org/10.12785/ijfst/040201.
4. A.A. Akl, A.S. Hassanien, Microstructure and crystal imperfections of nanosized

CdSxSe1-x thermally evaporated thin films. Superlattices and Microstructures (2015), doi: <http://dx.doi.org/10.1016/j.spmi.2015.05.011>

5. O. Okorie, A. D. A. Buba and A. M. Ramalan, Influence of thickness on the optical properties of Cadmium Sulphide Thin Film deposited by chemical bath deposition technique. *Physical Science International Journal* 16(1): 1-11, 2017; Article no. PSIJ.35738 ISSN: 2348-0130 DOI: 10.9734/PSIJ/2017/35738

6. Khan ZR, Zulfequar M, Khan MS. Optical and structural properties of thermally evaporated cadmium sulphide thin films on silicon [1 0 0] wafers. *Mat. Sci. and Eng.B.* 2010;174:145-149. DOI:10.1016/j.mseb.2010.03.006

7. Safwat A. Mahmoud, Shereen Alshomer<sup>1</sup>, Mou'ad A. Tarawneh. Structural and Optical Dispersion Characterisation of Sprayed Nickel Oxide Thin Films *Journal of Modern Physics*, 2011, 2, 1178-1186 doi:10.4236/jmp.2011.210147 Published Online October 2011

8. Pan, Anlian; Yang, Hua; Yu, Richeng; Zou, Bingsuo (2006). Fabrication and photoluminescence of high-quality ternary CdSSe nanowires and nanoribbons. *Nanotechnology*, 17(4), 1083–1086. doi:10.1088/0957-4484/17/4/040

9. A.A. Yadav; M.A. Barote; T.V. Chavan; E.U. Masumdar (2011). Influence of indium doping on the properties of spray deposited CdS<sub>0.2</sub>Se<sub>0.8</sub> thin films. , 509(3), 0–921. doi:10.1016/j.jallcom.2010.09.130

10. L. Dhatchinamurthy, P. Thirumoorthy, L. Arunraja, en S. Karthikeyan, "Synthesis and characterization of cadmium sulfide (CdS) thin film for solar cell applications grown by dip coating method", in *Materials Today: Proceedings*, 2019, vol 26, bl 3595–3599, doi: 10.1016/j.matpr.2019.08.219.

11. G. Ojeda-Barrero, A.I. Oliva-Aviles, A.I. Oliva, R.D. Maldonado, M. Acosta, G.M. Alonzo-Medina, Effect of the substrate temperature on the physical properties of sprayed-CdS films by using an automatized perfume atomizer, *Mater. Sci. Semicond. Proc.* 79 (2018) 7-13.

12. M. Thambidurai, N. Muthukumarasamy, N. Murugan, S. Agilan, S. Vasantha, R. Balasundaraprabhu, Development of mathematical model for prediction and optimization of particle size in nanocrystalline CdS thin films prepared by sol-gel spin-coating method, *Metall. Mater. Trans. B* 41 (2010) 1338 -1345.

13. S.H. Mousavi, M.H. Jilavi, T.S. Muller, P.W. de Oliveira, Formation and properties of cadmium sulfide buffer layer for CIGS solar cells grown using hot plate bath deposition, *J. Mater. Sci.: Mater. Electron.* 25 (2014) 2786-2794.

14. M. Esmaeili-Zare, M. Behpour, Fabrication and study of optical properties on CdS semiconductor as buffer layer for Cu(In,Ga)Se<sub>2</sub> thin film solar cells, *J. Mater. Sci.: Mater. Electron.* 28 (2017) 10173-10183.

15. Han Jun-feng, Fu Gan-hua, V. Krishnakumar, Liao Cheng, Wolfram Jaegermann, CdS annealing treatments in various atmospheres and effects on performances of CdTe/CdS solar cells, *J. Mater. Sci.: Mater. Electron.* 24 (2013) 2695-2700.

16. Riyadh Sami and Alaa J. Ghazai (2021) Preparation and characterization of structural and optical properties of CdS thin film spin coating prepared *J. Phys.: Conf. Ser.* 1999012070 doi:10.1088/1742-6596/1999/1/012070

17. Aliyu, M.; Diso, D.G.; Musa, A.O.; Abubakar, A.I. Effect of growth voltage on electrodeposited CdS thin films. *Bayero J. Pure Appl. Sci.* 2022, 13, 539–545.

18. Shanmugapriya, S.; Sakthivel, B.; Nandhabalaji, S. ZnSe/CdS Thin Films Prepared with Physical Vapour Deposition Technique. *ADALYA J.* 2020, 9, 635–640.

