IOSR Journal of Applied Physics (IOSR-JAP)
e-ISSN: 2278-4861.Volume 8, Issue 6 Ver. III (Nov. - Dec. 2016), PP 134-139
www.iosrjournals.org

8 MeV electron beam irradiation effects on Al/n-CdS thin film Schottky barrier diode

P. M. Parameshwari, Ganesh Sanjeev and K. Gopalakrishna Naik*
(Department of studies in Physics, Mangalore University, Mangalagangotri – 574199, India)

Abstract: *Electron irradiation on the Al/n-CdS Schottky barrier diode (SBD) was carried out by using 8 MeV electrons over a range of doses from 10 kGy to 75 kGy. Current-voltage (I–V) and capacitance-voltage (C–V) characteristics of the SBD were studied at room temperature. Diode parameters such as the ideality factor, series resistance, and Schottky barrier height were calculated from forward I–V characteristics. Effects of irradiation on the carrier concentration, depletion layer width and barrier height were studied from C–V characteristic. The ideality factor, series resistance, reverse saturation current and depletion layer width were found to increase with the increase of radiation dose. The carrier concentration and barrier height were found to decrease with increase in electron irradiation dose.*

Keywords: *CdS thin film, current – voltage, capacitance – voltage characteristics, electron irradiation, Schottky barrier diode.*

I. Introduction

Cadmium sulphide (CdS) is an important semiconductor material for applications in electronic and optoelectronic devices such as solar cells [1, 2], non-linear integrated optical devices [2], photo detectors [2 - 4], optical waveguides [2], thin film transistors [5] etc. CdS generally shows n-type conductivity due to native donors resulting from sulphur vacancies. A wide variety of techniques such as evaporation [6], sputtering [7], chemical bath deposition (CBD) [5], spray pyrolysis [8], electrode position [9], close spaced sublimation [10], successive ionic layer adsorption reaction (SILAR) [11], spin coating [12], etc. have been employed for the deposition of CdS thin films.

The metal-semiconductor (MS) rectifying contacts, the Schottky barrier contacts, are widely used in photo detectors, γ-ray detectors, solar cells, microelectronics and integrated circuits [13]. A proper understanding of the properties of a given Schottky barrier contact is very important for its intended applications. The barrier height of a SBD depend on the factors such as work function of the metal and electron affinity of the semiconductor, doping concentration of the semiconductor, the existence of native interfacial insulator layer and its thickness, and density of interface defects states [14, 15]. Any mechanism that affects the Schottky barrier interface will lead to changes in the SBD performance [16]. In space applications, SBDs are continuously exposed to various particles such as electrons, neutrons, protons and alpha particles having energy ranging from a few keV to hundreds of MeV. That will induce lattice defects that can alter the electronic structure of the MS interface [13]. Thus, it is essential to study the effect of radiation on a given semiconductor SBD so as to find its suitability for space applications.

There are several reports on metal/CdS SBDs using metals such as Al, Au, Ag, and Te [17, 18]. Tascioglu et al. [17] studied the effect of metal work function on the barrier height of the metal/CdS/SnO_2/In-Ga structures with several metals such as Ag, Au, Al, and Te. Several studies were reported on the Al/CdS SBDs [17, 18, 19] but the studies on radiation induced damages on the Al/CdS SBDs are scarce to the best of our knowledge. In the present work, the effect of 8 MeV electron irradiation on Al/n-CdS SBD prepared using spray pyrolysis deposited CdS thin film has been studied using *I–V* and *C-V* measurements.

II. Experimental Details

A simple and inexpensive spray pyrolysis method was used to deposit the CdS thin film. Aqueous solutions of 0.15M $CdCl_2$ and 0.15M $(NH_2)_2CS$ were mixed in an appropriate quantities in order to get the precursor solution with [Cd]/[S] = 0.5. The solution mixture was then stirred well and sprayed on to the ITO coated glass substrates kept at 400 °C in an ambient atmosphere at a spray rate of 10 ml/min. The grown film was annealed for 15 minutes at 400 °C and allowed to cool naturally to room temperature. The Al/CdS SBD was prepared by depositing Al metal dot of 125 nm in thickness and 0.014 cm^2 area through a mask on the CdS film at a pressure of $2x10^{-5}$ mbar using a HINDHIVAC vacuum coating unit - Model 12A 4. Ohmic contact was made by depositing indium on ITO. The prepared Al/CdS SBD was exposed to 8 MeV electron beam radiation over a range of doses from 10 kGy - 75 kGy using Microtron accelerator at Mangalore University. The salient features of the Microtron accelerator are detailed elsewhere [20].

