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THE INFLUENCE OF THICKNESS ON THE OPTICAL PARAMETERS OF THERMALLY EVAPORATED CdS THIN FILMS

Shadia J. Ikhmayies

Al Isra University; Faculty of Information Technology, Department of Basic Sciences-Physics; Amman, 16197, Jordan.

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Abstract

Cadmium sulfide (CdS) thin films with different thickness (50-700 nm) are prepared on glass substrates by using the thermal vacuum evaporation technique at ambient temperature. The optical parameters of the films are deduced from transmittance curves which are measured at room temperature in the wavelength range (290-1100 nm). The extinction coefficient (k), refractive index (n) and the real and imaginary parts of the dielectric constant (ε_r, ε_i) are calculated and their relations with photon's energy and film thickness are investigated. All of these optical parameters are found to be dependent on film thickness. These results are very interesting for the use of CdS in the design of optoelectronic devices and thin film solar cells such as CdS/CdTe solar cell.

Introduction

Cadmium sulfide (CdS), a metal chalcogenide semiconductor belonging to II–IV group, is one of the promising materials for use in various optoelectronic devices, light detectors, photo conductors, display panels, light emitting diodes and sensors [1]. Polycrystalline cadmium sulphide thin films have received intensive attention because of their very important roles in photovoltaic applications [2]. Cadmium sulfide, having an energy bandgap of 2.42 eV, is one of the most promising thin film materials for application as a window layer [2] in heterojunction solar cells such as CdS/CdTe thin film solar cells. CdS is preferred over other wideband gap materials for optical window applications due to its compact crystallographic cell and electronic affinity with $CuInSe_2$, InP, CdTe and other p-type semiconductors [1]. There are several methods for depositing CdS thin films, such as; chemical bath deposition (CBD) [3–5], spray pyrolysis (SP) [6–8], successive ionic layer adsorption and reaction (SILAR) [9], rf sputtering [10], pulsed laser deposition (PLD) [11], and thermal evaporation [12–16]. Thermal evaporation technique has been chosen for the deposition of CdS thin films as it is simple compared with other new and sophisticated techniques [16] beside that, deposition of the films by thermal evaporation does not present any compositional problems.

The study of optical properties such as transmission, refractive index and energy gap are of great importance in opto-electronics applications [13]. A lot of experimental work was devoted to the study of the optical properties of CdS thin films [2,3,12,16–18], but little work was found on the relation between the optical parameters and film thickness [16]. For thermally evaporated CdS thin films Sahay et al [16] investigated variations of the refractive index and extinction coefficient with film thickness for films of thickness 25–100 nm, whereas, the films prepared in this work have thickness 50–700 nm. In addition, Kariper et al. [3] prepared CdS films by CBD and studied the structural, electrical and optical properties of CdS thin films as a function of pH, but they also found a relation between the ph of the solution and film thickness. In this work the optical parameters of thermally evaporated CdS thin films of thickness in the range 50-700 nm were deduced from the transmittance. The refractive index, extinction coefficient, real and imaginary parts of the dielectric constant are calculated and their dependence on film thickness was investigated.

Experimental Part

Cadmium sulfide (CdS) thin films of thickness in the range 50–700 nm were grown on glass substrates of dimensions 2.5×6×0.1 cm^3 by evaporation at ambient temperature. Before deposition of the films, the substrates were cleaned by acetone then rinsed in distilled water and finally dried by air. The films are prepared in high vacuum (~10^{-5} mbar) by using a Turbo pump. The evaporation rate was about 10 Å/s and it was measured by using a cooled quartz crystal monitor. The source–substrate distance was around 30 cm. The transmittance of the films was measured at room temperature by using a double beam Shimadzu UV 1601 (PC) spectrophotometer with respect to a piece of glass of the same kind as the substrates in the wavelength range 290-1100 nm.

Results and Discussion

Figure.1 depicts the transmittance of six thermally evaporated CdS films of thickness in the range 50–700 nm measured at room temperature in the wavelength range 290–1100 nm. As the figure shows the transmittance is high, where it oscillates between about 70% and 100% in the transparent region ($\lambda \geq 510$ nm). 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 the differences in films' thickness. Transmittance measurements shown in Figure.1 were used to deduce the reflectance *R* which was used to deduce the other optical parameters of the films such as the refractive index, extinction coefficient, real and imaginary parts of the dielectric constant.

