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A Study of the Optical Parameters of Cds Thin Films Prepared by Thermal Evaporation

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Research Article

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Abstract

Cadmium sulfide is an interesting material for the use in solar cells as a window layer and in the manufacture of optoelectronic devices. The optimization of the optical parameters of this material is an important step in developing such uses. In this work polycrystalline cadmium sulfide (CdS) thin films with the same thickness (300 nm) are prepared on glass substrates at ambient temperature using the thermal evaporation technique. X-ray diffraction (XRD) revealed that the films mainly display a cubic (zinc blind) structure. The transmittance of the films is measured at room temperature in the wavelength range (290–1100 nm) and used to infer the optical parameters. The extinction coefficient (k), refractive index (n), the real and imaginary parts of the dielectric constant (ε_r and ε_i), and the dielectric energy loss ($\tan\delta$) are investigated. The dispersion parameters such as E_o (single-oscillator energy) and E_d (dispersive energy) of the deposited films are determined too.

Key Words: Thin films, Cadmium Sulfide, Solar cells, Optical parameters.

Özet

Kadmiyum sülfür, güneş pillerinde pencere katmanı olarak ve optoelektronik cihazların üretiminde kullanım için ilginç bir malzemedir. Bu malzemenin optik parametrelerinin optimizasyonu, bu tür kullanımların geliştirilmesinde önemli bir adımdır. Bu çalışmada, aynı kalınlıkta (300 nm) polikristalin kadmiyum sülfür (CdS) ince filmler, termal buharlaştırma tekniği kullanılarak ortam sıcaklığında cam substratlar üzerinde hazırlanır. X ışını kırınımı (XRD), filmlerin esas olarak kübik (çinko kör) bir yapı sergilediğini ortaya çıkarmıştır. Filmlerin geçirgenliği, dalga boyu aralığında (290-1100 nm) oda sıcaklığında ölçülür ve optik parametreleri çıkarmak için kullanılır. Yok olma katsayısı (k), kırılma indisi (n), dielektrik sabitinin gerçek ve hayali kısımları (ε_r ve ε_i) ve dielektrik enerji kaybı ($\tan\delta$) araştırılmıştır. Yatırılan filmlerin E_o (tek osilatör enerjisi) ve E_d (dağıtıcı enerji) gibi dağılım parametreleri de belirlenir.

Anahtar Kelimeler: İnce filmler, Kadmiyum Sülfit, Güneş pilleri, Optik parametreler.

1. Introduction

Heterojunction solar cells with a wide band gap window and a narrow band gap absorber region have undergone extensive investigations due to their beneficial features. Cadmium sulfide (CdS) of band gap energy of 2.42 eV at room temperature is one of the most promising thin film materials for application as a window layer [Naseem et al, 1996]. This material is also promising for nonlinear optical devices, photo-conducting cells, and other optoelectronic devices in the blue-to-ultraviolet spectral region [Kim et al., 2008]. There are several techniques for producing CdS thin films, such as spray pyrolysis (SP) [Ikhmayies & Ahmad-Bitar, 2008; Ikhmayies & Ahmad-Bitar, 2010; Ikhmayies & Ahmad-Bitar, 2011; Ikhmayies & Ahmad-Bitar, 2012a; Ikhmayies & Ahmad-Bitar, 2012b; Ikhmayies & Ahmad-Bitar, 2012c; Ikhmayies & Ahmad-Bitar, 2013a; Ikhmayies et al., 2013b; Ikhmayies, 2014a; Ikhmayies & Ahmad-Bitar, 2014b; Ikhmayies, 2015; Ikhmayies, 2016; Ikhmayies, 2017a; Ikhmayies, 2017b; Ikhmayies, 2017c; Ikhmayies, 2019], chemical bath deposition (CBD) [Metın & Esen, 2003; Ugwu & Onah, 2007], successive ionic layer adsorption and reaction (SILAR) [Ninomiya & Adachi, 1995], rf sputtering [Tsai et al., 1996], pulsed laser deposition (PLD) [Perna et al., 2004], and thermal evaporation [Naseem et al., 1996; Sahay et al., 2007; Singh et al., 2007; Ikhmayies, 2012d; Ikhmayies, 2013c; Ikhmayies, 2014c]. The thermal evaporation technique for thin-film deposition of CdS was chosen because it is simple compared to other new and sophisticated techniques [Sahay et al., 2007]. Besides, the deposition of the films by thermal evaporation does not present any compositional problems.

