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OPTICAL PROPERTIES AND PHOTOCONDUCTIVITY OF UNDOPED AND In-DOPED CdTe THIN FILMS

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ABSTRACT

Undoped and 5%In-doped CdTe thin films were deposited by thermal evaporation technique onto glass substrate maintained at constant substrate temperature of 423±10K. The influence of In doping on the optical properties and the photoconductivity of CdTe thin films were studied. Band gap values were found decreasing from about 1.56eV to 1.47eV and the optical constants were changed upon doping CdTe thin films with 5%In. The photoconductivity measurements were showed alteration of the power exponent δ from a value $\delta>1$ for undoped CdTe film to the value $\delta<1$ for 5%In-doped film which indicated the change in recombination mechanism process. The value of photosensitivity (σ_{Ph}/σ_D) of the prepared films showed an elevation with increasing light intensity. Also photosensitivity for 5%In-doped CdTe films was found about 2 to 3.5 times higher than for the corresponding undoped films.

Keywords: undoped and In-doped CdTe thin films**,** optical properties, photoconductivity.

I. INTRODUCTION

The semiconducting compounds belonging to the cadmium chalcogenides family are known as good materials for making semiconducting devices. In this regards the cadmium telluride is good candidate material for the fabrication of photo-semiconductor devices, such as field effect transistors, high efficiency solar cells, IR detectors and magneto-optic devices [1-6]. CdTe possesses a direct band gap of about 1.5eV and high optical absorption coefficient (>10^4 cm^{-1}) for the visible solar spectrum, accordingly only thin film layers of few microns thickness are needed for the absorption of the most of the solar spectra photons with energy higher than the band gap[7]. Moreover, CdTe is considered to be one of the most effective materials for the fabrication of X-ray and γ-ray detectors operating at room temperature, because of its specific properties, such as a high average atomic number, good charge-transport properties, high resistivity, and relatively large band gap energy [8, 9]. The doping

CdTe thin film with the appropriate metal atoms such as In, Zn, Ag, Bi, Sb, Al, etc., produces considerable changes in their structural and physical properties that make it very good candidate material in the technology of thin film devices [10-15].
The physical properties of this film depend on the technique used to deposit the film on the substrate. In this regard a variety of techniques have been employed to grow CdTe thin films including physical vapor deposition [16], pulsed laser deposition [17], RF-sputtering [18], close spaced sublimation [19], hot wall epitaxy [20], successive ionic layer adsorption and reaction method [21], thermal evaporation [22], chemical bath deposition[23], and electrodepositing technique [24]. In the present work, the thermal evaporation method was used to deposit undoped and 5%In-doped CdTe thin films on glass substrate. The effect of In doping on the optical properties and photoconductivity for CdTe films have been investigated.

II. EXPERIMENTAL PROCEDURE

Undoped and 5%In-doped CdTe thin films were deposited onto corning 7059 glass slides by thermal evaporation technique at vacuum about 10^{-6} Torr. CdTe powder of 99.999% and Indium 99.999% purity from Balzers were used as the source material and dopant respectively. The thickness (t) of the films was around 300±10nm. The temperature of the substrate was constant within 423±5%K. An optical transmittance and absorptance spectra were recorded, at room temperature, in the wavelength range 500-900nm using a Perkin-Elmer Lambda 800 UV-VIS spectrophotometer with Phillips computer at Sharjah University, UAE. The light source used for the photoconductivity measurements was a 120W Halogen lamp type Phillips. A d.c. voltage is applied across the films and the resulting current is measured by Keithley digital electrometer type 616.

III. RESULTS AND DISCUSSION

Optical measurement constitutes the most important tools of determining the band structure of semiconductors. Fig. (1) shows optical transmittance (T) spectrum of undoped and 5%In-doped CdTe thin films as a function of the wavelength (λ) in the range 500-900nm. It could be noted that the spectrum for undoped CdTe exhibit interference fringes in the spectral region λ>800nm and a transmittance of about 50-60%. The transmittance decreases and the absorption edge is less steep and shift to higher wavelength (lower energy) after doping CdTe thin film with 5%In. This indicated that the doped film have lower band gap value compared to that of undoped film.
The absorption coefficient (α) of undoped and In-doped CdTe thin films were calculated from the optical transmittance spectrum measurements using the formula [25]:

$$\alpha = \frac{1}{t}\ln\left(\frac{1}{T}\right) \qquad (1)$$

where T is the transmittance spectrum incident intensity. The nature of transition (direct or indirect) was determined according to Tauc relation [26]:

$$\alpha h\upsilon = A\left(h\upsilon - E_g\right)^r \qquad (2)$$

where hυ is the spectrum incident photon energy, E_g is the optical band gap energy, A and r are constants. For allowed direct transition, r=1/2 and for allowed indirect transition, r=2 [26].