I-V characteristics of the SBD were measured at room temperature, both before and after irradiation, using computer interfaced Keithley 236 source/measure unit at Microtron centre, Mangalore University. The *C-V* measurement was carried out before and after irradiation on the SBD at 1 MHz frequency using Agilent 4294 A LCR meter at CENSE, IISc, Bangalore.

III. Results And Discussions

Fig. 1 shows the *I-V* characteristics of the Al/n-CdS SBD irradiated with 8 MeV electrons of various doses ranging 10 kGy-75 kGy. As shown in Fig. 1, the forward current decreased and the reverse current increased with increase in the irradiation dose. The forward ln(I) versus V plot shows nearly a linear increase with increase in bias voltage up to ~0.4 V and this linear region is labelled as Region I in Fig.1. Above 0.4 V, the forward current-voltage characteristics show a non-linear behaviour. This nonlinear region of the forward *I-V* curve is labelled as Region II in Fig. 1.

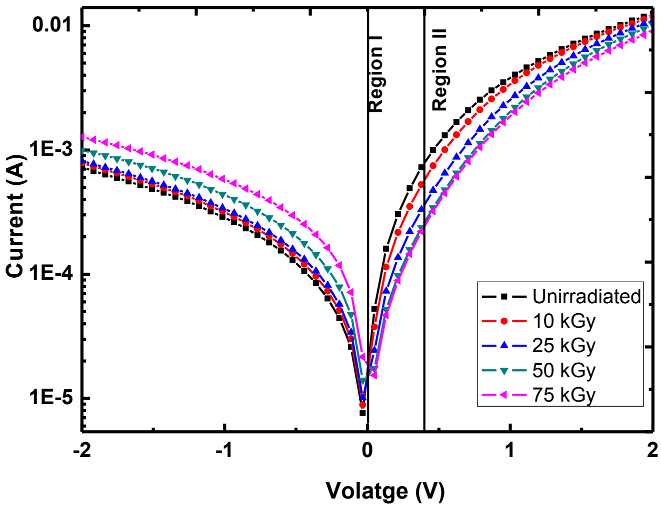

Fig. 1 *I–V* characteristics of Al/n-CdS SBD irradiated with various electron doses.

In moderately doped semiconductor SBDs the current flow can be described by thermionic emission theory [21]. Based on thermionic emission theory, I-V plot of the Al/n-CdS SBD in region I can be described by the equation [21]

$$I = I_S\left[\exp\left(\frac{qV}{nkT}\right)-1\right] \tag{1}$$

with saturation current I_S is given by the equation

$$I_S = AA^{**}T^2\exp\left(-\frac{q\phi_b}{kT}\right) \tag{2}$$

where q is the electron charge, k is the Boltzmann constant, V is the applied voltage, n is the ideality factor, A is the area of the diode, A^{**} is the Richardson constant, and ϕ_b is the Schottky barrier height. Equation (1) can also be expressed as

$$\ln(I) = \frac{qV}{nkT} + \ln(I_S) \tag{3}$$

Therefore, the saturation current and the ideality factor can be obtained from the intercept and slope of the forward ln(*I*) versus *V* plot using the equation (3). The measured ideality factor for the Al/n-CdS SBD was found to increase with the increase in the radiation dose as shown in the Table 1. The observed increase of ideality factor with the increase of the radiation dose may be due to the increase in the density of interface states [22].

From the saturation current, Schottky barrier height (ϕ_b) was calculated using the equation (2) as

$$\phi_b = \frac{kT}{q}\ln\left(\frac{AA^{**}T^2}{I_S}\right) \tag{4}$$

For calculating ϕ_b for the Al/n-CdS SBD using equation (4), A** was taken to be equal to 12 $AK^{-2}cm^{-2}$ for n-CdS [19]. The obtained values of ϕ_b decreased with the increase of radiation dose as shown in the Table 1. The decrease of ϕ_b with the radiation dose was also observed by A Rao et al. [22] and S Krishnan et al. [23] for Au/n-Si and Al/p-Si SBDs, respectively. The decrease of ϕ_b with increase in radiation dose may be due to the increase resistivity (decreasing concentration due to compensation) of CdS thin film.