Comprehensive investigation of the optical properties of CdS is very interesting for their use in the design of solar cells and optoelectronic devices. Even many workers investigated these characteristics, but most of this work was done to assess the energy band gap [Ninomiya & Adachi, 1995; Perna et al., 2004; Sahay et al., 2007; Singh et al., 2007; Kim et al., 2008; Lohitha et al.,2020]. Little work has been done on various optical parameters such as the refractive index, extinction coefficient, absorption coefficient, and the real and imaginary parts of the dielectric constant, and loss tangent, where some results in this field are found in references [Al-Zahrani et al., 2015; Rao & Ashith, 2015 ; Yahia et al. , 2018; Shkir et al., 2019, Manthrammel et al., 2020], and the author of this work have some other investigations [Ikhmayies, 2014c; Ikhmayies, 2015; Ikhmayies, 2017a]. This work is a continuation in the same line, and its objective is to deduce and discuss the optical parameters of thermally evaporated CdS thin films prepared at ambient temperature. The optical transmittance of the films is measured in the wavelength interval 290-1100 nm and used to deduce the reflectance from which the optical parameters, such as the refractive index, extinction coefficient, real and imaginary dielectric constants and dielectric energy loss and the dispersion parameters are all deduced.

2. Material and Methods

Thin films of cadmium sulfide (CdS) of thickness 300 nm are produced by thermal evaporation on glass substrates of dimensions 2.5×6×0.1 cm^3 which are cleaned with acetone then rinsed in distilled water and finally dried by air. The films are prepared in high vacuum (~10^{-5} mbar) using a Turbo pump. Evaporation rate is about 10 Å/s and it is measured using a cooled quartz crystal monitor. The substrate temperature is the ambient temperature, and the source–substrate distance is about

30 cm. The film transmittance at room temperature is measured using a double beam Shimadzu UV 1601 (PC) spectrophotometer with respect to a glass microslide similar to the substrates in the wavelength range 290-1100 nm. X-ray measurements are performed using a Philips PW1840 Compact X-ray diffractometer system with Cu K_α (λ = 1.5405 Å) at a diffraction angle 2θ from 2° to 60°.

3. Results and/or Discussion

Figure 1 displays the X-ray diffractogram for one of the films under study. From the figure, the film appears to be polycrystalline with a predominant zinc blind structure. Miller indices for the lines belonging to the cubic phase are indicated in the figure as C(hkl) while those belonging to the hexagonal (wurtzite) phase are referred as H(hkl). This pattern is also accompanied by a hump associated with the amorphous glass substrate.

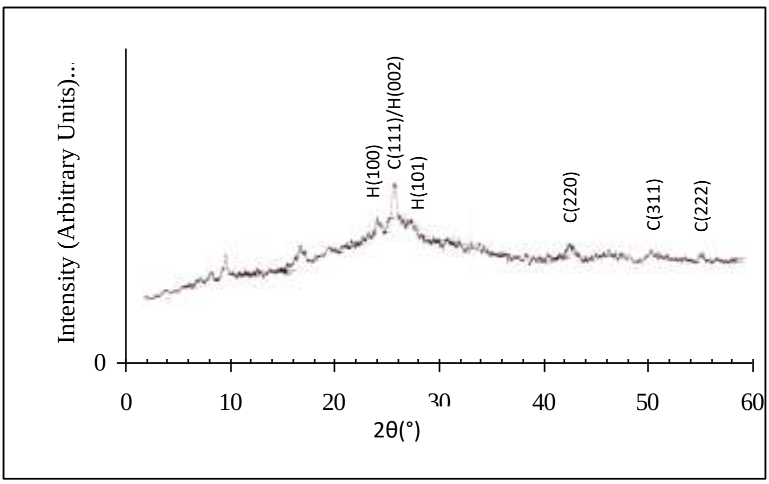

Figure 1. XRD diffractogram for one of the thermally evaporated CdS thin films

Figure 2 depicts the transmittance of three thermally evaporated CdS films with a thickness of about 300 nm measured at room temperature in the wavelength range 290–1100 nm. As the figure shows the transmittance is high and reaches a maximum of 100%. The presence of interference fringes is evidence on the smoothness of the surfaces of the films. The differences in the positions of the maxima and minima seen in the figure are due to slight differences in thickness of the films. The transmittance measurements shown in Figure 2 are used to deduce the reflectance which is used to deduce the other optical parameters for the films such as the refractive index, extinction coefficient, real and imaginary parts of the dielectric constant, a

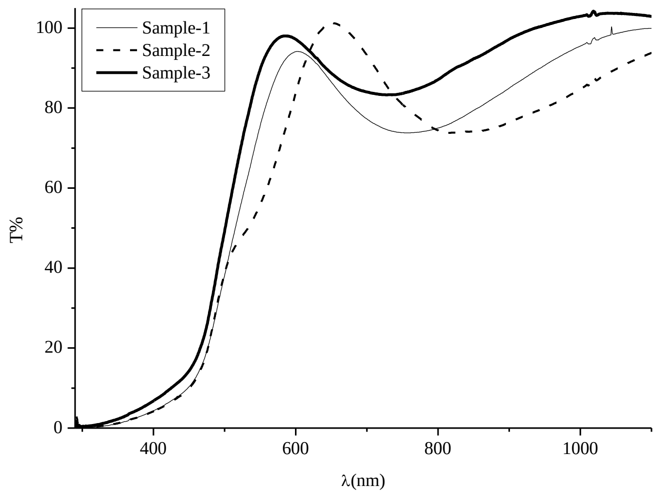

Figure 2. The plot of the transmittance of three CdS films of the same thickness (300 nm) against wavelength

