Journal of Theoretical and Applied Physics (2020) 14:265–274
https://doi.org/10.1007/s40094-020-00377-2

RESEARCH

A systematic study on chemically deposited cadmium sulfide (CdS) thin film

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Received: 21 December 2018 / Accepted: 22 May 2020 / Published online: 3 June 2020

Abstract

In this work, the conventional chemical bath deposition (CBD) technique and its growth parameters were systematically studied to deposit CdS thin films on the glass substrate. The samples were prepared using a simple aqueous solution containing cadmium sulfate ($CdSO_4 \cdot 8H_2O$), thiourea [$SC(NH_2)_2$], ammonium sulfate [$(NH_4)_2SO_4$] as a source of cadmium, sulfur, and a complexing agent, respectively. The deposited films were characterized to study the surface morphology, crystallographic structure, chemical composition, optical and electrical properties. Through this study, the structure was determined to cubic with (111) preferential orientation and the crystallinity of the films was improved with the increase of film thickness. The transmission spectra were recorded in the range of wavelength 300–600 nm. The optical bandgap of the optimized CdS films was varied from 2.43 to 2.74 eV. All the films exhibit n-type of conductivity which was found in the order of 10^{-4} to 10^{-5} (1/Ω-cm), suggesting that it would be suitable for the buffer layer in thin-film solar cells.

Keywords CBD · CdS · Thin film · Optical bandgap · Conductivity

Introduction

Thin-film semiconductor plays a functional role in the fabrication of photovoltaic devices, optoelectronic devices, magnetic devices, and photonic transducers due to the low cost and eases of sample preparation. A thin film of cadmium sulfide (CdS) is of great interest in the field of optoelectronic applications. CdS is an intrinsic n-type II-VI compound semiconductor which has high stability, compact crystallographic cell structure, low absorption loss, electronic affinity, and direct bandgap of 2.42 eV (bulk value) that enables CdS thin film to be suitable in electronic devices such as solar cell [1], photosensor [2], photodiode [3], and field-effect transistor (FET) [4]. In recent years, it has drawn remarkable attention in high-efficiency thin-film solar cells as a window material based on CdTe and Cu(In, Ga)Se_2 (CIGS) [5, 6].

CdS in thin-film form can be prepared by both physical and chemical methods like RF-magnetron sputtering [7], electron beam vacuum evaporation [8], thermal evaporation [9], hydrothermal synthesis [10], electrodeposition [11], sol–gel [12], and chemical bath deposition (CBD) [13]. Among these techniques, CBD seems a simple and cost-effective fabrication tool to obtain good-quality large area CdS thin films. The deposition of CdS thin films using CBD is based on the slow release of Cd^{2+} ions and S^{2-} ions in an aqueous alkaline bath and the subsequent condensation of these ions on the substrate suitably mounted in the bath. The slow release of Cd^{2+} ions is achieved by adding a complexing agent (ligand) to the Cd salt to form some cadmium complex species which, upon dissociation, results in the release of small concentrations of Cd^{2+} ions [14].

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A survey in the literature shows that different cadmium sources have been used to obtain Cd^{2+} ions from cadmium salt, such as cadmium sulfate ($CdSO_4$) [15], cadmium acetate [$Cd(CH_3COO)_2$] [16], and cadmium chloride ($CdCl_2$) [17]. Khallaf et al. studied the effect of cadmium sources on film properties and found that the highest growth rate, bandgap, carrier concentration, and mobility were obtained when $CdSO_4$ was used as Cd source [14]. Several complexing agents or ligands have been utilized in the deposition of CdS, such as triethanolamine (ETA) [18], ethylenediaminetetraacetic acid (EDTA) [19], nitrilotriacetic acid (NTA) [20], and amino acid [21]. However, the most commonly used complexing agent is ammonia that provides adequate alkaline medium [22]. Soundeswaran et al. reported that the ammonia evaporation from bath affects the pH of the solution and hence the amorphous film was obtained. So, they added ammonium sulfate as a second complexing agent which leads to the uniform growth of film and hence improves the surface morphology of the film [23]. Over the years, thiourea is commonly used as a source of S^{2-} ions [24]. The literature revealed the influence of thiourea concentration and found that the growth rate was faster when the quantity of thiourea is much greater than the cadmium ion concentration in the solution [14]. Zia et al. observed that the bandgap increases with the thiourea concentration. This increment in the effective bandgap yields CdS thin films a more efficient window material for photovoltaic applications [25].

This work aimed to optimize the growth parameters of CBD systematically to deposit CdS and then its characterization. The samples were prepared using a simple aqueous solution containing cadmium sulfate as Cd^{2+} ions and thiourea as S^{2-} ions source, respectively. To ensure a stable complex, ammonium sulfate was employed. For maintaining the pH within the range of 7.9–8.3, 30% ammonia (aqueous solution) was utilized. Growth parameters such as the concentration of ammonium sulfate, thiourea, and deposition time were optimized to get homogeneous, large-area deposition, and uniform thin films. The effects of growth parameters were investigated to assess CdS thin film's thickness as well as its structural, morphological, compositional, optical, and electrical properties. Thus, the characterization results of the CdS thin films were presented using surface profilometry, XRD, SEM, EDX, UV–Vis spectrophotometry, and Hall effect measurements.

