ISSN 2072-0149

The AUST

Journal of Science and Technology

Volume-2 Issue-1 January 2010

Ahsanullah University of
Science and Technology

THE AUST
Journal of Science and Technology
Volume-2, Issue-1, January-2010

Study of the optoelectrical properties of vacuum evaporated CdSe semiconducting thin films

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Abstract: *Cadmium Selenide (CdSe) belonging to group II-VI semiconductors is a promising material for its applications in the area of electronics and optoelectronics. CdSe thin films of different thicknesses ranging between 100-250 nm, were deposited (both from CdSe compound and from elemental Cd and Se) onto clean glass substrate by using vacuum evaporation technique. The optical properties were revealed by UV-Visible transmittance spectra. Absorption coefficients of the films were determined using spectrophotometric measurements of the transmittance T at normal incidence in the spectral range of 300-2500 nm and band gap energy was determined. The transmittance for CdSe was found about 70% and for Cd+Se (elemental source) about 60% of incident ray. Energy gap of CdSe was found about 1.7 eV. The conductivity of these thin films were determined by I-V measurement using the electrometer and found their resistivity ranges from* $0.4x10^4$ *to* $2.7x10^4$ *ohm-cm. Activation energy of CdSe thin films was also calculated.*

1. Introduction

For the last few decades the II-VI binary semiconducting compounds belonging to the cadmium chalcogenide family (CdS, CdSe, CdTe) have drawn interest of many researchers because of their potential applications in the solid-state devices. CdSe has been extensively investigated for its potential applications in photoelectrochemical solar cell, optoelectronic devices and gamma ray detectors, high efficiency thin film transistors and light emitting diodes, photo-detectors, light amplifiers, lasers, gas sensors, large-screen liquid crystal display and a promising photovoltaic material because of its high absorption coefficient and nearly optimum band gap energy for the efficient absorption of light and conversion into electrical power. Semiconductor devices based on CdSe thin films strongly depend on the structural and optical properties of the films obtained from various experimental conditions.

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Nowadays, major attention has been given to the investigation of electrical and optical properties of CdSe thin films in order to improve the performance of the device and also for finding new applications. These properties of CdSe are very sensitive to deposition conditions and to the technique used. Therefore, the study of the properties of CdSe with respect to different growing as well as ambient conditions is a matter of high importance. Thermal evaporation under high vacuum is a very convenient method for obtaining uniform film under different deposition parameters. In view of this, an effort has been made to study optical and electrical properties of CdSe thin films prepared by vacuum evaporation technique [1-4].

K Girija et. al. [1] deposited CdSe thin films on glass substrate using chemical bath technique at different bath temperatures 313 K, 333 K and 353 K. From the UV-Visible transmittance spectra of these films they revealed the optical properties and determined the band gap energy. C. Baban et. al. [2] reported optical properties of CdSe thin films deposited by thermal evaporation under vacuum onto glass substrates and determined the absorption coefficient, optical band gap energy and refractive index from transmission spectra and found the values of the optical band gap energy, E_g, from 1.65 to 1.75 eV. D. Patidar et. al. [3] deposited thin film of CdSe onto clean glass substrate by using vacuum evaporation technique and found energy band gap 1.67eV. They observed that the conductivity of these thin films increase with the increase of temperature, due to the increase of grain size and removal of defects, which are present in the film. Pradip Kr. Kalita et. al. [4] reported that the current (*I*)–voltage (*V*) characteristics of thermally evaporated CdSe thin films and found nearly linear dependence at low voltage and afterwards a non-linear behaviour at higher voltage range. M. G. Syed Basheer Ahamed et. al. [5] deposited CdSe films onto glass substrates at different substrate temperatures between room temperature and 300 °C and concluded that the band gap values decrease from about 1.92 eV to 1.77 eV with the increase of the substrate temperature.

Thin films of CdSe as a semiconductor is well suited for optoelectronic applications such as photo detection or solar energy conversion, due to its optical and electrical properties, as well as its good chemical and mechanical stability. In order to explore the possibility of using this in optoelectronics, the study of optical and electrical properties of this material is an important step. Based on the above view, the optical and electrical properties of CdSe films have been studied thoroughly in the present work.