Knowledge of the refractive index of the semiconductor in the energy region below or near the fundamental absorption edge is important in the design of the optoelectronic device design. To find the refractive index and the extinction coefficient, the definition of the reflectance of a film for a light wave incident normally from air, with refractive index n_0 = 1, on a medium of complex refractive index is used. The following relationship is considered [Babkair et al., 2011].

$$R = \frac{(n^* - 1)^2}{(n^* + 1)^2} = \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2} \qquad (1)$$

The complex refractive index of the film is given by;

$$n^{*} = n + ik \qquad (2)$$

where n is the refractive index and, k is the extinction coefficient of the film. If the value of the absorption coefficient α is known, then the extinction coefficient can be calculated using the following relationship

$$k = \frac{\lambda\alpha}{4\pi} \qquad (3)$$

where λ is the wavelength in free space. Solving Eq.(1) for the refractive index n gives;

$$n = \frac{(1+R) + \left[(1+R)^2 - (1-R)^2(1+k^2)\right]^{1/2}}{1-R} \qquad (4)$$

The values of the extinction coefficient are calculated using Eq.(3) and plotted against photon's energy (Figure 3). As the figure shows, the extinction coefficient has an oscillatory behavior in the transparent region and its value in this region is small (<0.1) but not zero. In the case of polycrystalline films, extra light absorption occurs at the grain boundaries. This results in a non-zero value of for photon energies smaller than the fundamental absorption edge [Sahay et al., 2007].

Comparing these curves with the curve obtained by [Sahay et al., 2007] for the film of thickness 250 nm which is the closest to the thickness of the films under study, it was found that they [Sahay et al., 2007] have larger values of . The difference can be attributed to many factors such as, the difference in film thickness, deposition temperature, and the ratio of Cd:S in the films. At the absorption edge rapidly increases with photon's energy then the increase becomes slower. This behavior is similar to the behavior of the absorption coefficient and also it is similar to behavior of for the film of thickness 250 nm obtained by [Sahay et al., 2007]. Lower values of in the transparent region are better for using CdS as a window layer in thin film solar cells.

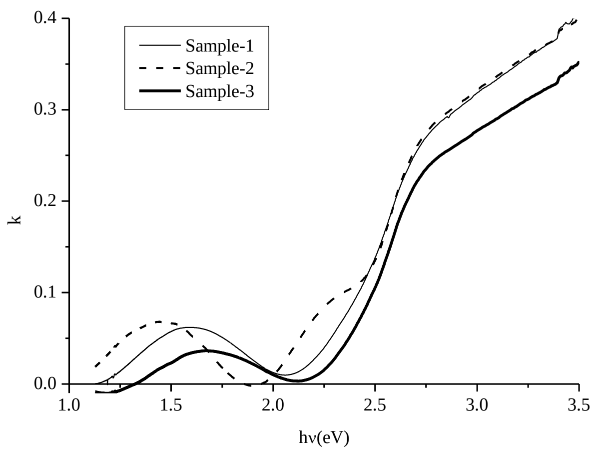

Figure 3. The plot of the extinction coefficient of three thermally evaporated CdS thin films of the same thickness against photon's energy

The refractive index n is calculated from Eq.(4) and plotted against the photon's energy hν (Figure 4), where the inset shows the same plot in a narrower range (1–2.5 eV) to clarify the variations of n in the transparent region. The refractive index shows an oscillatory behavior in this region and its value is restricted in the range 0.96–2.04. These values are smaller than the refractive index of bulk CdS which is ~2.3. Also these values are smaller than the values obtained by [Gordillo et al., 2003] for CdS_xTe_{1-x} films that are thermally evaporated at a thickness of 2.2 μm prepared at substrate temperature 250 °C when x = 0, where n values in the range 2–2.6 were obtained in the wavelength range 500–1000 nm. The smaller values of n obtained for the films under study can be attributed to disorder [Naseem et al, 1996], where disorder increases with the decrease in film thickness and there is more disorder in the polycrystalline form of a material than its monocrystalline form. Additionally, in the case of thin films, the values of the refractive index depend on the deposition rate [Naseem et al, 1996], deposition parameters, and the elemental ratios along with thickness. In the the absorption edge region and beyond up to 3.5 eV, the refractive index increases rapidly with the photon energy.

