GROWTH OF CdS AND $CdTe$ THIN FILMS AND ANALYSIS OF THEIR ELECTRICAL PROPERTIES FOR FABRICATION OF $CdS/CdTe$ SOLAR CELL.

ABSTRACT

Thin films of cadmium sulphide (CdS) and cadmium telluride ($CdTe$) have gained a great deal of interest due to its potential applications in solar cells. deposition of CdS and $CdTe$ thin films were performed on Soda Lime glass/FTO substrate at $400°C$ *and* $300°C$ *respectively using spray pyrolysis technique. The properties such as Hall effect were measured on the deposited CdS and $CdTe$ films. These results shows the resistivity and mobility of CdS and CdTe polycrystalline films deposited at 400°C* were $1.588 \times 10^4 \Omega cm$ *and* $5.619 \times 10^2 cm^2/Vs$, *respectively, while those of CdTe thin film deposited at 300°C were* $1.016 \times 10^4 \Omega cm$ *and* $1.998 \times 10^2 cm^2/Vs$. ~~*The electrical conductivity of the films was found to be within the range of* $10^{-4} - 10^{-6} (\Omega cm)^{-1}$,~~ *with CdS $n-type$ and $CdTe$ $p-type$ of conduction mechanism respectively, which are suitable as window and absorber layers for efficient solar cells.*

KEYWORD: Cadmium Sulphide, Cadmium Telluride FTO, P-type and N-type

1. INTRODUCTION

Thin films of cadmium sulphide (CdS) and cadmium telluride ($CdTe$) have gained a popular of attention because of their potential uses in solar cells (Fang *et al*., 2013). These are all direct band-gap semiconductors, which means they can ingest solar power at a far smaller thickness than silicon wafers used in crystalline silicon (Si) solar cells (Morales-Acevedo, 2006). CdS is an n-type semiconductor with a large direct band gap (2.42 eV) that is commonly employed as the window layer in hetero-junction thin film solar cells coated over p-type $CdTe$ (*Rahman et al.*, 2019; Tiwari *et al.*, 2014) or copper indium selenide ($CuInSe_2$)(Sajedur *et al.*, 2019). The value of 1.45 eV band gap of $CdTe$ suited the Air Mass (AM) of 1.5 solar spectrum. Although only a few millimetres of absorber film were needed for solar cell functioning, the high absorption coefficient was attributable to this phenomenon(Ahmad *et al*., 2022). CdS and CdTe thin-films are widely acknowledged as two of the most promising prospects for second-generation solar cells due to their wide range of inexpensive production methods and great efficiency (Kulkarni, Rondiya, Pawbake, Waykar, & Jadhavar, 2017). Mobility, resistivity, carrier concentration, and the types of semiconductors are all key issues in the electrical properties of semiconductor measurements (Seboui et al., 2013). Two important criteria that affect whether CdS and CdTe thin films may be used as window and absorber materials in CdS/CdTe heterojunction solar cells are electrical resistivity and carrier concentration (Garba, 2011).

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There are many techniques identified to be successful in deposition CdS and $CdTe$ thin-films The most significant ones are Close Space Sublimasion CSS(Sobayel *et al.*, 2020), Chemical Bath Deposition CBD (Ikhmayies & Ahmad-Bitar, 2010). Some techniques used to deposit material include electro-deposition, vacuum evaporation, sputtering, Vapor Transport Deposition (VTD), Metal Organic Chemical Vapor Deposition (MOCVD), Molecular Beam Epitaxy (MBE), screen printing, and Spray Pyrolysis Deposition. However, it has been discovered that layers produced using the Spry Pyrolysis method are among of the most effective second-generation solar cells to date (Ashour, 2003). Additionally, this method appeals to researchers since it is simple to use, has a rapid deposition rate, and can easily produce large quantities of commercial modules (Dharmadasa et al., 2014). Also with the use of this methodology, specialized materials can be quickly and efficiently deposited across enormous regions. It has been used for many years in the photovoltaic and solar cell industries for this reason, according to Ojeda-barrero, Oliva-avilés, Oliva, Maldonado, and Acosta (2018). This research examines the electrical properties of CdS and $CdTe$ thin film samples deposited using the Spray Pyrolysis process (at room temperature utilizing a Hall Effect Measurement instrument).The Hall effect measurement is a common, dependable, and more straightforward technique for determining the basic electrical characteristics of semiconductors (Miyake, Murase, Hirato, & Awakura, 2004).

2. THEORETICAL BACKGROUND

Hall Effect is one of the most important techniques in determination of parameters that characterizes a semiconductor from electrical point of view(Kulkarni *et al.*, 2017). The Hall effect is a phenomenon that occurs when a semiconductor carrying current I, is placed in a transverse magnetic field of flux density B. This phenomenon is known as the Hall effect and is used for the following purposes: I to identify the charge carrier of a semiconductor, which may be N=type or P=type; (ii) to find carrier concentration; (iii) to measure the conductivity of the materials; and (iv) to identify carrier mobility.

