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Optical and Electrical Properties of CdS: B Thin Film Deposited by Chemical Bath Deposition for Photovoltaic Application.

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Abstract: Globally, there is a high demand for clean, sustainable and renewable energy for domestic and industrial use. Conventional photovoltaic cell technology relies heavily on crystalline silicon wafers which render silicon-based solar cells expensive due to the initial cost of production and required complex deposition methods. Due to these challenges, great research interest is now directed towards thin-film solar cells. In this work, chemical bath deposition (CBD) method was chosen in the preparation of boron doped cadmium sulphide (CdS: B) thin film onto a glass slide substrate. The prepared CdS: B thin films were characterized and optimized as a window layer for solar light trapping. The transmittance of the CdS: B films varied between 70% and 81% for boron concentration ranging from 0.0 M to 0.06 M. With the increase in boron concentration, band gap and resistivity of the CdS: B varied from 2.96 to 3.72eV and 120 Ω-cm to 58Ω-cm, respectively. Based on the results obtained, we believe that CdS: B is suitable as a window layer for solar light trapping in the fabrication of a photovoltaic cell.

Keywords: Chemical bath deposition; CdS: B; Optical properties; Electrical properties; Photovoltaic cell.

1 Introduction

Solar energy is the principal source of energy due to its abundance. However, in most cases, it goes to waste [1]. The solar energy can be harnessed using a photovoltaic cell to produce reliable power for domestic use [2]. The photovoltaic cell is a transducer that converts light energy into electric energy by photoelectric effect [2]. A working photovoltaic cell was developed by utilizing a semiconductor of aluminum with a gold window layer to obtain a *p-n* junction [1]. By 1956 the cell enhanced effectiveness in terms of power conversion efficiency had improved to about 1% [3]. Since then, a lot of effort has been directed to research on thin films and as a result, different thin-film innovations undergoing development today are majorly targeted at decreasing the material's size for light absorption, subsequently lowering processing costs.

Among the wide range of photovoltaic cells, cadmium sulphide (CdS) cells have been broadly examined [4]. However, efficiencies are still very low [5].

The CdS are small in size and light in weight, they are also easily fabricated [6]. In addition, the CdS has a wide range of applications in electronic circuits such as radiation detectors and solar cells hence, researchers have focused on the improvement of its electrical properties [7], optical properties of un-doped [8] and doped [9] CdS films to deliver photovoltaic cells with high efficiency. Mostly, the CdS thin films are preferred as a window layer in the fabrication of solar cell because of their high transparency and wide band gap [10]. Sulphur vacancies cause changes from stoichiometry amid its development, consequently, the quality of the surface relies upon the technique utilized and it is critical that the films be free from defects [11].

Different deposition methods such as CBD, vacuum evaporation, splash techniques among others have been used to get quality photovoltaic cells [12]. Notably, every strategy has some limitations. For instance, stoichiometric CdS is hard to get through the thermal evaporation method while high temperatures are required in spray deposition. Boric acid as a source of a dopant in CdS was investigated using CBD [13]. The resistivity of the CdS: B films decreased substantially showing a minimum value of about 0.02 Ωm and an improved transmittance within the visible region (380nm-780nm). In another work, CdS/Cu_xS thin-

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film photovoltaic was deposited using chemical spray method. It was observed that the thickness of the film, grain size, spectral responses, structure, photovoltaic response, and current-voltage (I-V) characteristics depended on preparation techniques [14]. Vacuum evaporation procedure was also in another study to deposit CdS on a glass substrate [14]. From the deposited CdS thin film, the resistivity at 200ºC was 1.5 Ωm with a $1x10^{21}$ m^{-3} carrier concentrations and $6×10^{-4}$ m^2 v^{-1} s^{-1} mobility. Additionally, high vacuum deposition technique was utilized to deposit CdS: Cl films in which a combination of CdS and $CdCl_2$ powders with different concentrations of the dopant at room temperature were used [15]. The films showed that the chlorine doping and annealing improved the electrical properties.

From the above reports, it is evident that limited studies exist on CdS: B thin film deposited by CBD for photovoltaic application. In this work, therefore, the optical and electrical properties of the CdS: B deposited by CBD will be investigated and characterized for photovoltaic applications.