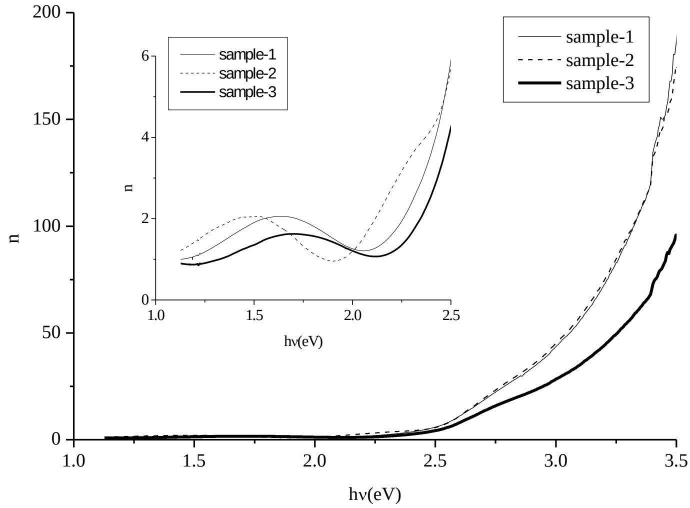

Figure 4. The plot of the refractive index of three thermally evaporated CdS thin films of the same thickness against photon's energy

Below the absorption edge, refractive index dispersion can be analyzed by the single oscillator model. Therefore the data obtained from the refractive index (n) is also analyzed to yield the long wavelength refractive index (n_∞) together with the average oscillator wavelength (λ_0) of the CdS thin films using the following relationship [Tüzemen et al., 2009]

$$\frac{n_\infty^2 - 1}{n^2 - 1} = 1 - \left(\frac{\lambda_0}{\lambda}\right)^2 \qquad (5)$$

where λ_0 and n_∞ are evaluated from the plots of $\left(n^2 - 1\right)^{-1}$ against λ^{-2} which is shown in Figure 5. The values of λ_0, n_∞, and $n_\infty^2 = \varepsilon_\infty$ are shown in Table 1. From these values, $E_0 = hc/\lambda_0$ the average excitation energy for electronic transitions (single oscillator energy) and $E_d = E_0\left(n_\infty^2 - 1\right)$ the dispersion energy, which is a measure of the strength of interband optical transitions, are calculated. These parameters are also included in Table 1. The obtained values of E_0 are smaller than the value obtained by [Ravangave & Biradar, 2013] for $Cd_{1-x}Zn_xS$ thin films prepared by chemical bath deposition when x =0 where they got $E_0 = 3.72eV$. Also the values of E_d are smaller than the value obtained by [Ravangave & Biradar, 2013] where they got $E_d = 23.1eV$. This difference is most likely due to the fact that the dispersion parameters change with deposition parameters as found by [Ilican et al., 2007].

The M_{-1} and M_{-3} moments of the optical spectra can be obtained from the relationships [Caglar et al., 2006],

$$E_0^2 = \frac{M_{-1}}{M_{-3}} \tag{6}$$

and

$$E_d^2 = \frac{M_{-1}^3}{M_{-3}} \tag{7}$$

The obtained values of M_{-1} and M_{-3} moments are listed in Table 1. The values of M_{-1} are smaller than the value obtained by [Ravangave & Biradar, 2013] for $Cd_{1-x}Zn_xS$ thin films when x =0, where they got M_{-1}= 6.71. The first two values of M_{-3} in Table 1 are greater than the value obtained by [Ravangave & Biradar, 2013] for $Cd_{1-x}Zn_xS$ at x = 0, while the last value in Table 1 is smaller than the value they got, which is M_{-3}= 0.49. Also the discrepancy is mainly due to the difference in the deposition parameters.

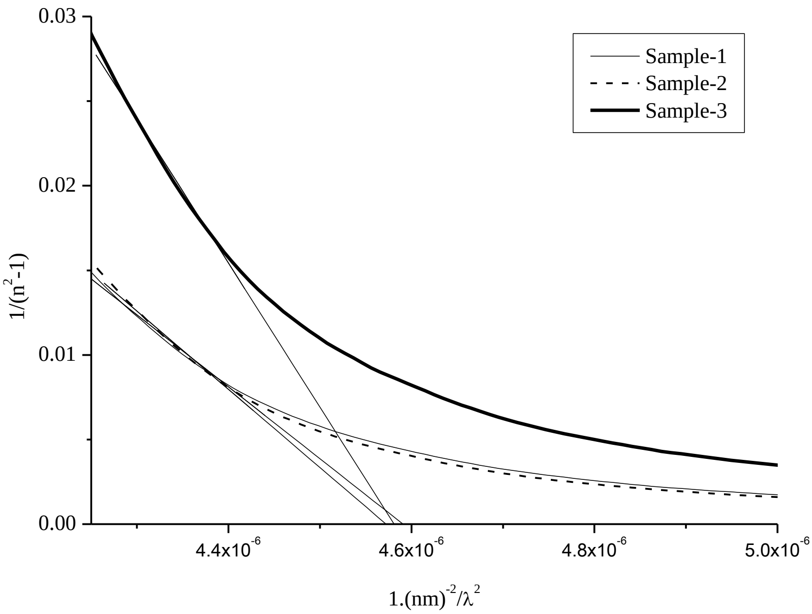

Figure 5. The plot of $1/(n^2-1)$ against $1/\lambda^2$ for CdS thin films of the same thickness

