CHARACTERIZATION OF STRUCTURAL AND ELECTRICAL PROPERTIES OF ELECTRO-DEPOSITED CADMIUM TELLURIDE (CdTe) THIN FILMS AT VARYING DEPOSITION TIME ON GLASS FTO

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Electro-deposited cadmium telluride (CdTe) thin films were grown on fluorine-doped glass (glass FTO) at varying deposition time of 30-180 minutes at room temperature of 27 ^{o}C and at the same cathodic voltage. The structural and electrical properties of the film samples were analyzed using X-ray diffractometer (XRD), energy dispersive spectroscopy (EDS), surface profiler and a four point probe. The XRD results show that cadmium telluride thin films deposited for less than 90 minutes are polycrystalline in nature and gradually changed to single crystals for thin film samples deposited for 90 minutes and above. Profound effects of deposition time on crystallite sizes evaluated with Sherrer's formula, the thin film composition, film thickness and electrical properties including sheet resistance, conductivity etc, obtained for the cadmium telluride thin films are reported in this paper.

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Keywords: Cadmium telluride, glass FTO, structural and electrical properties, Polycrystalline, Single crystals.

1. Introduction

Applications of CdTe thin films in the areas of photovoltaic devices, microelectronics, CdS/CdTe hetrojunctions, switching devices, thin film transistors for flat panel displays, etc [1-8] require greater understanding of its electrical and structural properties. The ability to vary thin film properties by methods of preparations and subsequent thermal treatment that affect the film thickness, crystal sizes, sheet resistance, conductivity and structural properties [9-14] provide the means to achieve desired objectives. However, more studies on the effect of deposition time are required.

In this study, the effect of variations in deposition time on the structural and electrical properties of electro-deposited CdTe thin films on glass FTO have been investigated and the results are presented in this paper.

2. Experimental details

2.1 Substrate Preparation

In preparing the substrates the glass/FTO sheets were cut into small sheets of about 4cm^2 each. Each small substrate was then washed in soap solution in ultrasonic bath for about 15 minutes followed by rinsing with de-ionized water. Methanol, acetone, nitric acid and acetic acid were also used in succession to clean the substrates and rinsing with de-ionized water in between.

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2.2 Deposition of CdTe thin films

A conventional three-electrode system consisting of a work electrode, counter electrode, and reference electrode were used for the electro-deposition. Each cleaned substrate was dried with nitrogen gas and attached to a graphite rod to serve as the cathode for electro-deposition. The counter electrode is also a graphite rod. In the case of the CdTe deposition, a reference electrode is used in addition. The solution for CdTe deposition consists of 800ml aqueous solution of 1M $CdSO_4$ and about 0.001M TeO_2 in 1 liter beaker. All reagents were of analytical grade and were used without further purification. The pH of the solution was finally adjusted to 2.0 after stirring for 24hours.

A wire was connected from the negative pole of the D.C power supply to common of the ammeter while the positive pole was connected to the counter electrode (graphite electrode). Another wire was connected from the positive pole of the ammeter to the work electrode (glass/FTO substrate). The positive of the voltmeter was connected to the counter electrode, while the common of the voltmeter was connected to the reference electrode. Next, the three electrodes were immersed into the electrolyte which contains a solution of the metal salt to be plated i.e $CdSO_4$ and TeO_2.

The voltage of the DC power supply and current in the ammeter were 5V and 0.01A respectively.

The samples were electro-deposited at the same cathodic voltage for different durations of 60 min, 30 min, 90 min, 120 min, 150 min and 180 min successively. After deposition, the films were rinsed with copious amounts of distilled water, dried in air under ambient condition and kept in an air tight container to avoid contamination. The reaction processes are as follows;

Reduction of Tellurium

$HTeO_2{}^{+}{}_{(aq)} + 3H_{(aq)}{}^{+} + 4e^{-} \rightarrow Te_{(s)}{}^{4+} + 2H_2O$

Deposition of Tellurium with the Cd^{2+} ions

$Te_{(s)} + Cd^{2+}{}_{(aq)} + + 2e^{-} \rightarrow CdTe_{(s)}$

Generally, the overall cathode reaction is

$Cd^{2+}{}_{(aq)} + HTeO_2{}^{+}{}_{(aq)} + 3H_{(aq)}{}^{+} + 6e^{-} \rightarrow CdTe_{(s)}{}^{4+} + 2H_2O$