Experimental details

To deposit CdS thin film, microscopic glass slides (25.4 mm × 76.2 mm × 1 mm) were used as the substrate. At first, the substrates were washed with liquid soap and rinsed thoroughly with normal water 2–3 times. After that, the substrates were scrubbed in methanol and then rinsed with de-ionized (DI) water. Then the scrubbed substrates were ultrasonically cleaned in methanol, ethanol, and DI water, respectively, and finally dried by the air flow before deposition.

The chemical deposition of CdS thin films was systematically deposited on the glass substrate at different concentrations of ammonium sulfate (0.30 M, 0.60 M, and 0.90 M), thiourea (0.30 M, 0.50 M, 0.70 M), and deposition time (30 min, 45 min, and 60 min). In all cases, the concentration of cadmium sulfate was kept fixed at 0.10 M. Each chemical bath contained 120 ml DI water kept under stirring at 70 °C. The cleaned substrates were held in the bath prior to the addition of any of the reagents. At first, cadmium sulfate and 10 ml of ammonia (aqueous solution) were introduced in DI water at room temperature (25 °C). Ammonium sulfate was employed as a buffer at 40 °C. Thiourea was added to the solution at 60 °C followed by 10 ml of ammonia (aqueous solution). The chemical bath process was continued for 45 min (70 °C). The final solution was about 140 ml. After deposition, the films were taken out from the bath and cleaned thoroughly in DI water to remove the loosely adherent CdS particles and finally dried in the air at room temperature. The growth mechanism and chemical reaction process were reported in many other works [26–28] which are beyond the scope of this work.

Results and discussion

Film thickness

Thickness measurements of the films were taken by Stylus Profilometer (DektakXT). Making several trials for different concentrations of ammonium sulfate, thiourea, and deposition time, different thicknesses of CdS films were obtained (Table 1).

Table 1 Thickness variation of CdS thin films. The film thickness depends on the concentration of ammonium sulfate, thiourea, and deposition time. For a shorter deposition time (30 min), the thickness of about 100 nm was obtained

Ammonium sulfate (M)	Thiourea (M)	Deposition time (min)	Thickness (nm)
0.30	0.30	45	190
0.60	0.30	45	170
0.90	0.30	45	75
0.30	0.50	45	200
0.30	0.70	45	205
0.30	0.50	30	100
0.30	0.50	60	280

It can be seen from Table 1 that the film thickness decreases with increasing concentrations of ammonium sulfate. This is because ammonium sulfate acts as complementary complexes of Cd^{2+} ions which slows the release of Cd^{2+} ions. At higher concentrations, Cd^{2+} ion releases slowly that results in much thinner films. For this reason, 0.30 M (190 nm) was chosen as an optimum. Then, at this fixed concentration of ammonium sulfate, the concentration of thiourea was varied. In this case, film thickness increases with the concentration of thiourea and after a certain concentration, film thickness increases slowly. This is because above a certain concentration, the rate of reaction is high and the solution approaches to supersaturation. As a result, at 0.50 M thiourea, the film thickness was found 200 nm and only an increase of 5 nm in film thickness was obtained at 0.70 M thiourea. Beyond this concentration, film thickness starts to decrease. This may be due to the peeling of material from the glass substrate that reduces the film thickness. Therefore, 0.50 M thiourea was chosen as an optimum. Finally, the deposition time was varied, keeping the concentration of ammonium sulfate at 0.30 M and thiourea at 0.50 M. It shows that the film thickness increases with the deposition time. For many important applications, the suggested thickness of CdS is about 100 nm [29, 30].

Structural property

XRD data were recorded on GBC Matrix SSD X-ray diffractometer in 2θ range of 20°–70° with Cu-Kα radiation ($\lambda = 0.15418$ nm). XRD pattern of CdS thin films of varying concentrations of ammonium sulfate is shown in Fig. 1. Only one diffraction peak was observed at the diffraction angle of 26.70° on the XRD spectrum for the CdS thin film prepared at 0.30 M ammonium sulfate. This diffraction pattern can be attributed to either the (002) plane of hexagonal structure or the (111) plane of cubic structure. However, it is reported that at high-temperature film structure is more likely hexagonal [31]. In the case of 0.60 M and 0.90 M ammonium sulfate, no peak was observed. This featureless spectrum in both films indicates that the film was amorphous in structure, and thus confirms the glassy nature of the CdS thin film.

For the variation of thiourea and deposition time (as shown in Figs. 2 and 3, respectively), all the films showed a predominant single peak around the diffraction angle of 27°, suggesting that the crystal structure of CdS is cubic with a preferential orientation along the (111) plane [28, 32]. However, the sharp intense peak was observed for the films deposited at 0.50 M thiourea, 30- and 60-min deposition time which indicates the better crystallinity of the films at that variation. For solar cell applications, hexagonal CdS films are preferable due to excellent stability [33].