For a Schottky with series resistance $R_{S,}$ the I-V equation (1) becomes

$$I = I_S\left[\exp\left(\frac{q(V-IR_S)}{nkT}\right)-1\right] \tag{5}$$

Equation (5) can be written as

$$\frac{dV}{d(\ln I)} = IR_S + \frac{nkT}{q} \tag{6}$$

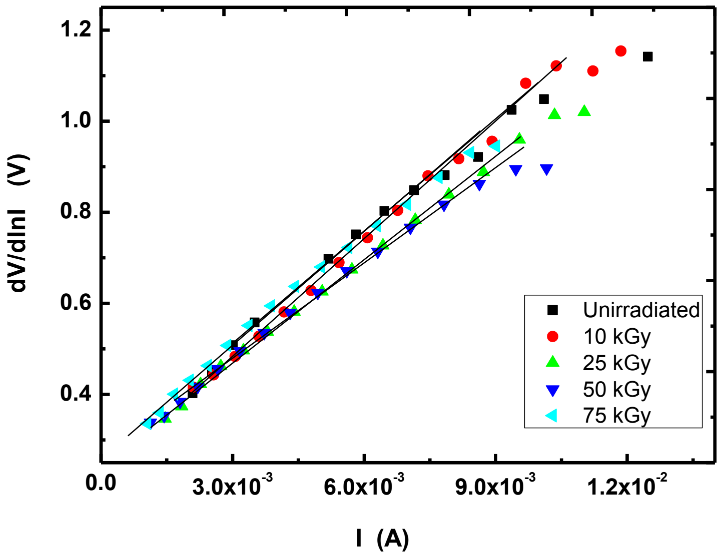

Fig. 2 d*V*/dln*I* vs. *I* plot of Al/n-CdS SBD irradiated for various electron doses.

For Region II of the I-V plot, the series resistance and the ideality factor were obtained from the slope and intercept of d*V*/dln*I* versus *I* plot using equation (6). The d*V*/dln*I* versus *I* plot is shown in Fig. 2. The calculated values of series resistance R_S and ideality factor n are listed in the Table 1, the series resistance increased with the increase in the radiation dose. This may be due to the reduction in the product of mobility and free carrier concentration with radiation dose. Mobility may reduce with the increase in the radiation dose because of the radiation induced defect centres which act as scattering centres for charge carriers. Increase of defect centres also lead to the reduction in free carrier concentration [22, 24], thus decreasing the product of free carrier concentration and the mobility. Increase of series resistance may be the main cause for the decrease of the forward current with the increase of the radiation dose.

Table 1. Ideality factor (n), series resistance (R_S) and barrier height (ϕ_b) variation of Al/CdS SBD with radiation dose.

Dose (kGy)	Ideality factor		Series resistance (Ω) 0.4 V<V<2 V	Barrier height eV
	0<V<0.4 V	0.4 V<V<2V		
Unirradiated	6.64	3.03	74.63	0.473
10	6.71	3.15	77.89	0.467
25	6.77	3.38	80.66	0.456
50	6.88	3.46	81.49	0.447
75	6.99	3.53	83.58	0.441

C-V characteristic is another important tool to study the electrical properties of a SBD. From the C-V measurements, the SBD diode parameters such as carrier concentration, built-in potential and depletion layer width (W) can be found out. Hence, in order to find the irradiation induced changes in the properties of the Al/n-CdS SBD, C–V measurement was carried out both before and after exposing the diode to 8 MeV electron beam irradiation of 75 kGy. The room temperature C–V profiles of the unirradiated and electron beam irradiated Al/n-CdS SBD are shown in the Fig. 3. The C-V relation for an n-type semiconductor SBD is given by the equation [25]

$$C = \frac{\varepsilon_s \varepsilon_0 A}{W} = A\left[\frac{q\varepsilon_s \varepsilon_o N_d}{2(V_{bi}+V)}\right]^{1/2} \quad (7)$$

where C is the capacitance, N_d is the carrier concentration, ε_s is the dielectric constant of the semiconductor, ε_0 is the absolute permittivity and V_{bi} is the built in potential and V is the bias voltage. The dielectric constant for n-CdS was taken to be equal to 5.7 [26]. The depletion layer width of the Al/n-CdS SBD was calculated using the equation (7). The depletion layer width for the unirradiated Al/n-CdS SBD was found to be 4.59 nm at zero bias and 10.4 nm at -2 V bias. After 75 kGy electron irradiation the depletion layer width of the Al/n-CdS SBD was found to be 4.95 nm at zero bias and 12.4 nm at -2 V bias which shows electron irradiation induced increase in the depletion layer width.

