Effect of cadmium sources on the structural, morphological, and optical properties of CdS films for solar cell applications

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Abstract. The variations in the structural, morphological, and optical properties of three CdS films deposited with different cadmium ion sources namely cadmium acetate, cadmium chloride, and cadmium sulfate are reported in this article. All three CdS films possess cubic crystalline structure with the most prominent cubic phase (111). The CdS film deposited with cadmium acetate showed the best crystallinity among them. The presence of both Cd and S with a difference in the percentage of its existence depending upon the type of cadmium source chosen is obtained in the elemental analysis of the CdS films. CdS film deposited from acetate based chemical solution exhibited broad transmittance behaviour in the visible wavelength region due to its superior surface morphology. The energy band-gap values for CBD-CdS films deposited with cadmium acetate, cadmium chloride, and cadmium sulfate are found as 2.30eV, 2.23eV, and 2.32eV, respectively. The film deposited with cadmium acetate showed better IR response and more intense PL emission peaks as compared to the other two films. The efficiency of the CdTe/CdS cell fabricated with CdS window layer deposited with cadmium acetate is found to be 10.02%.

1. Introduction
Solar energy is very attractive, clean, reliable, and effective way to meet the expected rise in energy consumption globally. Cadmium telluride (CdTe)/Cadmium sulphide (CdS) thin film solar cell is one of the most popular photovoltaic (PV) devices. In the film deposition process of different layers of a PV cell by chemical deposition techniques, the selection of appropriate precursors is a very important decision as it eliminates the complexities of the chemical reactions and reduces the time and labor of a researcher. Every material has some specific characteristics that can support or disturb the reaction rate during their addition to the final solution. This affects the film quality and its subsequent applicability for solar cell applications. Not only in chemical but also in physical deposition techniques, the usage of good quality cadmium and sulfur source in an adequate molar ratio ensures the deposition of CdS film up to some extent and the other deposition parameters can be controlled more efficiently [1-2]. Thiourea is a very popular choice of a sulfur ion source for the preparation of chemical solution to deposit CdS film as it offers flexibility in usage with different types of cadmium ion sources including cadmium acetate, cadmium sulfate, cadmium chloride, etc. [3-4].

2. Experimental details
In the present work, three CdS films were deposited by chemical bath deposition (CBD) technique using three different cadmium ion sources cadmium acetate (Cd(CH₃COO)₂·2H₂O), cadmium chloride (CdCl₂), and cadmium sulfate (CdSO₄) on fluorine doped tin oxide (FTO) glass substrates. Thiourea
(H$_2$NCSNH$_2$) and ammonium hydroxide (NH$_4$OH) were used as the sulfur ion source and complexing agent, respectively. Three different solutions were prepared using these three different cadmium ion sources separately, in which each of the chemical solutions contained 0.5M cadmium source material and 1M thiourea (H$_2$NCSNH$_2$). In each beaker, one FTO coated glass substrate was dipped vertically. Then beakers were placed for 1h in water bath which was already maintained at 70°C. After deposition, the substrates were rinsed with distilled water and dried in air. The deposited CdS films were annealed at 200°C for 1h in a hot air oven.

3. Results and discussions

3.1 Structural analysis
CdS thin films grown with different cadmium sources are in cubic crystalline structure as shown in the X-Ray diffraction (XRD) pattern (Figure 1). The XRD pattern of the first CdS film deposited with cadmium acetate exhibit peaks corresponding to diffraction angles 26.6°, 30.7°, and 43.8° which are characteristics of cubic phases (111), (200), and (220). In the XRD pattern of CdS film deposited with cadmium chloride, two characteristic peaks of CdS have been obtained which are situated at diffraction angle 26.6° and 43.8° respectively. These peaks are characteristics of cubic phases (111) and (220) [5]. In the XRD pattern of CdS film deposited with cadmium sulfate only one peak corresponding to diffraction angles 26.5° has been obtained which is a characteristic of cubic phase (111) [6]. The diffraction peaks corresponding to FTO are marked by *. In XRD spectra, the intensities of the preferential orientation peak (111) along with the other two peaks are higher for the CdS films deposited with cadmium acetate as compared to the CdS films deposited with the other cadmium source materials. Thus, the film deposited with cadmium acetate shows far better crystalline behaviour than the films deposited with cadmium chloride and cadmium sulfate.

![Figure 1. The XRD patterns of CBD-CdS films deposited with different cadmium sources.](image)

3.2 Morphological analysis
The morphologies of the CdS films deposited with different cadmium sources were investigated by scanning electron microscopy (SEM) and the SEM micrographs are shown in figure 2. The SEM analysis reveals that the morphologies of CdS films were sensitive to the change in the cadmium ion source and an interesting change has been observed in the morphology. As shown in the SEM images, there is a regular growth pattern of fine CdS particles on the surface of the film deposited with cadmium acetate and cadmium chloride. The surface of the film deposited with cadmium sulfate has some cracks that disturb the morphology and quality of CdS film. Here, surface of film deposited with cadmium...
acetate is best among all three films as it is more compact and smooth. Also, its surface is covered very well by the particles having defined grain boundaries that make it a more suitable choice for solar cell applications than the other films deposited with cadmium chloride and cadmium sulfate.

![SEM images of CdS films](image1)

**Figure 2.** SEM images of CdS films deposited with (a) cadmium acetate, (b) cadmium chloride, and (c) cadmium sulfate.

The energy dispersive X-ray (EDX) spectra of CdS films deposited with different cadmium sources is shown in figure 3. The images in figure 3 confirm the presence of cadmium and sulfur in all three CdS films deposited with cadmium acetate, cadmium chloride, and cadmium sulfate.

