Synthesis and Characterization of Nanocrystalline Screen-Printed CdS Thick Films

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ABSTRACT

This paper describes structural, optical and electrical properties of CdS thick film prepared by using screen printing method. For the preparation of CdS thick film, powder of CdS nanoparticles was prepared by using chemical precipitation method using cadmium acetate and sodium sulfide as a source of Cd^{2+} and S^{2-} respectively. XRD pattern confirms the formation of pure hexagonal CdS phase with crystallite size of the order of 29.12 nm for sintered CdS thick films. The transmittance spectra of sintered CdS thick film were recorded by using JASCO V-630 spectrophotometer in the wavelength range of 200-900 nm from which energy band gap has been determined and is found to be 2.30 eV for sintered CdS thick film. Electrical studies showed that the semiconducting behavior of the prepared films. It has been observed that at room temperature electrical resistivity value of the thick film are 2.65×10^5 Ωcm and value of activation energy comes out about 0.14 eV.

1. INTRODUCTION

The use of thin film nanocrystalline semiconductors has attracted much interest in an

expanding variety of applications in various electronic and optoelectronic devices. The technological interest in nanocrystalline-based devices is mainly caused by their very low production costs. CdS is an important II-VI group compounds semiconductor material. CdS films are regarded as one of the most promising materials for hetrojunction thin film solar cells. Wide band gap CdS has been used as the window material together with several semiconductors such as Cu_2S / CdS [1] and CdS / $CuInSe_2$ [2]. However due to high cost of such a material, studies were developed towards nanocrystalline semiconductor and particularly thin nanocrystalline films[3].

Several techniques have been used to produce CdS thin film such as chemical bath deposition[4,5], thermal evaporation[6,7], spray pyrolysis[8], screen printing followed by sintering[9] and chemical route using organic substances[10]. Generally in each of these methods, nanocrystalline, stable, uniform, adherent and hard films are obtained. Screen-printing is an inexpensive and convenient technique for large area preparation of the films. This technique is suitable for coating surfaces of any morphology and geometry. In particular screen-printing is low cost and relatively simple technique for achieving good quality thick films. CdS has been the subject of intensive research because of its intermediate band gap, high absorption coefficient, reasonable conversion efficiency, stability & low cost[11,12]. CdS thin films are well known for their extensive applications as an optoelectronic material in solar cells[13,14] and photo detectors[15].

In the present paper optimum conditions for depositing good quality CdS screen printed films and optical, structural, electrical properties have been studied.

2. EXPERIMENTAL DETAILS

In present investigation, CdS films were prepared by screen-printing followed by sintering process[16-19]. In the present work, powder of CdS nanoparticles was prepared by the chemical precipitation method using AR grade cadmium acetate $Cd(CH_3COO)_2.2H_2O$ and sodium sulfide ($Na_2S.9H_2O$) as a starting compounds were procured from Loba chemical company. Chemical reaction was carried out at room temperature. 50ml solution of 1M $Cd(CH_3COO)_2.2H_2O$ and 1M $Na_2S.9H_2O$ were prepared separately using deionized water, mixed in 250 ml beaker and the mixture continuously and vigorously stirred for 3 hours and consequently a dark yellow CdS precipitate formed which was filtered out and washed several times with distilled water and methanol. Finally, the product was dried for 24 hours in open air. When the precipitate was completely dried, it was then crushed to fine powder by grinding process using a mortar and pestle. The obtained powder was used for the preparation of CdS thick film by using screen printing method. A paste for the preparation of CdS thick film was prepared by mixing synthesized powder with $CdCl_2$ used as an adhesive agent, grinding in a mortar followed by addition of ethyl alcohol as a binder. The prepared paste was screen printed on glass substrates which have been cleaned using the standard procedure reported in[20]. The obtained film was dried at 120ºC for three hours in order to reduce the solvents partially and to avoid the cracks in the film[21,22]. The CdS thick film was then annealed in a muffle furnace in an open atmosphere at 250ºC for one hour so as to stabilize the film and to burn the organic

materials[22]. Thickness of the prepared CdS thick film was measured by using weight difference method and was found to be of the order of 8.5 μm. All the films were synthesized under the same experimental conditions.

3. TECHNIQUES OF CHARACTERIZATION

The optical transmittance versus wave length traces of the film were recorded in 200-900 nm wavelength range using a Jasco V-630 spectrophotometer. The XRD traces were recorded using Bruker D8 Advance X-ray diffractometer. The X-rays were produced using a sealed tube and the wavelength of x-ray was 0.154 nm (Cu K-alpha). The x-rays were detected using a fast counting detector based on Silicon strip technology (Bruker LynxEye detector). The electrical resistivity of the films was measured using standard two-probe technique.