2 Materials and Methods for Deposition of CdS: B

CBD technique was used in the deposition of CdS: B. Ammonium hydroxide ($\mathrm{NH_4OH,}$) served both as a complexation agent, as well as providing the alkalinity required of the required solution [15]. The complexing agent and alkalinity of the solution are provided by the solution of ammonium hydroxide as illustrated by equation Eq. (1).

$$NH_3 + H_2O \rightarrow NH_4 + OH^- \quad (1)$$

2.1Cleaning of Substrate

Glass slides were used as a substrate for the deposition of thin films. Before deposition, the glass slides were cleaned by a liquid detergent before being dipped in ethanol for 10 minutes to remove grease. Afterward, the glass slides were soaked in 100ºC 1.0 M hydrochloric acid for nucleation centers to be created. Finally, the glass slides were cleaned with distilled water for around 15 minutes, then dried at a temperature of 200^0C.

2.2 Deposition of CdS: B Thin Films

Solutions of 0.038 M $\mathrm{Cd(NO_3)_2}$, 0.076 M NH_4OH and 0.076 M thiourea were prepared and mixed. 15 ml of each solution was taken into different measuring glass beakers,

and distilled water was added to top the volume to 100 ml. This mixture was heated to a temperature of 78ºC. Using a burette, 29% NH_4OH was added slowly until a pH of 9 was reached, which was maintained throughout for each film deposited. Then, 10 ml boric acid (H_3BO_3) of varying concentrations (0.0, 0.02, 0.04, 0.06, 0.08 to 0.1 M) was added to the 100 ml solution to vary boron as a dopant for each film prepared. The deposition temperature was maintained at 82^0C for 55 minutes under continuous stirring. The films were characterized after annealing at a temperature between 200^0 C and 300^0C. The schematic diagram of the CBD method used in this work is shown in Fig.1.

2.3 Optical and Electrical Characterization of the CdS: B Thin Films

Once the thin films were prepared, their optical properties within the 380nm-780nm range of wavelengths were measured using UV-NIR VIS spectrophotometer 3700 DUV and recorded. Simulation of transmittance data was done to obtain optical constants such as refractive index (n) and band gap energy (E_g). The E_g was calculated from the allowed direct transition given by Eq. (3) [16].

$$\alpha h\nu = \left(h\nu - E_g\right)^{\frac{1}{2}} \quad (2)$$

where α is the absorption coefficient, *h* the Planck's constant, ν the photon frequency and E_g the band gap energy.

In addition, the electrical resistance of the CdS: B at boron concentration ranging from 0.0 M to 0.1 M, were analyzed. The sheet resistivity (ρ) was experimentally determined by utilizing a four-point probe (Fig.2). The current was set through the external probes 1 and 4 and instigates a voltage in the internal voltage probes 2 and 3. Using the current and voltage readings from the probe, sheet resistivity, ρ was calculated using Eq. (3).

$$\rho = \frac{\pi}{\ln(2)}\left(\frac{V}{I}\right)t \quad (3)$$

Where $\frac{\pi}{ln\,2} = 4.532$ and *t* is sample thickness.

3 Results and Discussions

3.1Optical Properties of the CdS: B Thin Film

3.1.1 Transmittance

The optical transmittance of the CdS: B thin films increased as boron concentrations increased (Fig.3). The increase is attributed to an improvement in film homogeneity [17]. Therefore, doping CdS with boron improves the

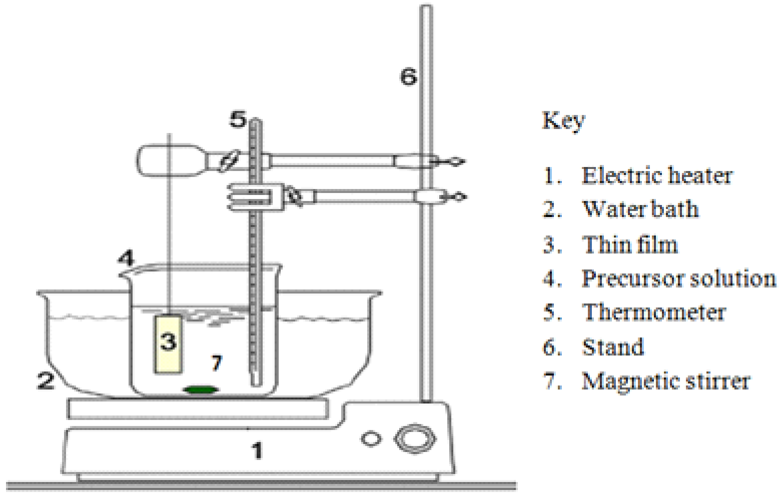

Fig.1: A schematic diagram of the chemical bath deposition setup.