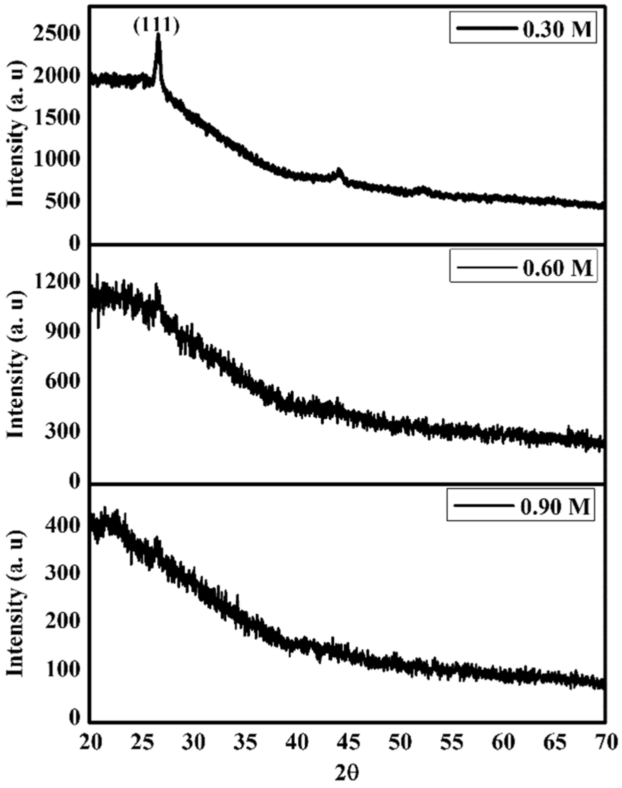

Fig. 1 XRD pattern of CdS thin films for ammonium sulfate: (**a**) 0.30 M, (**b**) 0.60 M, and (**c**) 0.90 M. For 0.30 M ammonium sulfate, one diffraction peak was observed, whereas no peak for 0.60 M and 0.90 M ammonium sulfate which indicates that the films were amorphous in the structure at these concentrations

The size of the crystallites in CdS thin films was calculated with the Debye–Scherrer equation [34] by resolving (111) peak for the cubic phase and is listed in Table 2,

$$D = k\lambda/\beta\cos\theta \tag{1}$$

where D is the crystallite size, k is the Scherrer constant (0.89), λ is the wavelength of X-ray radiation, β is the full width half maximum intensity (FWHM) of the peak, and θ is the Bragg's diffraction angle at the peak position.

Surface morphology

The two-dimensional surface morphological studies of CdS thin films were carried out by using a scanning electron microscope (SEM) operating at 20 kV. The as-deposited films were annealed in N_2 environment at 410 °C for 2 h.

It is seen in Fig. 4a that the as-deposited film surface for 0.30 M ammonium sulfate was smooth enough and homogeneous. No pinhole or cracks were present, and the substrate was covered very well. However, in Fig. 4b after annealing, few vacant spaces were observed which is

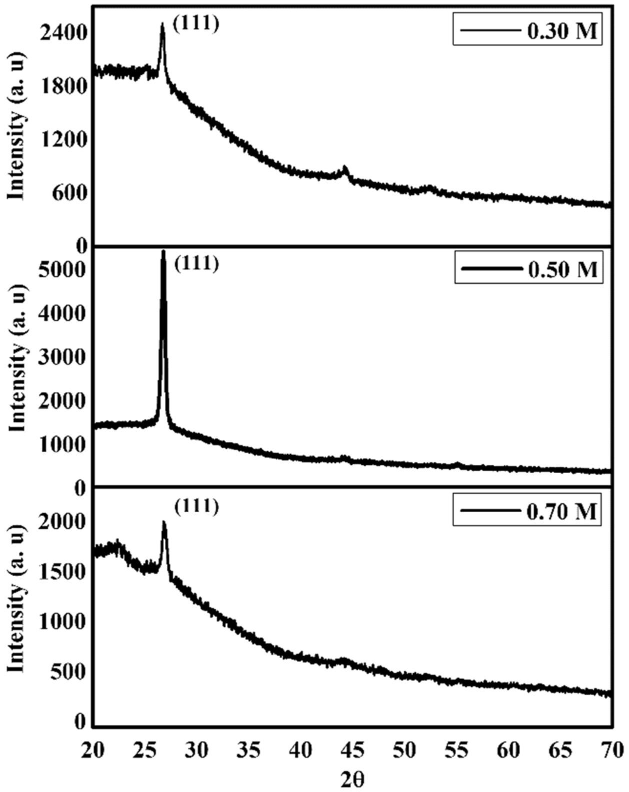

Fig. 2 XRD pattern of CdS thin films for thiourea: (**a**) 0.30 M, (**b**) 0.50 M, and (**c**) 0.70 M. All the films showed a predominant single peak around the diffraction angle of 27° and had a preferential orientation along the (111) plane with the cubic structure. A sharp, intense peak was obtained for 0.50 M thiourea