2. Experimental Details

2.1 Film Preparation

CdSe thin films were prepared from the commercially available CdSe compound material. For sample evaporation tantalum (melting point 3000°C) boat was used while melting point of CdSe is 1514°K or 1250°C. The evaporation was carried out at vacuum level 10^{-5} torr or better. The films were prepared under different conditions from the single boat at substrate temperature 200° C. Light brownish yellow colored CdSe thin films of area 2.6X2.6 cm^2 and thicknesses 100-200 nm were prepared. For CdSe thin films prepared from elemental sources, stoichiometric ratios of two elements were taken i.e. Cd: Se: 50: 50 atomic weights. Grinded Cd and Se material were placed in two separate boats at a distance 3 cm. So that the stream of two vapor-elements reaches central part of the substrate and react to give CdSe films of various thicknesses 200-250 nm at substrate temperature 30° C. Pure Al and Ag were taken for the preparation of electrode films for electrical measurement.

2.2 Spectrophotometric measurement

The spectrophotometric spectra were obtained by using a commercial spectrophotometer UV-NIR spectrophotometer (UV-3001 V spectrophotometer, SHIMADZU, JAPAN). From the reflection interferrometric pattern thickness of the films has been estimated.

2.3 I-V Studies and Resistivity measurement

Dc voltage from stable power supply (Heathkit Regulated H.V. Power Supply, Model IP-17) was applied across the electrodes at the two ends of the sample and the current through the sample was measured by a digital electrometer (Keithley, 614 Electrometer). The entire circuitry was kept inside a metal box for electrical shield. The box also ensured the current measurement in the dark.

2.4 Activation energy measurement

For the measurement of activation energy at high temperature i.e. above room temperature, the sample temperature was monitored by a digital thermometer. The variation of current passing through the sample was observed with the variation of temperature at a fixed voltage. From these I-T data conductivity may be evaluated as a function of temperature.

3. Result and Discussions

3.1 Spectrophotometric analyses

The optical transmittance spectra of CdSe thin films prepared at substrate temperatures200° C, is recorded as a function of wavelength in the range of 200-2500 nm as shown in Fig. 1. Transmission spectra indicate that the sharp absorption occur around 700 nm. The compound CdSe powder material deposited on the glass substrate showed a transmittance of 70% and for elemental Cd+Se powder the transmittance is about 60%. The optical absorption is known to arise through the interactions of the excited electrons with the lattice perturbed by variations or imperfections.

From the recorded optical transmission spectra of CdSe thin films, absorption coefficient and other parameters were calculated. The absorption coefficient α was plotted against the photon energy and shown in Fig. 2(a). It is observed that the α is high at lower wavelength and decreases sharply below a certain wavelength. The fundamental absorption, which corresponding to the transition from the valence band to the conduction band, can be used to determine the band gap of the material.