Similarly, anode reaction is

$4OH- \rightarrow O_2 + 4e^{-} + 2H_2O$

3. Results and discussions

3.1 Visual appearance of the CdTe thin films

Figure 3.1 shows the appearance of CdTe layers as a function of deposition time on glass FTO substrates. The average colour of the thin film samples is dark grey. As the deposition time increases the CdTe thin films become darker in colour which is attributed to the richness in cadmium and tellurium.

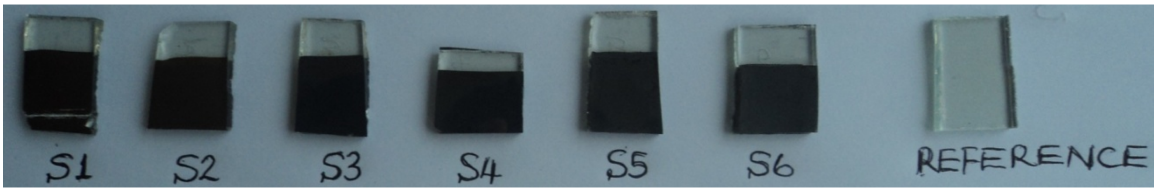

Fig. 3.1 Appearance of electro-deposited CdTe layers grown on glass FTO at different deposition times of 60,30,90,120,150 and 180 minutes for samples S1-S6 respectively.

3.2: X-ray Diffraction (XRD)

XRD technique was used to ascertain a wide variety of structural information. The maximum crystallite size of the thin film samples were estimated using Sherrer's formula [11]

$$D = k\lambda/\beta\cos\theta \qquad 3.1$$

where D is crystalline size, k is a constant = 0.9, λ is wavelength of the X-ray source. θ is Bragg's diffraction angle in degrees and β is Full-Width-at-Half-Maximum (FWHM).

Figures 3.2 (S1-S2) and 3.3 (S3-S6) show the X-ray diffraction patterns of six CdTe thin film samples deposited from 30-180 minutes. Depositions for 30 and 60 minutes show several diffraction peaks of varying intensity depicting the formation of polycrystalline structure [2], while depositions for 90 minutes and above exhibit single peak indicating formation of single crystals. The XRD patterns also show a major diffraction peak at $2\theta = 23.6^o$ for all the thin film samples; this corresponds to the cubic (111) as reported earlier [3]. The increasing intensity of the dominant peak (111) as other peaks diminish with increase in growth time also shows the presence of well formed single crystals. Table 3.1 shows the values of the XRD intensity, the grain size and FWHM. The grain size increased from 9.73 nm at 30 minutes growth time to 12.16 at growth times of 90 and 120 minutes and dropped back to 9.73 nm at growth time of 150 minutes and above with corresponding decrease in FWHM, This is due to coalescence of small crystals and formation of larger grains. The results are shown graphically in figures 3.4-3.6.