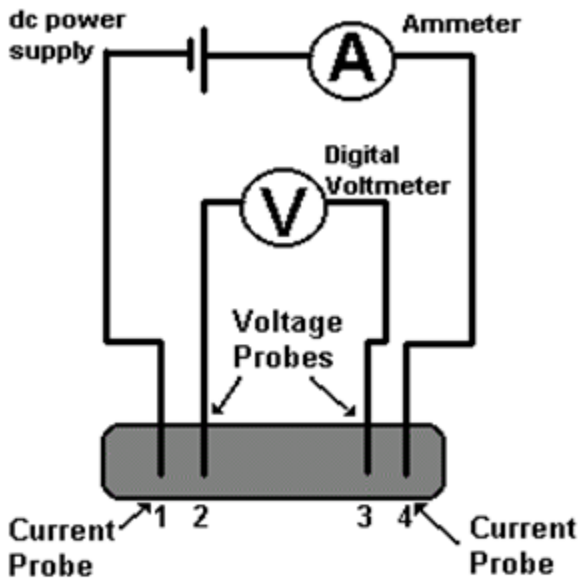

Fig.2: Four-point probe sheet resistivity measurement apparatus [18].

transparency of the deposited film. The transmittance values obtained in this work are in agreement with a previous study [13] in which the values were around 80%. Lower transmittance was also obtained in the wavelength above 450nm in another previous study [19]. At a wavelength of about 600 nm transmittance starts to decrease as a result of the uneven surface of the thin films [20].

The average transmittance curve of CdS: B samples within the visible region (380-780nm) obtained is shown in Fig 4. It was observed that the highest average percentage transmittance within the visible region of the deposited film was 81.38 ± 0.41 %. Transmittance varied with an increase in boron concentration and had its maximum value at 0.06 M. This was due to the reduction of voids within the CdS sample as well as improvement of the crystallinity and homogeneity of the films. Above the 0.06M boron concentration, the average transmittance decreased probably due to decreases in film crystallinity [21].

3.1.2 Reflectance

The CdS: B thin films prepared with a boron concentration of 0.02 M had the highest reflectance at around 450 nm and decreased sharply above 500 nm (Fig. 4). In addition, it is observed that reflectance increased for the wavelength range of 0-400nm. Boron ions in CdS lowered reflectance values of CdS films. This may be attributed to the formation of CdS nanocrystals [22]. [23] carried a similar study on CdS for the wavelength range of 400-1000nm and obtained reflectance below 55% which is in agreement with this work.

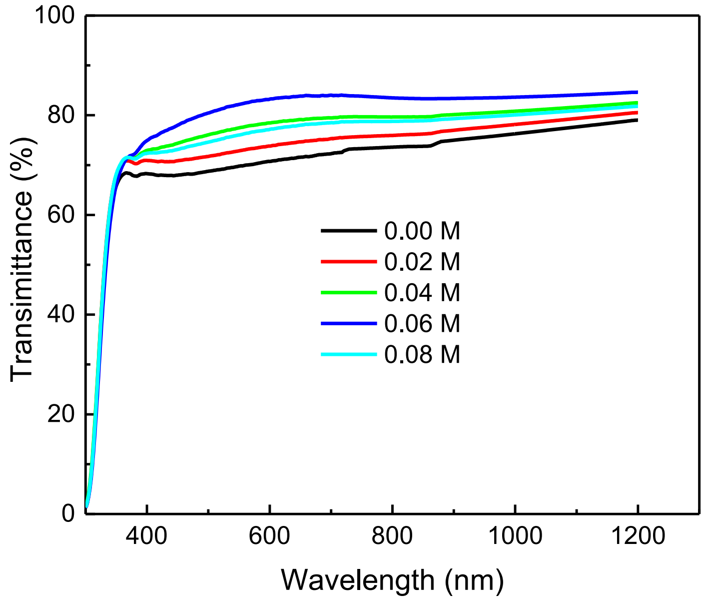

Fig.3: A graph of transmittance against wavelength for CdS: B films deposited at different boron concentrations.