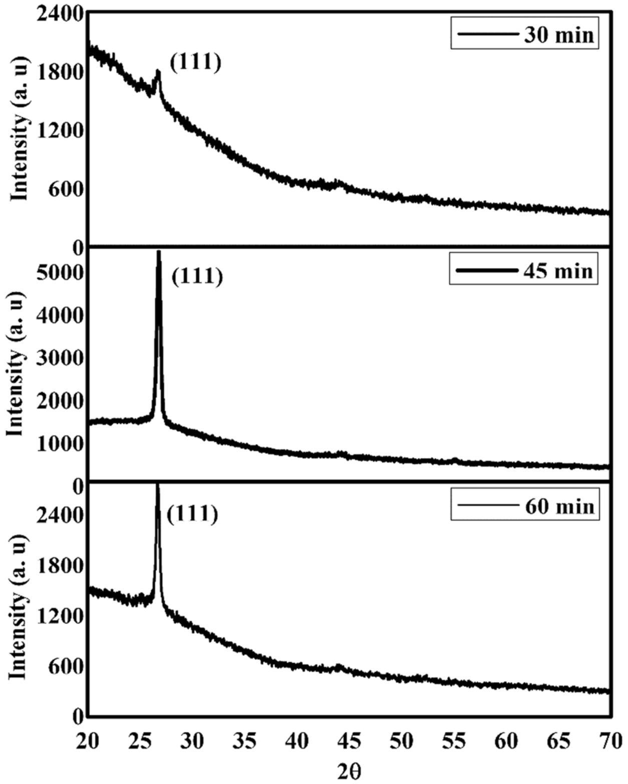

Fig. 3 XRD pattern of CdS thin films for the deposition time: (**a**) 30 min, (**b**) 45 min, and (**c**) 60 min. All the films were oriented along the (111) plane with the cubic structure

likely due to the recrystallization of particles. No significant change in crystallize size was observed for thermally annealed CdS thin films. In Fig. 5, for 0.50 M thiourea, the appearance of cracks was likely related to tensile stress generated from the lattice mismatch between substrate and film. After high-temperature annealing, more cracks were visible which may have formed due to the densification of the CdS thin films [35]. For a deposition time of 30 min, the SEM micrograph in Fig. 6a shows a compact structure composed of a single type of small, densely packed nanocrystals with few vacant spaces. However, after annealing in Fig. 6b, the distribution of nanoparticles becomes more ordered and the vacant spaces between them get occupied which can be attributed to the recrystallization process that densified the film and reduced the defects in the material. In addition, the surface is relatively uniform as the nanoparticles convert into bigger clusters which are likely due to the coalescence or diffusion of a large number of CdS nanoparticles [36].

Compositional analysis

Energy-dispersive X-ray (EDX) spectroscopy was used to survey quantitatively chemical composition in an atomic percentage of cadmium and sulfur in CdS thin films. From Table 3, the atomic ratio of Cd**:**S decreases gradually with the increasing concentration of ammonium sulfate. This is because ammonium sulfate acts as complementary complexes of Cd^{2+} ions which slow the release of Cd^{2+} ions that result in a deficiency of Cd. At higher concentrations, the atomic ratio (Cd**:**S) or stoichiometry of the film was poor (0.76). For thiourea variation, the stoichiometry of the film decreases slowly with the increasing concentration of thiourea which is due to the fact that thiourea was used as S^{2-} ions source, so increasing concentration of thiourea decreases the ratio. This ratio of Cd:S was found to be varied between 0.84 and 0.87 for thiourea variation. The stoichiometry of the films could be approached to nominal composition (Cd:S = 1:1) for longer deposition time. However, it is significant to note that all the films have S excess over Cd.

Table 2 XRD data analysis for crystallite size calculation. The size of the crystallites in CdS thin films was calculated by using well-known Debye–Scherrer formula and found to be varied between 15.62 and 19.93 nm

Ammonium sulfate (M)	Peak position (2θ deg)	θ (deg)	FWHM (β)	FWHM, β (radian)	Crystallite size, D (nm)
0.30	26.70	13.35	0.49788	0.008689	16.23
Thiourea (M)	Peak position (2θ deg)	θ (deg)	FWHM (β)	FWHM, β (radian)	Crystallite size, D (nm)
0.30	26.70	13.35	0.49788	0.008689	16.23
0.50	26.78	13.39	0.40552	0.007077	19.93
0.70	26.90	13.45	0.50347	0.008787	16.05
Deposition time (min)	Peak position (2θ deg)	θ (deg)	FWHM (β)	FWHM, β (radian)	Crystallite size, D (nm)
30	26.72	13.36	0.51721	0.009027	15.62
45	26.78	13.39	0.40552	0.007077	19.93
60	26.80	13.40	0.41678	0.007274	19.39

