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EVALUATION OF THE EFFECT OF GROWTH VOLTAGE ON THE OPTICAL AND STRUCTURAL PROPERTIES OF CdTe THIN FILMS

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ABSTRACT.

Cadmium Telluride (CdTe) thin films have attracted considerable attention due to their broad applications in optoelectronic and solar cells devices. This study explored the impact of growth voltage on the optical and structural properties of electrodeposited CdTe films using UV spectroscopy and XRD characterization respectively. CdTe thin films were deposited on fluorene-doped tin oxide (FTO) coated glass substrates at various growth voltages ranging from 1300mV to 1600mV. The optical bandgap of CdTe films were found to be 1.54 to 1.61 eV which was within the range of the bandgap of the bulk materials. The XRD analysis indicated that all the deposited films exhibited a cubic Zinc blende structure with a preferred orientation along the (111) plane. These results suggested that the grown CdTe thin film will be a good candidate for fabricating a solar cell.

Key Words. CdTe, Growth voltage, Optical bandgap, Thin films, UV spectroscopy, X-ray diffraction (XRD).

1.0 Introduction.

Solar energy is one of the promising renewable energy resources capable of addressing the growing global energy demand while mitigating environmental concerns associated with conventional energy sources. Central to the harnessing of solar energy are photovoltaic devices, which convert sunlight into electricity through the photovoltaic effect [1]. Among various photovoltaic technologies, thin-film solar cells have emerged as a viable alternative due to their lightweight, flexibility, and potential for low-cost fabrication. The integration of thin-film solar cells involves the deposition of successive layers of semiconducting and conductive materials onto substrates, forming a photovoltaic device capable of efficient energy conversion [3]. Also, solar energy can be by direct or indirect for the indirect we have photovoltaic cells.

Solar cells, or photovoltaic cells, directly convert sunlight into electricity. This process involves light-absorbing materials within the cell that generate electrons when struck by photons [4]. These cells are combined into modules, typically containing 28-36 cells, which produce a DC voltage, usually around 12V, under standard sunlight conditions[5]. Solar panels are further constructed by grouping multiple modules. Semiconducting materials with electrical conductivity between metals and insulators play a vital role in this process. Common types include elemental semiconductors like silicon and germanium, and compound semiconductors like gallium arsenide and cadmium telluride. In essence, solar cells function as electrical diodes, generating power when illuminated and behaving like a standard diode in the dark [6].

CdTe thin films were deposited using the two ways of deposition the dry and wet method which includes the chemical bath deposition technique CBT [7], the close-space sublimation (CSS) technique [8], the sputtering [9] or electrodeposition [10] & [11]. CdTe can be grown to be n-type or p-type without extrinsic doping, simply by changing the composition[12] as in the following methods electro chemical atomic-layer epitaxy (ECALE) [13], molecular-beam epitaxy (MBE) [1] metal organic chemical vapor deposition (MOCVD) [14] thermal evaporation [15] spray pyrolysis [16], the successive ionic layer adsorption and reaction (SILAR) method can be [17]. Among the two basic methods the wet is a low cost and also electrodeposition remain the simplest in the wet method due to its low cost, scalability, bandgap tuning, self-purifications, intrinsic doping among other advantages.

[16] Ascertained that CdTe thin films for solar cell structure has been fabricated using electrodeposition as simple, easy and low-cost methods onto FTO-coated conducting glass substrates. The optimized growth conditions are chosen for CdTe films by investigating the optical, structural and morphological properties of both the as-deposited and annealed films. The direct band gap was found to decrease from 1.75 eV to 1.48 eV with the treatment [19]. [16], Used X-ray to investigate the influence of deposition voltage on CdTe thin films and found significant improvements on its crystallinity. CdTe films were deposited on fluorine doped tin oxide (FTO) substrate of dimension 2.3 by 2.4 cm^2 at varied time of deposition and fabricated a solar cell of CdTe using electrodeposition [11]. [15] Reported that CdTe films of thickness 1.05µm were grown on glass and ITO substrates followed by wet $CdCl_2$ treatment and then heat treatment at 450 °C. However, monitoring the effect of deposition potential remains an obstacle of this technique.

