Charge transport properties of thermally deposited nanocrystalline CdS/CdTe based on annealing temperature for solar cell application

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Abstract. A CdS/CdTe thin film is prepared on a chemically cleaned ITO glass substrate by depositing CdS and CdTe one after another using Thermal Evaporation Technique. The vacuum inside thin film coating unit (VICO-12) is maintained at 10^{-5} m bar. The optical properties of individual CdS and CdTe in different annealing temperature have been investigated in Hitachi U-3900 UV Spectro-Photometer. The surface morphology of the highest annealed film was investigated by SEM analysis in JSM-6360. The charge transport properties of the CdS/CdTe film annealed at different temperature have been investigated. The efficiency of the CdS/CdTe has been investigated from the J-V characteristics of the film.

Key word- Annealing Temperature, CdS/CdTe Thin film, Optical property, XRD, SEM.

1. Introduction
As a renewable energy source photovoltaic (PV) cells are slowly occupying the global market. Out of different PV cells CdS/CdTe structure is popular because of ideal band gap (1.45 eV) and high absorption coefficient (>10^5) of CdTe[1,2]. On the other hand CdS has bandgap of 2.4eV and it transmits most of the light in the visible range[3]. Thus these properties make CdS a suitable hetero junction partner to CdTe as window layer[4-6]. In this paper Al/CdTe/CdS/ITO hetero- Junction film is prepared as shown in figure 1 by conventional vacuum evaporation technique in view of the post deposition processing applied to CdS and CdTe.

![Figure 1. Schematic diagram of CdS/CdTe solar cell structure.](image-url)
2. Material and method

Very high purity (99.99% pure) CdS and CdTe thin films were deposited by thermal evaporation in Vico Vacuum Coating Unit operating at about 10⁻⁵ mbar. Substrate temperature was kept at about 200°C for CdS and 150°C for CdTe film respectively. First CdS films were deposited onto cleaned ready made ITO glass substrate. As post deposition process CdS films were annealed at three different temperature 250°C, 300°C, 350°C and then CdTe film is further deposited on ITO/CdS films as well as on clean glass substrate and annealed at 200°C, 250°C and 300°C for an hour. CdS and CdTe film which showed better result further taken for solar cell parameter studies.

3. Result and Discussion

3.1 Optical Characterization

Before fabrication of the CdS/CdTe solar cell, first optical properties of individual CdS and CdTe films have been investigated at different annealing temperature. After that CdS/CdTe heterojunctions have been formed and annealed at different temperature. CdS/CdTe film which showed good result was then later taken for further analysis of CdS/CdTe solar performance. First CdS films have been deposited using thermal evaporation on clean ITO glass substrate keeping substrate temperature at 200°C after deposition films were then annealed at three different temperature 250°C, 300°C, 350°C named as IW1, IW2 and IW3. Figure 2 shows absorption and transmission spectra of CdS at different annealing temperature. Absorption spectra reveals that higher annealed film IW3 (annealed at 350°C) has lower absorption compared to other two, that may be due to crystallinity improves at higher annealing temperature. Transmission spectra reveals that IW3 has higher transmission at visible range which is may be due to improvement in perfection and stoichiometry of the film [7].

![Figure 2. Absorption and Transmission spectra of CdS film.](image)

Hence annealing temperature improves the optical properties of the films. Similarly CdTe films were also deposited on glass substrate at 150°C, followed by annealing at 200°C, 250°C and 300°C named as IIA1, IIA2 and IIA3 respectively. Absorption and transmission spectra are shown in figure 3.
From absorption spectra of CdTe IIA3 film has good absorption at visible range compared to other two, may be due to higher annealing temperature which improves the crystallinity of the film. Again from transmission spectra of figure 3, it can be revealed that films has lower transmittance value up to 800 nm that means it is good absorber layer in visible range. Also higher annealed film has slight shift of transmission threshold towards longer wavelength indicates decrease in band gap [8], Therefore it can be concluded that process of annealing yields good CdS and CdTe film.

3.2 Surface Morphology
Surface morphological structure of CdS annealed at 350°C and CdTe annealed at 300°C shows in figure 4 and 5 which reveals that deposition is continuous without any cracks and holes.

Figure 3. Absorption and transmission spectra of CdTe.

Figure 4. SEM image of CdS annealed at 350°C.

Figure 5. SEM image of CdTe annealed at 300°C.
3.3 Charge Transport Properties

For solar cell fabrication CdTe films were deposited on CdS/ITO films and studied the charge transport properties of CdS/CdTe films annealed at different temperature as shown in figure 6. After annealing 99.99% pure aluminium was deposited on CdTe/CdS/ITO/glass structure for back contact.

![Figure 6. I-V characteristics of CdS/CdTe hetero-junction film.](image)

The resistance, $R$, of the hetero-junction film was determined from the slope of the $I$-$V$ plot. From the figure 6 it has been observed that resistance increase with decrease of the annealing temperature. As the Conductance is the reciprocal of Resistance i.e. with increase of annealing temperature conductance will increase. Hence annealing temperature affect the resistance of the film and higher annealed film has better result. CdS/CdTe cell annealed at (350°C / 300°C) have been taken for further studies of solar cell parameter.

3.4 J-V Result of CdS/CdTe Solar cell

Figure 7 shows dark current density verses voltage (J-V) characteristics of CdS/ CdTe hetero junction solar cell. Dark Current-Voltage characteristics of the fabricate solar cell is asymmetric in nature; this behaviour is similar to p-n junction diode in forward direction and in reverse direction current increases continuously rather than saturation[9].

![Figure 7. Dark current J-V characteristics of CdS/CdTe hetero-junction film annealed at 300°C](image)
Figure 8 shows the current verses voltage characteristics of the CdS/CdTe hetero junction solar cell under illumination of 1000w/m². Different parameter $J_{sc}$, $V_{OC}$, FF, PCE were calculated from these J-V characteristics as tabulated in Table 1.

![J-V characteristics](image)

**Figure 8.** J-V characteristics of CdS/CdTe hetero-junction film annealed at 300°C under illumination.

| Annealing Temperature | Time | $J_{sc}$ (mA/cm²) | $V_{OC}$ (V) | FF  | PCE (%) |
|-----------------------|------|-------------------|-------------|-----|---------|
| 300°C                 | 1 hr | 10                | 0.43        | 44.65 | 3.75    |

Different parameters are obtained in Table 1 for CdS(350°C)/CdTe (300°C) cell. We can see that $J_{sc}$ is 10 mA/cm², $V_{OC}$ is 0.43 and FF is 44.65 and PCE is 3.75%.

4. **Conclusion**

As from the obtained result it can be concluded that CdS/CdTe solar cell have been formed. Charge transport properties show that annealing temperature affects the performance of CdS/CdTe solar cell. In the current study CdS/CdTe gives 3.75% PCE which is much lower than the efficiency of the said junction found in the literature which indicates that the large defect present in CdS/CdTe interface due to recombination and low value of FF value is due to series resistance of window layer and high resistance at back contact [9,10]. However to lower the resistance at the back contact it requires a metal with high work function but all metal having high work function is expensive[9,11,12]. So proper material and ultimate treatment for back contact is not yet been found. This observation will definitely help to find out these defects and may be overcome by new researcher.

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