Equation (7) can be rewritten as

$$\frac{1}{C^2} = \frac{2}{A}\frac{1}{q\varepsilon_0\varepsilon_s N_d}\left[V_{bi}+V\right] \quad (8)$$

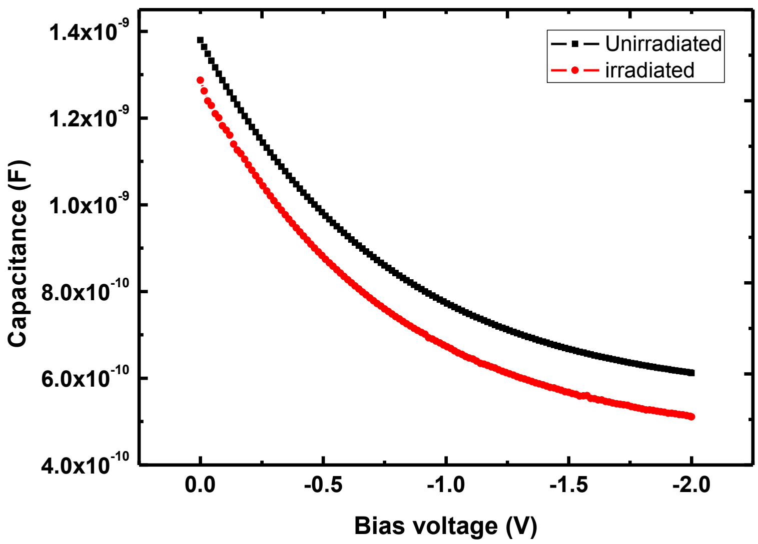

Fig. 3 C – V characteristics of unirradiated and irradiated Al/CdS SBD.

Therefore, as per equation (8), the value of the carrier concentration N_d and the built-in potential V_{bi} of the Al/n-CdS SBD can be found from the slope and intercept of $1/C^2$ versus V plot, respectively. Fig. 4 shows the dependence of $1/C^2$ on applied voltage for the unirradiated and the electron irradiated Al/n-CdS SBD. The $1/C^2$ versus V plot is linear only for low bias voltages, and as the bias voltage increases, it deviates from linearity. This may be due to a high leakage current in this SBD as shown in the I-V Characteristics in Section

3.1. The carrier concentration obtained from the C-V measurement was found to be 1.84 x 10^{23} m^{-3} and 1.46 x 10^{23} m^{-3} before and after irradiation, respectively. The built in potential obtained from the C-V measurement was found to be 0.121 eV and 0.132 eV before and after irradiation, respectively. The slight decrease in the carrier concentration after irradiation may be due to the irradiation induced electron capture levels or acceptor like defects at the Al/n-CdS junction [24].

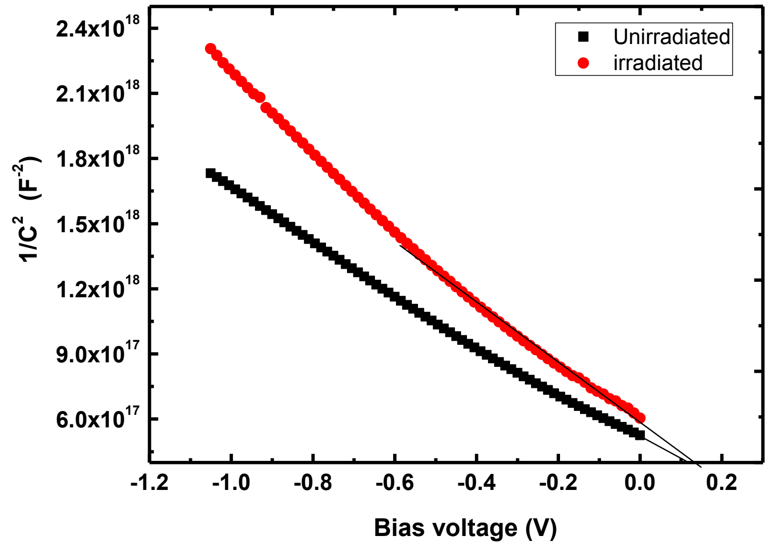

Fig. 4 $1/C^2$ vs V plot of pristine and irradiated Al/CdS SBD.