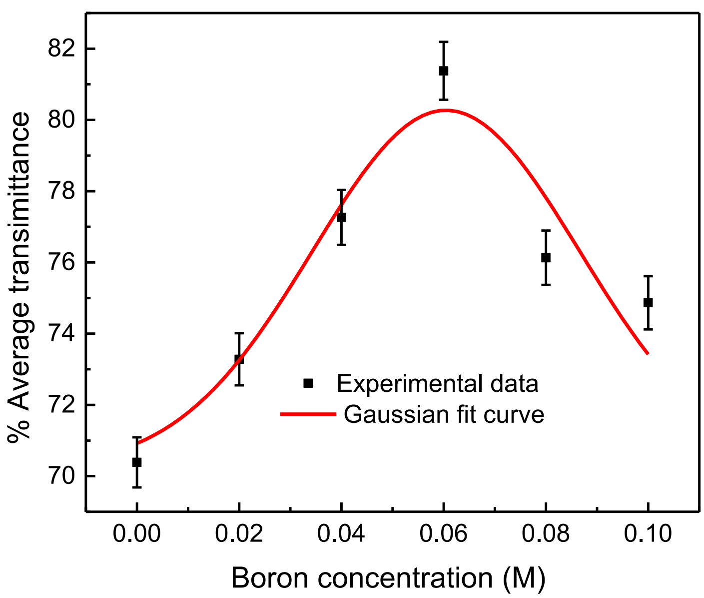

Fig.4: Graph of average transmittance (%) against boron concentration (mol/l).

3.1.3 Band Gap of CdS: B

The band gap (E_g) energy was obtained by extrapolating the linear part of the curve $(\alpha h\nu)^2$ which intercepts the energy axis, as described in Tauc Laurentz relation (Eq. (3)). In this work, E_g ranging from 2.96 - 3.72eV was obtained (table 1). In addition, the simulation was done using scouts' software of transmittance normalized data and the E_g values ranging between 3.01 and 3.69eV were also obtained which are similar to those obtained by Tauc Laurentz relation. It was observed that the E_g increased with an increase in boron concentration in the CdS, up to 0.06 M. This increase in band gap is attributed to the Burstein- Moss effect. As boron concentrations increases, the fermi-level is shifted into the conduction band. The dopant B^{2+} ions cause an increase in free carrier concentration; this lifts Fermi level up into the conduction band leading to an increase in the E_g [24]. Beyond the 0.06 M, the band gap decreased which can be attributed to the formation of defects as a result of too much dopant. Earlier measurements done on CdS yields E_g of 2.5 - 2.7 eV which agrees with our results [25]. In addition, E_g of 2.5 - 3.0 eV were obtained under the same deposition condition as in our study [19].

3.1.4 Refractive Index (n)

The average refractive index (*n*) reduced to a minimum value of 1.44 when boron concentration was 0.06 M (Fig 5). The presence of a boron dopant enhances transparency of the films and it was optimum at 0.06 M. After the 0.06 M, the *n* increased. This was as a result of a decrease in transparency of the deposited films. It is also observed that the values of *n* reduce as the boron concentration increases up to the optimum concentration of 0.06 M and then increases (Fig 5). Boron concentration enhances the transparency of the deposited thin films [25].

3.2Electrical properties of CdS: B Thin Film

The resistivity of CdS: B thin film decreased with an increase in boron ions to a minimum resistivity of 58±0.5Ω-cm obtained at 0.06 M boron concentration (Fig. 6). Boron substitutions in CdS improved its crystallinity [26]. After the 0.06 M boron concentration, the resistivity increased due to a reduction in both carrier concentration and carrier mobility [27]. In our work, the ranges of electrical resistivity observed were 70.0 Ω-cm to 120 Ω-cm. Using a spray pyrolysis method, a resistivity of 10^3 Ω-cm was reported [28]. The huge difference can be attributed to poor purity of the chemicals used.

Table 1: Energy band gaps at different boron concentration (mol/l).