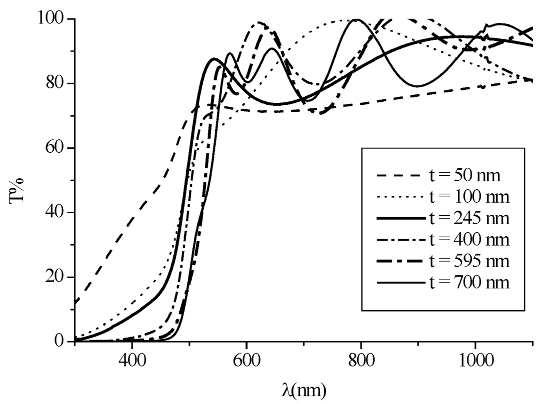

Figure 1. Transmittance of thermally evaporated CdS films against wavelength of radiation.

To find the refractive index and the extinction coefficient, the reflectance R of the films was deduced from the transmittance T, where $T + R = 1$. 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 n* is used. Reflectance is given by the following relation [19]

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

The complex refractive index of the film is given by;

$$n^* = n + ik \quad (2)$$

where n is the refractive index and k the extinction coefficient of the film. Knowing the value of the absorption coefficient α, which can be calculated from the transmittance, the extinction coefficient can be calculated using the relation

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

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

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

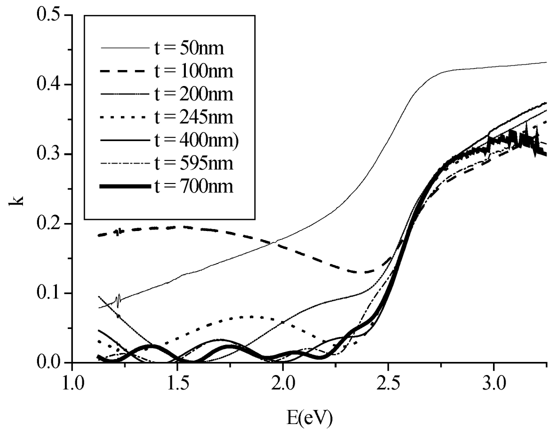

Figure 2. The extinction coefficient of thermally evaporated CdS thin films.

The extinction coefficient k was calculated from Eq.3 and plotted against photon's energy and displayed in Figure.2. As the figure shows, extinction coefficient has an oscillatory behavior in the transparent region. This is the same oscillatory behavior observed in the transmittance curves. The number of peaks increases with film thickness, so the oscillatory behavior is not apparent in the case of the film of thickness 50 nm. The value of k in the transparent region decreases with film thickness, where it has a maximum value of about 0.2 and a minimum value of about zero. The non-zero value of k was explained by Sahay et al. [16] who reported that: "In the case of polycrystalline films, extra absorption of light occurs at the grain boundaries. This leads to non-zero value of k for photon energies smaller than the fundamental absorption edge". Comparing these curves with the curves obtained by Sahay et al. [16], it is found that they [16] have larger values of k. The difference is mainly due to the larger values of film thickness in this study. In addition, synthesis parameters such as the deposition temperature, and the ratio of Cd:S in the films have strong influence on k. At the absorption edge k increases rapidly with photon's energy then the increase becomes slower. This behavior is similar to the behavior of the extinction coefficient in the work of Sahay et al. [16], but also they have larger values of k. Lower values of k in the transparent region are better for the use of CdS as a window layer in thin film solar cells.

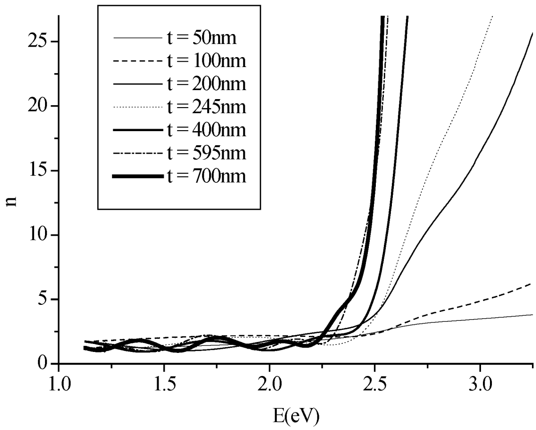

Figure 3. The refractive index of thermally evaporated CdS thin films.

The refractive index n was calculated from Eq.4 and plotted against the photon's energy hν and displayed in Figure .3. Also, the refractive index shows an oscillatory behavior in the transparent region following the behavior of the transmittance, and its values in this region are approximately restricted in the range1–2.2. These values are slightly smaller than the refractive index of bulk CdS which is ~2.3. The values of n obtained in this work are in good agreement with the values obtained by Gordillo et al. [20] for thermally evaporated CdS_xTe_{1-x} films of thickness 2.2 μm prepared at substrate temperature 250 °C when x = 0 where they got n values in the range 2–2.6 in the wavelength range 500–1000 nm. In the region of the absorption edge and beyond it until 3.5 eV, the refractive index increases rapidly with photon's energy, where its value increases with film thickness. The relation between n and film thickness is not apparent in the curves of Sahay et al. [16], due to the presence of the oscillatory behavior, but the peak values of the refractive index for their films of different thicknesses vary in the range of 2.53 to 2.64.

