ELECTRICAL CHARACTERIZATION OF CHEMICALLY GROWN CdS AND $CdTe$ THIN FILMS FOR SOLAR CELL APPLICATION.

ABSTRACT

Thin films of Cadmium Sulphide (CdS) and Cadmium Telluride ($CdTe$) have gained a great deal of interest due to their potential applications in solar cells. Deposition of CdS and $CdTe$ thin films were performed on Soda Lime glass and FTO substrate at $400℃$ and $300℃$ respectively using spray pyrolysis technique. The Hall Effect property was measured for the deposited CdS and $CdTe$ films. These results shows the resistivity and mobility of CdS and CdTe polycrystalline films deposited at $400℃$ 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*$300℃$ *were* $1.016 \times 10^4 \Omega cm$ *and* $1.998 \times 10^2 cm^2/Vs$*. were* CdS $n-type$ *and* $CdTe$ $p-type$ *of conduction mechanism respectively, which are suitable as window and absorber layers for efficient solar show.*

Key Words: 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, Verma, Jain, & Bajpai, 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 spectrums. 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 *et al*, 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). The two important criteria that affect whether CdS and $CdTe$ Thin films could be used as window layer or absorber layer in $CdS/CdTe$ heterojunction solar cells are electrical resistivity and carrier concentration (Garba, 2011).

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), Other techniques used to deposit material include Electrodeposition, 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 Spray 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). More over 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-Barreto *et al*, (2018).

This study examined 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 *et al.*, 2004).

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: (i) to identify the charge carrier of a semiconductor, which may be N=type or P=type; (ii) find carrier concentration; (iii) measure the conductivity of the materials; and to identify carrier mobility.

Hall coefficient is mathematically given as;

$$R_H = \frac{1}{nq} \tag{1}$$

Charge carrier mobility;

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

The Hall mobility,

$$\mu = \left|\frac{R_H}{\rho}\right| or\ \mu = |R_H|\sigma \tag{3}$$

The Resistivity is given as;

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

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

2. MATERIALS AND METHODS

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$(CH_3COO)_2$.2H_2O 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 setup. The solution was sprayed onto a glass substrate that had already been cleaned. The temperature of the substrate was kept constant at 400℃. 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

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

2.1 FOR CADMIUM TELLURIDE DEPOSITION

Deposition procedure was covered in five stages:

Stage I; $0.056g\ TeO_2$ Was added to $100ml\ NH_3$ at room temperature, the solution was stirred using magnetic stirrer until the solution turned 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 the solution turned milky. Deionized water was added to the mixture while hydrazine as a complexing agent 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 observed.

Step III; the resulting solution was put into two necks round bottom flask on the lab tech mantle heater set at $200°C$. The solution was heated for about 6 hours, after which it was left 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 $3minutes$ at $4000rpm,$ the process was repeated five times. While the centrifuging was 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$= 20cm$, (ii) spray solution concentration$= 0.1M$, (iii) carrier N_2 gas flow rate=$10l/min$, (iv) deposition time$= 20minutes$, and (v) solution flow rate$= 5ml/min$. After completing the $CdTe$ thin film coating process which lasted $20minutes$ by spray pyrolysis technique the films were naturally cooled at the room temperature. The chemical reaction that took place in the chamber is presented as;

$$Cd^{2+} + Te + 2e^- \rightarrow CdTe \tag{6}$$

3. RESULTS AND DISCUSSION

The three primary electrical properties of the deposited CdS and $CdTe$ Thin films, are 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 electrodes the 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 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 Hall Effect measurements

SAMPLE	RESISTIVITY (Ωcm)	MOBILITY cm^2/Vs	BULK CONCENTRATION cm^{-3}	$AVERAGE\ HALL\ COEFFICIENT$ cm^3/C
$CdS\ at\ 1hr$	1.588×10^4	6.619×10^2	6.996×10^{11}	8.923×10^6
$CdS\ at\ 30mins$	2.234×10^4	7.262×10^2	3.629×10^{11}	-1.769×10^7

From the Table 1, the resistivity marginally decreases with respect to deposition time, ranging from $2{,}234 \times 10^4$ to $1.588 \times 10^4 \Omega cm$. Mousavi et al, (2014) reported that the rise in particle packing density with the increase in grain size causes the resistivity to drop.

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 $4.106 \times 10^{-5}\ and\ 6.297 \times 10^{-5} ((\Omega cm)^{-1})$ 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 was found to be increased from 3.629×10^{11} to 6.996×10^{11} for the increasing of deposition time from 30minutes to 1hour and this was in agreement with the work of (Miyake *et al*., 2004). The film's thickness and crystallinity have a significant impact on the bulk concentration and mobility were improved. All CdS films displayed semiconducting activity, with resistivity's ranging from 10^{-3} to $10^{-5}\Omega cm$ (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 1hour deposition time. The values of electrical resistivity, bulk concentration, mobility for the deposited films were presented in Table 2.

Table 2. The Hall Effect measurements.

SAMPLE	$RESISTIVITY$ (Ωcm)	$MOBILITY$ cm^2/Vs	$BULK\ CONCENTRATION$ cm^{-3}	$AVERAGE\ HALL\ COEFFICIENT$ 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, *et al*,(2004) reported similar values of resistivity of the order10^4 to 10^8. Hall effect measurement revealed that the $CdTe$ thin film exhibited $p-type$ 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 was 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$(CH_3COO)_2.2H_2$O and Thiourea $(NH_2)_2$CS, while mixture of Cd$(CH_3COO)_2.2H_2$O and Tellurium oxide TeO_2 were used for the synthesis of $CdTe$ thin film. From Hall Effect measurements, it was 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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