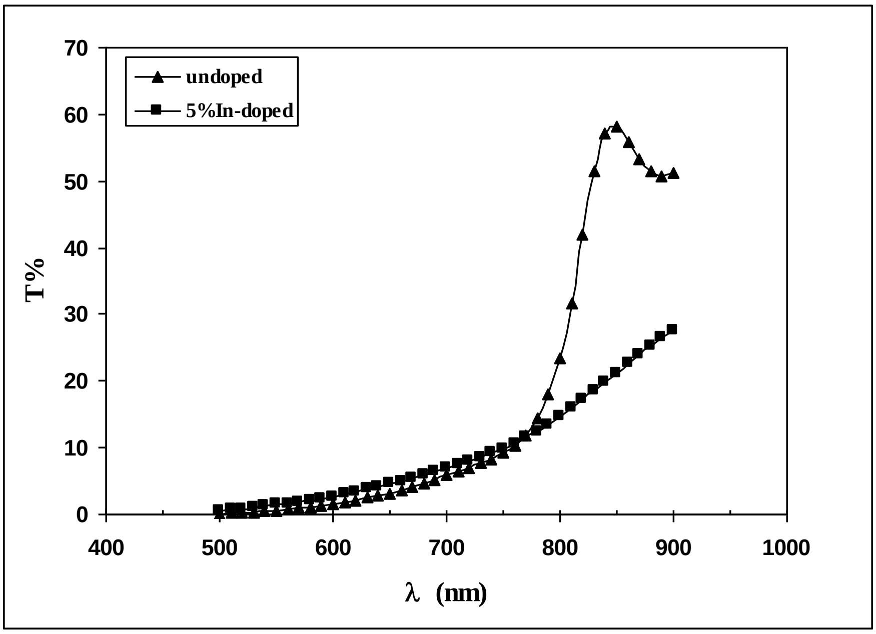

Figure 1: Transmittance spectra of undoped and 5%In-doped CdTe thin films.

The variation of $(\alpha h\upsilon)^2$ versus hυ was plotted in Fig. (2). It is observed that curves for undoped and 5%In-doped CdTe thin films have straight line portion in the high energy region, at which the absorption coefficient $\alpha \geq 10^4 cm^{-1}$.This behavior is indicating the undergoes of direct transition for the thin film. Extrapolating of the linear portion of the plots to $(\alpha h\upsilon)^2 = 0$ yielded the optical band gap value as illustrated in Fig. (2). The estimated band gap energy was found to be 1.56eV and 1.47eV for undoped and 5%In-doped CdTe thin films respectively. This decrease in E_g value after doping with 5%In is attributed to that In introduces interband energy levels in the band gap of CdTe thin films which were responsible for the shift of E_g to lower band gap energy. A similar manner was found by other researchers for different dopant atoms [12, 14, 27].

It is important to determine the optical constants of thin films such as refractive index (n), extinction coefficient (k), and the real (ε_r) and imaginary (ε_i) parts of dielectric constant.

The index of refraction of undoped and In-doped CdTe thin films was estimated from the reflectance (R) data using the relation [28]:

$$n = \frac{1+R}{1-R} + \sqrt{\frac{4R}{(1-R)^2} - k^2} \qquad (3)$$

where k (=$\alpha\lambda/4\pi$) is the extinction coefficient and λ is wavelength of incident light.
The real and imaginary parts of dielectric constant were evaluated using the formulas [29]:

$$\varepsilon_r = n^2 - k^2 \tag{4}$$

$$\varepsilon_i = 2nk \tag{5}$$

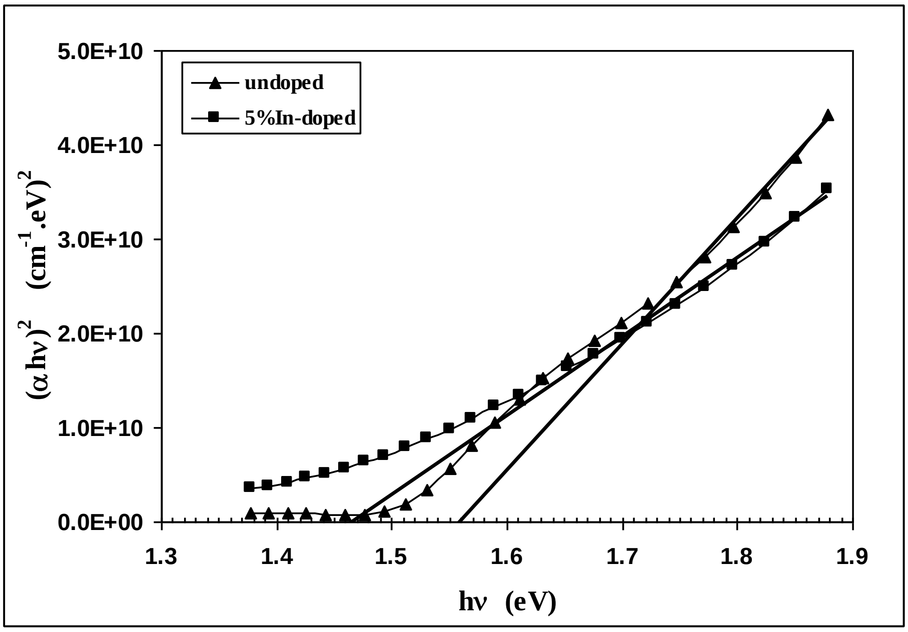

Figure 2: $(\alpha h\upsilon)^2$ vs. $h\upsilon$ of undoped and 5%In-doped CdTe thin films.

Plots of n, k, ε_r, and ε_i versus wavelength in the range 500-900nm for undoped and 5%In-doped CdTe thin films are shown in Figs.(3-6) respectively. It should be noted that the variation of n with λ characterized by a peak round wavelength 820nm for undoped CdTe thin film as shown in Fig.(3) .This might be attributed to the onset of absorption at the fundamental absorption edge. A similar behavior is also reported by other workers [30, 31]. For polycrystalline CdTe films this peak was found at wavelengths within the range (820-845nm) [30]. A shift in the refractive index peak towards higher wavelengths was observed after doping CdTe films with 5%In (Fig. (3)). The extinction coefficient for undoped and 5%In-doped CdTe thin films decreases as the wavelength increases up to 900nm as seen in Fig.(4). Another noticeable remark from this figure is showed that the extinction coefficient value near and above the absorption edge for 5%In-doped CdTe film was higher than for the corresponding undoped film. This behavior may be correlated with the increase in absorption coefficient in the studied spectral range upon doping thin film of CdTe with 5%In. A similar manner of the variation of n with λ is shown for ε_r with λ for undoped and 5%In-doped CdTe films as shown in Fig.(5). Moreover the values of ε_r are higher than ε_i values (Fig. (6)).

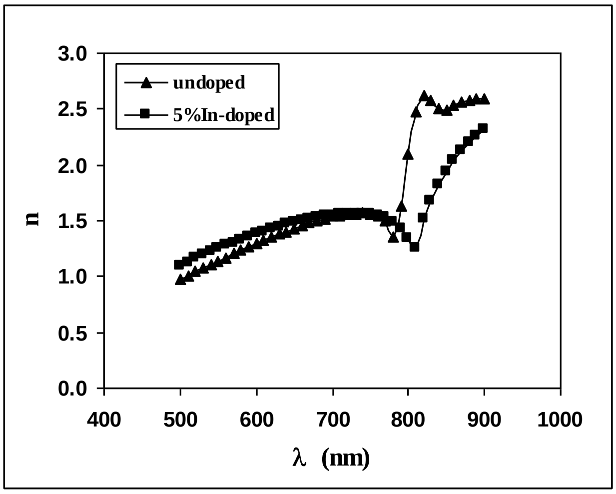

Figure 3: Variation of n with λ of undoped and 5%In-doped CdTe thin films.