Table 1. The optical parameters of thermally evaporated CdS thin films

Sample	n_∞	ε_∞	λ_0(nm)	E_0(eV)	E_d(eV)	M_{-1}	M_{-3}(eV)$^{-2}$
1	2.474	6.122	466.7	2.657	13.609	5.125	0.726
2	2.394	5.732	467. 7	2.651	12.545	4.730	0.673
3	1.888	3.564	467.2	2.654	6.805	2.564	0.364

The complex dielectric constant is a fundamental intrinsic material property. The real part of it is associated to the refractive index and thus the speed of light in the material. The imaginary part of the dielectric constant is associated with the absorption of light into the material. The real and imaginary parts of the dielectric constant are determined using the following equations [Alnajjar et al., 2012]

$$\varepsilon_r = n^2 - k^2 \tag{8}$$

$$\varepsilon_i = 2nk \tag{9}$$

Figure 6 displays the relationship between ε_r and the photon's energy, where the inset shows the same relationship in the range from 1–2.5 eV. It is evident from the figure that ε_r increases as the photon's energy increases. From the inset of Figure 6 it is observed that the values of ε_r in the transparent region of the three films vary in an oscillatory behavior between 1 and 4. In the region near the absorption edge ε_r sharply increases with increasing photon's energy.

Figure 7 depicts the relationship between ε_i and the photon's energy, where the inset shows the same relationship in the range 1–2.5 eV. The oscillatory behavior of ε_i also appears in the transparent region, and a sharp increase with photon's energy is observed at the absorption edge. So, the real and imaginary parts follow the same pattern, and it is noticed that the values of the real part are higher than the imaginary part.

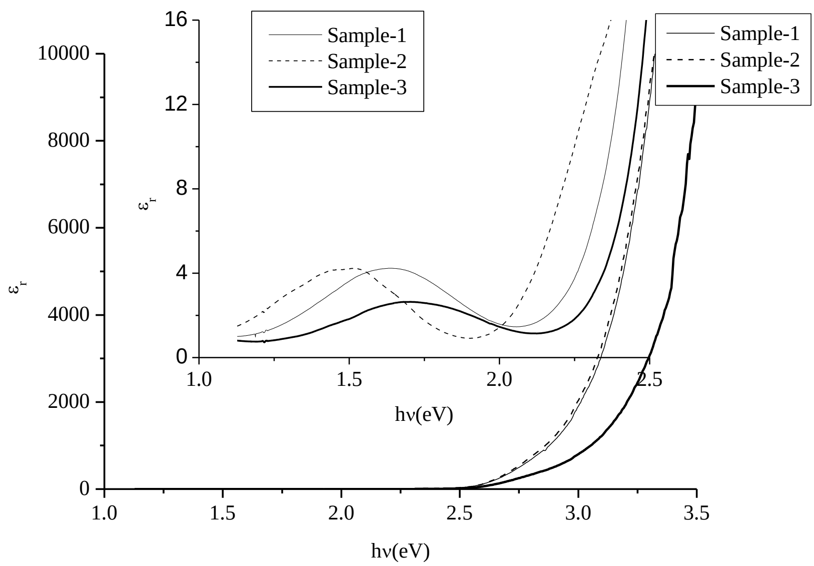

Figure 6. The plot of the real part of the dielectric constant and photon's energy for thermally evaporated CdS thin films

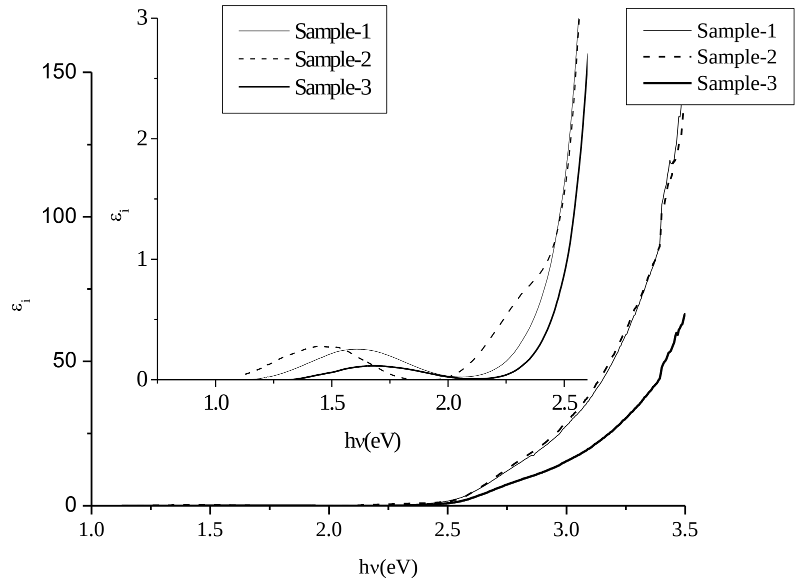

Figure 7. The plot of the imaginary part of the dielectric constant and photon's energy for thermally evaporated CdS thin films