The aim of this research was to grow CdTe alternative solar cell energy materials using electrodeposition as a growth technique by considering the influence of growth voltage on the thin films' layers deposited.

2.0 THEORETICAL BACKGROUND

The optical parameters were determined from normal-incidence transmission spectra of the layers using equation (1). The bandgap energy and transition type can be derived from Stern relationship [13].

$$\alpha = \frac{c\left(hv-E_g\right)^{\frac{1}{2}}}{hv} \qquad (1)$$

where c is a constant, h is a plank's constant, v is the frequency of the incident light.
The absorbance and absorption coefficient are also related to the transmittance by [22].

$$A = log_{10}\left(\frac{1}{T}\right) \qquad (2)$$

Or

$$\alpha = -\frac{lnT}{d} \qquad (3)$$

where d is the thickness of the thin film, A is the absorbance and T is the transmittance.

The refractive index, n plays an important role in the search for an appropriate optical materials for solar cell fabrication. It is also used to determine the propagation of velocity of photons in the materials. The value of n was calculated using relation (4) [23].

$$R = \frac{(n-1)^2}{(n+1)^2} \qquad (4)$$

where R is the normal reflectance
A measure of the rate of the reduction of transmitted light through a substance can be obtained using extinction coefficient, k [5]

$$k = \frac{\alpha\lambda}{4\pi} \qquad (5)$$

where λ is the wavelength

3.0 MATERIALS AND METHOD

This section describes the procedures adopted for the growth of the solar cell materials.

3.1 Preparations for CdTe

The initial Cd-precursor was prepared by dissolving 0.3M Cd $(NO_3)_2.4H_2O$ of 99.999% purity in 25ml of deionized water. Then, the prepared solution was electro-purified by applying a cathodic potential just below the required potential for reduction of Cd^{2+} for ~60 hours. The initial Te-precursor was prepared by adding 2m grams of 99.999% (5N) TeO_2 powder into dilute nitric acid (HNO_3) and continuously stirring for 7hours. Thereafter, about 1 ml of prepared TeO_2 solution was added into 25ml aqueous solution containing purified 0.3M Cd $(NO_3)_2.4H_2O$. The pH of the resulting deposition electrolyte was adjusted to 2.00 ± 0.02 using ammonium hydroxide (NH_4OH) at room temperature. Both Cd $(NO_3)_2.4H_2O$ and TeO2 used in the deposition electrolyte were purchased from Sigma Aldrich. The substrates used for electro-purification and electrodeposition were TEC-7 glass/FTO (fluorine-doped tin oxide) with sheet resistance of ~7Ω/m and purchased from Sigma Aldrich. Prior to electrodeposition, the glass/FTO substrates were cut into small pieces with dimensions of 2×2 cm^2 and washed for 15 minutes in an ultrasonic bath containing soap solution followed by rinsing with deionized water. Subsequently, the glass/FTO substrates were cleaned with methanol and rinsed with deionized water followed by a similar cleaning with acetone and deionized water.

4.0 RESULTS AND DISCUSSIONS

This section discusses the results obtained following the various measurements techniques.

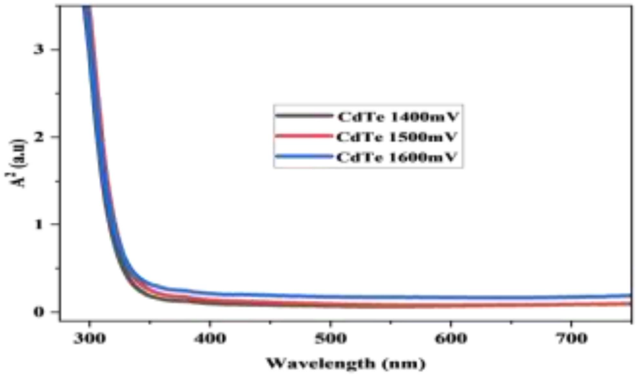

Fig. 3.1. Absorbance verses wavelength of CdTe grown from 1400 to 1600mV.

