

## PHOTOCONDUCTIVITY AND PHOTOLUMINESCENCE STUDIES OF CHEMICALLY DEPOSITED Cd(S-Se):CdCl<sub>2</sub>,Dy FILMS

R. S. SINGH, S. BHUSHAN<sup>a</sup>

*S.o.S. in Physics, Pt. Ravishankar Shukla University, Raipur (C.G.)-492010, India.*

*<sup>a</sup>Present address : Shri Shankaracharya College of Engineering & Technology, Junwani, Bilai, Durg (C.G.)*

Results of SEM and XRD studies, Optical Absorption Spectra and Photoconductivity (PC) rise and decay are reported for Cd(S-Se):CdCl<sub>2</sub>,Dy films prepared by chemical deposition method on glass substrates at 60<sup>o</sup>C in a water bath (WB). SEM studies show ball type structure with voids which is related to layered growth. XRD studies show prominent diffraction lines of CdS and CdSe along with lines of CdCl<sub>2</sub>. The values of strain ( $\epsilon$ ), grain size (D) and dislocation density ( $\delta$ ) are evaluated from XRD studies and the nature of crystallinity of the films are discussed. Optical Absorption spectra also show the presence of Dy in the lattice. From the results of optical absorption spectra, the band gaps are determined. Sufficiently high photo current ( $I_{pc}$ ) to dark current ( $I_{dc}$ ) ratios with a maximum value of the order of 10<sup>6</sup> are obtained. This high photosensitization is related to increase in mobility and life time of carriers due to photo excitation. PL emission spectra consist of peaks due to transitions in Dy levels.

(Received November 22, 2008; accepted December 3, 2008)

*Keywords:* Photoconduction, Photoluminescence, Energy band gap, X-ray diffraction.

### 1. Introduction

PC studies form an important class of electro-optical property of materials, particularly on CdS type materials, because of their wide technological applications such as IR detectors and solar cells etc. PL studies on such materials are also important because of their applications as lamp phosphors and display devices etc. Impurities, particularly the rare earth ions play a great role in these phenomena. These ions when incorporated into a solid show distinct spectral lines of absorption and emission as a result of the electronic transitions within the 4f<sup>N</sup> shell configuration [1]. The rare-earth ions are characterized by a partially filled 4f shell that is well shielded by 5s<sup>2</sup> and 5p<sup>6</sup> orbitals. The emission transitions, therefore, yield sharp lines in the optical spectra. The use of rare-earth element-based phosphors, therefore, based on “line-type” f-f transitions, can narrow the emission in the visible region, resulting in both light efficiency and a high lumen equivalent [2]. Although preparation of CdS films were reported by a variety of techniques e.g. vacuum evaporation, spray pyrolysis, molecular beam epitaxy etc.[3], the chemical deposition technique has drawn interest of a number of workers. This is one of the cheapest and simplest techniques for forming films. Chemical deposition techniques for metal chalcogenide semiconductor thin films refer to the deposition of thin films on substrates maintained in contact with dilute chemical bath containing the metal and chalcogen ions [4]. Bhushan and coworkers [5-8] used chemical deposition technique and reported quite high photo-sensitivity, PL, Photovoltaic effect and AC electro-luminescence in such films. The utility of chemical deposition method in metal chalcogenide thin films was reviewed by Mane and Lokhande [9]. Since Cd(S-Se) has advantage over CdS in changing the band gap of the material [for CdS : E<sub>g</sub> = 2.4 eV, for CdSe : E<sub>g</sub> = 1.7 eV] which subsequently influences its electro-optical properties, in the present work films of

mixed system Cd(S-Se) doped with Dy<sup>3+</sup> have been prepared using chemical deposition technique. For its proper incorporation into the lattice, CdCl<sub>2</sub> has been used as flux which may also help in recrystallization of Cd(S-Se).

In the present paper, various characterization techniques such as SEM, XRD, optical spectroscopy are employed to study the Cd(S-Se):CdCl<sub>2</sub>,Dy films, not explored earlier and the corresponding results are discussed.

## 2. Experimental

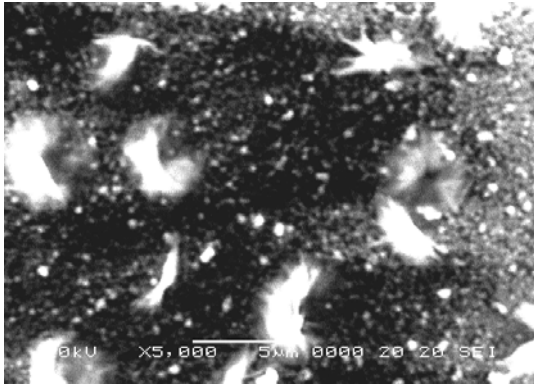
**Preparation of films** : Chemical bath deposition technique was used to deposit films of Cd(S-Se):CdCl<sub>2</sub>;Dy on glass substrates (cleaned with acetone and doubled distilled water) of dimensions(24 mm x 75 mm) dipped vertically into a mixture of solutions of 1M cadmium acetate, appropriate ratio of thiourea and sodium seleno-sulphate [Na<sub>2</sub>SeSO<sub>3</sub>] solution { prepared by heating elemental selenium (99.9% pure) in aqueous solution of sodium sulphite [Na<sub>2</sub>SO<sub>3</sub>] at 90<sup>0</sup>C for 5 hrs.}, triethanolamine and 30% aqueous ammonia. All the chemicals used were of AR grade (make : S.D.Fine-chem. Ltd., Mumbai). All the solutions were prepared in double distilled water. For preparing doped films, calculated proportions of 0.01M solutions of dysprosium nitrate and cadmium chloride were added to the original mixture. After the depositions, the films were cleaned by flushing with distilled water and then dried by keeping the samples in open atmosphere at room temperature.

