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Optical Properties of In-doped CdS Thin film prepared by Electrochemical Deposition Used as Window Layer in Thin film Solar Cell

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Abstract

Pure CdS and In-doped CdS thin films were deposited using simplified 2-electrode electrochemical deposition technique and investigated using cyclic voltammetry, XRD, UV-Visible spectroscopy and Hall Effect by vander pauw method. 1%, 2%, and 3% 0.1 M $InCl_3$ was used for In-doping. The effect of In-doping on dislocation density and microstrain has been estimated from XRD data. Absorption, transmittance, and refractive index were investigated in spectral range 200-1100 nm by variation upon In-doping. The band gap was found to decrease from 2.40 to 2.20 eV with increase in In-content from 1% to 2%, and increases about 2.26 eV at increase in In-content from 2% to 3%. 2% In-content in CdS thin film show highest transparency due to low refractive index at wavelength 565 nm in visible region. The electrical resistivity, carrier concentration, mobility, and hall coefficient were directly estimated by vander pauw method. In-doped CdS thin film show n-type electrical conductivity and it may be further used as window layer in thin film solar cell.

1.Introduction:

CdS is the II-VI group semiconductor material has lot of attention in material science from very few decades due to modification of optical and structural properties quantum confinement effect [1,2] and electro-optical properties was varied by various ion doping [3,4]. CdS is n-type semiconductor material with direct optical bang gap energy 2.4 eV at room temperature. Due to its electro-optical properties its use in application thin film solar cell [5, 6], thin film transistor [7, 8], photo diodes [9], and light emitting diode [10]. CdS can be exist in two crystal phase cubic (Zinc blende) and Hexagonal (Wurtzite) [11]. CdS can be deposited by various techniques such as spray pyrolysis [12], chemical vapour deposition [13, 14], RF sputtering [15], chemical bath deposition [16], electrochemical deposition [17]. The electro-optical properties of CdS can be controlled by doping process. CdS can be doped with metallic ions such as Al^{3+} [18], Ni^{2+} [19], In^{3+} [20], Cu^{2+} [21]. Doping can improve the structural and electro-optical properties of CdS. In this work we have prepared pure and In-doped CdS thin film by using simplified 2-electrode electrochemical deposition technique. For this method, cadmium sulphate and sodium thiosulphate were used as precursor for pure CdS thin film. The In-content in CdS thin film can be regulated by adding controlled amount of Indium trichloride with desired percentage in ml with respect to total electrolyte bath of pure CdS film. The effect of In-content on structural, optical, and electrical properties of CdS thin film was investigated in details.

2.Experimental Details:

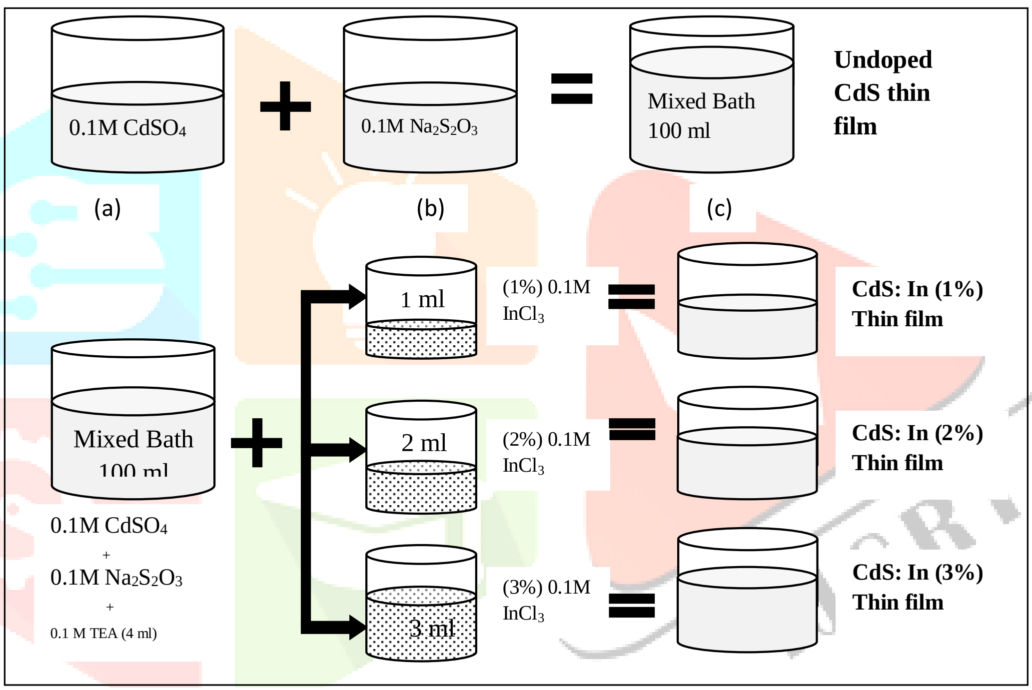

Fig.1 .Illustrate the chemical abstract for preparation on undoped and In- doped CdS thin film