*CdS thin films prepared at 0.60 M and 0.90 M ammonium sulfate contain no peak

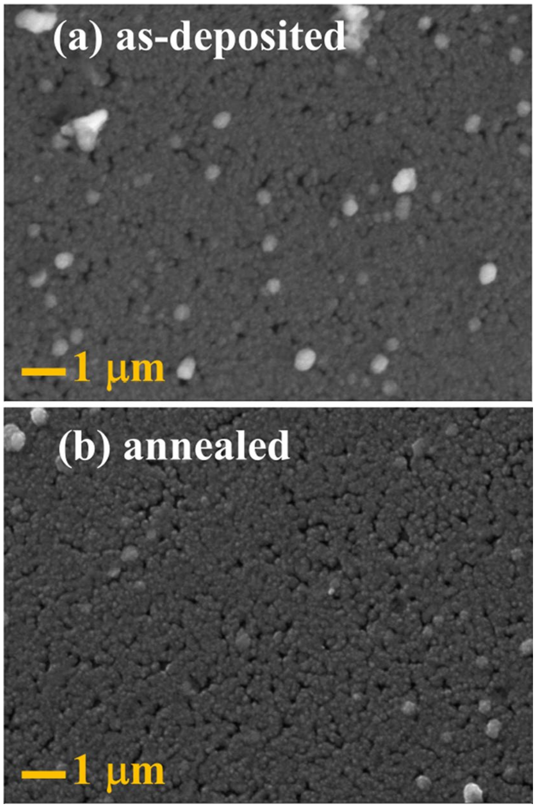

Fig. 4 SEM micrographs of CdS thin films for 0.30 M ammonium sulfate: (**a**) as deposited and (**b**) annealed. Few pinholes and voids were present in all the samples

Optical analysis

A double-beam spectrophotometer (UV–Visible Spectrophotometer UH4150) with the automatic computer data acquisition was employed to record optical spectra over the wavelength range of 300–600 nm.

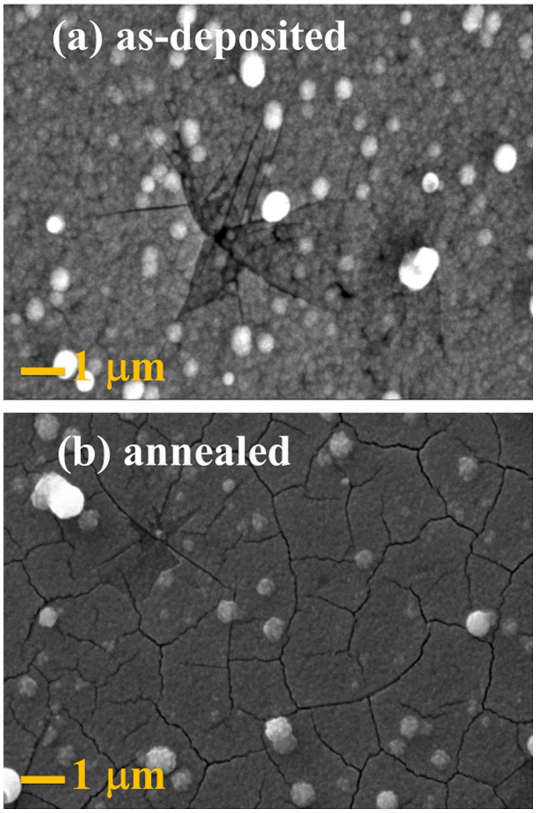

Fig. 5 SEM micrographs of CdS thin films for 0.50 M thiourea: (**a**) as deposited and (**b**) annealed. The cracks were increased after thermal annealing

Transmittance

The CdS transmission spectra exhibit what is best described as ‘S’-shaped curve or sigmoid curve. The transmittance spectra of CdS thin films deposited at different

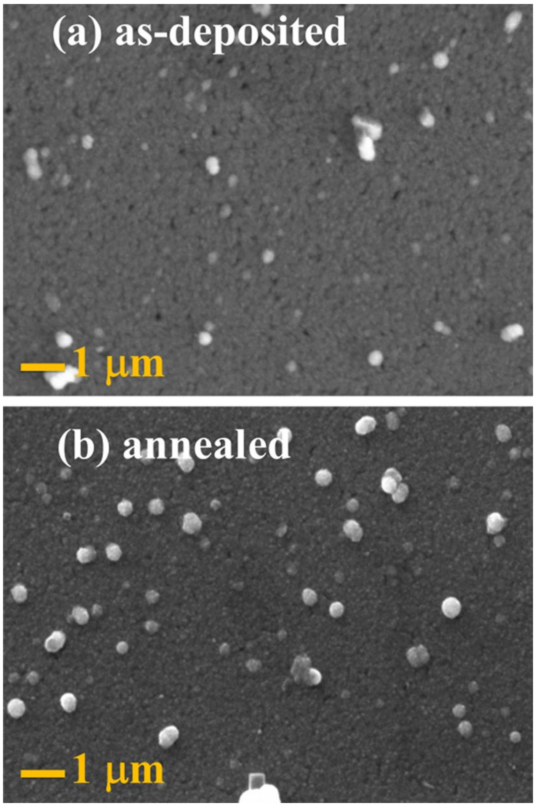

Fig. 6 SEM micrographs of CdS thin films for 30-min deposition time: (**a**) as deposited and (**b**) annealed

concentrations of ammonium sulfate, thiourea, and deposition time are shown in Figs. 7, 8 and 9, respectively.

For ammonium sulfate variation, the film deposited at 0.30 M shows low transmittance near the UV region and the moderately high transmittance in the visible region of the solar spectrum. However, at higher concentrations (0.60 M and 0.90 M), the transmittance in the low wavelength region extends up to 300 nm indicating the presence of disorders or amorphous components in the film which is in good agreement with the XRD pattern [37].

For the variation of thiourea and deposition time, all the films exhibit a sharp absorption edge near 500 nm which corresponds to the optical bandgap of CdS and exhibits high transmittance above the absorption edge. Relatively high transmission of CdS films and sharp fall of transmission at band edge are an indication of low surface roughness and good homogeneity of the film [38].