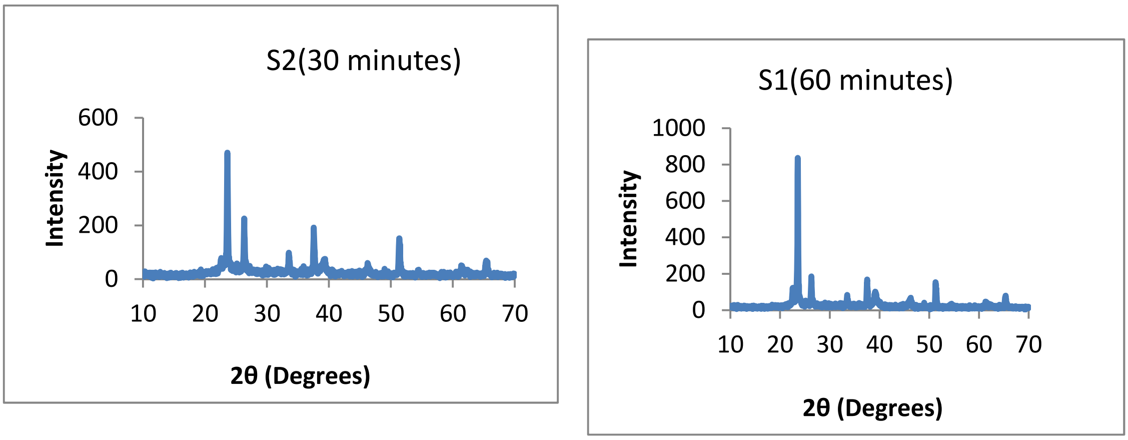

Fig. 3.2: X-ray Diffraction (XRD) patterns of CdTe thin film samples S1, S2 for different deposition times of 30 and 60 minutes.

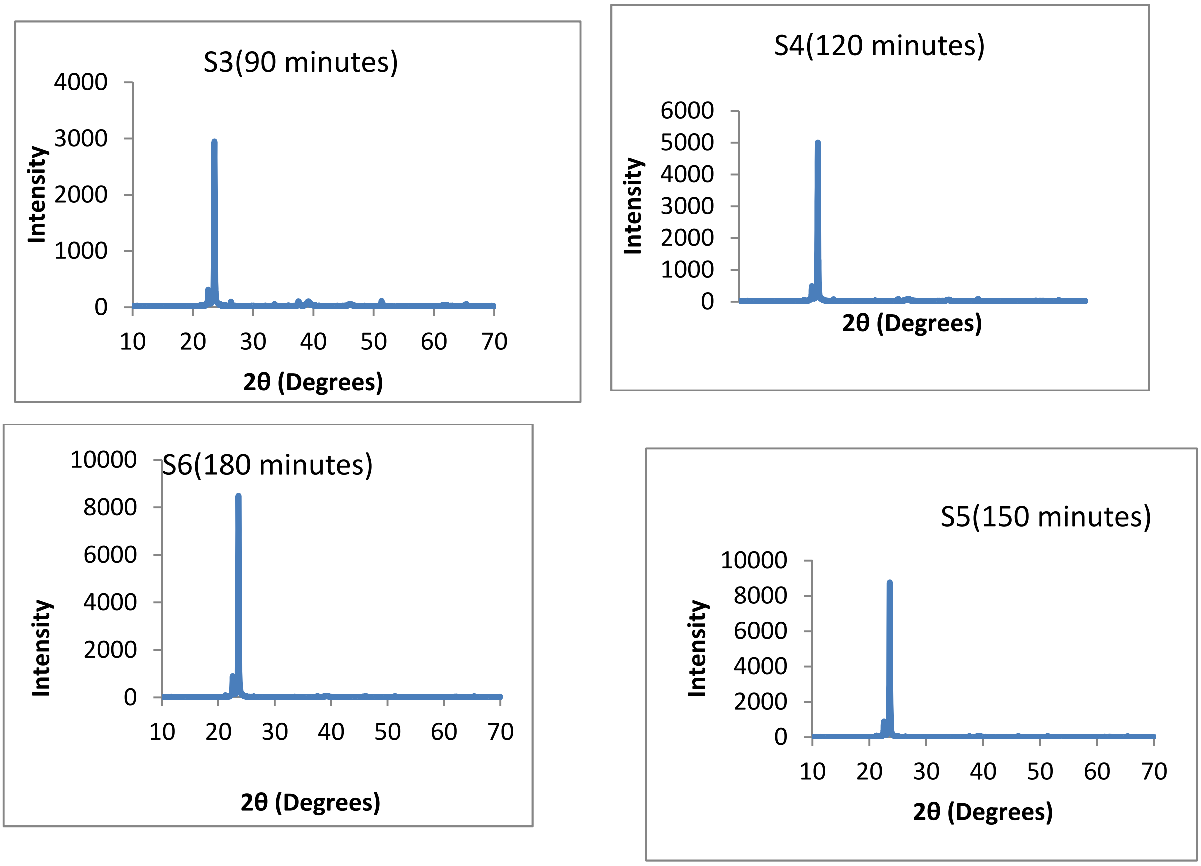

Fig. 3.3 X-ray Diffraction (XRD) patterns of CdTe thin film samples S3-S6 for different deposition time of 90-180 minutes