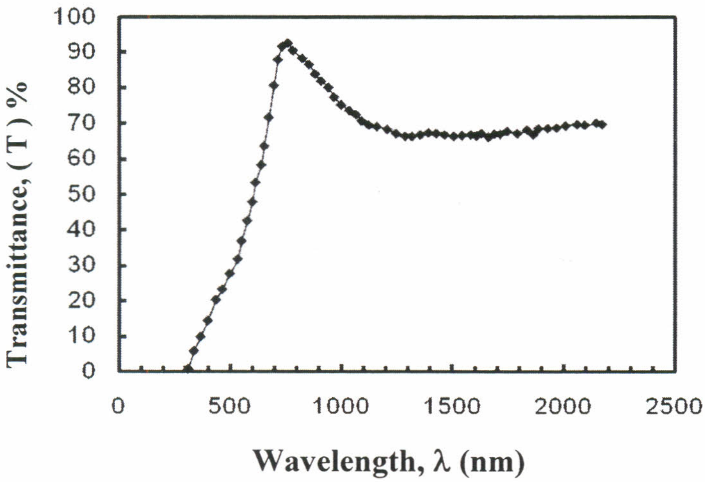
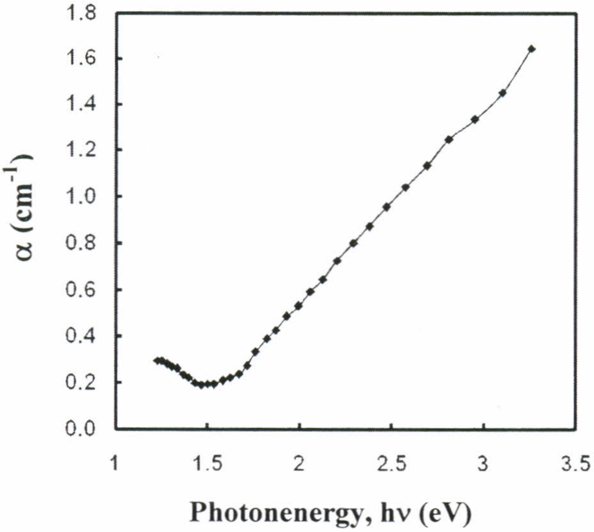


Fig 1. Optical transmittance T(%) at different photon wavelength of CdSe thin films prepared at 200° C.



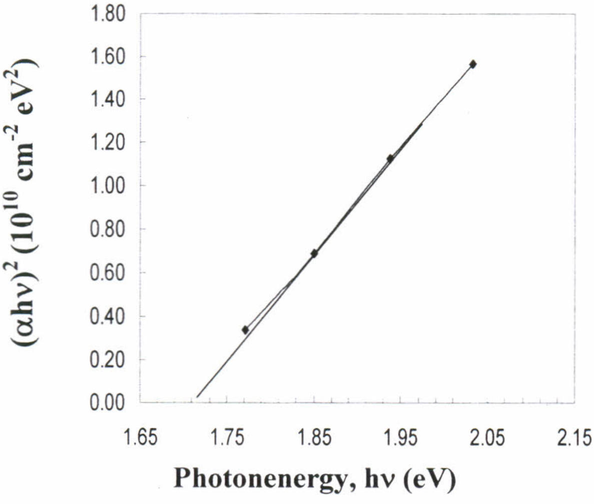


Fig.2 The dependence of (a) absorption coefficient, α and (b) $(\alpha h\nu)^2$ on photon energy ($h\nu$) of CdSe thin films, prepared at 200°C.

In order to determine the optical band gap the Tauc relation [6] was used : $(\alpha h\nu) = A\,(h\nu - E_g)^n$, where A is a constant, E_g, is the energy band gap of the material and the exponent n is an index that may have values ½ or 2 depending on the type of electronic transitions. Using this relation, a graph is plotted between $(\alpha h\nu)^2$ and $h\nu$ to obtain a straight line which is shown in Fig. 2 (b). From the intercept of $h\nu$ axis we have estimated energy gaps E_g of CdSe thin films prepared at various substrate temperatures, assuming that for direct band gap semiconductors $h\nu \propto (h\nu\text{-}E_g)^{1/2}$ holds good. Energy gap was found about 1.7 eV, which is believed to be standard forbidden gap energy of CdSe thin films [3, 7].