Bandgap

The optical bandgap values of CdS thin films were determined by Tauc's relation [39]:

$$(\alpha h\upsilon) = C(h\upsilon - E_g)^m \tag{2}$$

where C is an energy-independent constant, E_g is the optical bandgap, and m is an index that depends on the type of optical transition that prevails. Specifically, m is 1/2, 3/2, 2, and 3 when the transition are direct allowed, direct forbidden,

Table 3 Quantitative analysis of CdS thin films. For 0.90 M ammonium sulfate, the atomic ratio of Cd:S was lowest (0.76)

Ammonium sulfate (M)	Element	Weight (%)	Atomic (%)	Ratio (Cd/S)
0.30 M	Cd L	75.4	46.6	0.87
	S K	24.6	53.4	
0.60 M	Cd L	74.8	45.4	0.83
	S K	25.2	54.6	
0.90 M	Cd L	72.6	43.1	0.76
	S K	27.4	56.9	
Thiourea (M)	**Element**	**Weight (%)**	**Atomic (%)**	**Ratio (Cd/S)**
0.30 M	Cd L	75.4	46.6	0.87
	S K	24.6	53.4	
0.50 M	Cd L	75.1	46.3	0.86
	S K	24.9	53.7	
0.70 M	Cd L	74.7	46.1	0.84
	S K	25.3	54.9	
Deposition time (min)	**Element**	**Weight (%)**	**Atomic (%)**	**Ratio (Cd/S)**
30 min	Cd L	74.7	45.7	0.84
	S K	25.3	54.3	
45 min	Cd L	75.1	46.3	0.86
	S K	24.9	53.7	

[*] All the films have S excess over Cd

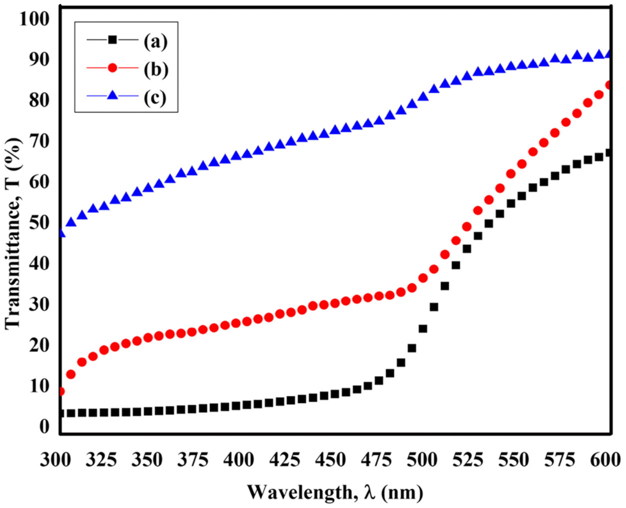

Fig. 7 Transmittance spectra of CdS thin films for ammonium sulfate: (**a**) 0.30 M, (**b**) 0.60 M, and (**c**) 0.90 M. The sample prepared at 0.90 M ammonium sulfate shows high transmittance near the UV region

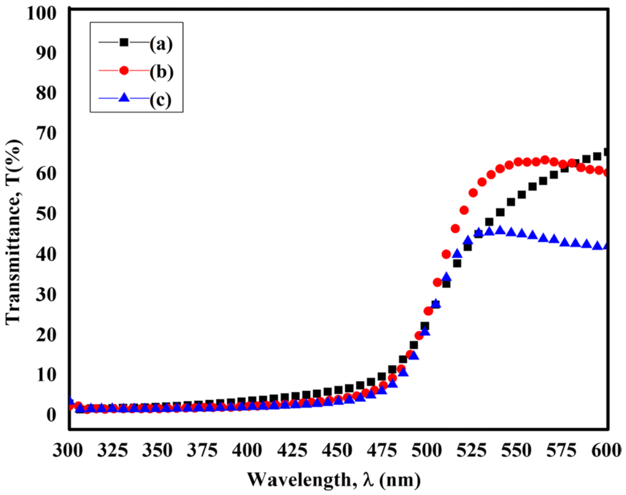

Fig. 8 Transmittance spectra of CdS thin films for thiourea: (**a**) 0.30 M, (**b**) 0.50 M, and (**c**) 0.70 M. All the films exhibit a sharp absorption near 500 nm

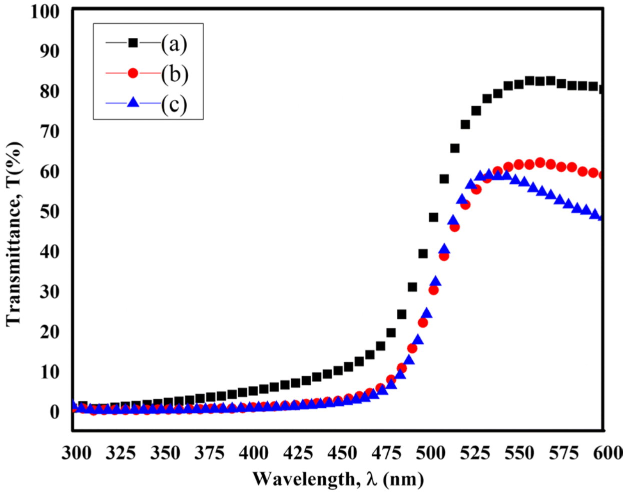

Fig. 9 Transmittance spectra of CdS thin films for deposition time: (**a**) 30 min, (**b**) 45 min, and (**c**) 60 min. For 30-min deposition time, the film shows high transmission above the absorption edge