Triethanolamine and ammonia solution were used to adjust pH of the reaction mixture and to increase film adherence. To obtain good quality films time, temperature of deposition and pH of the solution were optimized. The optimum time, temperature and pH were observed to be 1 hr., 60<sup>0</sup>C and 11.2 respectively. Film thickness were determined by optical interference method and were found to lie in the range of 0.4694 –0.4837 μm. Annealing of the films was done at a temperature of 400<sup>0</sup>C for 2 minutes.

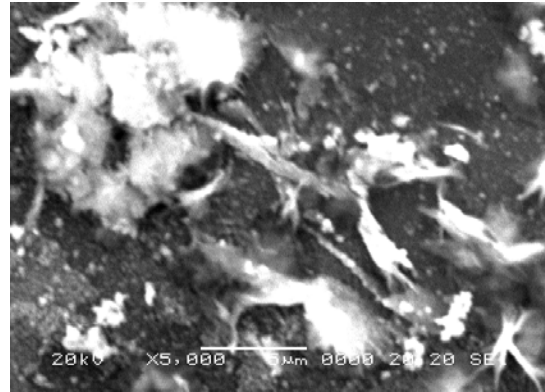
**PC and PL Cells** : For PC studies, coplanar electrodes (1.5 mm wide and 24 mm long at a separation of 2 mm) were formed by applying colloidal silver paint to the surface of the film. The photocurrents were measured by exposing the total area of the film. The PL cell consisted of the film deposited on the substrates.

## 3. Results and discussions

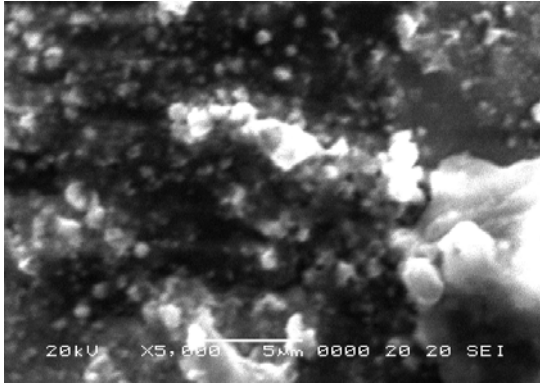
**SEM studies** : The SEM micrograph of the unannealed as well as annealed Cd(S-Se):CdCl<sub>2</sub>,Dy films chemically deposited on glass substrate at 60<sup>0</sup>C in WB are presented in figs.- 1(a), (b), (c) and (d) respectively. The micrographs show ball type structures, which indicate formation of layered type growth. In some of the cases, needle type structure is also seen.



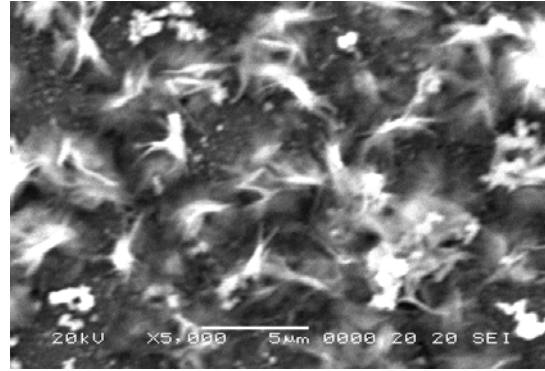
*Fig.-1(a) SEM Micrograph of  $Cd(S_{0.95}-Se_{0.05}):CdCl_2(3\text{ ml}),Dy(6\text{ ml})$*



*Fig.-1(b) SEM Micrograph of  $Cd(S_{0.7}-Se_{0.3}):CdCl_2(2\text{ ml}),Dy(2\text{ ml})$*



*Fig.-1(c) SEM Micrograph of annealed  $Cd(S_{0.95}-Se_{0.05}):CdCl_2(3\text{ ml}),Dy(6\text{ ml})$  [annealed]*



*Fig.-1(d) SEM Micrograph of annealed  $Cd(S_{0.7}-Se_{0.3}):CdCl_2(2\text{ ml}),Dy(2\text{ ml})$  [annealed]*

**XRD studies** : The X-ray diffractograms of  $Cd(S-Se):CdCl_2,Dy$  films chemically deposited on glass substrate at  $60^{\circ}C$  in WB and their annealed samples are presented in figs.- 2(a), (b), (c) and (d) respectively. The corresponding data are presented in table 1.

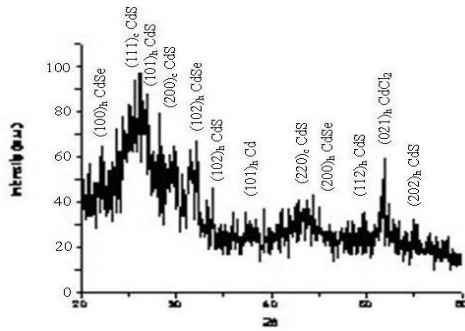


Fig. 2(a) X-ray diffractogram of  $Cd(S_{0.95}-Se_{0.05}):CdCl_2(3\text{ ml}), Dy(6\text{ ml})$