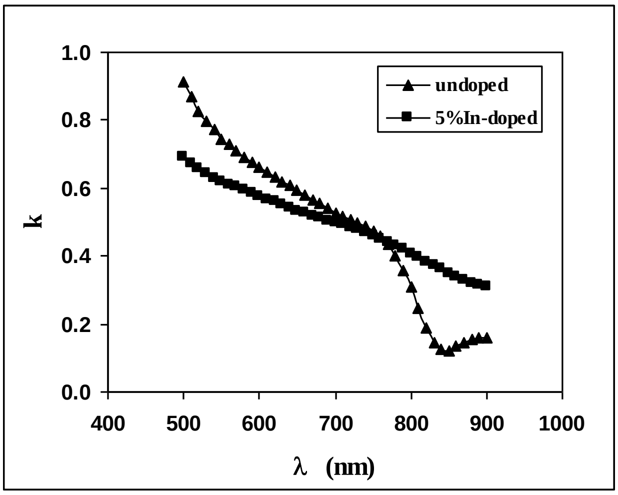

Figure 4: Variation of k with λ of undoped and 5%In-doped CdTe thin films.

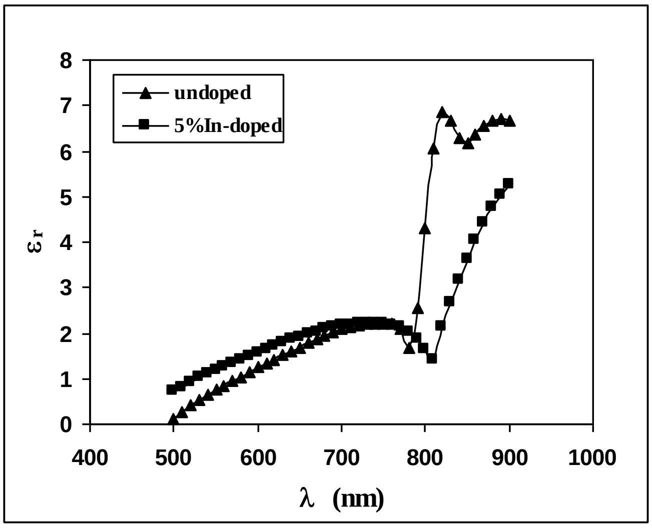

Figure 5: Variation of ε_r with λ of undoped and 5%In-doped CdTe thin films.

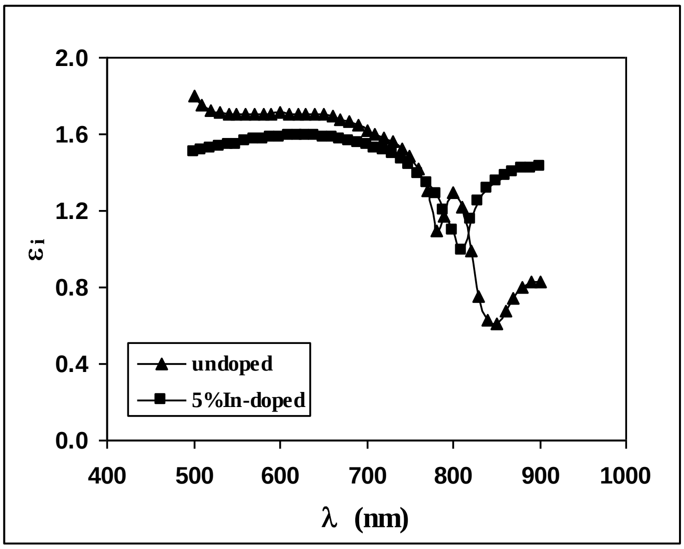

Figure 6: Variation of ε_i with λ of undoped and 5%In-doped CdTe thin films.

One of the common tools used for film characterization is the ways that the film photoconductivity is behaved with impurity doping. In this regards the following expression is used [32]:

$$\sigma_{Ph} = \sigma_L - \sigma_D \qquad (6)$$

where σ_L and σ_D are conductivities under illumination and in dark, respectively.
Fig. (7) shows the dependence of photoconductivity (σ_{Ph}) on incident power intensity (F =50, 75, 100, and 125mW/cm^2) of undoped and 5%In-doped CdTe thin films. It is clear from this figure that ln($\sigma_{Ph)}$ versus ln(F) curves are nearly straight lines which indicates that variation of photoconductivity with intensity follows a power law, (σ_{Ph} α F^{δ}), [33]. The values of power δ is a term which represent the recombination mechanism in thin films and its value estimated from the slopes of the ln($\sigma_{Ph)}$ vs. ln(F) plots. In the case of monomolecular recombination, δ=1 and δ=0.5 corresponds to the situation of bimolecular recombination [33]. From data of curves in Fig. 7, the values of δ are equal to 1.27 and 0.92 for udoped and 5%In-doped CdTe thin films, respectively. These data show doping CdTe films by 5%In results a decrease in the δ value (δ<1) which might be indicated that excess-carrier recombination is converted to the bimolecular one.
Material photosensitivity (σ_{Ph}/σ_D) is another important parameter used for photosensitive devices performance [33]. The variations of photosensitivity as a function of the light intensity of undoped and In-doped CdTe thin films have been shown in Fig.(8). It is observed from this figure that photosensitivity increases with the increase in light intensity. Another noticeable remark is that σ_{Ph}/σ_D increases about 2-3.5 times with 5%In-doped film, which may be attributed to a decrease in the density of defect states after In addition.

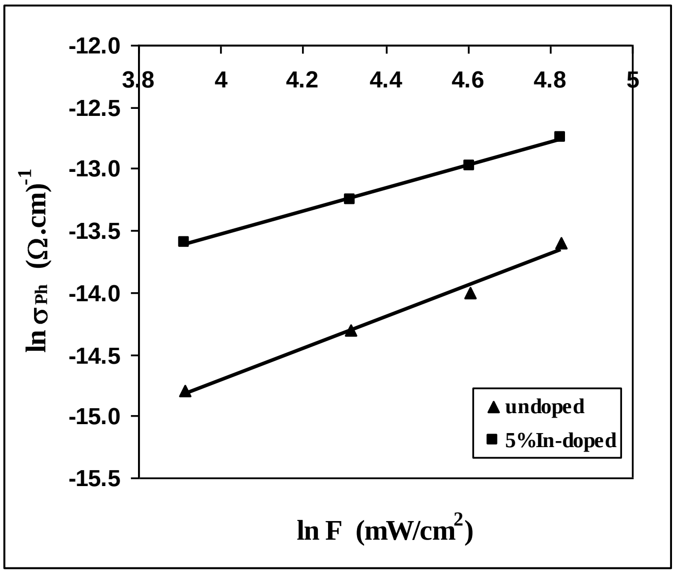

Figure 7: Variation of ln($\sigma_{Ph)}$ vs. ln(F) of undoped and 5%In-doped CdTe thin films.

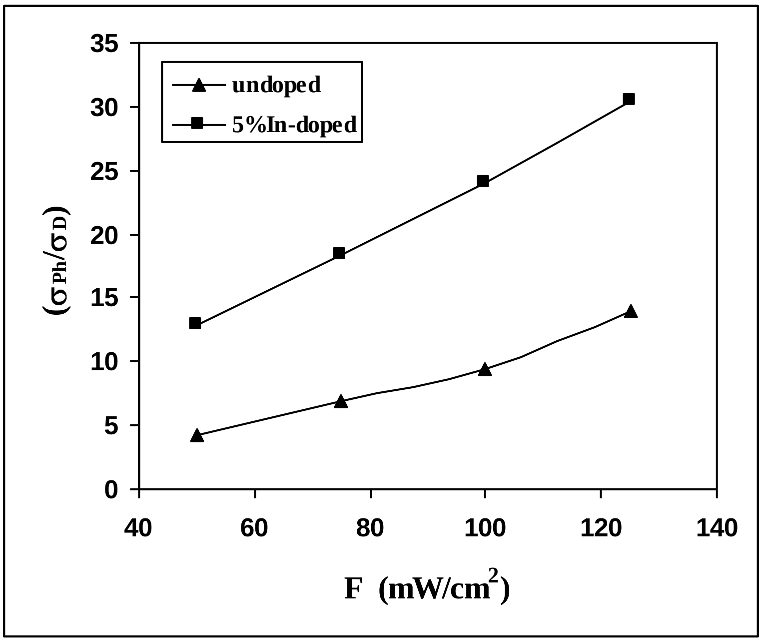

Figure 8: Variation of σ_{Ph}/σ_D with F of undoped and 5%In-doped CdTe thin films.