The absorption spectra were in the wavelength range of 500 – 1400 nm of CdTe thin films. Figure 3.1 shows absorptions against wavelength of CdTe grown at 1400mV to 1600mV. The absorptions edges were 325 nm each. This variation might be an effect of concentrations of the chemical bath which indicated that both have photonic absorption abilities in visible region. The absorption edges of CdTe were gradually expanded towards high wavelength with increasing voltage, indicating that there is optical property enhancement [24]. The absorption at 325 nm in CdTe might be due to a combination of factors such as Quantum confinement effects in the nanostructured material, which increase the bandgap and shift the absorption to shorter wavelengths. The presence of surface states, defects, and potential impurities in the material, which introduces additional absorption features at higher energies can also be the reasons to this effect [25] This absorption behavior is characteristic of nanomaterials and thin films, where the electronic structure can be significantly different from that of the bulk material [6].

3.2. Fig. 3.2 Shows the Energy Bandgap of CdTe

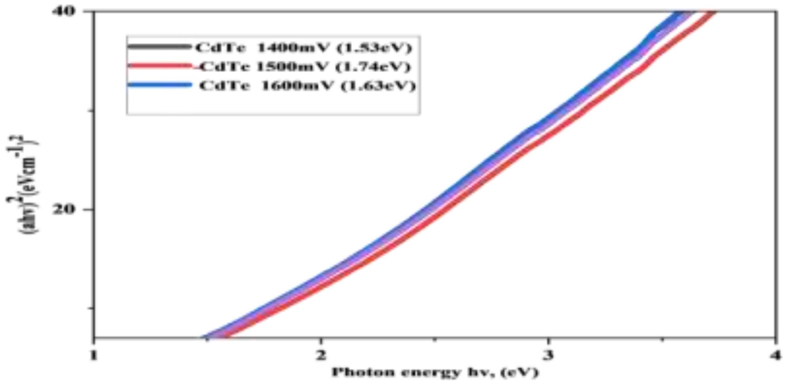

Fig. 3.2. A^2 verses bandgap energy CdTe grown from 1400 to 1600mV.

Important optical properties studied include absorbance and optical bandgap of the thin films, this is shown in Figure 3.2. The theoretical value of energy bandgap of CdTe was 1.57eV [27], while the calculated values we obtained be ~ 1.53 eV to ~ 1.74 eV which indicated that the deposited layer gives a good bandgap which is within the range of the bandgap reported by [20, 25, 29 & 30]. The 1.63 eV bandgap observed in this electro-deposited CdTe at a growth voltage 1600mV gave the best value of the CdTe bandgap which shows that the CdTe thin film layer grown at this voltage is the best layer for solar cell application.

3.3. Fig 3.3 Shows the Transmittance for CdTe

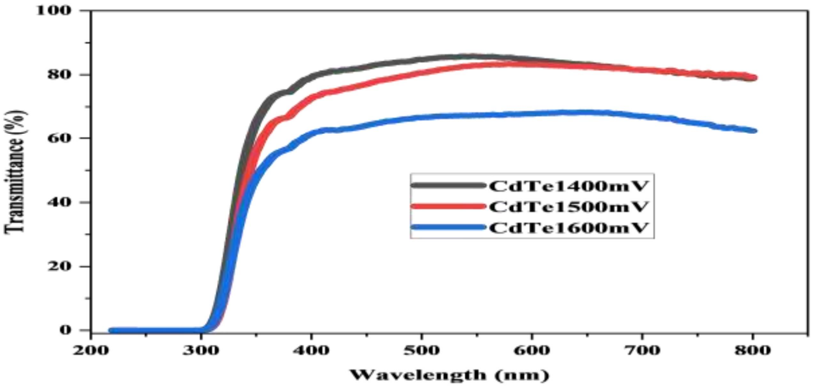

Fig. 3.3. CdTe Transmittance graphs of growth voltages from 1400mV to 1600mV.

The normal- incidence transmittance spectra of electrodeposited CdTe layers deposited at various growth voltages is shown in Figure 3.3. Measurements were taken in the wavelength range 200-800nm on the deposited films. The transmission coefficient for deposited CdTe layers grown at 1600mV exhibited transmittance of ~40% in the visible region, at an absorption of 350nm while 50% and 70% for the growth potentials 1500 and 1400mV respectively. It was also noted that transmittance increases as incident photon wavelength increases. Furthermore, all the samples deposited at various V_g have pinholes . [30] reported that a shaper absorption edge indicates fewer defect and impurity energy levels in the film.