4. RESULTS AND DISCUSSION

4.1 Optical Properties

The optical transmittance of the films was measured at room temperature in 200-800 nm wavelength range using a UV-VIS spectrophotometer. Almost all the II-VI compounds are direct band gap semiconductors. According to Tauc relation[23], the absorption coefficient for direct band gap material is given by

$$\alpha h\nu = A (h\nu - E_g)^n \tag{1}$$

Where $h\nu$ is photon energy, A is constant which is different for different transitions and E_g is the band gap, and n is equal ½ for direct band gap material. It has been observed that plots of $(\alpha h\nu)^2$ Vs $(h\nu)$ are linear over a wide range of photon energies indicating the direct type transitions. The extrapolation of these plots on the energy axis gives energy band gaps. Fig.1 represents the transmittance spectra of CdS screen-printed sintered film. For determination of band gap we have plotted a graph between $(\alpha h\nu)^2$ Vs $(h\nu)$ as shown in fig. 2. The extrapolation of straight line on the energy axis gives a band gap of 2.30 eV for CdS screen printed sintered film, which is very close to values reported in other studies[8-10].
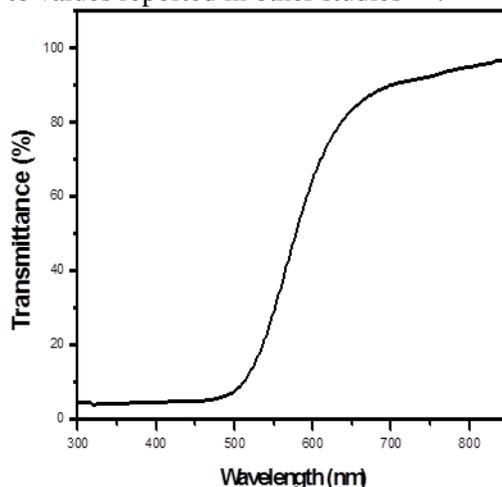

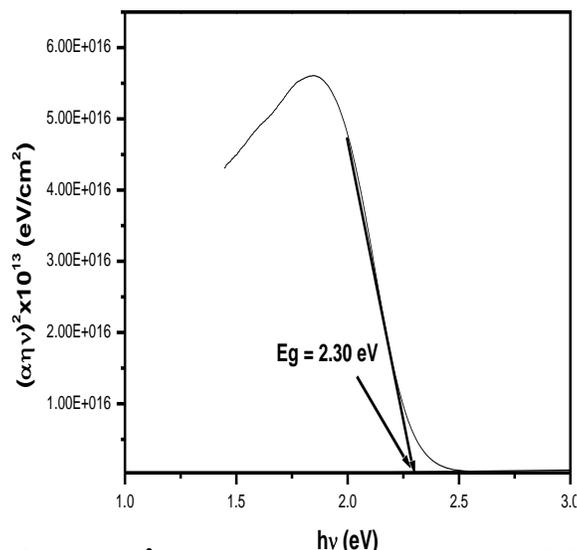**Fig 1. Optical transmission spectra of screen-printed sintered CdS film.**

Fig. 2. Plot of $(\alpha h\nu)^2$ Vs. hν of the screen-printed sintered CdS film.
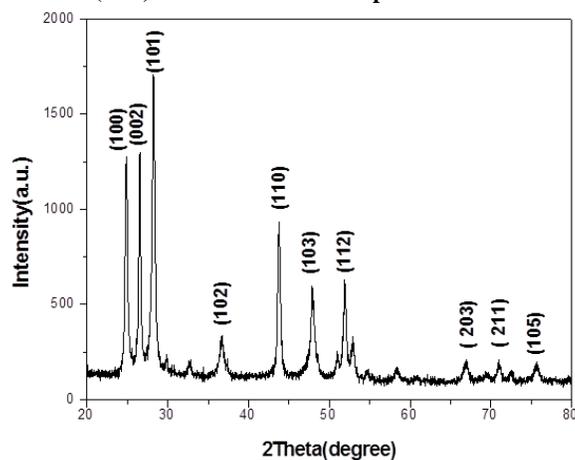

Fig 3. XRD Pattern of CdS screen-printed sintered thick film.

4.2. Structural Properties

The X-ray diffraction pattern of CdS screen printed sintered film for structural analysis is shown in Fig 3. The d-values were calculated by calculating θ values from the peaks of the X-ray spectrum by using Bragg's relation $2d\sin\theta = n\lambda$ (n=1 in present study and λ= 1.54045 for CuKα). These d values were compared with the standard ASTM data to confirm the structure of CdS. Fig. 3 is X-ray diffraction pattern of screen printed CdS film with CuKα radiation. The experimental d-values of CdS screen-printed sintered film are in good agreement with the ASTM d-values of CdS having hexagonal structure, shown in Table 1. The

well-defined peaks at 2θ correspond to reflections from planes of pure hexagonal CdS phase, respectively[24]. The presence of sharp structural peaks in XRD confirmed the polycrystalline nature of CdS films.