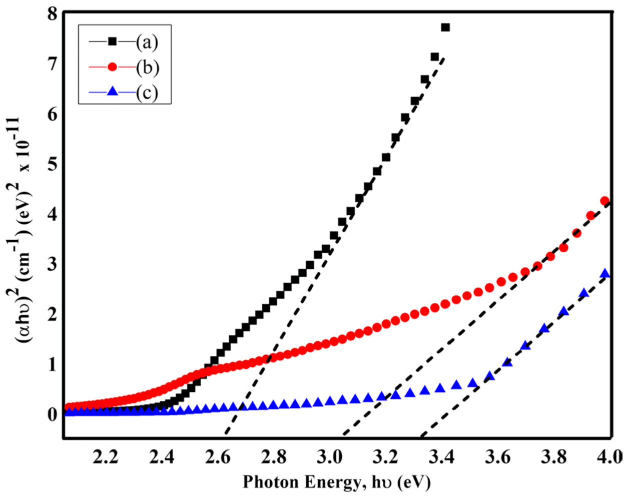

Fig. 10 The plot of $(\alpha h\nu)^2$ versus $(h\nu)$ of CdS thin films for ammonium sulfate: (**a**) 0.30 M, (**b**) 0.60 M, and (**c**) 0.90 M. Here α is absorption coefficient, h is Plank's constant, and ν is frequency. The optical bandgap is found to be thickness dependent

indirect allowed, and indirect forbidden, respectively. According to theoretical and experimental results, CdS exhibits direct-allowed interband transitions. Thus, m can be chosen as ½ [40]. By plotting the graph of $(\alpha h\nu)^2$ versus $(h\nu)$ the bandgap (E_g) value can be determined by extrapolating the linear portion. Figures 10, 11, and 12 illustrate the plots of $(\alpha h\nu)^2$ versus $(h\nu)$ of CdS thin films for ammonium sulfate, thiourea, and deposition time variation, respectively.

For ammonium sulfate variation, as seen in Fig. 10, the bandgap energy (E_g) was in the range of 2.64–3.32 eV. In the case of the thinnest film (75 nm), E_g was found to be 3.32 eV, while for other films E_g decreases from 3.32 to 2.64 eV with the increasing film thickness which is consistent with the previous work [27, 32, 41]. The lower value of Eg may be attributed to the creation of allowed energy states in the bandgap at the time of film preparation, while the higher value of Eg may be accounted for the very small grain size of the film [42, 43]. A similar decrease in the energy bandgap with the increasing film thickness was also obtained for thiourea variation shown in Fig. 11, and the value of Eg was found to be varied between 2.48 and 2.64 eV. However, the energy bandgap increases from 2.43 to 2.74 eV with the film thickness in case of deposition time variation (shown in Fig. 12) likely due to the increase in crystallinity as well

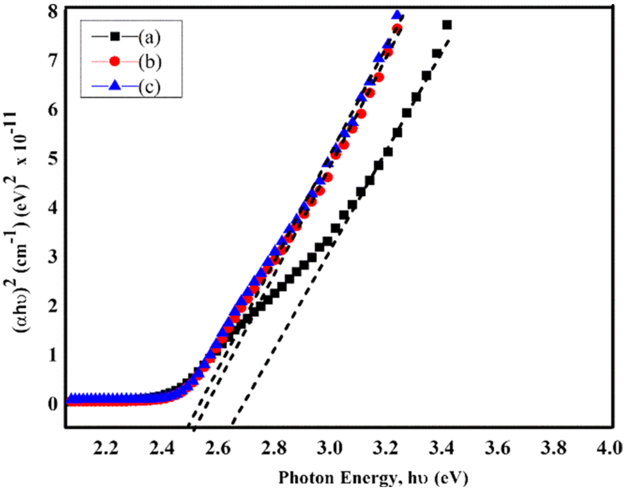

Fig. 11 The plot of $(\alpha h\nu)^2$ versus $(h\nu)$ of CdS thin films for thiourea: (**a**) 0.30 M, (**b**) 0.50 M, and (**c**) 0.70 M

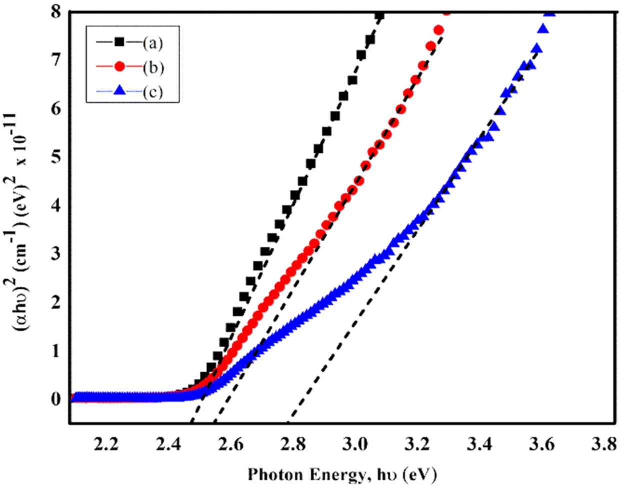

Fig. 12 The plot of $(\alpha h\nu)^2$ versus $(h\nu)$ of CdS thin films for deposition time: (**a**) 30 min, (**b**) 45 min, and (**c**) 60 min. For 30-min deposition time, the obtained bandgap was 2.43 eV which is close to the bulk value of 2.42 eV

as the crystallite size [44–47] and it is in good agreement with Fig. 3.