19. Shaikh, S.S.; Shkir, M.; Masumdar, E.U. Facile fabrication and characterization of modified spray deposited cadmium sulphide thin films. *Phys. B Condens. Matter* 2019, 571, 64–70. <https://doi.org/10.1016/j.physb.2019.06.051>

20. P. Gopalakrishnan<sup>1</sup>, L. Amalraj<sup>2</sup> and K. Vijayakumar<sup>3,\*</sup> Deposition and Characterization of Spray Pyrolytic Cadmium Sulphide Thin Film *Int. J. Thin.Film. Sci. Tec.* 12, No. 1, 9-12 (2023) <http://dx.doi.org/10.18576/ijfst/120102>

21. Hamad, N. H., Faraj, M. G. and taha, A. H. (2023) "Structural and Optical Properties of Cadmium Sulfide-doped Silver Deposited on Glass and Polymer Substrates by Chemical

- Spray Pyrolysis", *ARO-The Scientific Journal of Koya University*, 11(1), pp. 32-37. doi: 10.14500/aro.11097.
22. Holi, A.M.; Al-Zahrani, A.A.; Najm, A.S.; Chelvanathan, P.; Amin, N. PbS/CdS/ZnO Nanowire Arrays: Synthesis, Structural, Optical, Electrical, and Photoelectrochemical Properties. *Chem. Phys. Lett.* 2020, 750, 137486. <https://doi.org/10.1016/j.cplett.2020.137486>. *Coatings* 2022, 12, 1400 20 of 22
23. Najm, A.S.; Chowdhury, M.S.; Munna, F.T.; Chelvanathan, P.; Selvanathan, V.; Aminuzzaman, M.; Techato, K.; Amin, N.; Akhtaruzzaman, M.D. Impact of cadmium salt concentration on cds nanoparticles synthesized by chemical precipitation method. *Chalcogenide Lett.* 2020, 17, 537–547.
24. Mohamed S, Mona M, Hany H. Morphological and optical study of Sol-Gel spin coated Nanostructure CdS thin films. *Int. Org. Sci. Res.* 2015;7(6-1):19-22. DOI: 10.9790/4861-07611922.
25. Sharma, B., Lalwani, R. & Das, R. Spectroscopic Studies of CdS Nanocrystalline Thin Films Synthesized by Sol–Gel Spin Coating Technique for Optoelectronic Application: Influence of Co-Doping. *Braz J Phys* 53, 42 (2023). <https://doi.org/10.1007/s13538-023-01257-1>
26. Ziaul RK, Zulfequar M, Khan MS. Effect of thickness on structural and optical properties of thermally evaporated cadmium sulfide polycrystalline thin Films *Chalcogenide Letters.* 2010;7(6): 431-438
27. Nafiseh M, Seyeed MR, Isabella C, Alberto V. Deposition of nanostructure CdS thin films by thermal evaporation method: Effect of substrate temperature. *J. Mat.Sci.* 2017;10:773-780. DOI: 10.3390/ma10070773
28. A. Alam , S. Kumar , D.K. Singh, Cadmium sulphide thin films deposition and characterization for device applications. *Materials Today: Proceedings* 62 (2022) 6102–6106 <https://doi.org/10.1016/j.matpr.2022.04.1018>
29. Najm, A.S.; Naeem, H.S.; Alwarid, D.A.R.M.; Aljuhani, A.; Hasbullah, S.A.; Hasan, H.A.; Sopian, K.; Bais, B.; Al-Iessa, H.J.; Majdi, H.S.; et al. Mechanism of Chemical Bath Deposition of CdS Thin Films: Influence of Sulphur Precursor Concentration on Microstructural and Optoelectronic Characterizations. *Coatings* 2022, 12, 1400. <https://doi.org/10.3390/coatings12101400>
30. F.T.Z. Toma, K.M.A. Hussain, M.S. Rahman and Syed Ahmed Preparation and characterization of CdS thin film using chemical bath deposition (CBD) technique for solar cell application. *World Journal of Advanced Research and Reviews*, 2021, 12(03), 629–633 <https://doi.org/10.30574/wjarr.2021.12.3.0746>
31. Tsuchikado, H., Chen, M., Guan, G. *et al.* Efficient photoanode characteristics of cadmium sulfide films multi-deposited through a chemical bath deposition process. *J Appl Electrochem* (2023). <https://doi.org/10.1007/s10800-022-01838-z>
32. Martinez JL, Martinez G, Torres-Delgado G, Guzman O, Del Angel P, Lozada-Morales R. Cubic CdS thin films studied by spectroscopic ellipsometry. *Journal of Materials Science: Materials in Electronics.* 1997;8(6):399-403
33. Sengupta, S., Aggarwal, R. & Raula, M. A review on chemical bath deposition of metal chalcogenide thin films for heterojunction solar cells. *Journal of Materials Research* 38, 142–153 (2023). <https://doi.org/10.1557/s43578-022-00539-9>
34. Narayana Swamy T N, Pushpalatha H L, Ganesha R. Chemically deposited CdS thin film and its photoelectric performance. *J. Chem. Bio. Phy. Sci. Sec. C.* 2017;7(1):119-130.
35. Lothian GF. *Absorption spectrophotometer 2nd edition*" Hisher and Watts Ltd London. 1958;19-20.
36. Pankove JI. *Optical processes in semiconductors.* Prentice – Hall New York; 1971.
37. Ruby D, Suman P. Comparison of Optical Properties of Bulk and Nano Crystalline Thin Films of CdS using different Percursors" *Int. J. Mat. Sci.* 2011;1:35-40.