IV. CONCLUSIONS

Optical properties and photoconductivity measurements of undoped and 5%In-doped CdTe thin films deposited by thermal evaporation technique were studied. The outcome of this investigation can be summarized as follows:

- Optical absorption shows the presence of direct transition with band gap energy 1.56 eV of undoped CdTe thin film and it deceases to 1.47 eV upon doping with 5%In.
- Doping CdTe thin films with 5%In results an alteration in its values of refractive index, extinction coefficient, and real and imaginary parts of dielectric constant over the wavelength range 500-900 nm.

- The light intensity dependent of photoconductivity indicate that it increases as a power law, where δ is found to be varied from 1.27 to 0.92 after doping with 5%In indicating the change in recombination reaction.
- The photosensitivity increases with the increase of light intensity and upon doping CdTe thin films with 5%In.

References

[1]Florica C, Archir I, Ion L, Enculessu I, Antohe V, Radu A, Radu M, Chisulescu G, Dina N, Antohe S., "Production and Characterization of CdTe Wire Arrays for Hybrid Inorganic/Organic Photovoltaic Cells", Digest Journal of Nanomaterials and Biostructures **6**, 21 (2011).

[2]Wang Y., "Luminescent CdTe and CdSe Semiconductor Nanocrystals: Preparation, Optical Properties and Applications", Journal of Nanoscience and Nanotechnology, **8**,1068 (2008).

[3]Babkair S., "Charge Transport Mechanisms and Device Parameters of CdS/CdTe Solar Cells Fabricated by Thermal Evaporation", KAU:Sci; **22**, 21 (2010).

[4]Ryu Y, Kang T, Kim T., "Effects of in Situ Thermal Annealing on the Structural, Optical, and Electrical Properties in $Hg_{0.7}Cd_{0.3}Te$ Epilayers Grown on CdTe Buffer Layers", Appl Surf Sci **253,** 2652 (2006).

[5]Alver U, Bacaksiz E, Yanmaz E. , "Structural, Magnetic and Optical Properties of Co-diffused CdTe Thin Films," J of Alloy and Compounds **456**, 6 (2008).

[6]Gad S, Boshta M, Abo El-Soud A, El-Gendy Y., "Effect of the Annealing Temperature on the Structure and Optical Properties of $Cd_{1-x}Mn_xTe$ Thin Films", International Journal of the Physical Sciences, **5**, 1004 (2010).

[7]Bacaksiz E, Altunbas M, Yilmaz S, Tomakin M, Parlak M., "Effects of $CdCl_2$ Treatment on Properties of CdTe Thin Films Grown by Evaporation at Low Substrate Temperature," Cryst Res Tech. **42** ,890 (2007).

[8]Lovergine N, Prete P, Tapfer L, Marzo F, MancinA I. , "Hydrogen Transport Vapor Growth and Properties of Thick CdTe Epilayers for RT X-ray Detector Applications", Cryst Res Tech. **40**, 1018 (2005).

[9]Katlander J, Bargholtz Chr, Batres-Estrada G,. Behrooz K., "Development of Methods to Use CdTe Detectors in Field Measurements", Journal of Physics Conference Series, **41**, 523 (2006).

[10]Castro-Rodriguez R, Zapata-Torres M, Moo V, Bartolo-Perez P Pena, J., "Evidence of Scattering Effect on the Thermal Transport in Indium-doped CdTe Films", J. Phys. D: Appl Phys. **32**, 1194 (1999).

[11]G. Rusu, "Structural, Electronic Transport and Optical Properties of Zn-doped CdTe Thin Films, "Journal of Optoelectronics and Advanced Materials, **8** 931 (2006).

[12]Shah N, Ali A, Aqili A, Maqsood A., "Physical Properties of Ag-doped Cadmium Telluride Thin Films Fabricated by Closed-space Sublimation Technique", Journal of Crystal Growth **290,** 452 (2006).

[13] Becerril M, Galan O, Puente G, Meza E, Angel O., "Physical Properties of Bi-doped CdTe Thin Films Deposited by Co sputtering", Physica Status Solidi (a), **204**, 768 (2007).

[14]Shanmugan S, Balaji S, Muther asu , "Synthesis and Characterization of 10%Sb Doped CdTe Thin Films by Stacked Elemental Layer (SEL) Method", Materials Letter **63**; 1189 (2009).