The complex dielectric constant is a fundamental intrinsic material property. The real part of it is associated with the refractive index and hence the speed of light in the material. The imaginary part of the dielectric constant is related with the absorption of light in the material. The real and imaginary parts of the dielectric constant are determined by using the following equations [21]

$$\varepsilon_r = n^2 - k^2 \quad (6)$$

$$\varepsilon_i = 2nk \quad (7)$$

where ε_r is the real part and ε_i is the imaginary part. Figure.4 displays the relation between ε_r and the photon's energy for the aforementioned set of films. From the figure it is obvious that ε_r increases with increasing photon's energy. It is noticed that the values of ε_r in the transparent region for the six films vary in an oscillatory behavior between 1 and 5. In the region near the absorption edge ε_r sharply increases with the increase in photon's energy and it increases with film thickness. These values are comparable to the values obtained by Sahay et al. [16] for films of thickness 25-100 nm, where they got ε_r in the transparent region such that $1<\varepsilon_r<5$.

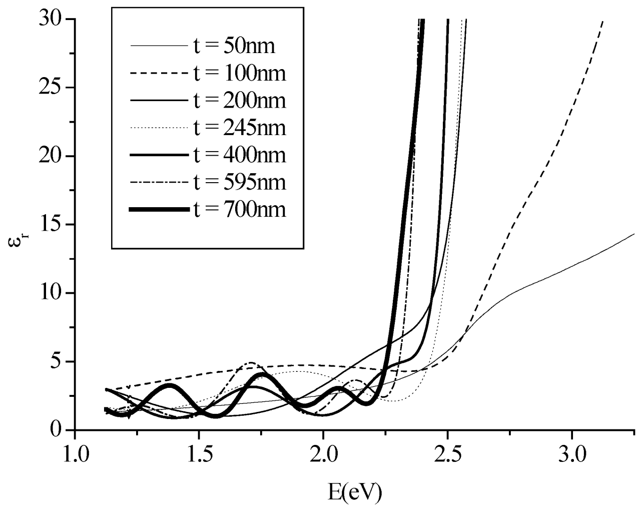

Figure 4. The relation between the real part of the dielectric constant and photon's energy for thermally evaporated CdS thin films.

Fig.5 depicts the relation between ε_i and the photon's energy, where ε_i in the transparent region is approximately constant between 0 and 0.8, which decreases with film thickness. A sharp increase of ε_i with photon's energy is observed at the absorption edge too, and it also increases with film thickness. So, the real and imaginary parts follow the same pattern and it is seen that the values of the real part are higher than the imaginary part.

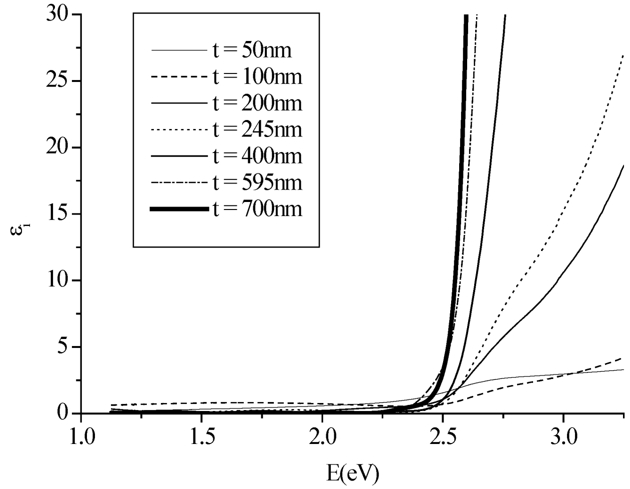

Figure 5. The relation between the imaginary part of the dielectric constant and photon's energy for thermally evaporated CdS thin films.

Conclusions

Cadmium sulfide (CdS) thin films of thickness 50–700 nm were produced by thermal evaporation at ambient temperature on glass substrates. The transmittance of the films was recorded at room temperature in the wavelength range 290–1100 nm and used to deduce reflectance. From the relations between reflectance and the complex refractive index the refractive index and extinction coefficient were calculated and their relations with photon's energy and film thickness were investigated. The real and imaginary parts of the dielectric constant were obtained and their relations with photon's energy and film thickness were discussed too. It was found that all of these optical parameters depend on film thickness. 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.