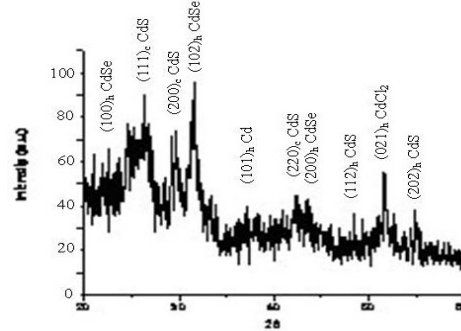


Fig. 2(b) X-ray diffractogram of  $Cd(S_{0.7}-Se_{0.3}):CdCl_2(2\text{ ml}), Dy(2\text{ ml})$

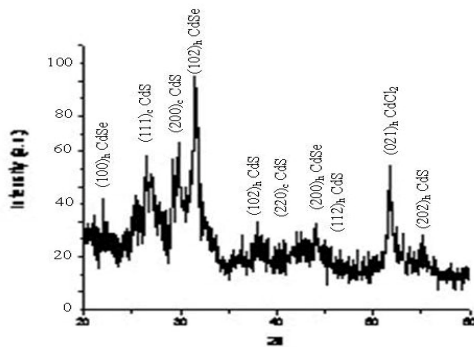


Fig. 2(c) X-ray diffractogram of  $Cd(S_{0.95}-Se_{0.05}):CdCl_2(3\text{ ml}), Dy(6\text{ ml})$  [annealed]

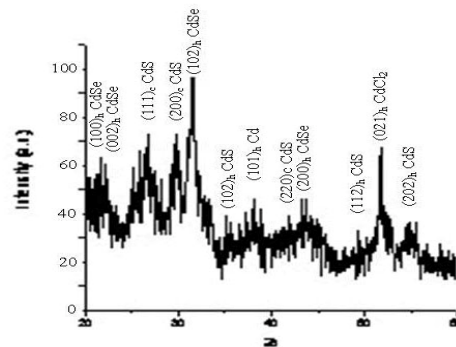


Fig. 2(d) X-ray diffractogram of  $Cd(S_{0.7}-Se_{0.3}):CdCl_2(2\text{ ml}), Dy(2\text{ ml})$  [annealed]

Table-1 XRD data of different  $Cd(S-Se):CdCl_2, Dy$  films chemically deposited on glass substrate at  $60^\circ C$  in WB

d-values		Relative Intensities		hkl	Lattice-constants ( $\text{\AA}$ )	
Obs.	Rep.	Obs.	Rep.		Obs.	Rep.
<b>(a) <math>Cd(S_{0.95}-Se_{0.05}):CdCl_2, Dy(6ml)</math></b>						
3.7294	3.7239	63	100	(100) <sub>h</sub> CdSe	a=4.3063	a=4.3, c=7.02
3.3615	3.36	100	100	(111) <sub>c</sub> CdS	a=5.8223	a=5.818
3.181	3.16	89.23	100	(101) <sub>h</sub> CdS	a=4.102, c=6.5633	a=4.135, c=6.71
2.914	2.9	76.07	40	(200) <sub>c</sub> CdS	a=5.828	a=5.818
2.5539	2.5542	65.23	40.59	(102) <sub>h</sub> CdSe	a=4.3063, c=7.01	a=4.3, c=7.02
2.456	2.4502	44.72	25	(102) <sub>h</sub> CdS	a=4.139, c=6.719	a=4.135, c=6.71
2.317	2.345	36.2	100	(101) <sub>h</sub> Cd	a=2.984, c=5.622	a=2.974, c=5.62
2.0589	2.058	38.46	80	(220) <sub>c</sub> CdS	a=5.8234	a=5.818