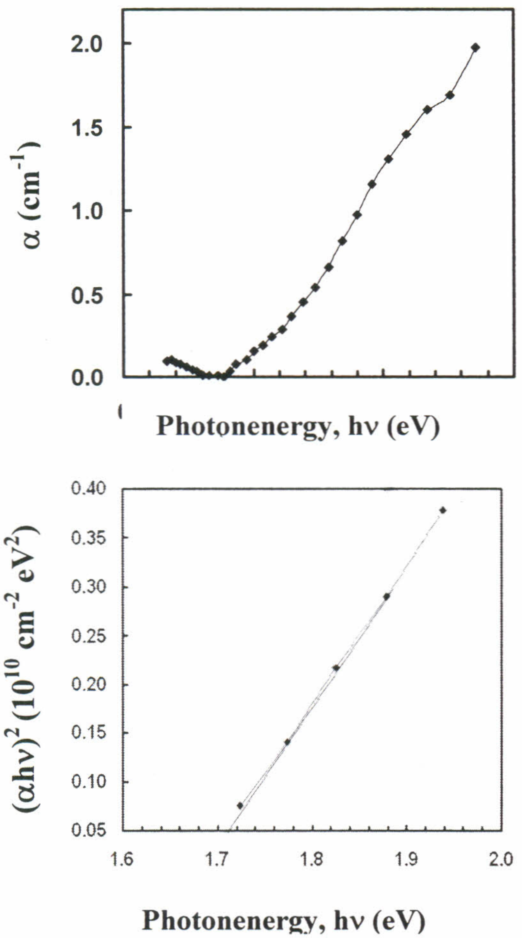


Fig. 3 The dependence of (a) absorption coefficient, α and (b) $(\alpha h\nu)^2$ on photon energy $(h\nu)$ of CdSe thin films, deposited simultaneously from elemental (Cd and Se) sources at 50°C.

Again, CdSe thin films were prepared from the elemental sources (Cd and Se) at 50° C, by evaporating Cd and Se simultaneously. The absorbance of these samples are plotted as a function of photon energy in Fig.3(a). The calculated energy gap E_g is found to be 1.71 eV from $(\alpha h\nu)^2$ versus photon energy curve Fig. 3(b).

3.2 I-V characteristics

Variation of current (I) with applied voltage (V) for the considered thin films are linear (ohmic) within the entire range of applied voltage and shown in Fig. 4. The I-V characteristics have been studied over a wide range of applied voltage up to 120 V. Throughout this voltage range ohmic behavior has been found to remain valid since the injected charge carrier density is lower than the thermally generated carrier density and that leads to ohmic behavior [4]. From the study of I-V characteristics we have evaluated the resistivity and conductivity of CdSe samples. All the samples show very high resistivity lying in the range $(0.4\text{-}2.7)*10^4$ ohm-cm.

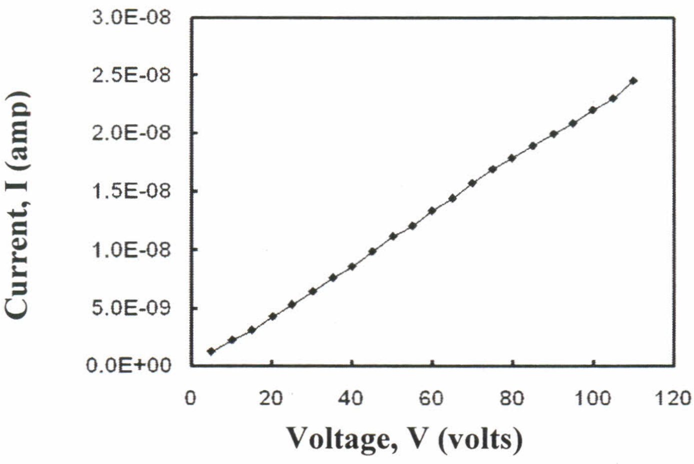


Fig.4. I-V characteristics of CdSe thin films.

3.3 Activation energy measurement

The variation of current versus temperature is shown in Fig.5. There is not much variation till the temperature is reached 80°C and then there is a rapid increase of current. The initial rise may be due to the presence of impurities or native lattice defects and sharp increase may be due to intrinsic inter band transition. This is explained in terms of structural changes occurring in this thin film with temperature. In as deposited thin films of CdSe, there is some lattice defects, geometrical and physical imperfections randomly distributed on the surface and the volume of the film [8]. The roughness of the surface, grain boundaries and inclusions in the volume are the main components of the geometrical imperfections. The important factor, which is responsible for the physical properties of thin film, is the structure. The film is composed of randomly oriented grains with the appearance of the grain boundaries. An increase of temperature of the films affects the structure significantly causing a considerable increase in the mean size of the grain [3] and a decrease in the grain boundary area.