References

1. Raghavender Tummala, Ramesh K. Guduru, and Pravansu S. Mohanty, "Solution Precursor Plasma Deposition of Nanostructured CdS Thin Films," *Materials Research Bulletin* 47 (2012), 700–707.

2. P.A. Chate et al., "Synthesis, Optoelectronic Properties and Photoelectrochemical Performance of CdS Thin Films," *Physica B* 411 (2013), 118–121.

3. A. Karipera et al., "The Structural, Electrical and Optical Properties of CdS Thin Films as a Function of pH," *Materials Chemistry and Physics* 129 (2011), 183– 188.

4. E.I. Ugwu and D.U. Onah, "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) (2007), 155–161.

5. Hülya Metın and R. Esen, "Photoconductivity Studies on CdS Films Grown by Chemical Bath Deposition Technique," *Erciyes Üniversitesi Fen Bilimleri Enstitüsü Dergisi* 19 (1-2) (2003), 96–102.

6. Shadia. J. Ikhmayies, "Production and characterization of CdS/CdTe thin film photovoltaic solar cells of potential industrial use". (Ph.D Thesis. University of Jordan, 2002), 116-117.

7. Shadia J. Ikhmayies and Riyad N. Ahmad-Bitar, "Effects of Annealing in Nitrogen Atmosphere and HCl-Etching on the Photoluminescence Spectra of Spray-Deposited CdS:In Thin Films," *Applied Surface Science* 255 (20) (2009), 8470–8474.

8. Shadia J. Ikhmayies and Riyad N. Ahmad-Bitar, "Direct Observation of Infrared Photoluminescence of Spray-Deposited CdS:In Thin Films," *J. Luminouscence* 128 (4) (2008), 615–619.

9. Susumu Ninomiya and Sadao Adachi, "Optical Properties of Wurtzite CdS," *J. Appl. Phys.* 78 (2) (1995), 1183–1190.

10. C. T. Tsai et al., "Studies of Grain Size Effects in rf Sputtered CdS Thin Films," *J. Appl. Phys.* 79 (12) (1996), 9105–9109.

11. G. Perna et al., "Structural and Optical Characterization of Undoped CdS Films Grown by Pulsed Laser Deposition," *Thin Solid Films* 453-454 (2004), 187–194.

12. Shadia J. Ikhmayies, "Characterization of Nanocrystalline CdS Thin Films Prepared by Thermal Evaporation," *International Journal of Materials and Chemistry* 3(2) (2013), 28-33.

13. N.A. Shah et al., "Physical Properties and Characterization of Ag Doped CdS Thin Films," *Journal of Alloys and Compounds* 512 (2012), 27– 32.

14. Shahzad Naseem et al., "Evaporated Thin Films of CdS and CdTe: Optimization for Photovoltaic Applications," *J. Mater. Soc. Technol.* 12 (1996), 89–94.

15. M. Singh, Y. K. Vigay, and B. K. Sharma, "A Variable Electron Beam and its Irradiation Effect on Optical and Electrical Properties of CdS Thin Films," *Pramana – J. Phys.* 69 (4) (2007), 631–638.

16. P. P. Sahay, R. K. Nath, and S. Tewari, "Optical Properties of Thermally Evaporated CdS Thin Films," *Cryst. Res. Technol.* 42(3) (2007), 275 – 280.

17. Mujdat Caglar et al., "Effect of Indium Incorporation on the Optical Properties of Spray Pyrolyzed $Cd_{0.22}Zn_{0.78}S$ Thin Films," *Czechoslovak Journal of Physics* 56(3) (2006), 277-287.

18. Mahir N. Thomail, "Studying the Optical Properties of CdS Thin Films Prepared by Thermal Vacuum Evaporation Technique with a Different Thickness," *J. of University of Anbar for Pure Science* 6(1) (2012), (4 pages).

19. Saeed Salem Babkair, Najat Mohammad Al-Twarqi, and Azhar Ahmad Ansari, "Optical Characterization of CdTe Films for Solar Cell Applications," *Karachi University Journal of Science* 39 (2011), 1-5.

20. G. Gordillo, F. Rojas, and C. Calderón, "Optical Characterization of $Cd(S_x, Te_{1-x})$ Thin Films Deposited by Evaporation," *Superficies y Vacio* 16(3) (2003), 30–33.

21. A.A. Alnajjar, F. Y. Al-Shaikley, and M.F. A.Alias, "Optical Properties and Photoconductivity of Undoped and In-Doped CdTe Thin Films," *Journal of Electron Devices* 16 (2012), 1306-1314.