38. K. S. Usha, R. Sivakumar, C. Sanjeeviraja, Optical constant and dispersion energy of NiO thin films prepared by radio frequency magneto sputtering technique, *J. of Appl. Phys.* 114, 2013, 123501-10.
39. Ajaya Kumar Sharma, Ankit Kumar Vishwakarma, Lallan Yadava, Optical and structural properties of CdS-ZnO thick film, *Materials Letters: X*, Volume 17, 2023, 100180, ISSN 2590-1508, <https://doi.org/10.1016/j.mlblux.2022.100180>.
40. Z. Z. You, G. J. Hua, Electrical, Optical and microstructure properties of transparent conducting GZO thin films deposited by magnetron sputtering, *J. Alloys and Compounds* 530, 2012, 11-17. <https://doi.org/10.1016/j.jallcom.2012.03.078>.
41. M. S. Aziz, H. M. El-Mallah, Electrical and Optical Properties of azo dye, *Indian J. Pure Appl. Phys.* 47, 2009, 530-534.
42. H. N. Desai J. M. Dhimmar, B. P. Modi. Study of Linear and Non-Linear Optical Parameters of Zinc Selenide Thin Film *Int. Journal of Engineering Research and Applications* www.ijera.com ISSN : 2248-9622, Vol. 5, Issue 6, ( Part -3) June 2015, pp.117-122
43. A.S. Hassanien, Studies on dielectric properties, opto-electrical parameters and electronic polarizability of thermally evaporated amorphous Cd<sub>50</sub>S<sub>50-x</sub>Se<sub>x</sub> thin films, *Journal of Alloys and Compounds*, 671, 2016, 566 – 578. doi:10.1016/j.jallcom.2016.02.126
44. P. Sharma, V. Sharma, S. C. Katyal, Variation of Optical constant in Ge<sub>10</sub>Se<sub>60</sub>Te<sub>30</sub> thin film, *Chalcogenide Letters* 3, 2006, 73-79.
45. F. Wooten, *Optical Properties of Solids*, Academic Press New York London; 1972.
46. Wemple, S.; DiDomenico, M. (1971). Behavior of the Electronic Dielectric Constant in Covalent and Ionic Materials., 3(4), 1338–1351. doi:10.1103/physrevb.3.1338
- 47 Ahmad, A.A.; Alsaad, A.M.; Albiss, B.A.; Al- Akhras, M-Ali; El-Nasser, H.M.; Qattan, I.A. (2015). *The effect of substrate temperature on structural and optical properties of D.C. sputtered ZnO thin films. Physica B: Condensed Matter*, 470-471(), 21–32. doi:10.1016/j.physb.2015.05.005
48. Yeh, Pochi; Hendry, Michael (1990). *Optical Waves in Layered Media. Physics Today*, 43(1), 77–. doi:10.1063/1.2810419
49. Ikhmayies, S.J. (2020), A Study of the Optical Parameters of Cds Thin Films Prepared by Thermal Evaporation., *Journal of Amasya University the Institute of Sciences and Technology*, 1(1), 56-73
50. T. S. Moss, G. J. Burell, E. Ellis, *Semiconductor Opto-Electronic*, (Butterworths, London, 1973).
51. M. A. M. El-Morsy, H. H. Wahba, Determination of the optical Properties of a bent Optical Fiber by Using an automatic Fringe Pattern Analysis, *J. of Korean Physical Society* 59(5), 2011, 3080-3085.
52. Olson, James D. (1975). The refractive index and Lorenz–Lorentz function of fluid methane. *The Journal of Chemical Physics*, 63(1), 474–. doi:10.1063/1.431127