[15]Becerril M, Vigil-Galan O, Contreras-Puente G, Zelaya-Angel O., "Aluminum doping of CdTe Polycrystalline Films Starting From the Heterostructure CdTe/Al", Rev Mex Fis **57**, 304 (2011).

[16]Rusu G. , "On the Electrical and Optical Properties of Nanocrystalline CdTe Thin Films", Journal of Optoelectronics and Advanced Materials **3**, 861 (2001).

[17]Pandey S, Tiwari U, Raman R, Prakash C, Krishma V, Dutta V, Zimik K, ”Growth of Cubic and Hexagonal CdTe Thin Films by Pulsed Laser Deposition”, Thin Solid Films **473**, 54 (2005).

[18]Melendez-Lira M, Becerril-Silva M, Zapata-Torres M, Mendoza-Galvan A, Jimenez-Sandoval S. , ”Semiconductor Thin Films Grown by RF-co-sputtering of CdTe and Al Targets”, Superficies Y Vacio **18**, 22 (2005).

[19]Pinheiro W, Falcao V, Cruc L, Ferreira C. , ”Comparative Study of CdTe Sources Used for Deposition of CdTe Thin Films by Close Spaced Sublimation Technique”, Materials Research **9**, 47 (2006).

[20]Ferreira S, Leal F, Faria T Oliveria, J, Motisuke P, Abramof E. , ”Characterization of CdTe Thin Films Grown on Glass by Hot Wall Epitaxy”, Brazilian Journal of Physics **36**, 317 (2006).

[21]Ubale A, Kulkarni D. , ”Studies on Size Dependent Properties of Cadmium Telluride Thin Films Deposited by Using Successive Ionic Layer Adsorption and Reaction Method”, Indian Journal of Pure and Applied Physics **44**, 254 (2006).

[22]Singh S, Kumar R, Sood K. , ”Structural and Electrical Studies of Thermally Evaporated Nanostructure CdTe Thin Films”, Thin Solid Films **519**, 1078 (2010).

[23]Deivanayaki S, Jayamurugan P, Mariappan R, Ponnuswamy V., ”Optical and Structural Characterization of CdTe Thin Films by Chemical Bath Deposition Technique”, Chalcogenide Letters **7**, 159 (2010).

[24]Gangawane S, Dhaygude H, Patit S, Fulari V. , ”Surface Deformation of Cadmium Telluride Thin Films by DEHI Technique”, Archives of Applied Science Research **3**, 186 (2011).

[25]Rizwan Z, Zakaria , Ghazali M, Jafari A, Ud Din F, Zamiri R., "Effect of Annealing Temperature on the Optical Spectra of CdS Thin Films Deposited at Low Solution Concentration by Chemical Bath Deposition (CBD) Technique”, Int. J. Mol. Sci. **12**, 1293 (2011).

[26]Tauc J. , ”Amorphous and Liquid Semiconductors”, Plenum Press, London and New York (1974).

[27]Saha S, Pal U, Chaudhubi A, Rao V, Banerjee H., ”Optical Properties of CdTe Thin Films”, Phys. Stat. Sol.(a) **114,** 721 (1989).

[28] Aksoy S, Caglar Y, Ilican S, Caglar M., ”Effect of Sn Dopants on the Optical and Electrical Properties of ZnO Films”, Optica Applicata **XL1**, 7 (2010).

[29]Kazmerski L. , ”Polycrystalline and Amorphous Thin Films and Devices”, Academic Press (1980).

[30]Myers T, Edwards S, Scheizina J. , ”Optical Properties of Polycrystalline CdTe Films”, J. Appl. Phys. **52**, 4231 (1981).

[31]El-Shazly A, El-Shair H., ”Some Parameters Affecting the Optical Constants of CdTe Thin Evaporated Films”, Thin Solid Films **78,** 287 (1981).

[32]Kalita P. , ”Temperature Dependence of dc Photoconductivity in CdTe Thin Films”, Pramana Journal of Physics **60**, 1247 (2003).

[33]Pal R, Yadav S, Agnihotri A, Kumar D, Kumar A. , ”Composition Dependence of Photoconductivity in Amorphous $Se_{70}Te_{30-x}Zn_x$ Thin Films”, Journal of Non-Oxide Glasses **1**, 285 (2009).