Hall coefficient is given as;

$$R_H = \frac{1}{nq} \qquad (1)$$

Charge carrier mobility;

$$\mu = \left|\frac{V_d}{E}\right| \text{ and its unit is } m^{-2}V^{-1}s^{-1} \qquad (2)$$

The Hall mobility,

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$$\mu = \left|\frac{R_H}{\rho}\right| \; or \; \mu = |R_H|\sigma \qquad (3)$$

The Resistivity is given as;

$$\rho = \frac{1}{N_e\mu} \qquad (4)$$

Where ρ is resistivity, μ mobility, N_e bulk concentration(Mohammed, 2018).

3. MATERIALS AND METHOD

~~The practical steps for depositing (CdS and $CdTe$) thin films are covered in this study.~~ Spray Pyrolysis was used to deposit CdS and $CdTe$ layers on soda lime glass substrates. For CdS thin films, an aqueous solution of Cadmium acetate dihydrate Cd$(CH_3COOH)_2.2H_2$O and Thiourea $(NH_2)_2$CS were employed as Cd and S sources respectively. The pumping and exhausting gas scrubbing systems, the reaction chamber where the substrate was heated, the precursor solution and carrier gas (air) assembly connected to the spray nozzle, and a temperature controller with a Copper-Constantan thermocouple to control the substrate temperature make up the deposition set-up. The solution was sprayed onto a glass substrate that had already been cleaned. The temperature of the substrate was kept constant at 400°C. The normalized distance between the spray nozzle and the substrate was adjusted to 20 cm. The pressure of the carrier gas (air) was kept constant at 1 bar. The solution flow rate was kept constant at 0.5 ml/m throughout the experiment. The grown CdS films colour changes with the time from greenish yellow to bright yellow. The possible chemical reaction that takes place on the heated substrate to produce CdS is shown

$$Cd(CH_3COOH)_2.2H_2O + (NH_2)_2CS + H_2O \rightarrow CdS \downarrow + CO_2 \uparrow + CH_4 \uparrow + steam \qquad (5)$$

3.1 FOR CADMIUM TELLURIDE DEPOSITION.

Deposition procedure was covered in five stages.

Stage I; $0.056g\ TeO_2$ Was added to 100 ml NH_3 at room temperature, the solution was stir using magnetic stirrer until solution turn colourless.

Stage II; $10.66g\ Cd(CH_3COOH)_2.2H_2O + 18.6g\ EDTA$ Disodium salt was dissolved in deionized water, and the mixture was stirred continuously until it took on a milky. ~~appearance.~~ Deionized water was added to the mixture while hydrazine was added, stirring constantly to maintain the PH level. Deionized water was continuously added until the desired concentration, and stirring was done until the solution was completely dissolved and crystal clear .

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Comment [U51]: Cd($CH_3COOH)_2.2H_2O$. Also refer to Thiourea $(NH_2)_2CS$

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Step III; the resulting solution was put into two necks round bottom flask on the lab tech mantle heater set at 200℃. A total of six hours were spent heating the solution, after which it was let to cool at room temperature. The resulting mixture was centrifuged four times, resulting in the separation of the components.

Step IV; the solution was divided into two equal parts in test tubes by weighing on analytical digital balance. The two test tubes were then placed on a centrifuge model 800 machine to centrifuge for three $3\ minutes$ at $4000\ rpm$. ~~this~~The process was repeated five times. The centrifuging is for proper separation. The pair of $CdTe$ solutions were mixed together and rinsed with saturated Cadmium Chloride $CdCl_2$ in N-methyl-2 Pyridine NMP.

Stage V; before the deposition of $CdTe$ solution on the SLG substrate, the spray chamber was purged with nitrogen gas for 15 min. In addition, nitrogen gas was used as a carrier gas for spraying the final precursor solution on substrates. The films were deposited on thoroughly cleaned substrates at 300 °C using the following processing parameters: (i) spray gun nozzle to substrate distance= $20\ cm$, (ii) spray solution concentration= $0.1\ M$, (iii) carrier N_2 gas flow rate=$10\ l/min$, (iv) deposition time= $20\ minutes$, and (v) solution flow rate= $5\ ml/min$. After completing the $CdTe$ thin film coating process which lasted for about $20\ minutes$ by spray pyrolysis ~~method~~, The films were cooled naturally to the room temperature. The chemical reaction that ~~takes~~ place in the chamber

$$Cd^{2+} + Te + 2e^{-} \rightarrow CdTe \quad (6)$$

4. RESULTS AND DISCUSSION

The three primary electrical properties of the ~~formed~~ Cd and CdTe thin films~~, namely~~ carrier concentration, mobility, and resistivity, were determined at room temperature using Hall and resistivity measurements. For this, the Abuja Science and Technical Laboratory Complex's ECOPIA Hall effect measurement system (HMS-3000), which is combined with a resistivity measurement tool, was employed. For the Hall measurements, the system employs the four-probe van der Pauw method. Throughout the trials, a constant magnetic field was created using two permanent magnets and then applied orthogonally to the top surface of the films. The thin film samples were electrically coupled to a constant DC current source and a DC (direct current) was generated through one of the two diagonal pairs of gold electrodeshe voltage created in the hall was detected by the remaining electrode pair. The applied magnetic field's strength stayed constant at 0.51 T. The system employed a positive (+) or

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negative (-) symbol to denote the type (p or n) of the CdS and CdTe films in front of the numerical value of the carrier concentration.

