Synthesis and characterization of CdTe thin film on FTO by electrodeposition technique for CdTe/CdS solar cells

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Abstract. In this work, the synthesis of the CdTe thin film (absorber layer) on fluorine-doped Tin oxide (FTO) substrate by electrodeposition technique of CdTe/CdS solar cell has been presented. As a result of the superior efficiency in energy conversion by absorbing energy in a broad range of the solar spectrum, thin film CdS/CdTe solar cells have been paid attention worldwide as a potential candidate for photovoltaics (PV). The electrodeposition (ED) technique is suitable for the synthesis of CdTe material due to its ease, low cost, scalability and manufacturability. Usually, the quality of these deposited thin films depends on several growth parameters, and the type of conducting glass substrate plays a crucial role. CdTe material grown up on the top of the FTO coated glass substrate having dimensions 75mm* 25mm*1mm and was characterized for its optical properties by UV-Vis spectrometer (UV-Vis), Photoluminescence (PL) and Fourier transform infrared spectrometer (FTIR). XRD result confirms the cubic crystalline character of the deposited material. The band gap of CdTe film estimated using Tauc’s plot is found to be 1.5eV. It is expected that this article will enrich the features of CdTe/CdS devices for solar energy conversion and stimulate further innovative research interest on this interesting topic.

1. Introduction
Cadmium Telluride (CdTe) is an II-VI group compound semiconductor. Due to its band gap of 1.5 eV (direct) and high photoluminescence quantum efficiency, it is having various imaging applications. CdTe can be used in several optoelectronic devices such as gas sensors, photo catalysis, biological detection, solar devices, photo detectors, UV sensors, nonlinear optical materials, various luminescence devices, etc. [1]. CdTe photovoltaic (PV) has the lowest emissions of coal, the lowest consumption of water, and the shortest energy reimbursement time for any current PV technology. Efficient photonic devices based on thin films can be produced using a variety of thin film manufacturing technologies such as radio frequency magnetron sputtering, chemical vapour deposition, laser ablation, electrodeposition (ED), and closed space sublimation [2-5]. ED is a simple and economically cheap method for the preparation for the CdTe absorption layer of the solar cell. The traditional ED process requires the use of a 3-electrode device [cathode (working electrode), anode (counter electrode), and the reference electrode] and mainly the researches has been done were based on the three-electrode method [6]. In the 3-electrode system, the use of the reference electrode is due to changes in the concentration of electrolytes throughout the deposition. Impurities such as Ag⁺ and
K⁺ ions which present in the reference electrode, will leak into the electrolyte deposition and significantly decrease the efficiency of CdTe-based solar cells [7]. Thus, the simple 2-electrode system is used in this study, instead of the traditional 3 electrode system. To examine its suitability for the electronic and PV applications, this article reports a comprehensive study on CdTe layers developed by the 2-electrode ED process.

2. Materials and methods
Before the deposition, the fluorine tin oxide (FTO) coated glass substrates were washed carefully with diluted HCL and acetone. After that the slides were thoroughly washed by deionised water several times. CdTe thin films have been deposited by ED technique. CdTe electroplating deposition was carried out by the combination of 2 electrodes: (a) cathode (glass / FTO) (b) anode (carbon electrode) immersed in an electrolyte. This method is usually performed in an aqueous electrolyte containing high concentration (0.5–2.0M) of Cd ions from cadmium sulfate (CdSO₄) and very low concentrations (~1.0–5.0mM) of Te from tellurium dioxide (TeO₂) in aqueous solutions. Initially, the electro-purification process was carried out for 50h to remove the impurities present in the solution. An appropriate amount of diluted TeO₂ solution was added to adjust the concentration level of Te, and 1000 ppm of CdCl₂ was added into the solution. At the beginning when precipitation started, stirring was done using magnetic stirrer for 20min at a temperature of 85°C and pH of the solution was maintained at 2±0.02. The deposition was made in static condition. After the deposition, the deposited films were rinsed with double distilled water and dried out at room temperature. Characterization of the CdTe films was using specific techniques to determine their structural, optical, and luminescence properties. The deposition process of CdTe is governed by the following chemical reactions [8]:

\[
\text{TeO}_3^{2-} + \text{Cd}^{2+} + 3\text{H}_2\text{O} + 6\text{e} \rightarrow \text{CdTe} + 6\text{OH}^{-}
\]

The electrodeposited CdTe is shown in Figure 1. The deposited film is almost uniform and blackish in color.