Electrical property

The electrical properties such as resistivity, carrier concentration, mobility, conductivity, and Hall coefficient of the films were determined by studying the Hall effect of the samples. The Hall effect measurements were taken by using the Ecopia Corp HT55T3 (Korea–0.545 T) system at 300 K temperature and are recorded in Table 4.

The order of conductivity and resistivity in the present work is in the range of 10^{-4} to 10^{-5} (1/Ω-cm) and 10^4 to 10^5 (Ω-cm), respectively. These results are quite similar to those obtained by Su and Choy, Ashour et al. [40, 48]. However, the obtained resistivity results are suitable for the application of CdS films as a buffer layer in thin-film solar cells based on $CuInSe_2$. The mobility was found to be in the order of 10^0–10^1 (cm^2). The negative value in Hall coefficient and carrier concentration indicates that the deposited CdS thin films have n-type conductivity [31].

Conclusions

In this work, a systematic study of the solution method to deposit CdS thin films was shown. The growth parameters such as the concentration of ammonium sulfate, thiourea, and deposition time were optimized followed by standard characterization techniques to assess the quality of the deposited CdS thin films.

XRD pattern indicated that the deposited CdS thin films contain cubic structure with preferential orientation along (111) plane. The crystallinity of the films was improved with the increase of film thickness so does the crystallite size which was calculated using the Debye–Scherrer formula and found to be 16.05–19.93 nm. Analysis of SEM images suggested that thermal annealing improves the orderly distribution of nanoparticles and the vacant spaces between them get occupied which can be attributed to the recrystallization process. The atomic ratio (Cd**:**S) or stoichiometry of the film was found to be varied between 0.76 and 0.87, and all the films had S excess over Cd. The optical bandgap of the films was seen to be decreased from 3.32 to 2.48 eV with the film thicknesses for ammonium sulfate and thiourea variation. On the other hand, the increase in the bandgap from 2.43 to 2.74 eV with the film thickness, in case of deposition time variation, attributed to improved crystallinity of the film. The electrical conductivity and resistivity at room temperature were found to be the order of 10^{-4} to 10^{-5} (1/Ω-cm) and 10^4 to 10^5 (Ω-cm), respectively, suggesting that the deposited CdS thin films can be suitable for buffer layer of the solar cell.

Table 4 Electrical analysis of CdS thin films. The order of conductivity and resistivity was found to be in the range of 10^{-4} to 10^{-5} (1/Ω-cm) and 10^4 to 10^5 (Ω-cm), respectively. All the films have n-type conductivity

Ammonium sulfate (M)	Resistivity (Ω-cm)	Carrier concentration (/cm^2)	Mobility (cm^2/Vs)	Conductivity (1/Ω cm)	Hall coefficient (cm^3/C)
0.30	4.405×10^4	-2.407×10^8	1.118×10^1	2.270×10^{-5}	-4.927×10^5
0.60	7.687×10^4	-2.260×10^8	6.109×10^0	1.301×10^{-5}	-4.696×10^5
0.90	2.065×10^5	-1.828×10^8	1.240×10^0	4.843×10^{-4}	-2.561×10^5
Thiourea (M)	Resistivity (Ω-cm)	Carrier concentration (/cm^2)	Mobility (cm^2/Vs)	Conductivity (1/Ω cm)	Hall coefficient (cm^3/C)
0.30 M	4.405×10^4	-2.407×10^8	1.118×10^1	2.270×10^{-5}	-4.927×10^5
0.50 M	4.079×10^5	-4.121×10^8	1.530×10^0	1.452×10^{-5}	-3.029×10^5
0.70 M	3.835×10^4	-4.720×10^8	1.571×10^1	2.512×10^{-5}	-7.441×10^5
Deposition time (min)	Resistivity (Ω-cm)	Carrier concentration (/cm^2)	Mobility (cm^2/Vs)	Conductivity (1/Ω cm)	Hall coefficient (cm^3/C)
30 min	7.289×10^4	-7.352×10^8	1.165×10^0	1.372×10^{-5}	-8.491×10^4
45 min	4.079×10^5	-4.121×10^8	1.530×10^0	1.452×10^{-5}	-3.029×10^5
60 min	6.939×10^4	-1.414×10^9	1.781×10^0	1.441×10^{-5}	-1.236×10^5

*(−) ve sign indicates the n-type conductivity

Acknowledgements This research work was partly financially supported by United International University Research Grant 2016. The authors acknowledge the Institute of Fuel Research & Development (IFRD), Bangladesh Council of Scientific and Industrial Research (BCSIR), for their technical and scientific assistance.

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