1.8639	1.862	36.69	12.72	(200) <sub>h</sub> CdSe	a=4.3045	a=4.3, c=7.02
1.7757	1.76	35.08	45	(112) <sub>h</sub> CdS	a=4.118, c=6.78	a=4.135, c=6.71
1.661	1.658	60.4	12	(021) <sub>h</sub> CdCl <sub>2</sub>	a=3.851, c=17.91	a=3.84, c=17.49
1.58	1.58	24.69	7	(202) <sub>h</sub> CdS		a=4.135, c=6.71
<b>(b) Cd(S<sub>0.7</sub>-Se<sub>0.3</sub>):CdCl<sub>2</sub>,Dy (2ml)</b>						
3.7216	3.7239	74.02	100	(100) <sub>h</sub> CdSe	a=4.2973	a=4.3, c=7.02
3.3669	3.36	90.87	100	(111) <sub>c</sub> CdS	a=5.8316	a=5.818
2.925	2.9	70.87	40	(200) <sub>c</sub> CdS	a=5.85	a=5.818
2.5551	2.5542	100	40.59	(102) <sub>h</sub> CdSe	a=4.3063,c=7.0223	a=4.3, c=7.02
2.315	2.345	38.21	100	(101) <sub>h</sub> Cd	a=2.945, c=5.573	a=2.974, c=5.62
2.0578	2.058	44.22	80	(220) <sub>c</sub> CdS	a=5.8203	a=5.818
1.8619	1.862	42.64	12.72	(200) <sub>h</sub> CdSe	a=4.2999	a=4.3, c=7.02
1.766	1.76	32.50	45	(112) <sub>h</sub> CdS	a=4.126, c=6.75	a=4.135, c=6.71
1.660	1.658	34.82	12	(021) <sub>h</sub> CdCl <sub>2</sub>	a=3.849, c=17.81	a=3.84, c=17.49
1.5812	1.58	35.88	7	(202) <sub>h</sub> CdS		a=4.135, c=6.71
<b>(c) Cd(S<sub>0.95</sub>-Se<sub>0.05</sub>):CdCl<sub>2</sub>,Dy (6ml)[annealed]</b>						
3.7256	3.7239	42.63	100	(100) <sub>h</sub> CdSe	a=4.3020	a=4.3, c=7.02
3.3685	3.36	59.93	100	(111) <sub>c</sub> CdS	a=5.834	a=5.818
2.902	2.9	62.86	40	(200) <sub>c</sub> CdS	a=5.804	a=5.818
2.5546	2.5542	100	40.59	(102) <sub>h</sub> CdSe	a=4.3063,c=7.015	a=4.3, c=7.02
2.4601	2.4502	30.49	25	(102) <sub>h</sub> CdS	a=4.146, c=6.723	a=4.135, c=6.71
2.059	2.058	28.25	80	(220) <sub>c</sub> CdS	a=5.8237	a=5.818
1.8621	1.862	31.84	12.72	(200) <sub>h</sub> CdSe	a=4.3003	a=4.3, c=7.02
1.764	1.76	20.12	45	(112) <sub>h</sub> CdS	a=4.14, c=6.715	a=4.135, c=6.71
1.658	1.658	50.73	12	(021) <sub>h</sub> CdCl <sub>2</sub>	a=3.851, c=17.98	a=3.84, c=17.49
1.581	1.58	22.91	7	(202) <sub>h</sub> CdS		a=4.135, c=6.71
<b>(d) Cd(S<sub>0.7</sub>-Se<sub>0.3</sub>):CdCl<sub>2</sub>,Dy (2ml)[annealed]</b>						
3.7274	3.7239	64.3	100	(100) <sub>h</sub> CdSe	a=4.3048	a=4.3, c=7.02
3.5224	3.52	60.30	65.85	(002) <sub>h</sub> CdSe	a=4.2986,c=7.0448	a=4.3, c=7.02
3.3669	3.36	74.24	100	(111) <sub>c</sub> CdS	a=5.8334	a=5.818
2.902	2.9	74.92	40	(200) <sub>c</sub> CdS	a=5.826	a=5.818
2.5502	2.5542	100	40.59	(102) <sub>h</sub> CdSe	a=4.3061,c=7.0114	a=4.3, c=7.02
2.4587	2.4502	39.37	25	(102) <sub>h</sub> CdS	a=4.142, c=6.721	a=4.135, c=6.71
2.3194	2.345	46.19	100	(101) <sub>h</sub> Cd	a=2.989, c=5.569	a=2.974, c=5.62

2.0585	2.058	38.36	80	(220) <sub>c</sub> CdS	a=5.8223	a=5.818
1.8632	1.862	42.08	12.72	(200) <sub>h</sub> CdSe	a=4.3029	a=4.3, c=7.02
1.7616	1.76	30.5	45	(112) <sub>h</sub> CdS	a=4.13, c=6.758	a=4.135, c=6.71
1.659	1.658	68.05	12	(021) <sub>h</sub> CdCl <sub>2</sub>	a=3.853, c=17.90	a=3.84, c=17.49
1.582	1.58	34.81	7	(202) <sub>h</sub> CdS		a=4.135, c=6.71

The assignments were made by comparing with ASTM data, and calculation of lattice constants and their comparison with the reported values. The different assigned peaks are mentioned in the figures. Peaks of CdS [(111)<sub>c</sub>, (101)<sub>h</sub>, (200)<sub>c</sub>, (220)<sub>c</sub>, (112)<sub>h</sub> and (102)<sub>h</sub>] and CdSe [(100)<sub>h</sub>, (002)<sub>h</sub> and (110)<sub>h</sub>] along with two peaks of Dy [(101)<sub>h</sub> and (104)<sub>h</sub>] and one peak of CdCl<sub>2</sub> [(021)<sub>h</sub>] are observed. The intensities of (111)<sub>c</sub> peak of CdS and (100)<sub>h</sub> peak of CdSe are dominant. Different layers of CdS are observed in cubic as well as hexagonal phases. The formation of the hexagonal and cubic phases are known to be created through different arrangements of atomic layers. The hexagonal phase consists of the sequence of atomic layers defined as ABABAB----- and that of cubic in ABCABCABC----- [10]. It is also possible to find mixed forms with random stacking of very long period repeats as is found in polytypes of SiC [11]. The total crystal consists of different atomic layers of CdS in cubic as well as hexagonal phases along with some atomic layers of CdSe in hexagonal phases. According to Langer et al [12], one might think of solid solutions as mixtures of microcrystalline regions of the pure CdSe and CdS, where each microregion might consist of a number of unit cells of each material with the lattice-constant of CdS stressed by surrounding CdSe and that of CdSe compressed by its CdS neighbours. Such a model can explain uniform shift of absorption edge with composition. A possibility of solid solution consisting of statistical distribution of CdSe and CdS with respect to their overall concentration was also mentioned by these workers. It should be noted that shift of absorption edge has already been observed in the present case.

The particle size D [13], strain value  $\epsilon$  [14] and dislocation density  $\delta$  [15] were obtained for (111)<sub>c</sub> peak of CdS by using the well known formulae and corresponding values are listed in table-2. It is noticed that with annealing of films; FWHM, strain value and dislocation density decrease, whereas the particle-size increases. The decrease in dislocation density suggests that films become more crystalline. Annealing of thin films increases the grain size resulting in better crystallinity.