Table:3.1 Values of XRD intensity, FWHM and Crystallite size of CdTe layers deposited on glass/FTO/substrate at different growth time

Sample label/ Deposition time (minutes)	XRD Intensity (arb. Units)	FWHM (β)	Grain size D(nm)
S2/30	434.41	0.1624	9.73
S1/60	821.52	0,1624	9.73
S3/90	2874.24	0.1299	12.16
S4/120	5024.70	0.1299	12.16
S5/150	8558.45	0.1624	9.73
S6/180	8273.63	0.1624	9.73

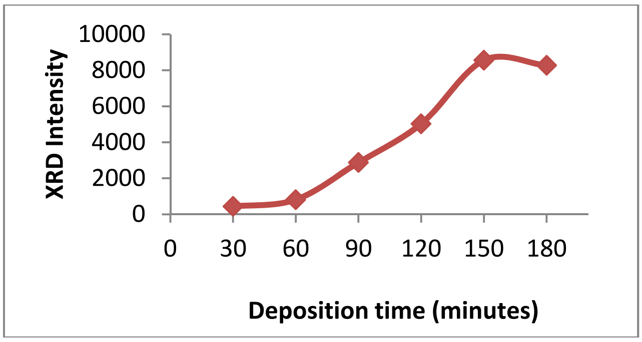

Fig. 3.4 XRD intensity of (111) peak observed for CdTe thin films grown at different deposition time.

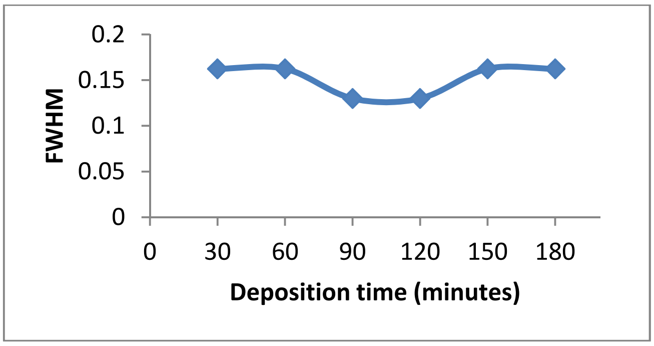

Fig. 3.5 FWHM of (111) peak observed for CdTe thin films grown at different deposition time.

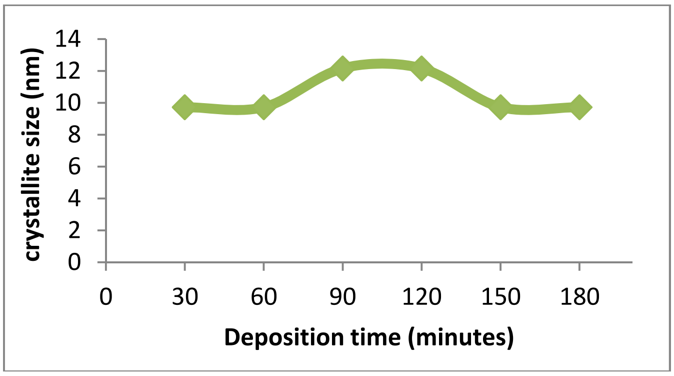

Fig. 3.6 Grain size estimated from (111) peak for CdTe thin films grown at different deposition time.