4.1 ELECTRICAL PROPERTIES

The mobility, resistivity, and carrier concentration of a semiconductor are revealed by the Hall Effect measurement. Mobility is a metric for the epitaxial layer's impurity level, consistency, and homogeneity. The current density to electrical field ratio is known as resistivity (Munna *et al*., 2020). ~~Table 1 includes the electrical resistivity, bulk concentration, and mobility data for the deposited films.~~

Table 1: The values of electrical resistivity, bulk concentration, mobility obtained from Hall Effect measurements

Samples	Resistivity (Ωcm)	Mobility (cm^2/Vs)	Bulk Conc. (cm^{-3})	$Aver.\ Hall\ Coeff.(cm^3/C)$
$CdS\ (1hr)$	1.588×10^4	6.619×10^2	6.996×10^{11}	8.923×10^6
$CdS\ (30mins)$	2.234×10^4	7.262×10^2	3.629×10^{11}	-1.769×10^7

~~According to~~ From Table 1, the resistivity marginally decreases with ~~regard~~ to deposition time, ~~going~~ from 2.234 104 to 1.588 104 cm. ~~It is well known~~ that the rise in particle packing density with the increase in grain size ~~is what~~ causes the resistivity to drop (~~Mousavi, Jilavi, Mu, & Oliveira, 2014).~~Faraj, Eisa, & Pakhuruddin,(2019) also reported that the nearer resistivity value for CdS film by Spray Pyrolysis technique. The CdS films deposited have the conductivity value about 4.106×10^{-5} *and* $6.297 \times 10^{-5}((\Omega cm)^{-1})$ which are in good agreement with the previous report of (Ahmad et al., 2022). The prepared CdS thin film has $n-type$ conductivity(Kerimova, Bagiyev, Aliyeva, & Bayramov, 2017).

The bulk concentration is found to be increased from 3.629×10^{11} to 6.996×10^{11} (cm^{-3}) for the increasing of deposition time from 30 minutes to 1 hour.it was in agreement with work of (Miyake et al., 2004). The film's thickness and crystallinity have a significant impact on how well the bulk concentration and mobility are improved. All CdS films displayed semiconducting activity, with resistivities ranging from 10-3 to 10-5 cm (Ashour, 2003). The film's resistivity was seen to decrease with longer deposition times.

For CdTe thin film deposited on soda lime glass substrate at 1 hour deposition time. The values of electrical resistivity , bulk concentration and mobility for the deposited films are listed in Table 2.

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Table 2: ~~The values of electrical resistivity, bulk concentration, mobility obtained from Hall Effect measurements~~.

Sample	$Resistivity(\Omega cm)$	$Mobility$ cm^2/Vs	$Bulk\ Concentration$ cm^{-3}	$Aver.\ Hall$ $Coeff.$ cm^3/C
$CdTe$	1.016×10^4	1.996×10^2	3.074×10^{12}	2.030×10^6

From Table 2, the resistivity value of $CdTe$ thin film was $1.016 \times 10^4 \Omega cm$. This is in agreement with previous works of (Rahman et al., 2019). Miyake, Murase, Hirato, & Awakura,(2004) reported similar values of resistivity of the order 10^4 to 10^8. Hall effect measurement revealed that the $CdTe$ thin film had $p-type$ conductivity as the average hall voltage value was found to be positive (Nithyayini & Ramasesha, 2015). The bulk concentration of the $CdTe$ thin film value was observed to be $3.074 \times 10^{12} cm^{-3}$. This is in agreement with previous work of (Ahmad et al., 2022).

5. CONCLUSION

CdS and $CdTe$ thin films were fabricated by ~~a~~ spray pyrolysis technique. For CdS thin films, an aqueous solution of Cadmium acetate dihydrate Cd$(CH_3COOH)_2$.$2H_2$O and Thiourea $(NH_2)_2$CS, while mixture of Cd$(CH_3COOH)_2$.$2H_2$O and Tellurium oxide TeO_2 were used for the production of $CdTe$ thin film. From Hall-effect measurements, it is observed that the electrical resistivity of CdS thin films decreased from 2.234×10^4 to $1.588 \times 10^4 \Omega cm$ with respect to deposition time while the conductivity increases. The negative sign and positive sign of the Average Hall coefficient confirmed the $n-type$ nature of the semiconducting CdS films and p-type nature of $CdTe$ thin film.

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