Table-2 Values of FWHM, Particle size, Strain and Dislocation density corresponding to (111)<sub>c</sub> peak of CdS for different Cd(S-Se):CdCl<sub>2</sub>,Dy films chemically deposited on glass substrate at 60<sup>o</sup>C in WB

Sample	FWHM ' $\beta$ ' (radian)	Particle Size 'D' (nm)	Strain ' $\epsilon$ ' ( $\text{lin}^{-2}\text{m}^{-4}$ )	Dislocation Density ' $\delta$ ' ( $\times 10^{15}$ $\text{lin}/\text{m}^2$ )
Cd(S <sub>0.95</sub> -Se <sub>0.05</sub> ):CdCl <sub>2</sub> ,Dy (6ml)	0.2282	6.5254	0.00555	2.34847
Cd(S <sub>0.7</sub> -Se <sub>0.3</sub> ):CdCl <sub>2</sub> ,Dy (2ml)	0.2796	5.3060	0.006828	3.55192
Cd(S <sub>0.95</sub> -Se <sub>0.05</sub> ):CdCl <sub>2</sub> ,Dy (6ml) [annealed]	0.1630	9.1545	0.003958	1.19325
Cd(S <sub>0.7</sub> -Se <sub>0.3</sub> ):CdCl <sub>2</sub> ,Dy (2ml) [annealed]	0.2326	6.3874	0.005673	2.45105

**Optical absorption spectra :** The optical absorption measurements of the Dy doped Cd(S-Se) films have been carried out at room temperature by placing an uncoated identical glass substrate in

the reference beam. The optical spectra of the films have been recorded in the wavelength range 300-700 nm. The energy band gaps of these films were determined from absorption spectra.

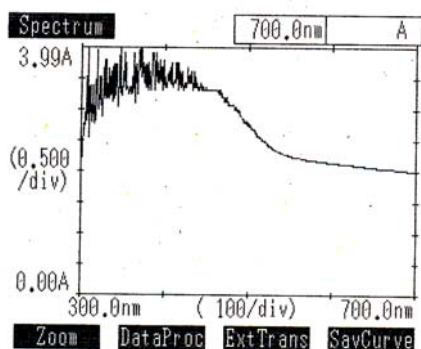


Fig.-3(a) Absorption spectrum of  $Cd(S_{0.95}-Se_{0.05})$ -film

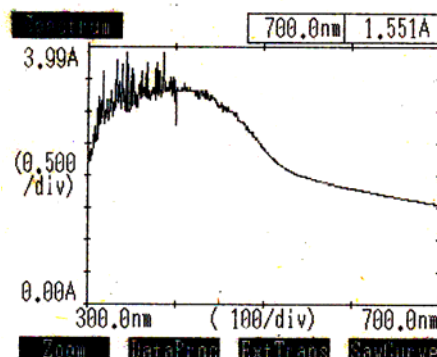


Fig.-3(b) Absorption spectrum of  $Cd(S_{0.95}-Se_{0.05}):CdCl_2(3ml)$ -film

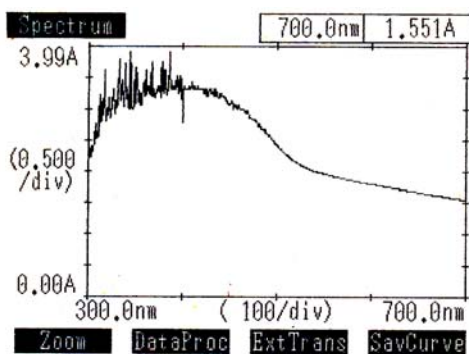


Fig.-3(c) Absorption spectrum of  $Cd(S_{0.95}-Se_{0.05}):CdCl_2(3ml),Dy (6ml)$ -film

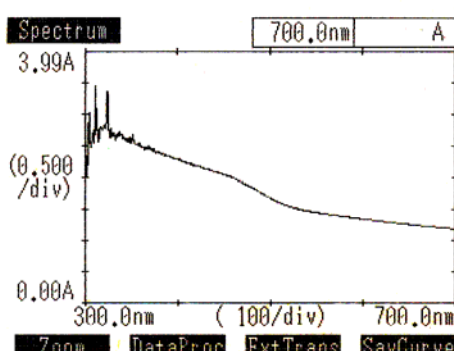


Fig.-3(d) Absorption spectrum of  $Cd(S_{0.7}-Se_{0.3}):CdCl_2(2ml),Dy (2ml)$ -film

The optical absorption spectra of different Cd(S-Se) films prepared on glass substrates are shown in figs.- 3(a), (b), (c) and (d). Band gaps were determined from the extrapolation of the plots between  $(\alpha h\nu)^2$  vs  $h\nu$  (Tauc's plots) (fig.-4). It is found that with increase in concentration of CdSe the band gap decreases [ $Cd(S_{0.95}-Se_{0.05})$ : 2.36 eV;  $Cd(S_{0.9}-Se_{0.1})$ : 2.33 eV;  $Cd(S_{0.8}-Se_{0.2})$ : 2.26 eV;  $Cd(S_{0.7}-Se_{0.3})$ : 2.19 eV;  $Cd(S_{0.6}-Se_{0.4})$ : 2.12 eV]. A plot of  $E_g$  versus CdS/CdSe ratio is shown in fig.-5. This shows that a common lattice of Cd(S-Se) is formed through the solid solution formation. Slight changes in band gaps are observed in presence of  $CdCl_2$  and Sm. The overall absorption in presence of Se and Dy decrease which shows that the films become more transparent in their presence. The spikes observed at around 300 nm may also occur due to nano-crystalline effects under which the continuum of states in conduction band (CB) and valence band (VB) are broken into discrete states [16].