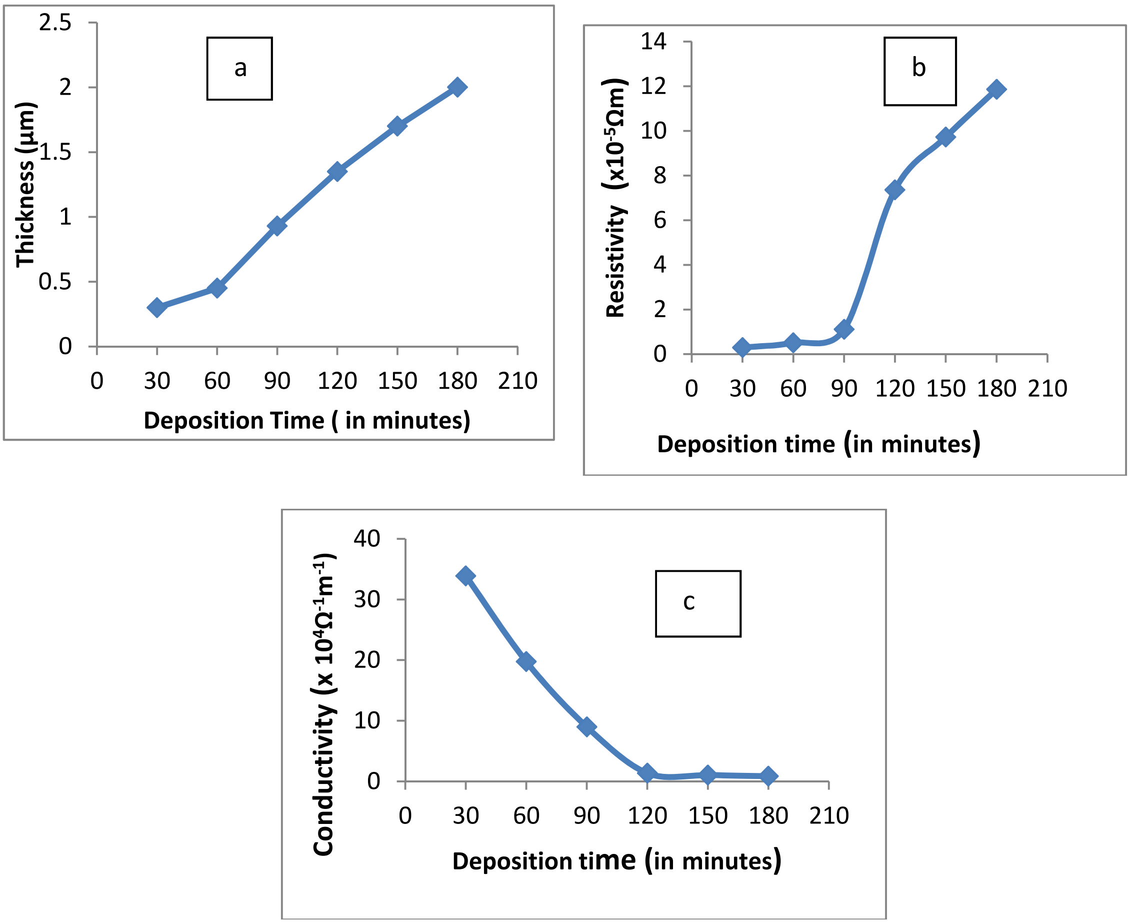

Fig. 3.7: Variations with deposition time of CdTe thin films for (a) film thickness (b) resistivity and (c) conductivity.

3.3:Thickness of thin films of CdTe

Result of the CdTe thin film thickness fig. 3.7(a) clearly shows increase in the film thickness with deposition time of the CdTe layers as expected. The highest thickness of 2.0 µm occurs at growth time of 180 minutes. A thickness of approximately 1-2 µm is enough to absorb all incident light with energy above 1.45 eV [6]. The results of the surface profile used to obtain the film thickness are shown in fig. 3.8 (a-f).

3.4: The Electrical properties of CdTe thin films

The electrical properties of CdTe thin films are dependent on various film and growth parameters such as film thickness and growth time as shown in table 3.2 and the graphic representations of fig.3.7 (b, c). Clearly, for deposition time of more than 90 minutes the resistivity has a sharp increase, while the conductivity dropped to zero at deposition time of 120 minutes and above. The sheet resistance in table 3.2 also shows remarkable increase with increase in growth time.

