Opto-Electrical Characterization of Annealed Cdse And Cdte Thin Films Synthesized Via Thermal Evaporation Technique

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Abstract

This study reports the synthesis and characterization of CdSe and CdTe multilayer thin films via Thermal evaporation technique. The multilayer thin films were respectively prepared sequentially at 100 ^oC in a vacuum of about 2.0 x 10^{-5} torr and annealed in vacuum at 120 ^oC for 15 mins. The thickness of Cd was 500 Å while Se and Te were respectively 150 Å. Optical properties were studied using UV-Vis Spectrophotometer. The electrical characterization was carried out using Keithley Four-point Probe. UV-Visible analysis of the film showed a direct optical band gap which is found to be 1.90 eV and 1.00 eV for the CdSe and CdTe films respectively, with an enhanced light absorption in the range of 350 nm to 950 nm (at infra-red region) spectrum. The Electrical results revealed that the CdSe exhibited n-type semi-conductivity because of non-stoichiometry with optimum resistivity of 0.86 x 10^{-3} Ωcm^{-1} while CdTe exhibited a p-type semi-conductivity. It could be concluded that CdSe is a good material for window layer while CdTe is a good material for absorber in photovoltaic applications.

Keywords: thermal evaporation, optical band gap, electrical conductivity, absorber layer, window layer and photovoltaic application.

Introduction

Solar energy is a non-polluting, inexhaustible energy source that can aid the increasing human energy demand that can be distributed all over the place as it does not have any harmful by-products to the environment. The provision of clean and sustainable energy to satisfy our ever-growing needs is one of the most critical challenges currently facing mankind. At the present time our primary energy sources are dominated by non-renewable fossil fuels, with nearly 80% of global energy demand supplied from crude oil, natural gas, and coal (Fanchi, 2004; Randolph and Masters, 2008). Also, energy production by burning fuel produces hazardous pollutants, such as oxides of sulphur and nitrogen, hydrocarbons and most significantly, carbon monoxide. Thus, traditional fossil energy resources are not only rapidly depleting, but also contribute to unpredictable and possibly irreversible climate changes the world is facing (Trykozko, 1997). These and other factors have prompted scientists and researchers all over the world to look for alternative sources of energy. Energy consumption has increased steadily with civilization. Energy crisis due to a decline in fossil fuel stocks and increasing carbon dioxide emissions that are causing global warming has enhanced interest in the development of clean renewable sources of energy. To sustain human development, more electrical energy consumption is expected in future (Kuo-Jui, 2010). Hence, renewable energy sources seem to provide an optional solution to the global energy problem. Due to their sustainable nature, renewable energy technologies are capable of preserving resources, ensuring the security and diversity of the energy supply and providing energy services virtually without any environmental impact. A more sustainable pattern of energy supply and end-use for the future shall inevitably lead to the need for greater utilization of renewable energy sources, such as solar, wind and biomass energy as well as geothermal energy which many people consider to be sustainable, at least for the foreseeable future (Krylova et al., 2014). Among renewable energy sources, solar energy is an exciting alternative to fossil fuels (Yafei et al., 2012). Solar energy is the most abundant, inexhaustible and clean of all the renewable energy resources till date. The power from the sun intercepted by the earth is about 1.8×10^{11} MW, which is many times larger than the present rate of all the energy consumption (Parida et al., 2011). There is no doubt that the natural energy flows that are driven by the sun represent a vast resource; sufficient both to replace the fuels and to meet the expected future increased demand for energy. Therefore, solar energy is perhaps the most popular choice in this regard. It is almost inexhaustible, non-polluting source of power, as it does not have any dangerous by-products harmful to the environment, and distributed all over the globe (Kemell et al., 2005). It is for this reason that intense efforts are being made in many parts of the world to make more extensive use of solar energy to meet our growing energy needs. The major elemental materials used to overcome the opto-electronic devices in term of energy is semiconductors which are a group of materials either inorganic or organic compounds having electrical conductivities intermediate between metals and insulators. It is significant that the conductivity of these materials can be varied over orders of magnitude by changes in temperature, optical excitation and impurity content. This variability of electrical properties makes the semiconductor materials natural choices for electronic device fabrications. One of the most important characteristics of a semiconductor, which distinguishes it from metals and insulators, is its energy band gap (e.g.). Semiconductor devices such as diodes, transistors and integrated circuits can be found everywhere in our daily lives, in Walkman, televisions, automobiles, washing machines and computers. The world has come to rely on them and increasingly have come to expect higher performance at lower cost. In recent year, major attention is being shown in II-VI semiconductor compounds because of their specific optoelectronic properties, such as high efficiency of radioactive recombination, high absorption coefficient in the visible and infrared regions of the solar spectrum (Patel et al., 2009), good electrical properties, increased capability in obtaining adjustable n-type or p-type conductivity by doping and direct band-gap (Perez and Arreolas, 2009). Semiconductors derive their great importance from the fact that their electrical conductivity can be greatly altered via an external stimulus (voltage, photon flux, etc), making semiconductors critical parts of many different kinds of electrical circuits and optical applications. Currently, solar cells are used for various device configurations and employing single crystal, polycrystal and amorphous thin film structures (Hersch and Zweibel,1982; Sze, 1981). Polycrystalline thin film solar cells based on copper indium diselenide ($CuInSe_2$) and its alloys-cadmium telluride (CdTe) appear to be the most promising candidates for large scale application of photovoltaic energy conversion (Asim et al., 2012). Recently, researches have been focused on polycrystalline thin film materials of copper indium diselenide ($CuInSe_2$) and cadmium telluride (CdTe) based solar cells and little researches have been reported on CdTe and CdSe Thin Films deposited via Thermal Evaporation. This motivated the current study. The films were characterized with the view to finding out its optimization level for opto-electronic applications and contributing to the existing knowledge.