Fig.1. showed the chemical abstract of preparation of In-doped thin film process. The main advantages of electrochemical deposition process are simplicity, low cost, and low chemical waste. The simplified 2-electrode electrochemical deposition method has been used to deposit pure and In-doped CdS thin film. The stainless steel and FTO glass were used as substrate. 0.1 M $CdSO_4$ (Cadmium Sulphate), 0.1M $Na_2S_2O_3$ (Sodium Thiosulphate), and 0.1M $InCl_3$ (Indium Trichloride) were used as precursor for Cd, S, and In ions respectively. A triethanolamine (TEA) was used for complexing agent. 1%, 2%, and 3% 0.1 M $InCl_3$ was added in main electrolyte bath to regulate the In-doping in CdS thin film. In this work we have prepared pure and In-doped CdS thin film by electrodeposition method and further characterized by XRD, and UV-Visible spectroscopy for structural and optical properties studied respectively.

3.Result and Discussion:

Cyclic Voltammetry:

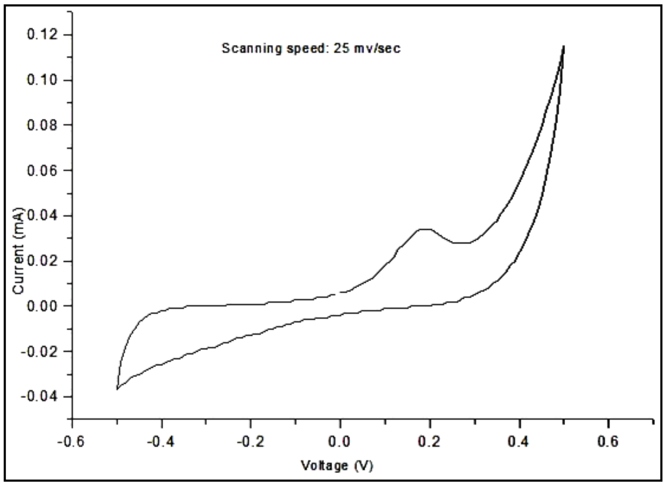

Fig.2 cyclic voltammetry of 0.1 N $CdSO_4$, 0.1 N $Na_2S_2O_3$ and 0.1 N $InCl_3$ mixed electrolyte bath at scanning speed 25 mV/Sec

As per fig.2.The cyclic voltammetry was used to investigate electrochemical behavior of Cd, S, and In ions. During the forward scanning at speed 25 mV/Sec the anodic peak was found at +0.5V with respect to reference electrode Ag/AgCl due to dissociation of ions. During recerse scanning cathodic peak was found at -0.5 V with respect to Ag/AgCl. It concluded that, the In-doped CdS thin film was well deposited at -0.5 V.

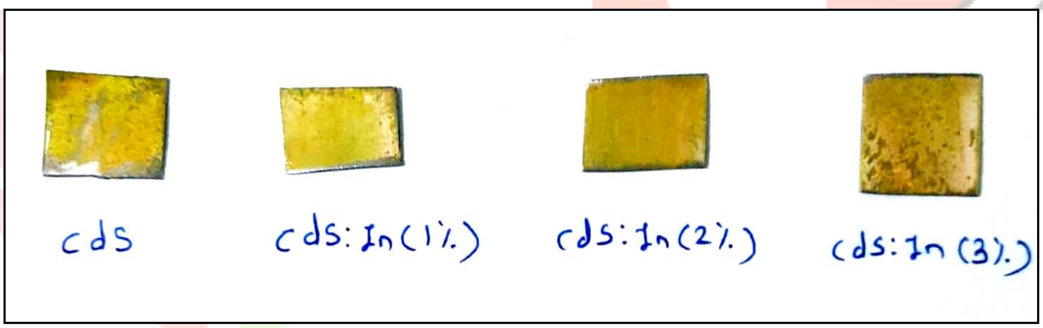

Fig.3. Illustrate the undoped –CdS and In-doped CdS thin films deposited by simplified 2-electrode electrochemical deposition method

X-ray Diffraction Analysis:

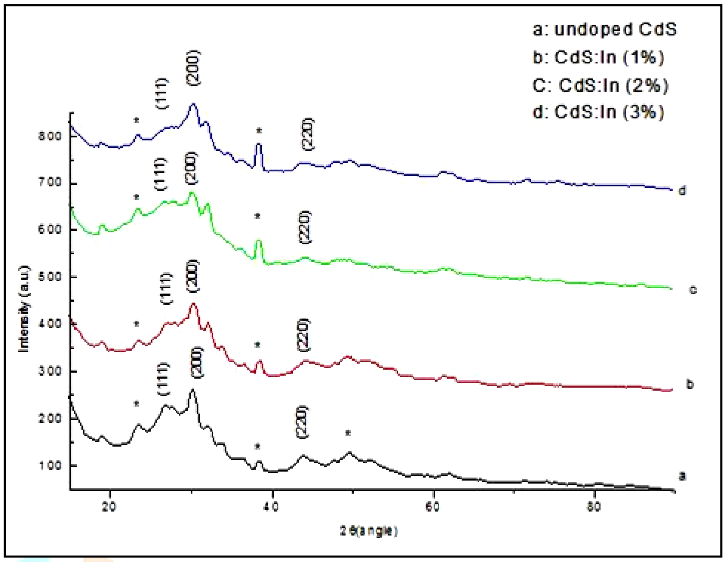

Fig.4. XRD pattern of (a) Undoped CdS (b) CdS: In (1%) (c) CdS: In (2%) (d) CdS: In (3%) thin films

Figure.4 shows the XRD pattern of Pure and In-doped CdS thin films. After XRD pattern investigated the peaks were found at orientation of plane (111), (200), and (220) are perfectly matched to standard database (JCPDS No-01-080-0019). It confirmed the deposited film crystal exhibit Zincblende cubic structure with no peaks of In_2S_2 were detected. The crystallite size of Pure CdS, CdS: In (1%), CdS: In (2%) and CdS: In (3%) thin films at preferred orientation of plane (220) were estimated by using equation Debye Scherrer equation about 11.18 nm, 9.63 nm, 8.45 nm and 10.16 nm respectively. The decrease in crystallite size due to adding of the indium ions substitutionally and interstitially causes lattice strain or compression. The dislocation density and microstrain were also estimated and are listed in Table-1

Table.1 Shows estimated values of average crystallite size, dislocation density and microstrain of a) undoped CdS thin film b) CdS: In (1%), c) CdS: In (2%) and d) CdS: In (3%) thin films

Thin film Samples	2θ for plane (220)	d-spacing	Lattice constant a(A^0)	FWHM	Average Crystallite Size (nm)	Dislocation density(δ)x 10^{-3}(nm^{-2})	Microstrain (ϵx10^{-3})
Undoped CdS	43.72	2.0673	5.84	0.8	11.18	8.00	498.62
CdS: In (1%)	44.12	2.0493	5.79	0.93	9.63	10.78	573.79
CdS: In (2%)	44.25	2.0463	5.78	1.06	8.45	14.00	651.90
CdS: In (3%)	43.58	2.0764	5.87	0.88	10.16	9.68	550.41

UV-Visible spectroscopy:

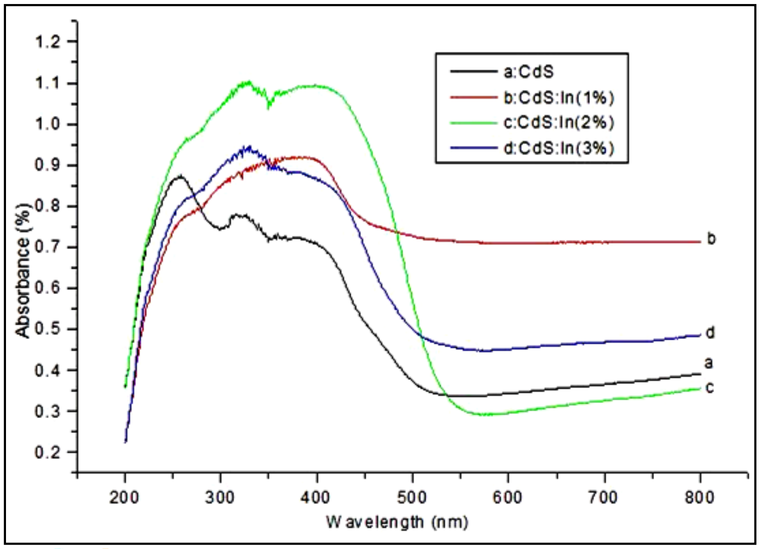

Fig.5. Optical absorption spectra of a) Undoped CdS thin film b) CdS: In (1%) c) CdS: In (2%) d) CdS: In (3%) e) CdS: In (4%) thin films

The optical properties such as absorption spectra were carried out by UV-Visible spectroscopy with scanning wavelength from 200 nm to 800 nm. As per fig.5 it has been found that the absorption increases from 436 nm to 543 nm upon increasing In-content in CdS thin film.