Table 3.2: Average values of the electrical properties of Electrodeposited glass/FTO/CdTe thin films

Sample/ Depostion time (minutes)	Film Thickness (μm)	Resistance R(Ω)	Sheet Resistance R_s(Ω)	Resistivity (x 10^{-5}Ωm)	Conductivity σ_E(x$10^4\Omega^{-1}m^{-1}$)
S1/60	0.45	2.49	11.263	0.506	19.736
S2/30	0.30	2.17	9.837	0.295	33.893
S3/90	0.93	2.66	12.031	1.113	8.985
S4/120	1.35	12.03	54.511	7.359	1.359
S5/150	1.7	12.65	57.211	0.726	1.028
S6/180	2.0	13.09	59.303	11.861	0.843

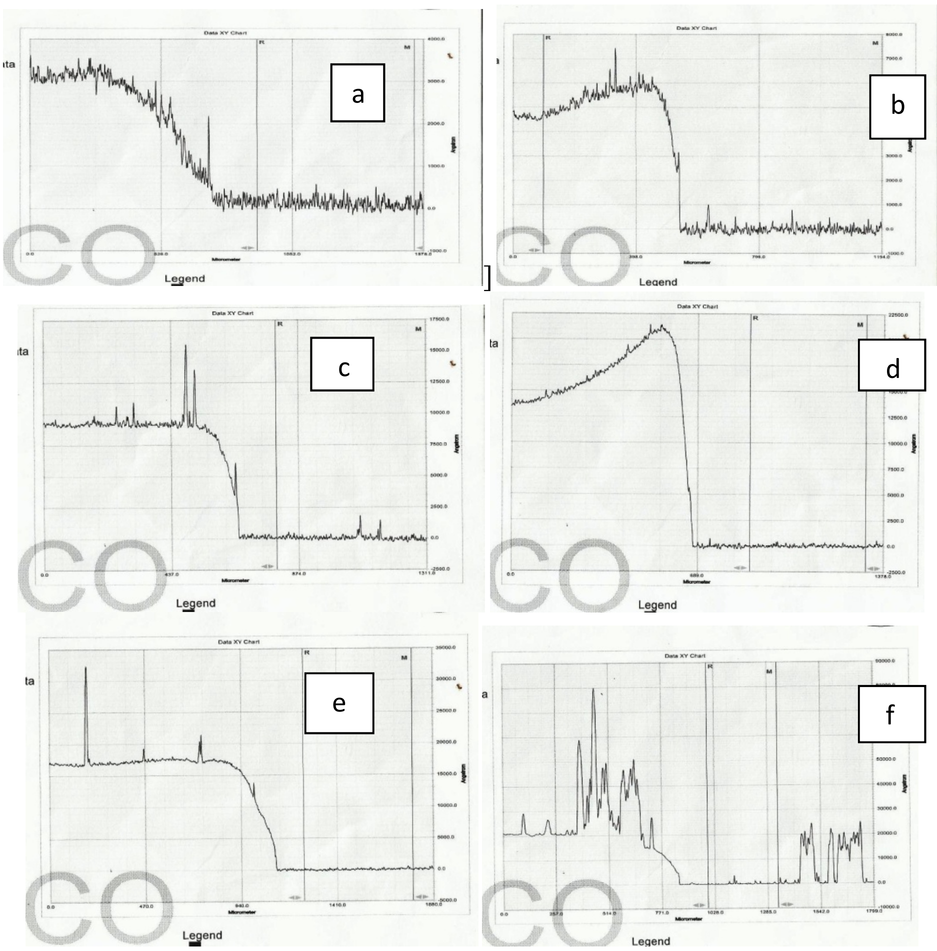

Fig. 3.8 Surface Profile of CdTe thin films deposited at (a) 30 mins (b) 60 mins (c) 90 mins (d) 120mins (e) 150 mins (f) 180 mins.

4. Conclusions

Electro-deposition of CdTe thin films has been successfully grown on glass/FTO and the effects of variations in deposition time on the film thickness, crystallite size and structure, FWHM, resistivity, conductivity and film composition have been investigated. XRD results show that for deposition time of 90 minutes and above, the CdTe thin films changed from polycrystalline to single crystals with increasing diffraction peak intensity depicting well formed single crystals. Results from the surface profiler also show distinct increase in film thickness with increase in deposition time.

The resistivity for CdTe film samples deposited for more than 90 minutes showed remarkable increase while conductivity dropped to zero for film samples deposited for more than 120 minutes. The crystallite size increased between deposition time of 60-150 minutes. The richness of the samples in cadmium and tellurium is portrayed in the dark grey colour of the thin films.

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