Materials and Methods

The cadmium powder, selenium pellet and tellurium pellets were of Sigma Aldrich® source. Cadmium selenide was first to be deposited in which cadmium powder 99.999 % as the first layer with about 500 nm thickness and selenium pellet 99.999 % were also deposited as the second layer with thickness of about 200 nm. Cadmium telluride which was used for the second deposition in which cadmium was deposited as the first layer and tellurium 99.999 % as the second layer with the same composition as the CdSe. The substrates used in this study were soda lime glass (SLG) due to their availability. The substrates were washed gently for four to six minutes with detergent soap and cotton wool to remove the dirt on the glass, rinsed thoroughly in distilled water for about five times. After which the substrates were washed again with mixtures of trichloroethylene, acetone and methanol to remove hydrocarbon and grease from the glass. The substrates were then thoroughly rinsed with distilled water and carefully placed in a desiccator to air dry and also to prevent dust particle contamination on them. Thermal Vacuum Evaporation was adopted for this study because thermal evaporation is one of the commonly used technique with very high deposition, low material consumption and low cost of operation (Seshan, 2002). The materials were evaporated at 100 ^{0}C from different molybdenum boats to avoid contamination using the same boat for different elements. CdTe and CdSe stacks were prepared at room temperature by using Physical Vapour Deposition unit supplied by Kurt J. Lesker® Company NANO 36. The pure (99.999 %) Te and Cd powders were procured from Sigma Aldrich. The base pressure of the chamber was ~2×10^{-5} torr. Sequential layer of Cd followed by Se was coated on the cleaned soda lime glass. The deposition rate and thickness of the individual layers were monitored by a quartz crystal thickness monitor equipped with a vacuum coating unit. The deposition rate was maintained as 3 A/s for both Te and Cd films. To achieve the desired stochiometry, thickness of Te and Cd elemental layer were adjusted. In order to get good film uniformity, the distance between the substrate and source was fixed at 10 cm. To enhance the film uniformity, rotary drive assembly was used and speed was fixed at 25 rpm. The stacked layers CdSe and CdTe were allowed to isochronal annealing from 100 °C to 120 °C for about 15 minutes in Ar gas atmosphere with a separate vacuum furnace. The transmission spectra of all annealed stack were recorded using Avantes Avalight® spectrophotometer in the wavelength range from 239 nm to 999 nm. The dimensions of the films were 3.7 cm × 2.5 cm.

Results and Discussion

Optical Characterization of the Films

A room temperature optical transmittance was measured by a dual beam (Shimadzu UV-3100, Japan) UV-VIS spectrophotometer was used to obtain the optical data of the CdSe and CdTe films. The UV-Visible spectrum of the CdSe and CdTe thin films are presented on Table 1. The spectrum is a plot of absorbance against incident photon wavelength at normal incidence and at room temperature. The absorption coefficient (α) and energy (E) in electron volts (eV) were also calculated from the absorbance data.