The potential difference between the Fermi level and the top of the valence band (V_P) in CdS was calculated using equation [18],

$$V_P = kT \ln\left(\frac{N_C}{N_d}\right) \tag{9}$$

where N_C is the density of states in the conduction band of CdS, equal to 2 x 10^{24} m^{-3} [27]. V_P was found to be 0.0068 eV and 0.0062 eV before and after irradiation, respectively.

The effective barrier height (ϕ_b) was calculated from *C-V* measurements using equation,

$$\phi_b = V_{bi} + V_P \tag{10}$$

The effective barrier height (ϕ_b) was increased from the unirradiated value of 0.127 eV to 0.138 eV after irradiation. The value of barrier height obtained from *C-V* measurement was smaller than that obtained from *I-V* characteristics. This may be due to the presence of an interface layer or due to spatial inhomogeneities at the MS interface of abrupt Schottky contact [24].

IV. Conclusion

CdS thin film was deposited on ITO coated glass substrate by spray pyrolysis. Al/n-CdS SBD was formed by depositing Al metal contact on n-CdS film by thermal evaporation. Irradiation induced changes in the Al/n-CdS SBD parameters were studied from *I-V* and *C-V* measurements both before and after irradiation. Increase in the ideality factor and the series resistance with irradiation were observed. A decrease in the Schottky barrier height and the increase in reverse current were also observed for irradiated sample. The degradation of SBD properties after irradiation may be due to irradiation induced defect states at the Al/n-CdS junction. Also, Carrier concentration decreased from the unirradiated value of 1.84 x 10^{23} m^{-3} to 1.46 x 10^{23} m^{-3} after irradiation.

Acknowledgements

One of the authors (PPM) thanks UGC, Govt. of India for providing financial support (RFSMS). The authors acknowledge INUP, Center for Nanoscience, IISc, Bangalore for providing *C-V* characterization facility. Authors gratefully acknowledge the help and support of staff and research scholars of Department of Physics, and Microtron centre - Department of Physics, Mangalore University, during the course of this work.

References

[1]. S. S. Hegedus and B. E. McCandless, CdTe contacts for CdTe/CdS solar cells: effect of Cu thickness, surface preparation and recontacting on device performance and stability, *Sol. Energy Mater. Sol. Cells, 88*, 2005, 75–95.

[2]. H. Metin and R. Esen, Annealing studies on CBD grown CdS thin films, *J. Cryst. Growth, 258,* 2003, 141–148.

[3]. N. Hernandez-Como, S. Moreno, I. Mejia and M A Quevedo-Lopez, Low- temperature processed ZnO and CdS photodetectors deposited by pulsed laser deposition, *Semicond. Sci. Technol., 29, 2014,* 085008.

[4]. Sh. A. Mirsagatov, R. R. Kabulov and M. A. Makhmudov, Injection Photodiode Based on an *n*-CdS/*p*-CdTe Heterostructure, *Semiconductors, 47*, 2013, 825–830.

[5]. G. Arreola-Jardon, L. A. Gonzalez, L. A. G. Cerda, B. Gnade, M. A. Q. Lopez, and R. R. Bon, Ammonia-free chemically deposited CdS films as active layers in thin film transistors, *Thin Solid Films, 519*, 2010, 517–520.

[6]. V. Singh, B. P. Singh, T. P. Sharma, and R. C. Tyagi, Effect of ambient hydrogen sulphide on the optical properties of evaporated cadmium sulphide films, *Opt. Mater., 20*, 2002, 171–175.

[7]. N. S. Das, P. K. Ghosh, M. K. Mitra, and K. K. Chattopadhyay, Effect of film thickness on the energy band gap of nanocrystalline CdS thin films analyzed by spectroscopic ellipsometry, *Physica E, 42*, 2010, 2097–2102.

[8]. J. Hiie, T. Dedova, V. Valdna, and K. Muska, Comparative study of nano- structured CdS thin films prepared by CBD and spray pyrolysis: Annealing effect, *Thin Solid Films, 511 – 512,* 2006, 443 – 447.

[9]. K. Zarebska, and M. Skompska, Electrodeposition of CdS from acidic aqueous thiosulfate solution – Invesitigation of the mechanism by electrochemical quartz microbalance technique, *Electrochim. Acta 56*, 2011, 5731–5739.

[10]. A. E. Abken, D. P. Halliday and K. Durose, Photoluminescence study of polycrystalline photovoltaic CdS thin film layers grown by close-spaced sublimation and chemical bath deposition, *J. Appl. Phys., 105,* 2009, 064515.