![EDX spectra of CdS films](image2)

**Figure 3.** EDX spectra of CdS films deposited with different cadmium sources.

The presence of both Cd and S with a difference in the percentage of its existence is found in the EDX spectra, which depends on the different cadmium sources and the Cd/S concentrations taken during
the preparation of CdS films [7]. The EDX analysis confirms that the elemental composition is not disturbed drastically for any of the CdS film suggesting that all three cadmium sources (cadmium acetate, cadmium chloride, and cadmium sulfate) can make valid pair with thiourea (sulfur source) for the deposition of a CdS film.

3.3 Optical analysis
The Optical characteristics of the window layer play an important role in determining the performance of solar cells [8]. Optical transmittance spectra of the CBD-CdS films were measured by UV–VIS spectrophotometer and it was recorded in wavelength range 400–700 nm. Figure 4 presents the transmittance spectra of the CdS films deposited with different types of cadmium ion sources. Here, the CdS films deposited with cadmium acetate and cadmium chloride show 60-90% optical transmission, but the film deposited with cadmium sulfate exhibit significantly lesser transmittance (less than 60%). In this case, the transmittance spectra complement the SEM investigation also as the CdS film deposited with cadmium acetate, which had the best surface morphology, shows the highest transmittance among all three films.

![Transmittance spectra of CdS films deposited with different cadmium sources.](image)

**Figure 4.** Transmittance spectra of CdS films deposited with different cadmium sources.

The energy band-gap (E_g) of the CdS films deposited with different cadmium sources is determined by Tauc’s plot (Figure 5).

As per the extrapolation of the linear part of the curves plotted between (αhν)^2 versus (hν) to the intercept on the horizontal axis, the band-gap values of CdS films deposited with cadmium acetate, cadmium chloride, and cadmium sulfate are found as 2.30eV, 2.23eV, and 2.32eV, respectively. These values are in good agreement with the literature [9].

3.4 PL study
Photoluminescence (PL) spectroscopy has been used to study the luminescence spectra of CBD-CdS films with an excitation wavelength of 435nm. The PL spectra of the deposited CdS films have been recorded in the wavelength range from 400nm to 650nm (Figure 6). As the PL spectra indicate, the CdS films exhibited two distinct PL bands but the peak positions and PL intensities of the films were different for films deposited by different cadmium sources. The film deposited with cadmium acetate had PL emission peaks centered around 470nm and 546nm. The film deposited with cadmium chloride had PL emission peaks centered around 446nm and 549nm. The film deposited with cadmium sulfate and
cadmium chloride had PL emission peaks centered around 442nm and 546nm. The PL intensities of all bands are higher for CdS film deposited with cadmium acetate than the rest of the two films.

![Figure 5](image)

**Figure 5.** Tauc’s plots of CdS films deposited with different cadmium sources.

![Figure 6](image)

**Figure 6.** PL spectra of CdS films deposited with different cadmium sources.

3.5 FT-IR study

Figure 7 depicts the Fourier transform infrared (FT-IR) spectra of deposited films are recorded on a Bruker FT-IR spectrometer. The broad absorption band around 1300 cm$^{-1}$ is due to the presence of C-S stretching band, while bands around 1450 cm$^{-1}$ and 1960 cm$^{-1}$ are assigned to the presence of triple-bonded S–C–N vibrations. The narrow and weak bands around 1645 cm$^{-1}$ are due to the bending vibrations of CdS. The other weak bands observed in CBD-CdS films between 700 cm$^{-1}$ and 900 cm$^{-1}$ are due to the presence of C-S and Cd-S stretching band of CdS. The characteristics peaks obtained for
CdS films deposited with cadmium acetate are in good accordance with the literature [10]. However, in the IR spectra of CdS film deposited with cadmium sulfate, some of the characteristic peaks are missing and the positions of characteristic peaks were found to be scattered in the IR spectra of the film deposited with cadmium chloride. Comparatively, the intensities of these bands vary significantly for films deposited with different cadmium sources, which shows that the IR spectra of the films depend on the choice of a suitable cadmium source.

3.6 Determination of PV parameters of the CdTe/CdS solar cell

CdS film deposited with cadmium acetate has good crystallinity, better morphology, and higher optical transmittance. So it has been used for the fabrication of the CdTe/CdS solar cell. For this, a CdTe absorber layer is deposited on the pre-deposited CBD-CdS window layer by electrodeposition technique. To complete the cell structure a silver back contact was used. Figure 8 shows I–V curve obtained at room temperature for CdTe/CdS solar cell having a CdS window layer deposited with cadmium acetate.
The PV parameters of the cell were measured using current-voltage (I-V) curve under the light illumination of 100mW/cm² by class AAA Solar Simulator. The fabricated CdTe/CdS solar cell demonstrates a short circuit current (I_sc) = 21.25 mA, open circuit voltage (Voc) = 0.78 V, a fill factor = 0.60 or 60%, and an efficiency (η) = 10.02%.

4. Conclusions
The variations in the structural, morphological, and optical properties of three CdS films deposited with different cadmium ion sources are studied extensively. All three CdS films possess cubic crystalline structure and the CdS film deposited with cadmium acetate exhibited best crystallinity. CdS film deposited using cadmium acetate showed very good transmittance behaviour due to its superior surface morphology. Energy band-gap values for CBD-CdS films deposited with different cadmium sources are found in the range of 2.23eV to 2.32eV. Film deposited with cadmium acetate showed better IR response and PL behavior. The efficiency of the CdTe/CdS cell is found to be 10.02%.

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