Table 1: *Absorbance Wavelengths of the CdTe and CdSe Thin Films*

Wavelengths λ (nm)	CdTe	CdSe
250.0	3.173	2.830
350.0	0.681	0.379
450.0	0.672	0.248
550.0	0.740	0.199
650.0	0.692	0.118
750.0	0.576	0.050
850.0	0.497	0.030
950.0	0.452	0.023

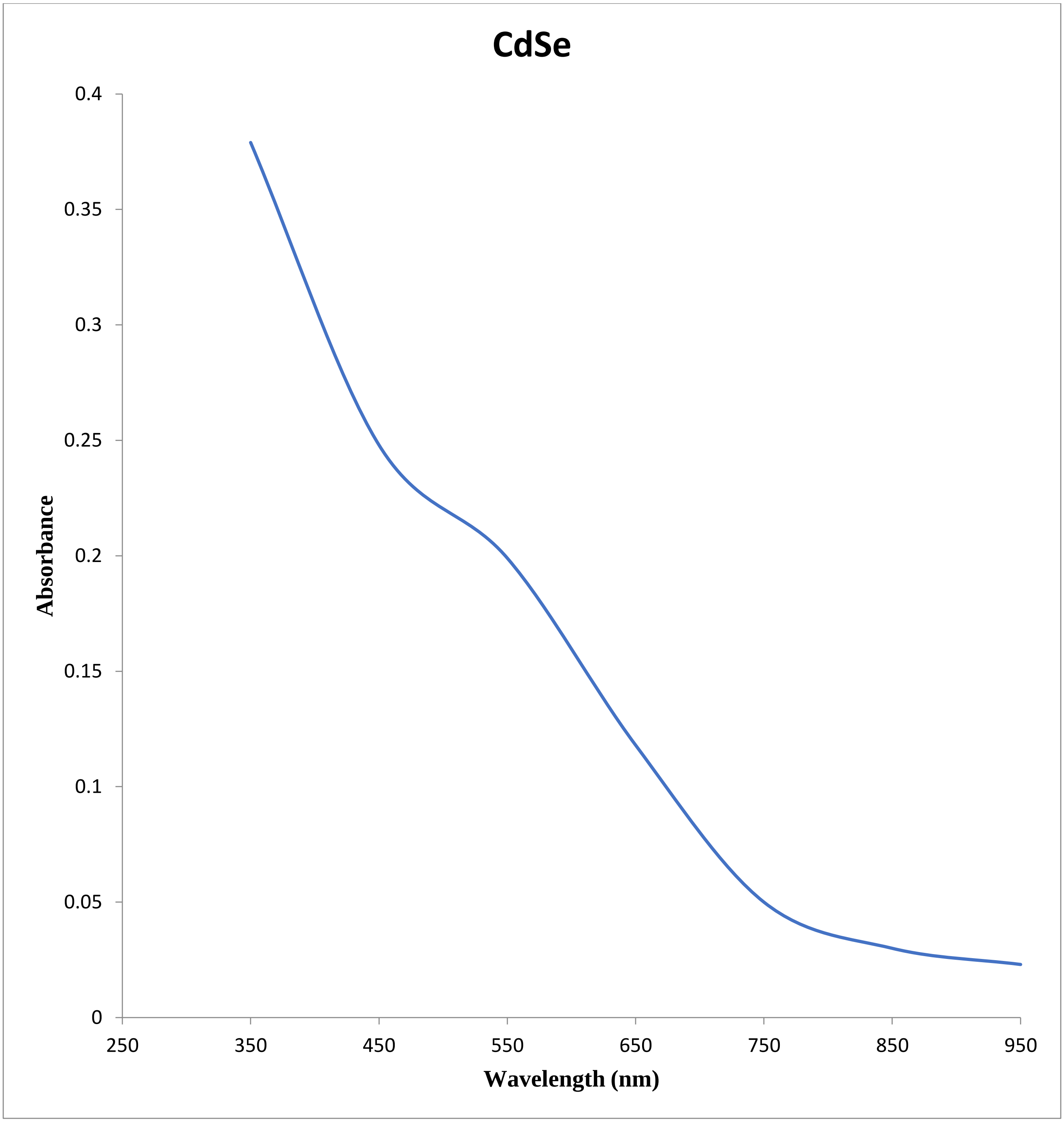

Figure 1a: Absorbance against wavelength of the Annealed CdSe thin film

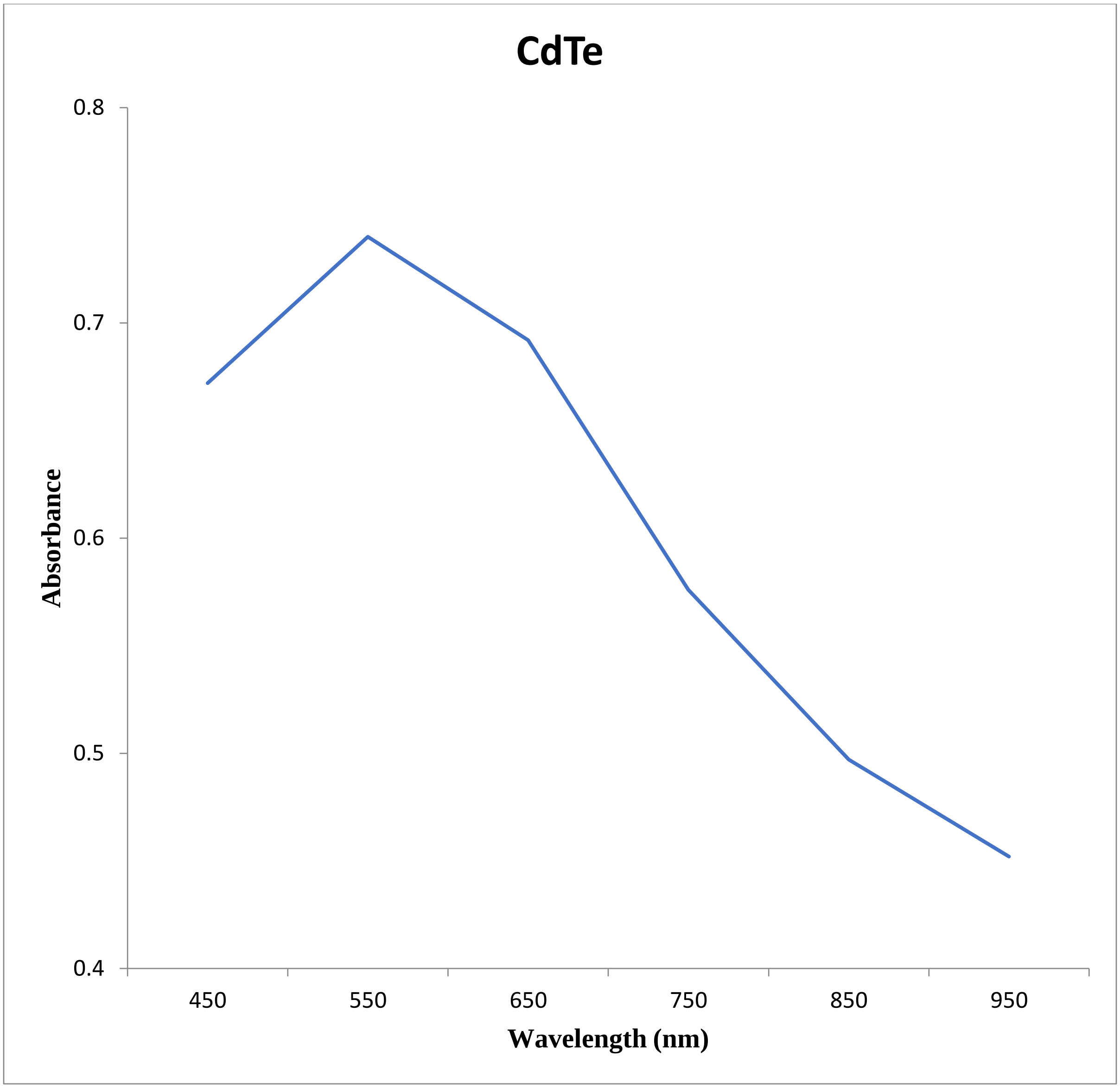

Figure 1b: Absorbance against wavelength of the Annealed CdTe thin film

Figures 1a and b show interference patterns in the higher wavelength regions, which is an indication of semiconducting nature of the film. The thin films have shown the higher transparency whose transmission is above 85 % around wavelengths 350 nm and 550 nm for CdSe and CdTe respectively which shows a sharp absorption in both spectra accordingly.