Conc. Of Boron in CdS (mol/l)	E_g (eV) Tauc L.R	E_g (eV) Simulation
0.00	2.96 ±0.04	3.01 ±0.09
0.02	3.29 ±0.03	3.31 ±0.04
0.04	3.52 ±0.02	3.48 ±0.06
0.06	3.72 ±0.02	3.69 ±0.04
0.08	3.50 ±0.02	3.46 ±0.04
0.10	3.05 ±0.01	2.91 ±0.07

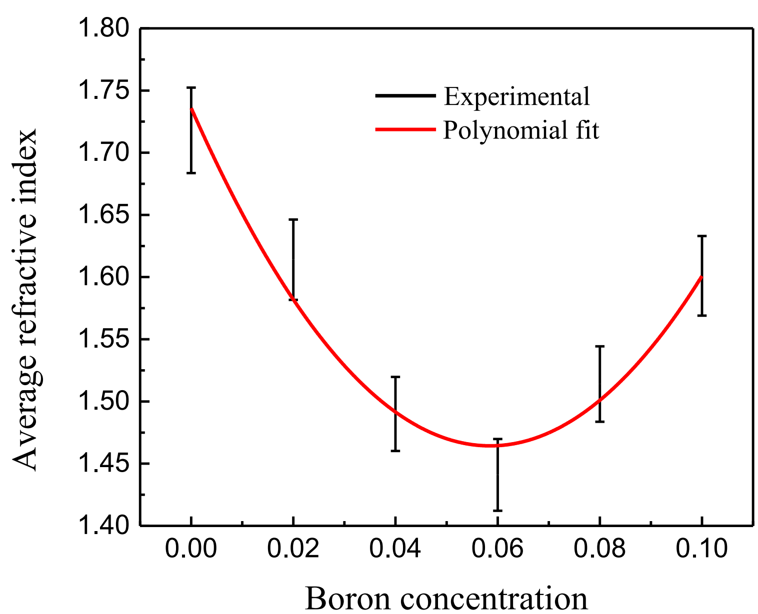

Fig.5. A graph of average refractive index against boron conc. (mol/l).

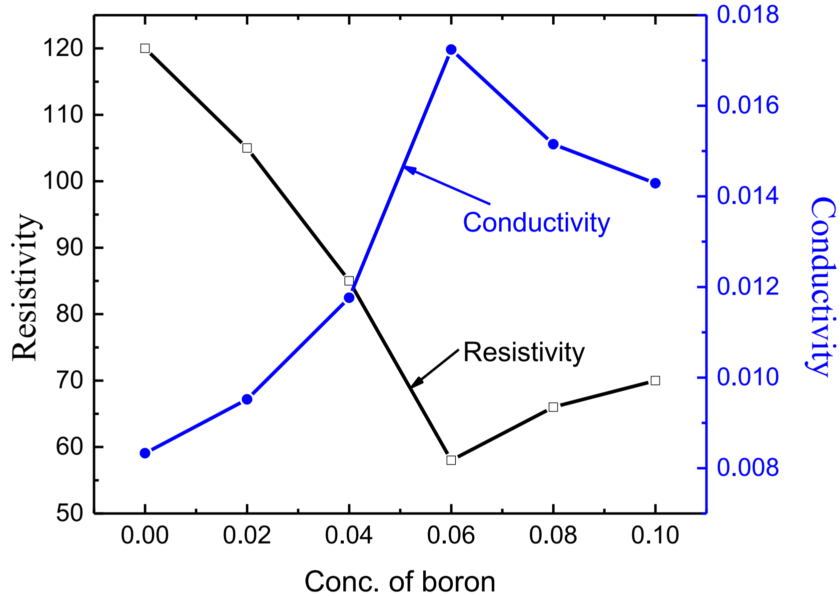

Fig.6: The plot of conductivity and resistivity against the concentration of boron ions obtained from the values tabulated in table 5.6.

4 Conclusion

CBD method was successfully used to deposit CdS: B thin films. Electrical and optical properties of the deposited CdS: B thin films were investigated for photovoltaic applications. The CdS: B thin films had an average transmittance of 70-81% within the visible region. The E_g was found to between 2.96-3.72 eV. Electrical conductivity increased from $8.33x10^{-2}$ -$1.72x10^{-1}$ $[\Omega\text{-cm}]^{-1}$ as concentration of boron increased from 0.0-0.06M. Presence of boron substitutions in CdS improved the homogeneity of the thin films. The results of this work indicate that CdS: B thin films can be used as a window layer in the fabrication of photovoltaic cell.

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