The average crystallite size was calculated for well-defined peaks by Debye-Scherer's formula[25]. It was found to be 29.12 nm for annealed CdS thick films.

Table 1

Sr.No.	2θ	d(exp)(A^0)	d(ASTM)(A^0)	Plane hkl
1.	24.858	3.5787	3.5688	(1 0 0)
2.	26.508	3.3568	3.3410	(0 0 2)
3.	28.195	3.1601	3.1480	(1 0 1)
4.	36.700	2.4466	2.4390	(1 0 2)
5.	43.742	2.0645	2.0605	(1 1 0)
6.	47.896	1.8969	1.8895	(1 0 3)
7.	51.895	1.7597	1.7537	(1 1 2)
8.	66.916	1.3970	1.3926	(2 0 3)
9.	71.003	1.3263	1.3222	(2 1 1)
10.	75.642	1.2561	1.2515	(1 0 5)

4.3. Electrical properties

The electrical transport properties of the materials are of great importance in determining the congruency of the material with our necessities. The electrical properties are dependent on various films and growth parameters such as film composition, thickness, and substrate temperature and deposition rate. For photovoltaic applications, important characterization includes electrical resistivity.

4.3.1 Electrical Resistivity measurements

The measurements on electrical resistivity of the CdS thick films were carried out in the temperature range 300-423 K on rectangular-shaped samples with typical size of 10 mm^2, using a standard DC two point probe method under dark. The variation of log ρ versus inverse of absolute temperature ($\frac{1000}{T}$) for the film shown in Fig.4 reveals that the resistivity variation obeys the relation,

$$\rho = \rho_0 \exp\left(\frac{Ea}{kT}\right) \quad\quad\quad (2)$$

where Ea is the activation energy and k is the Boltzmann constant. It is well known that the resistivity of a semiconducting material strongly depends on the temperature, carrier concentration and mobility. In a semiconductor, carrier concentration is a rapidly increasing function of temperature. This increase due to thermal excitation of electrons, either from imperfections or across the band gap. It is clear from Fig.4 that the resistivity decreases as the temperature increases, showing semiconducting behavior of the CdS thick films. Yadav *et al.*[26]

also observed similar kind of result for the CdS thin film prepared by spray pyrolysis technique. The room temperature electrical resistivity value of the thick film are 2.65 x 10^5 'Ωcm and value of activation energy comes out about 0.14 eV, which is in good agreement with reports[27].

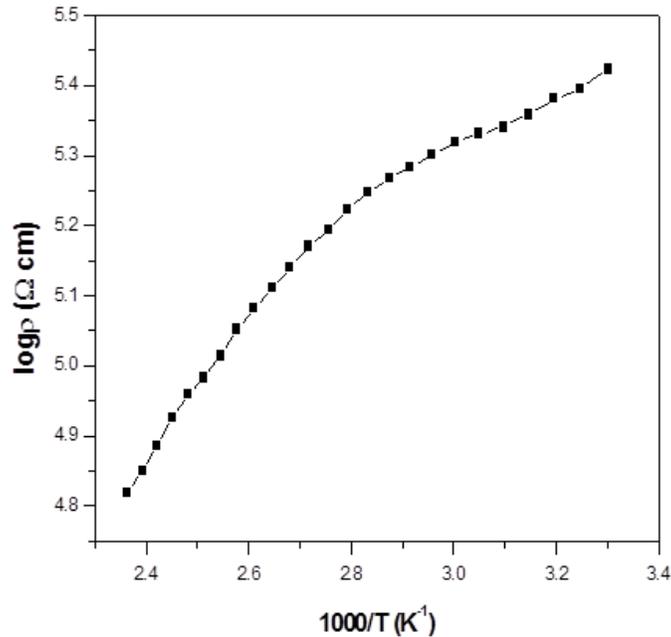**Fig 4. Plot of log ρ versus 1000/T for CdS screen-printed thick film.**

5. CONCLUSIONS

The optical, structural and electrical properties of screen-printed sintered CdS films were investigated. The band gap of CdS screen-printed thick film comes out to be 2.30 eV. Films of CdS were found to be polycrystalline in nature and have hexagonal wurtzite structure. It has been observed that at room temperature electrical resistivity value of the thick film are 2.65 x 10^5 'Ωcm and value of activation energy comes out about 0.14 eV Due to optimum band gap, polycrystalline nature, stable material, fairly electrical resistivity and activation energy, CdS screen printed sintered films may be suitable for solar cells, wide band gap window material and other photovoltaic devices. Screen-printing technique is simple, inexpensive, viable and attractive means of obtaining films of II-VI semiconductors.

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