Determination of the optical band gap

The energy band gap and transition type were derived the data obtained from optical absorbance versus wavelength in relation to the Stern (1963) relationship of near-edge absorption as summarized in Table 2. The optical band gap was found to be 1.90 eV and 1.00 eV for the CdSe and CdTe films respectively (see Figures 2 and 3) which is in good agreement with earlier reports of Esparza-Ponce et al., 2009 and Zhao et al., 2013. It was slightly lower in comparison with Chander and Dhaker (2015), whose study showed that the optical energy band gap of CdTe film was found in the range 1.52eV - 1.94eV and observed to decrease with thickness. The variation of $(\alpha h\nu)^2$ versus $(h\nu)$ shown in Figures 2 and 3 was linear at the absorption edge, which confirmed that CdSe is a semiconductor with a direct band gap. The optical band gap determined from optical absorption spectroscopy, was found to be 1.90 eV with direct transition for CdSe, this is in agreement with the work of Fekadu et al. (2015) who reported the optical band to be 1.86 eV in CdSe but in disagreement with that of Vishwakarma et al. (2013) who reported same to be 1.39 eV on different substrates' temperatures.

Table 2: *Absorption Coefficient as a Function of Photon Energy*

λ(nm)	E (eV)	CdTe 100 ^{0}c $\alpha=\frac{2.30A}{T}$	CdSe 120 ^{0}c $\alpha=\frac{2.30A}{T}$	CdTe $(\alpha hc)^2$	CdSe $(\alpha hc)^2$
250.0	4.969	0.125	0.025	0.621	0.124
350.0	3.548	0.562	0.036	1.994	0.127
450.0	2.760	1.226	0.042	3.384	0.115
550.0	2.258	1.727	0.045	3.899	0.102
650.0	1.910	2.008	0.051	3.835	0.097
750.0	1.655	1.869	0.064	3.093	0.106
850.0	1.461	1.664	0.078	2.431	0.114
950.0	1.307	1.587	0.089	2.074	0.116