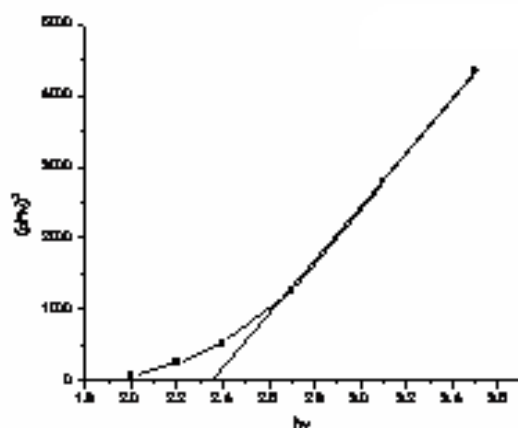


Fig.-4 Band-gap ( $E_g$ ) of unannealed  $Cd(S_{0.95}-Se_{0.05})$ -film

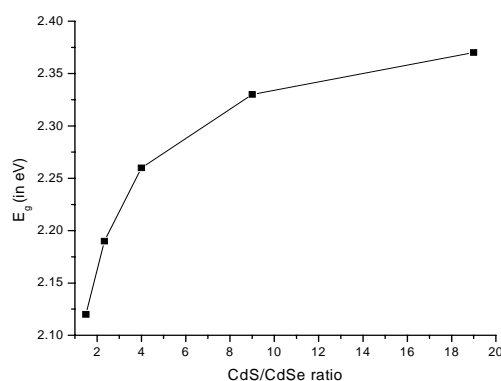


Fig.-5 Plot of variation of energy-gap ( $E_g$ ) vs CdS/CdSe ratio

In Dy doped film, a weak absorption peak is observed at around 464 nm. Li Yu Chun et al [17] have shown that, after excitation with wavelengths 458 nm and 478 nm corresponding to the direct excitation from ground  $^6H_{15/2}$  to higher energy levels dominant excitation to  $^4I_{19/2}$  and  $^4F_{9/2}$  states of  $Dy^{3+}$  ion, the emission spectrum is dominated by  $Dy^{3+}$  luminescence mainly in the visible region which are assigned to the intra-4f-shell transition from  $^4F_{9/2} \rightarrow ^4H_{13/2}$ ,  $^4F_{9/2} \rightarrow ^6H_{13/2}$  and  $^4F_{9/2} \rightarrow ^6H_{15/2}$ . This process occurs through energy transfer from host to impurity levels.

**PL spectra :** Maximum PL emission is observed for 0.7:0.3 combination of CdS:CdSe studies. In the presence of flux, at its different concentrations, the highest emission appears at a volume of 2 ml  $CdCl_2$ . Therefore, this and hence this combination was used for PL concentration was used in the presence of impurities.

PL emission spectra of  $Cd(S_{0.7}-Se_{0.3})$  films were found to consist of two peaks (reported in our earlier paper [18,19]. These peaks were deconvoluted into two Lorentzian curves one at 494 nm and the other at 559 nm [fig.-6]. These peaks were attributed to the radiative decay of free exciton and exciton-donor complexes found in presence of S / excess Cd respectively. Plots of PL intensity versus wavelength for varying volumes of  $Dy^{3+}$  is shown in fig.-7.

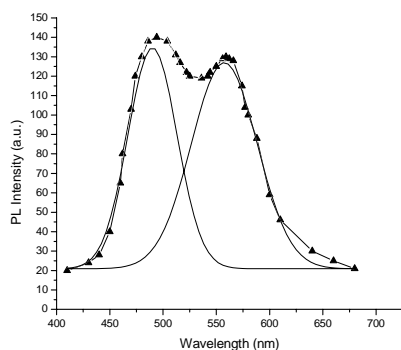


Fig.-6 Original peak of PL emission spectrum of  $Cd(S_{0.7}Se_{0.3})$  is deconvoluted into two Lorentzian curves located at 494 nm and 559 nm

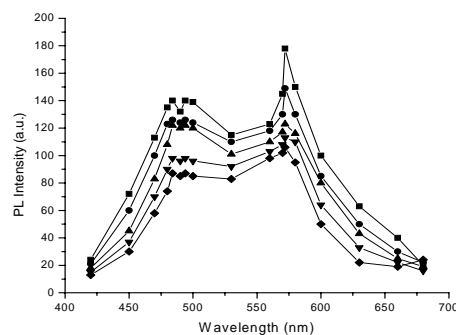


Fig.-7 PL emission spectra of  $Cd(S_{0.7}Se_{0.3}):CdCl_2(2ml),Dy(2ml)$  films prepared on glass substrates at  $60^\circ C$  at different volumes of  $Dy(NO_3)_3 [0.01M]$  :  $\blacksquare$  2ml,  $\bullet$  4ml,  $\blacktriangle$  6ml,  $\blacktriangledown$  8ml and  $\blacklozenge$  10ml

In presence of Dy, along with the peak at 494 nm, the other peaks observed are at 484 nm and 573 nm respectively. These peaks may be associated to the characteristic emission of  $Dy^{3+}$  due to the transitions of  ${}^4F_{9/2} \rightarrow {}^6H_{15/2}$  and  ${}^4F_{9/2} \rightarrow {}^6H_{13/2}$  respectively [fig.-8]. The broad bands correspond to host absorption while the peaks are induced by the f-f transitions of  $Dy^{3+}$ . The transition  ${}^4F_{9/2} \rightarrow {}^6H_{13/2}$  belongs to the hypersensitive transition with  $\Delta J = 2$ , which is strongly influenced by the outside environment of  ${}^4F_{9/2} \rightarrow {}^6H_{13/2}$ . Increasing dysprosium concentration causes slowly decrease in PL intensity. This is typical property named concentration quenching of lanthanide-doped system.