The dielectric loss is the energy loss that goes into heating the dielectric material in a varying electric field. The variations of dielectric loss with photon's energy are represented in Figure 8. The dielectric loss is given by the relationship [Hasnat & Podder, 2012]

$$\tan\delta = \frac{\varepsilon_i}{\varepsilon_r} \qquad (10)$$

where δ is the loss angle. From Figure 7, it is observed that dielectric loss has an oscillatory behavior in the transparent region and after the absorption edge it decreases with increasing of photon energies.

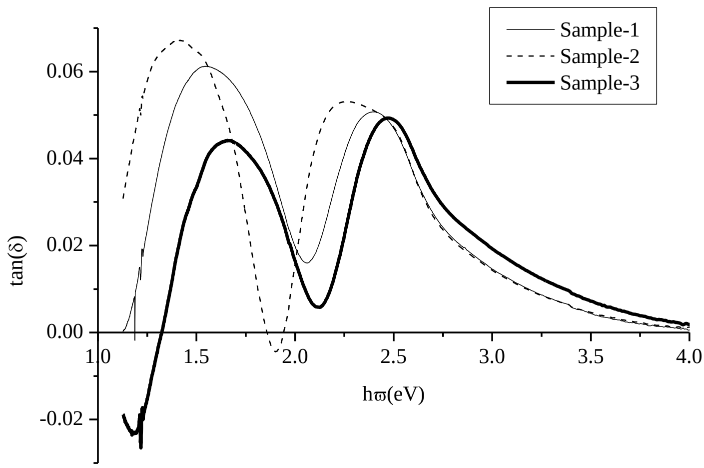

Figure 8. The plot of the loss tangent (tanδ) against photons energy hυ

4. Conclusions

Polycrystalline CdS thin films of 300 nm thickness are produced by thermal evaporation at ambient temperature. The transmittance of the films is recorded at room temperature in the 290–1100 nm wavelength range, and used to deduce reflectance. From the relationships between reflectance and the complex refractive index the refractive index and extinction coefficient are calculated and discussed. Dispersion parameters are estimated and compared to those obtained by other authors. The real and imaginary parts of the dielectric constant are obtained using the refractive index and extinction coefficient and used to find the dielectric energy loss. The study of these optical parameters is important for the use of CdS in the design of optoelectronic devices and for the use of CdS thin films as a window material in thin film solar cells.

5. References

Alnajjar, A.A., Al-Shaikley, F.Y., & Alias, M.F.A. (2012), Optical properties and photoconductivity of undoped and In-doped CdTe thin films. Journal of Electron Devices 16, 1306–1314.

Al-Zahrani, J.H., El-Hagary, M., & El-Taher, A. (2015). Gamma irradiation induced effects on optical properties and single oscillator parameters of Fe-doped CdS diluted magnetic semiconductors thin films. *Mat. Sci. Semicon. Proc.,* 39, 74–78. DOI : https://doi.org/10.1016/j.mssp.2015.04.042

Babkair, S.S., Al-Twarqi, N.M., & Ansari, A. A. (2011), Optical characterization of CdTe films for solar cell applications, *Karachi University Journal of Science* 39, 1–5.

Caglar, M., Zor, M., Ilican, S., & Caglar, Y. (2006), Effect of indium incorporation on the optical properties of spray pyrolyzed $Cd_{0.22}Zn_{0.78}S$ thin films, *Czech. J. Phys.,* 56(3), 277– 287. DOI: 10.1007/s10582-006-0088-4

Gordillo, G., Rojas, F., & Calderón, C. (2003), Optical characterization of $Cd(S_x, Te_{1-x})$ thin films deposited by evaporation, *Superficies y Vacio* 16(3), 30–33.

Hasnat, A. & Podder, J. (2012), Dielectric properties of spray pyrolized aluminum doped cadmium sulfide (Al-doped CdS) thin films, *Int. J. Phys. Sci.*, 7(47), 6158–6161.