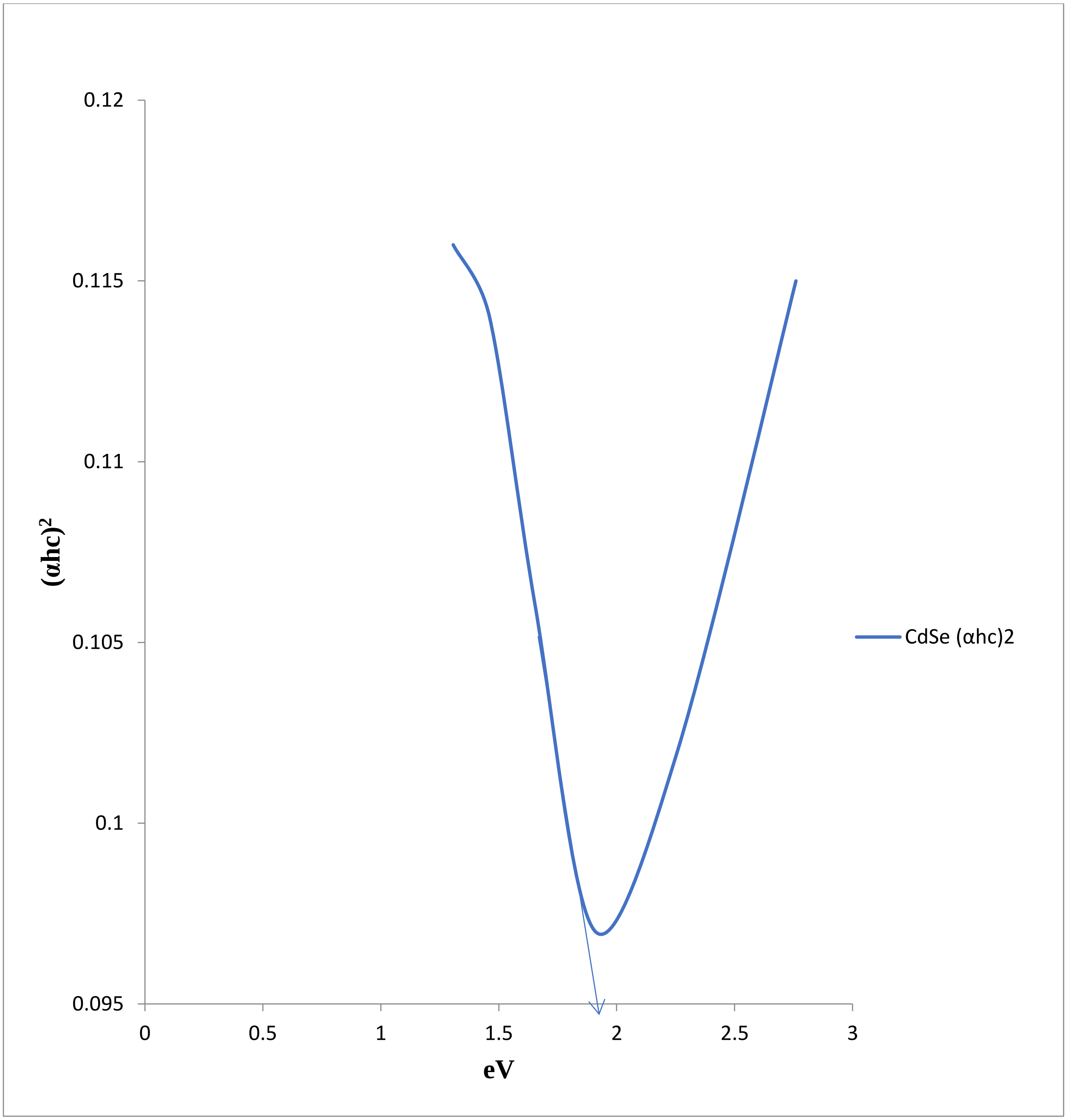

Figure 2: Graph of $(\alpha hc)^2$ plotted as a function of the photon energy (eV) for CdSe Thin Film