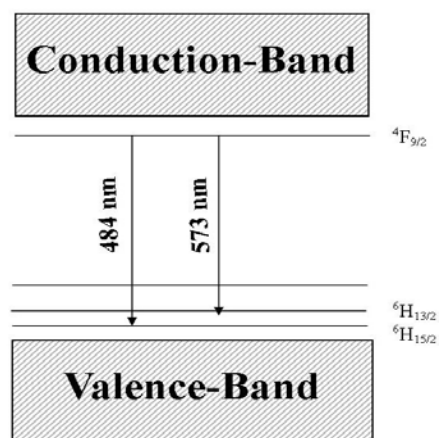


Fig.-8 Schematic diagram showing various emission transitions in  $Cd(S_{0.7}Se_{0.3}):CdCl_2(2ml),Dy(2ml)$ -films

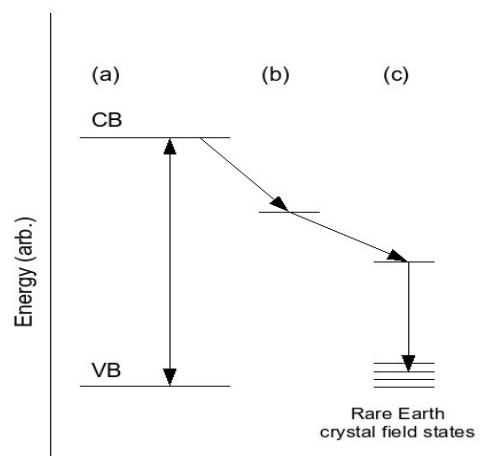


Fig.-9 Schematic diagram showing proposed energy transfer mechanism.

- (a) UV light absorbed within the host band gap;  
 (b) relaxation to host defect states occurs;  
 (c) energy transfer to crystal field states of the rare-earth ion, exhibiting PL..

A proposed model of energy transfer from host to impurity level is shown in fig.-9.

**PC rise and decay studies :** When light is illuminated on the film, the photocurrent is high. Initially high value of the photocurrent is due to absorption of photons by the films, which excites the electrons from the VB to the CB. This creates e-h pairs in CB and VB. Most of the electrons are from the surface of the film which moves from VB to CB. Photon absorption increases the process of pair generation initially, which in turn increases the carrier concentration, resulting in high photocurrent. The photocurrent decreases with time and after some time, the photocurrent is almost constant. Since the recombination of carriers starts becoming effective after some time, the rate of increase of carriers becomes lower and further after, a balance between the generation and recombination gives rise to saturated value of current. When light is turned off, photocurrent decreases abruptly and after a few seconds, it decreases steadily with respect to time. Here surface recombination is very high and it leads to a lower carrier concentration at the surface. The system tends to its initial stage by relaxation process, which gives low and steady decay of photocurrent.

The PC rise and decay curves of different Cd(S-Se) films are shown in fig -10.

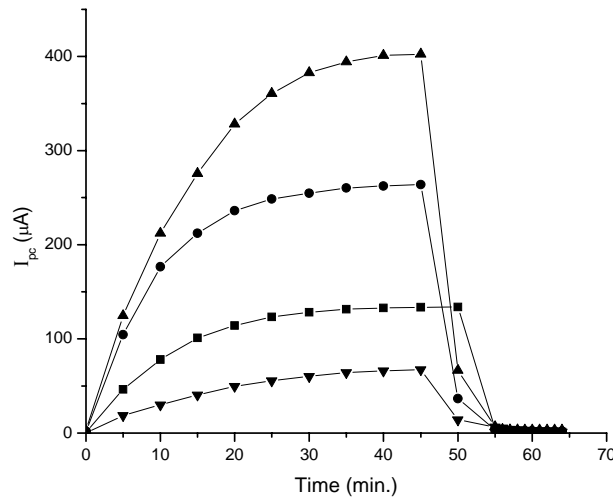


Fig.-10 PC rise and decay curves of different Cd(S-Se) films prepared on glass substrates at  $60^{\circ}C$  :  $\blacksquare$   $Cd(S_{0.95}Se_{0.05})$ ,  $\bullet$   $Cd(S_{0.95}Se_{0.05}):CdCl_2$ ,  $\blacktriangle$   $Cd(S_{0.95}Se_{0.05}):CdCl_2,Dy$  (6ml) and  $\blacktriangledown$   $Cd(S_{0.95}Se_{0.05}):CdCl_2,Dy$  (6ml)[annealed].

Maximum photocurrent was observed in the case of 0.95:0.05 combination of CdS to CdSe. In the presence of  $CdCl_2$ , the maximum current was observed for a volume of 3 ml (0.001M). The values of  $I_{pc}/I_{dc}$  ratio, trap-depths, lifetime and mobility were evaluated by methods described in earlier publications [5-8, 20-24] and the corresponding values for the different cases are summarized in the table-3.

Table-3 Values of  $I_{dc}$ ,  $I_{pc}$ ,  $I_{pc}/I_{dc}$ , Lifetime ( $\tau$ ), Mobility ( $\mu$ ) and Trap depth ( $E$ ) for different Cd(S-Se) films. (Temp. of preparation = 60°C; duration = 1hr).