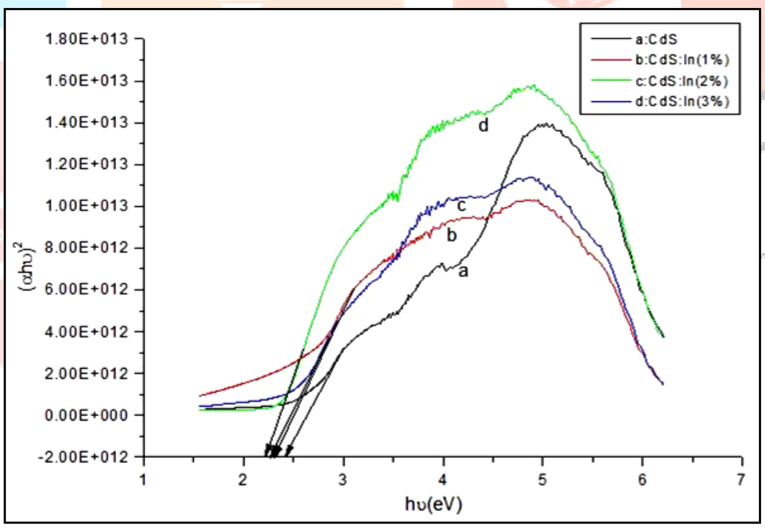

Fig.6. Energy Band Gap of a) Undoped CdS thin film b) CdS: In (1%) c) CdS: In (2%) d) CdS: In (3%) thin films

The band gap energy of pure CdS and In-doped CdS thin films were estimated tauc plot by equation (1) shown in fig.6.

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

The optical band gaps energy was estimated about 2.40 eV, 2.30 eV, 2.20 eV, and 2.26 eV of pure CdS, CdS: In (1%), CdS: In (2%), and CdS: In (3%) respectively. The band gap energy was varied from 2.40 eV to 2.26 eV upon increasing In-content in CdS from 1%-3%. The band gap energy was found lowest about 2.26 eV at 3% In content in CdS thin film.

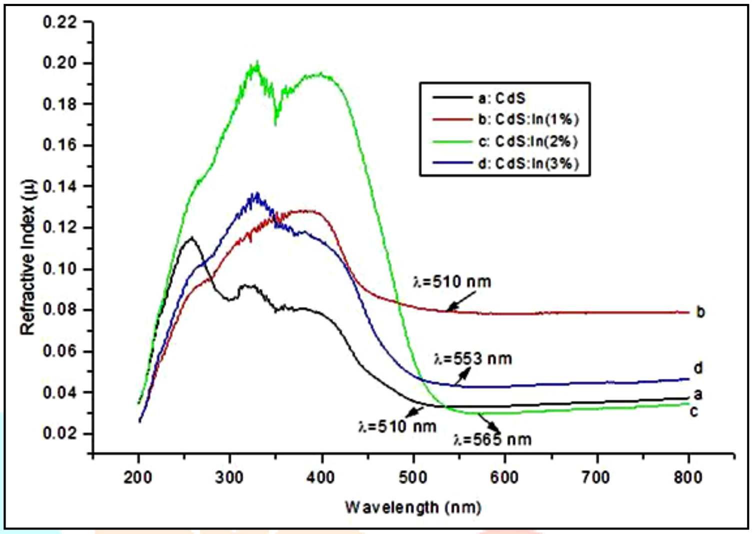

Fig.7. Refractive index versus wavelength relationship of a) undoped CdS b) CdS: In (1%) c) CdS: In (2%), and d) CdS: In (3%) thin film

The refractive index of pure CdS and In-doped CdS thin films was estimated by using following equation

$$n = \frac{1}{TS} + \sqrt{\frac{1}{Ts-1}} \qquad (2)$$

Where, n is refractive index, Ts is percent transmittance. The percent transmittance (Ts) was calculated by using following equation

$$Ts = 10^{(-A)} X100 \qquad (3)$$

Where, A is absorbance, CdS: In (2%) has highest transparency due to very low refractive index has been found at wavelength 565 nm in visible region. So CdS: In (2%) thin film may be employed for window layer in thin film solar cell. The refractive index was varied upon In-content in CdS thin film.

4. Conclusion:

The pure CdS and In-doped CdS thin film was successfully deposited by 2-electrode electrochemical deposition technique. The XRD pattern shows that Zincblende cubic phase exist with average crystallite size was ranging from 11.18 nm to 8.45 nm. Upon In-doping microstrain and dislocation density was found to increase at In-2%. The optical band gap shift from 2.40 to 2.26 eV. The band gap was decreased upon In-doping. The highest transparency due to low refractive index was found at In-2% in CdS thin film. The refractive index was varied upon In-content in CdS thin film.

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