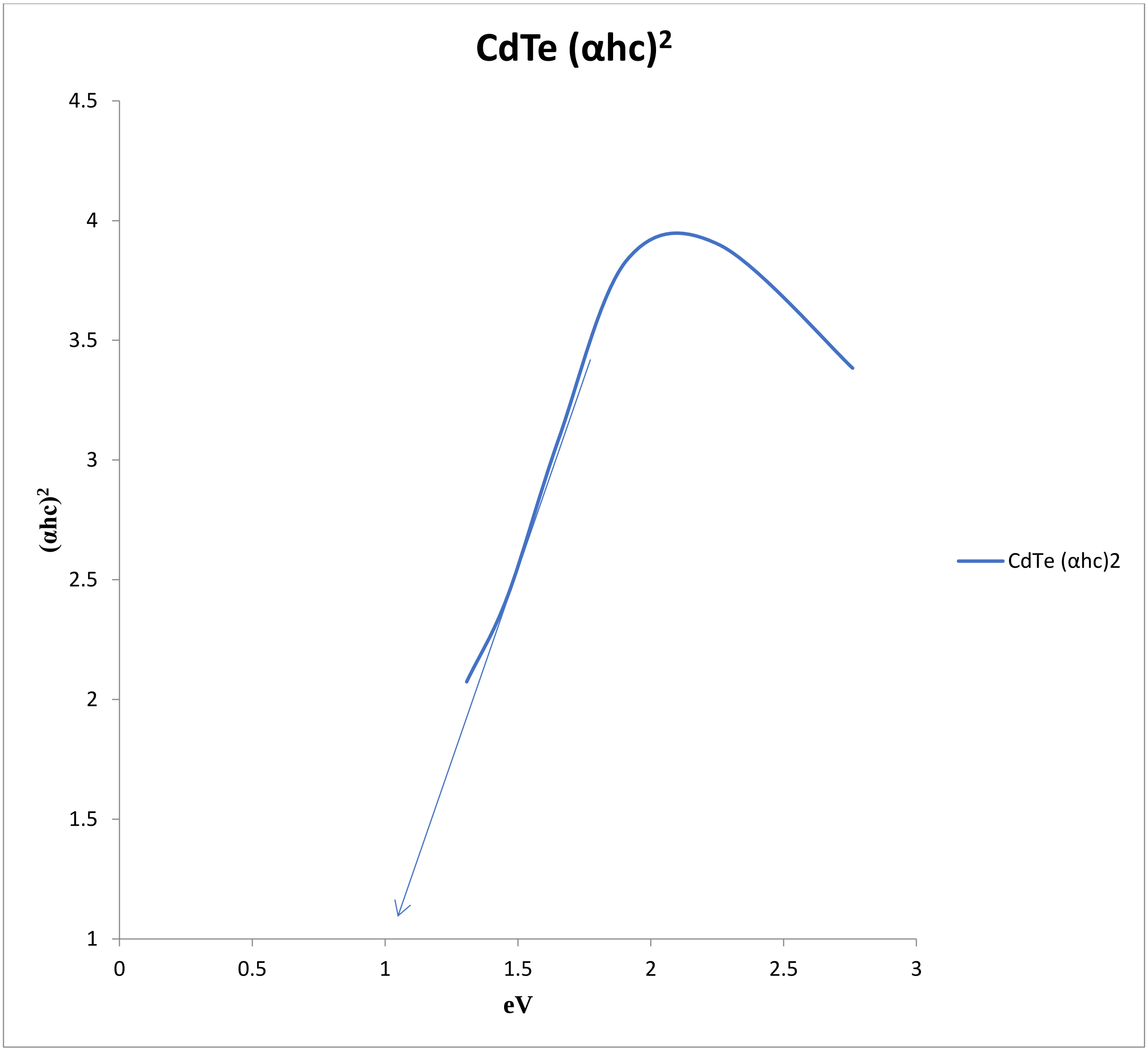

Figure 3: Graph of $(\alpha hc)^2$ plotted as a function of the photon energy (eV) for CdTe Thin Film

Electrical Characterization of the Films

The electrical characterization of the film was done using the Keithley Four-point probe machine. The sheet resistance, Rs of the film was obtained using equation 1;

$$Rs = K\frac{V}{I}\Omega/sq \qquad 1$$

where K, is a constant dependent on the configuration and spacing of the contacts.

K, can be expressed as

$$K = \frac{\pi}{ln2} = 4.533 \qquad 2$$

The resistivity, ρ was estimated using equation 2.

$$\rho = R_s t_y \qquad 3$$

where t_y, is the estimated thickness of the film.

The conductivity value was also determined using the inverse of the resistivity. The average generated voltage, the average generated current, the sheet resistance, the resistivity which is in agreement with the value of the film is in the order of 10^{-4} Ωcm^{-1} reported by Lade et al., (2001) and the conductivity of the film was calculated and summarized as shown in Table 3. The electrical conductivity of the film was carried out using the Keithley four-point probe. The CdSe thin films exhibit n-type semi conductivity because of non-stiochiometry, that is, Se vacancies in thin films. The resistivity observed in present study varied from other workers' result with optimum resistivity of 0.86 $x10^{-3}$ $\Omega^{-1}cm$ (Vishwakarma et al. 2013), 5.85 $x10^{5}$ $\Omega^{-1}cm$ (Hus and Parlak, 2008). The electrical results observed in CdTe showed that it is a p-type semiconductor and the results could also be affected by the quantity of samples deposited at a particular deposition.

Table 3: *The Result of Sheet Resistance, Conductivity and Resistivity*

Samples	Sheet resistance(Rs)	Average voltage (v)	Average current (A)	Thickness of the film (nm)	Resistivity ($\Omega^{-1}cm$)	Conductivity (S)
CdTe	3.65×10^{8}	9.9×10^{-2}	1.24×10^{-9}	118.0	4.3×10^{10}	2.31×10^{-11}
CdSe	2.83×10^{8}	9.99×10^{-2}	1.6×10^{-9}	571.0	1.62×10^{11}	6.81×10^{-12}

Conclusion

CdTe and CdSe have been successfully deposited on soda lime glass (SLG) substrates by thermal evaporation technique, multilayer thin films with various sublayer thicknesses were prepared using physical vapour deposition technique which were sequentially deposited and annealed at 100 ^{o}C and 120 ^{0}C respectively. Optical band-gap were determined which revealed that CdTe thin films may be used as absorber layer while CdSe thin films may be used as a window layer in solar cells. The electrical properties such as sheet resistance, resistivity and conductivity obtained from Four-point probe results were equally reported.

Recommendation

CdTe and CdSe thin films are recommended as good materials for photovoltaic applications owing to their electrical and optical characterizations. However, morphological, structural and elemental characterizations of CdTe and CdSe deposited via thermal evaporation are recommended for future work.

Conflict of Interest

Authors declare no conflict of interest.

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