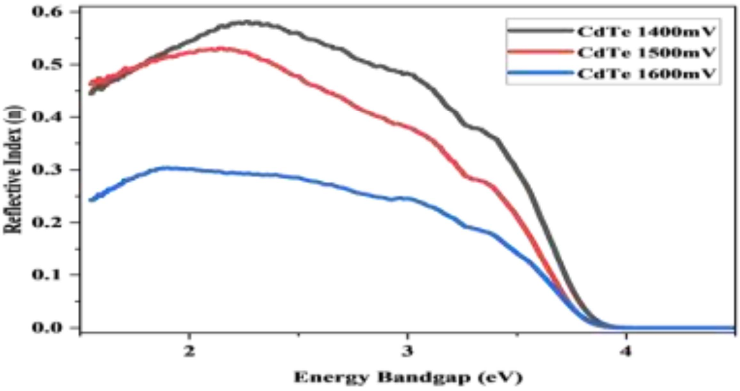

Fig. 3.4. CdTe Reflective Index graphs of growth voltages from 1400mV to 1600mV.

Figure 3.4. presents the refractive index of the CdTe layers as a function of energy bandgap. As seen from the figure, the refractive index decreases for all the samples as the energy bandgap increase. Furthermore, at higher energy bandgap, in the ultraviolet region, the refractive indices of all the samples tend to become very close to one another. The refractive index of the sample deposited at V_g 1400mV is ~0.55 which is the highest value compare with the remaining samples while 1500 and 1600mV were 0.47 and 0.25 respectively as the reflective index which indicates that the reflective index was decreasing as the growth potentials increases. Thus, a decrease in *n* value means an increase in the velocity, *v* at which light propagates in the layer [31]. Therefore, light will propagate faster in the CdTe samples deposited at V_g ~1600mV and means that 1600mV as the best growth voltage for CdTe based on the outcome of this research.

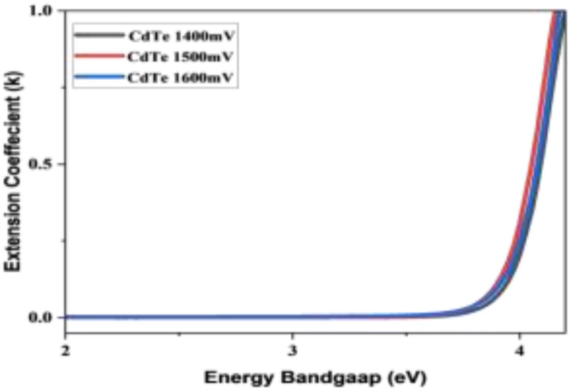

Fig. 3.5. CdTe Extension Coefficient (k) graphs of growth voltages from 1400mV to 1600mV.

Figure 3.5 show the extinction coefficient versus energy bandgap for the ED-CdTe layers. Sample deposited at V_g 1400mV shows different results with respect to the remaining ones, this may be due to the quality of the layer (black) in which light absorbs more [22]. The values of *k* for the samples deposited at V_g 1400mV and 1600mV coincide at the same energy bandgap of ~3.65eV. From the figure, the CdTe layer deposited at these V_g 1600mV become more stable and improved in quality a similar observations was reported by [26] .

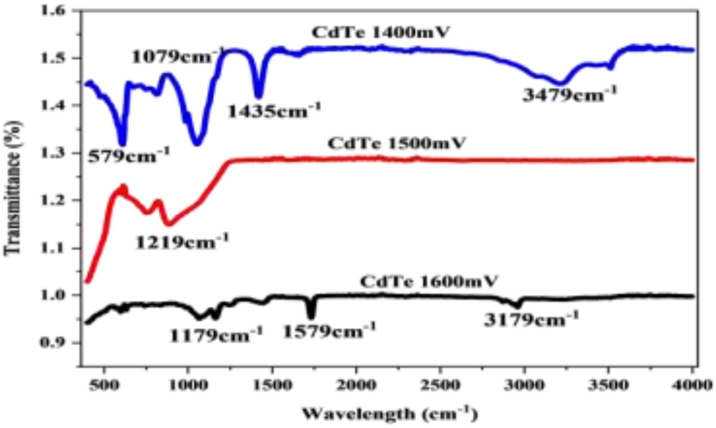

Fig. 3.6. CdTe FT-IR graphs of growth voltages from 1400mV to 1600mV.