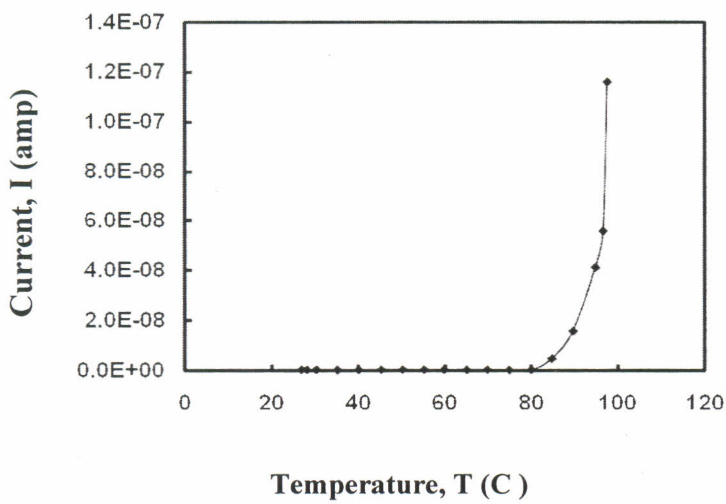


Fig.5. The dependence of current I (amp) on temperature T(C), of CdSe thin films prepared at 200° C.

This decrease is due to the migration of the smaller crystallites and joining of those grains, which are similarly oriented, to form bigger crystallites. Because of these structural changes the intergrain boundary area decreases i.e. there is a decrease in the scattering of electrons. Consequently, the carrier concentration also increases with the increase of temperature.

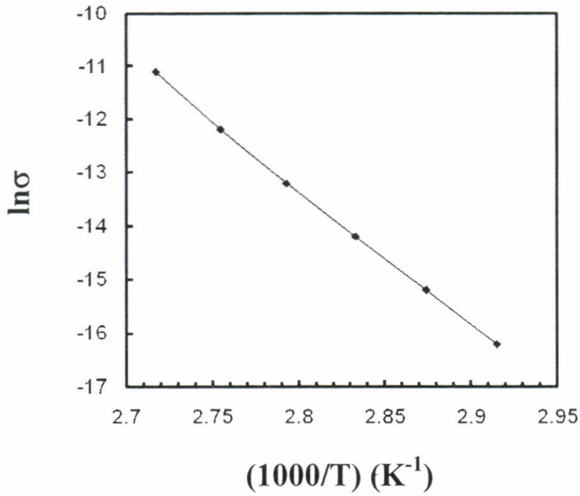


Fig.6 Variation of lnσ versus (1000/T) for CdSe thin films prepared at 200°C.

This in turn increases the conductivity of a given sample. For highly resistive thin films conductivity (σ) can be expressed as a dependent of temperature in terms of activation energy of the state responsible for contribution to conductivity rather than band energy E_g i.e. $\sigma = \sigma_o \exp(E_a/kT)$ where E_a is the activation energy of the electrical conduction, k is the Boltzmann constant and T is the absolute temperature. The average activation energy was found 1.8 eV from the plot of lnσ versus (1/T) X 1000 which is shown in Fig.6. It suggests that the conduction in these thin films is due to the thermally assisted tunneling of the charge carriers through the grain boundary barrier and transition from donor level to conduction band [9].

4. Conclusions

CdSe thin films of different thicknesses have been prepared by vacuum evaporation technique. The transmittance for CdSe was found about 70% and for Cd+Se about 60% of incident ray. Energy gap of CdSe was found about 1.7 eV which is the same as the reported value. I-V measurement shows the ohmic nature of the films. The increase in the electrical conductivity with the increase of temperature is due to the increase of grain size and carrier density. From resistivity measurement it is found that these films are highly resistive and their resistivity ranges from $0.4\mathrm{X}10^4$ to $2.7\mathrm{X}10^4$

ohm-cm. So these films are good candidate for manufacturing different electronic circuits. This study reveals that, if carefully controlled experiment could be done to evaporate the source materials, films could be fabricated that may prove useful in semiconductor devices.

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