[11]. V. Senthamilselvi, K. Saravanakumar, R. Anandhi, A. T. Ravichandran, and K. Ravichandran, Effect of annealing on the stoichiometry of CdS films deposited by SILAR technique, *Optoelectronics and Advanced materials , 5,* 2011, 1072 – 1077.

[12]. M. Thambidurai, N. Murugan, N. Muthukumarasamy, S. Agilan, S. Vasantha and R. Balasundaraprabhu, Influence of the Cd/S Molar Ratio on the Optical and Structural Properties of Nanocrystalline CdS Thin Films, *J. Mater. Sci. Technol., 26,* 2010, 193-199.

[13]. P. Veeramani, M. Haris, S. Moorthy Babu, D. Kanjilal, and P. Sugathan, Investigation of swift heavy ion irradiation effects on Au/CdTe and Au/CdZnTe Schottky barrier diode, *Radiation Measurements, 43,* 2008, 56 – 61.

[14]. R. Wang, M. Xu, P. D. Ye, and R. Huang, Schottky-barrier height modulation of metal/$In_{0.53}Ga_{0.47}As$ interfaces by insertion of atomic layer deposited ultrathin Al_2O_3, *J. Vac. Sci. Technol. B, 29,* 2011, 041206.

[15]. Y. Ando, Y. Gohda, and S. Tsuneyuki, Dependence of the Schottky barrier on the work function at metal/SiON/SiC(0001) interfaces identified by first-principles calculations, *Surf. Sci. 606*, 2012, 1501.

[16]. A. T. Sharma, Shahnawaz, S. Kumar, Y. S. Katharria, and D. Kanjilal, Barrier modification of Au/n-GaAs Schottky diode by swift heavy ion irradiation, *Nucl. Instrum. Methods Phys. Res., Sect. B, 263,* 2007, 424–428.

[17]. I. Tascioglu, S. Altindal, I. Polat, and E.Bacaksiz, The effect of metal work function on the barrier height of, metal/CdS/SnO2/IneGa structures, *Current Applied Physics, 13, 2013,* 1306 – 1310.

[18]. A. A. M. Farag, I. S. Yahia, and M. Fadel, Electrical and photovoltaic characteristics of Al/n-CdS Schottky diode, Int. J. *Hydrogen Energy, 34,* 2009, 4906 – 4913.

[19]. S. Gupta, D. Patidar, M. Baboo, K. Sharma and N. S. Saxena, Investigation of Al Schottky junction on n-type CdS film deposited on polymer substrate, *Front. Optoelectron. China, 3,* 2010, 321–327.

[20]. K. Siddappa, Hemnani, Ganesh, S. S Ramamurthy, Y. Sheth, H.C. Soni, and P. Srivastava, Variable energy Microtron for R&D work, *Radiat. Phys. Chem., 51*, 1998, 441.

[21]. S. M Sze and K. K. Nag, Physics of Semiconductor Devices. 3rd edn. (2007), John Wiley & Sons, Inc. Page No. 153- 158.

[22]. A. Rao, S. Krishnan, G. Sanjeev, and K. Siddappa, Effect of 8 MeV Electrons on Au/n-Si Schottky diodes, *International Journal of Pure and Applied Physics, 5,* 2009, 55–62.

[23]. S. Krishnan, G. Sanjeev, and M. Pattabi, Electron irradiation effects on the Schottky diode characteristics of p-Si, *Nucl. Instrum. Methods Phys. Res., Sect. B, 266,* 2008, 621–624.

[24]. E. Ugurel, S. Aydogan, K. Serifoglu, and A. Turut, Effect of 6 MeV electron irradiation on electrical characteristics of the Au/n-Si/Al Schottky diode, *Microelectron. Eng., 85*, 2008, 2299–2303.

[25]. S. M Sze and K. K. Nag, Physics of Semiconductor Devices. 3rd edn. (2007), John Wiley & Sons, Inc. Page No. 137- 138.

[26]. K. Koc, F. Z. Tepehan and G. G. Tepehan, Growth kinetics of MPS-capped CdS quantum dots in self-assembled thin films, *Nanoscale Research Letters, 7,* 2012, 610–617.

[27]. L. Kronik, L. Burstein, M. Leibovitch, Y. Shapira, D. Gal, E. Moons, J. Beier, G. Hodes, D. Cahena, D. Hariskos, R. Klenk, and H. W. Schock, Band diagram of the polycrystalline CdS/Cu(In,Ga)Se_2 heterojunction, *Appl. Phys. Lett., 67,* 1995, 1405–1407.