FT-IR spectroscopy is a type of vibration spectroscopy. Infrared beams are absorbed by vibrational movements of molecules. FT-IR spectroscopy is a tool used in characterizing organic and inorganic compounds [33 & 34]. FT-IR spectrum obtained at fast and high resolution provides characteristic peaks for several groups. Thus, it becomes easier to reveal characteristic groups and consequently analyze the structure of material for which the spectrum was obtained. FT-IR study can identify the types of functional groups on the surfaces and enables us to distinguish foreign molecules [24]. For ED-CdTe the FT-IR Peaks presented in Figure 3.6 were distributed from 3500 cm^{-1} down to 4000 cm^{-1} due to its crystallinity in the thin film layer form. The absorption bands at 579 cm^{-1} in the spectra were due to T− stretching vibration band of water molecule absorbed on the surface of the sample due to the presence of moisture. The band around 1219 cm^{-1} is due to Te-O_2 groups stretching mode.

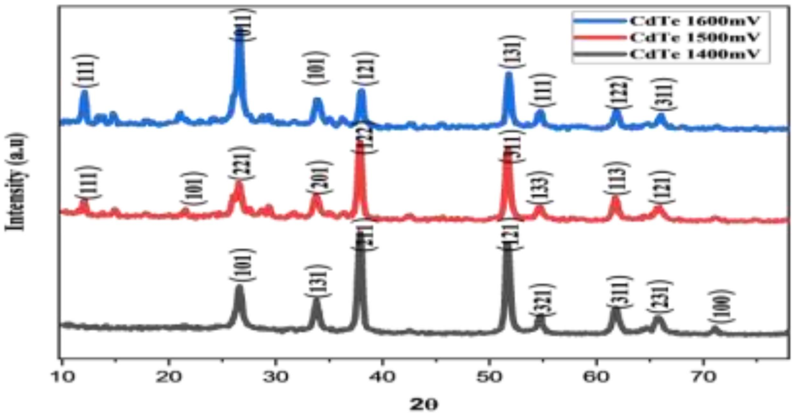

Fig. 3.7. XRD Graphs of CdTe grown from 1400mV to 1600mV.

The crystal structure and phase compositions were analyzed by X-ray diffraction (XRD), XRD is a valuable tool for examining the crystal structure of the thin films. The XRD peaks present valuable information about the material's crystallinity, type of structure, crystallite size, etc [22]. XRD was carried out to identify the phases, crystal structure and degree of crystallinity of the ED-CdTe layers grown on glass/FTO substrates. In this work, the aim was to determine the growth voltage corresponding to stoichiometric CdTe layers, by observing the most intense XRD peak, within the cathodic potentials ranges of 1400mV to 1600mV. Then, the XRD patterns of the thin film CdTe layers were plotted against angle (2θ) and results are shown in Figures 3.7. In this work, CdTe layers were shown to be polycrystalline with cubic crystal structure and strongly oriented along (111) plane. However, CdTe can be found in hexagonal crystal structures [35]. In this report, the most intense XRD peak was observed at cathodic potential of 1600 mV.

5.0 Conclusion

CdTe layers were successfully electrodeposited using 2-electrode system from an acidic and aqueous solution containing $Cd(NO_3)_2.4H_2O$ precursor at cathodic potential of −1400mV to 1600mV and deposition time of 160mins, while stirring the bath at 80 rpm. The optical bandgap of CdTe films were found to be 1.54 to 1.61 eV which was within the range of the bandgap of the bulk materials. The XRD analysis indicated that all the deposited films exhibited a cubic Zinc blende structure with a preferred orientation along the (111) plane. These results suggested that the grown CdTe thin film will be a good candidate for fabricating a solar cell. We suggested a fabrication of solar cell using this optimum growth voltage in feature work.

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