3. Results and Discussions
3.1 UV-Visible (UV-Vis) spectrum
For the development of PV devices, the study of optical parameters including optical absorption, transmission, and the band gap energy (Eₜ) is very important. Using Shimadzu 1800 UV visible spectrometer, optical absorption measurement was performed. Spectral absorption study provides the information about the nature of the band gap (i.e. direct or indirect) of semiconducting materials [9]. Optical absorption spectrum of ED-CdTe film is shown in figure 2(a) and the Eₜ value of this film is

![Figure 1. CdTe film electrodeposited on FTO.](image.png)
estimated using Tauc’s plot as shown in figure2(b). The enhancement in absorption helps to increase
the amount of photo-generated charge carriers in the CdTe film, which gives the beneficial impact on
the performance of the solar cell. The observed average band gap value is found to be $E_g = 1.5\text{eV}$ which
is consistent with the literature [10].

![Absorption spectrum of ED deposited CdTe thin film.](image)

**Figure 2.** (a) Absorption spectrum of ED deposited CdTe thin film.

![Tauc’s plot of ED deposited CdTe thin film.](image)

**Figure 2.** (b) Tauc’s plot of ED deposited CdTe thin film.

3.2 Photoluminescence (PL) studies

PL is a reliable method to examine the transitions of electrons from higher energy levels to lower
energy states. Figure 3 represents the room temperature PL spectrum of electrodeposited CdTe layer in
the wavelength range of 750-850nm. The wavelength of the laser beam used as the source of
excitation (He-Ne) was 635nm (1.96eV). The PL spectrum of the film exhibit two different bands,
centered at 797nm ($E_g = 1.55\text{eV}$) and 840nm ($E_g = 1.47\text{eV}$), which is very close to the previous studies
[11]. Such spectral lines are caused by the excitons in the shallow acceptors or donors [12].
3.3 Fourier transforms infrared spectroscopy (FTIR) analysis

FTIR is an analytical technique to identify the nature of the material as well as it gives information about the impurities present in the deposited film. Bruker Alpha FTIR spectrometer was used to record IR absorption spectrum. Figure 4 presents the FTIR transmission spectrum of electrodeposited CdTe thin film. The spectrum consists two intense bands at: 1642 cm$^{-1}$ due to the C=O stretching vibration and 3398 cm$^{-1}$ due to the C–O–H stretching vibrations of the carboxylic acid group [13]. The absorption band around 1123 cm$^{-1}$ is assigned to the presence of C=O stretching vibrations [14].

3.4 X-Ray Diffraction (XRD)

XRD is an effective analytical method to determine the phase and determine the crystalline size of deposited materials [15]. The XRD spectrum for ED-CdTe film grown on FTO substrate is displayed in figure 5, which was recorded in 2θ range of 0º-60º using Cu Kα radiation of 1.5406 Å wavelength. The diffraction peaks (111), (002), (022) and (113) validated to the cubic phase of the CdTe thin film.

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Figure 3. PL spectrum for ED deposited CdTe thin film.

Figure 4. FTIR spectrum for ED deposited CdTe thin film.
from JCPDS data card no.98-062-0533. The respective peaks are corresponding to the diffraction angles 23.5, 27.2, 38.9 and 46.0. Thus the CdTe film exhibit cubic crystalline nature.

Figure 5. XRD spectrum for ED deposited CdTe thin film.

With the help of following equations (1), (2), and (3) crystallite size (D), dislocation density (δ) and strain (ε) of CdTe material are calculated as shown in table 1.

\[
D = \frac{0.9λ}{β\cosθ} \quad \text{...(1)}
\]

\[
δ = \frac{1}{D^2} \quad \text{...(2)}
\]

\[
ε = \frac{β\cosθ}{4} \quad \text{...(3)}
\]

Where,

D = crystalline size

λ = wavelength of x-ray radiation

β = full width of half maxima (FWHM)

θ = Braggs angle

| Parameters                  | CdTe  |
|-----------------------------|-------|
| Average crystalline size (D)| 44.78nm |
| Dislocation density (δ)     | 49.9 lin/m² |
| Microstrain (ε)             | 0.15 lin²/m² |

4. Conclusions

In the present work CdTe layer has been successfully electrodeposited using 2-electrode system. Optical and structural properties of CdTe thin film were investigated by using different characterization techniques. The optical band-gap of deposited CdTe film is found as 1.51 eV. PL
spectrum of CdTe layer consist two characteristics PL peaks situated at 797nm and 840nm. In the FTIR spectrum C=O and C-O-H stretching vibrations are found to dominate. XRD analysis shows that the CdTe film is cubic crystalline in nature with preferred orientations in (111), (002), (022), and (113) directions.

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