Ikhmayies, S.J., & Ahmad-Bitar, R.N. (2008). Direct observation of infrared photoluminescence of spray-deposited CdS:In thin films, J. Luminouscence, 128 (4), 615–619. DOI: 10.1016/j.jlumin.2007.10.011

Ikhmayies, S.J., & Ahmad-Bitar, R.N. (2010). Characterization of the SnO_2:F/CdS:In structures prepared by the spray pyrolysis technique. *Sol. Energy Mater. Sol. Cells.*, 94(5), 878-883. DOI: 10.1016/j.solmat.2010.01.011

Ikhmayies, S.J., & Ahmad-Bitar, R.N. (2011). The use of I-V characteristics for the investigation of selected contacts for spray-deposited CdS:In thin films. *Vacuum,* 86, 324-329. DOI: 10.1016/j.vacuum.2011.07.056

Ikhmayies, S.J., & Ahmad-Bitar, R.N. (2012a). Interface photoluminescence of the SnO_2:F/CdS:In/CdTe thin film solar cells prepared partially by the spray pyrolysis technique. *J. Luminouscence*, 132, 502-506. DOI: 10.1016/j.jlumin.2011.09.030

Ikhmayies, S.J., & Ahmad-Bitar, R.N. (2012b). Photoluminescence and transmittance of $CdS_{1-x}Te_x$ thin films. *J. Luminouscence*, 132, 2826-2831. DOI: 10.1016/j.jlumin.2012.06.011

Ikhmayies, S.J., & Ahmad-Bitar, R.N. (2012c). $CdS_{1-y}Te_y$ thin films: production and bandgap investigation, *Sol. Energy.,* 86(9), 2613-2619. DOI: 10.1016/j.solener.2012.05.032

Ikhmayies, S.J. (2012d). Nanocrystalline CdS thin Films prepared by vacuum evaporation. In: *Characterization of Minerals, Metals, and Materials* (Hwang, J.-Y., Monteiro, S.N., Bai , C. ‐ G., Carpenter, J., Cai, M., Firrao, D., Kim, B. -G. eds.). John Wiley & Sons, Inc., Hoboken, New Jersey, USA. p.: 293-302. DOI: 10.1002/9781118371305.ch35

Ikhmayies, S.J., & Ahmad-Bitar, R.N. (2013a). Temperature dependence of the photoluminescence spectra of CdS: In thin, films prepared by the spray pyrolysis technique, *J. Luminescence*, 142, 40-47. DOI: https://doi.org/10.1016/j.jlumin.2013.03.033

Ikhmayies, S.J., Juwhari, H. K., & Ahmad-Bitar, R.N. (2013b). Nanocrystalline CdS:In thin films prepared by the spray-pyrolysis technique, *J. Luminouscence*, 141, 27-32. DOI: https://doi.org/10.1016/j.jlumin.2013.02.045

Ikhmayies, S.J. (2013c). Characterization of nanocrystalline CdS thin films prepared by thermal evaporation. *International Journal of Materials and Chemistry,* 3(2), 28-33. DOI:10.5923/j.ijmc.20130302.02

Ikhmayies, S.J. (2014a). Tuning the properties of nanocrystalline CdS thin films, JOM., 67(1), 46-60. DOI: https://doi.org/10.1007/s11837-013-0819-5

Ikhmayies, S.J., & Ahmad-Bitar, R.N. (2014b). Dependence of the photoluminescence of CdS:In thin films on the excitation power of the laser, *J. Luminouscence*, 149, 240-244. DOI: https://doi.org/10.1016/j.jlumin.2014.01.046

Ikhmayies, S.J. (2014c). The influence of thickness on the optical parameters of thermally evaporated CdS thin films. In: *TMS 2014: 143rd Annual Meeting & Exhibition* (The Minerals, Metals & Materials Society. Eds.). Springer, Cham, Switzerland. P.: 383-390. DOI: https://doi.org/10.1007/978-3-319-48237-8_48

Ikhmayies, S.J. (2015). Optical parameters of spray-deposited CdS:In thin films. In: *TMS 2015 144th Annual Meeting & Exhibition, Annual Meeting Supplemental Proceedings* (The Minerals, Metals & Materials Society (TMS). eds.). Springer International Publishing, Cham, Switzerland. P.: 585 – 592

Ikhmayies, S.J. (2016). S-Rich $CdS_{1-y}Te_y$ thin films produced by the spray pyrolysis technique. *Energies,* 9, 234. DOI: 10.3390/en9040234

Ikhmayies, S.J. (2017a). The influence of heat treatment on the optical parameters of spray-deposited CdS:In thin films, *JOM*, 69(2), 144-161. DOI: https://doi.org/10.1007/s11837-016-2200-y

Ikhmayies, S.J. (2017b). Optical parameters of spray-Deposited $CdS_{1-y}Te_y$ thin films, *JOM*., 69 (2), 191–197. DOI: https://doi.org/10.1007/s11837-016-2199-0

Ikhmayies, S.J. (2017c). Properties of the CdS_xTe_{1-x} solid solution: as a single product and as a part of the CdS/CdTe solar cell, *Journal of Energy Systems*, 1(3),102-110. DOI: https://doi.org/10.30521/jes.355507

Ikhmayies, S.J. (2019). Spray deposited thin films of SnO_2: F/CdS: In bilayers produced using different fluorine sources: NH_4F and HF. *Journal of Energy Systems* 3(3), 111-122. DOI: https://doi.org/10.30521/jes.605085

Ilican, S., Caglar, M., & Caglar, Y. (2007). The effect of deposition parameters on the physical properties of $Cd_xZn_{1-x}S$ films deposited by spray pyrolysis method, *J. Optoelectron. Adv. Mater.,* 9(5), 1414 – 1417

Kim, D.J., Yu, Y.-M., Lee, J.W., & Choi, Y.D. (2008). Investigation of energy band gap and optical properties of cubic CdS epilayers, Applied Surface Science 254, 7522–7526.