Sl. No.	Sample	$I_{dc}$ (nA)	$I_{pc}$ ( $\mu$ A)	Gain $I_{pc}/I_{dc}$	Lifetime $\tau$ (sec)	Mobility $\mu$ ( $\text{cm}^2/\text{Vs}$ )	Trap depth (eV)
1.	Cd(S <sub>0.95</sub> -Se <sub>0.05</sub> )	0.2	134	6.7x10 <sup>5</sup>	39.41	45.33	E <sub>1</sub> =0.673, E <sub>2</sub> =0.665
2.	Cd(S <sub>0.95</sub> -Se <sub>0.05</sub> ):CdCl <sub>2</sub>	0.1	264	2.64x10 <sup>6</sup>	48.01	93.33	E <sub>1</sub> =0.684, E <sub>2</sub> =0.668
3.	Cd(S <sub>0.95</sub> -Se <sub>0.05</sub> ):CdCl <sub>2</sub> ;Dy at 60°C in WB	0.05	402.41	8.05x10 <sup>6</sup>	61.9	148.19	E <sub>1</sub> =0.696, E <sub>2</sub> =0.679
4.	Cd(S <sub>0.95</sub> -Se <sub>0.05</sub> ):CdCl <sub>2</sub> ;Dy at 60°C in WB [annealed]	~0	54.2	very high	67.4	Very high	E <sub>1</sub> =0.699, E <sub>2</sub> =0.681

It has been observed that, the values of lifetime and mobility both increase in the presence of impurities, which accounts for the better photo-response.

#### 4. Conclusions

Reasonably good photosensitive materials can be prepared by a simple technique of chemical deposition of Cd(S-Se) films doped with rare earths. SEM studies show ball type structures, which may be due to layered growth. X-ray diffractograms of Cd(S-Se):CdCl<sub>2</sub>, Sm films show the presence of CdS and CdSe along with lines of CdCl<sub>2</sub> and Dy. From the calculation of strain and dislocation density, crystallinity is found to be better in RT preparation. PC rise and decay studies show  $I_{pc}/I_{dc}$  ratio of the order of 10<sup>6</sup>. Such higher photosensitization occurs due to increase in life-time and mobility of carriers. PC response and PL emission are found to be maximum at different concentrations of impurities.

#### Acknowledgements

The authors are grateful to IUC-DAE, Indore (M.P.) for giving consent for completing SEM and XRD studies at the consortium. One of the authors (R.S.S.) acknowledges the University Grant Commission, C.R.O., Bhopal, for the award of Teacher Fellowship (TF) under 10<sup>th</sup> plan.

#### References

- [1] Reisfeld R., Saraidarov T., Ziganski E., Gaft M., Lis S. and Pietraszkiewicz M., J. Lumin. **243**, 102 (2003).
- [2] Feldmann C., Jussel T., Ronda C. R. and Schmidt P. J., Adv. Funct. Matter, **13**(7), 511 (2003).
- [3] Karanjai M. K. and Dasgupta D., Thin Solid Films **150**, 309, (1987).
- [4] Chopra K. L., Kaintela R. C., Pandya D. R. and Thakoor A. P., Physics of Thin Films, edited by G. Hass, M. H. Francombe and J. C. Vossen (Academic New York), **12**, 201 (1982).
- [5] Bhushan S., Mukherjee M. and Bose P., J. Mater. Sci. **13**, 581 (2002).
- [6] Bhushan S., Shrivastava S. and Shrivastava A., J. Mater. Sci. **41**, 7483 (2006).
- [7] Khare A. and Bhushan S., Cryst. Res. Technol. **41**, 689 (2006).
- [8] Bhushan S. and Pillai S., Rad. Eff.

- Def. Sol., **163**, 241 (2008).
- [9] Mane R. S. and Lokhande C., Mater. Chem. Phys. **65**, 1 (2000).
- [10] Kittel C. Introduction to Solid State Physics (7<sup>th</sup> edition) (John Wiley & Sons) p.18 (1995).
- [11] Ibach Herald & Hans Lüth Solid State Physics (An Introduction to Theory and Expt.) (Springer International Student Edition) p.25 (1991).
- [12] Langer D. W., Park Y. S. & Euwama R. N. Phys. Rev. **152**(2), 788 (1966).
- [13] Wilson A. P. J. Mathematical theory of X-ray powder diffractometry (New York : Gordon and Breach) p.62 (1963).
- [14] Senthilkumar V., Venketachalam S., Vishwanatham C., Gopal S., Narayandass S. K., Mangalraj B., Wilson K. C. and Vijaykumar V. Cryst. Res. Technol. **40**, 573 (2005).
- [15] Williamson G. B. and Smallman R. C. Phil. Mag. **1**, 34 (1956).
- [16] Efros A. L. and Efros A. L. Sov. Phys. Semicond. **16**, 722 (1982).
- [17] Li Yu-Chun, Chang Yen-Hwei, Lin Yu-Feng, Chang Yee-Shin, Lin Yi-Jing, Journal of Alloys and Compounds **439**, 367 (2007).
- [18] Bhushan S. and Oudhia A., Optoelectronic Review (Romania) 17 (1) "Photoconductivity and photoluminescence in chemically deposited films of Cd(S-Se):CdCl<sub>2</sub>,Ho" [In press].
- [19] Singh R.S. and Bhushan S., Bulletin of Material Science "Structural and Optical properties of chemically deposited Cd(S-Se):CdCl<sub>2</sub>,Sm films" [Accepted].
- [20] Bhushan S., Mukherjee M. and Bose P., Rad. Eff. Def. Sol. **153**, 367 (2001).
- [21] Mukherjee M. and Bhushan S., Rad. Eff. Def. Sol. **158**, 491 (2003).
- [22] Chandra T. and Bhushan S., J. Mater. Sci. **39**, 6303 (2004).
- [23] Bhushan S. and Shrivastava S., Opt. Mat. **28**, 1334 (2006).
- [24] Bhushan S. and Pillai S., Crystal Res. Technol. (Germany) **43**, 762 (2008).