Lohitha, B., Thanikaikarasan, S. & Marjorie, S.R. (2020). Structural and optical properties of electroplated cadmium sulphide thin films. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2020.05.236

Manthrammel, M. A., Shkir, M., Anis, M., Shaikh, S.S., Elhosiny Ali, H., AlFaify, S. (2020). Facile spray pyrolysis fabrication of Al:CdS thin films and their key linear and third order nonlinear optical analysis for optoelectronic applications. Opt. Mater., 100, 109696. DOI: https://doi.org/10.1016/j.optmat.2020.109696

Metın, H., & Esen, R. (2003). Photoconductivity studies on CdS films grown by chemical bath deposition technique, *Erciyes Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, 19(1-2), 96–102.

Naseem, S., Nazir, D., Mumtaz, R., & Hussain, K. (1996). Evaporated thin films of CdS and CdTe: Optimization for photovoltaic applications, J. Mater. Soc. Technol., 12: 89–94.

Ninomiya, S., & Adachi, S. (1995). Optical properties of wurtzite CdS. *J. Appl. Phys.,* 78(2), 1183–1190. DOI: https://doi.org/10.1063/1.360355

Perna, G., Capozzi, V., Ambrico, M., Augelli, V., Ligonzo, T., Minafra, A., Schiavulli, L. & Pallara, M. (2004). Structural and optical characterization of undoped CdS films grown by pulsed laser deposition. *Thin Solid Films,* 453-454, 187–194. DOI: https://doi.org/10.1016/j.tsf.2003.11.105

Rao, K.G., & Ashith, V.K. (2015), Influence of deposition parameters on the structural and optical properties of CdS thin films obtained by micro-controlled SILAR deposition, *J. Phys. Chem. Solids*., 77, 14–22. DOI: https://doi.org/10.1016/j.jpcs.2014.09.008

Ravangave, L.S., & Biradar, U.V. (2013), Study of optical parameters of chemical bath deposited $Cd_{1-x}Zn_xS$ thin films, Materials Physics and Mechanics 16(1), 25-33. DOI: 10.15373/22778160/January2013/34

Sahay, P.P., Nath, R.K., & Tewari, S. (2007). Optical properties of thermally evaporated CdS thin films, *Cryst. Res. Technol.*, 42(3), 275 – 280. DOI 10.1002/crat.200610812

Shkir, M., Ashraf, I.M., AlFaify, S., El-Toni, A.M., Ahmed, M., & Khan, A. (2019). A remarkable effect of Pr doping on key optoelectrical properties of CdS thin films prepared using spray pyrolysis technique for high-performance photodetector applications. *Ceram. Int.* DOI: https://doi.org/10.1016/j.ceramint.2019.10.196

Singh, M., Vigay, Y.K., & Sharma, B.K. (2007). A variable electron beam and its irradiation effect on optical and electrical properties of CdS thin films, *Pramana – J. Phys,.* 69(4), 631–638. DOI: 10.1007/s12043-007-0161-y

Tsai, C.T., Chuu, D.S., Chen, G.L., & Yang, S.L. (1996). Studies of grain size effects in rf sputtered CdS thin films, *J. Appl. Phys.,* 79(12), 9105–9109. DOI: https://doi.org/10.1063/1.362645

Tüzemen, E.Ş., Eker, S., Kavak, H., Esen, R. (2009), Dependence of film thickness on the structural and optical properties of ZnO thin films, *Appl. Surf. Sci.,* 255, 6195–6200. DOI: https://doi.org/10.1016/j.apsusc.2009.01.078

Ugwu, E.I., & Onah, D.U. (2007). Optical characteristics of chemical bath deposited CdS thin film characteristics within UV, visible, and NIR radiation. The Pacific Journal of Science and Technology 8(1), 155–161. DOI: http://www.akamaiuniversity.us/PJST.htm

Yahia, I.S., El Radaf, I.M., Salem, A.M., & Sakr, G.B. (2018). Chemically deposited Ni-doped CdS nanostructured thin films: Optical analysis and current-voltage characteristics. *J. Alloy. Compd.* DOI: https://doi.org/10.1016/j.jallcom.2018.10.285