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Current-Voltage and Capacitance-Voltage measurements on Al/$Cd_{0.8}Zn_{0.2}S$ Schottky barrier diodes subjected to 8 MeV electron beam irradiations

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Abstract

Al/n-$Cd_{0.8}Zn_{0.2}S$ thin film Schottky barrier diode (SBD) was fabricated by depositing Al metal film by thermal evaporation on spray deposited $Cd_{0.8}Zn_{0.2}S$ thin film. The fabricated Al/n-$Cd_{0.8}Zn_{0.2}S$ SBD diode was exposed to 8 MeV electrons for various doses ranging 10 kGy-75 kGy at room temperature. Irradiation induced changes in the *I-V* and *C-V* characteristics were studied at room temperature. Diode ideality factor, series resistance and Schottky barrier height were calculated from *I-V* characteristics. It was found that, the ideality factor and the series resistance increased and the Schottky barrier height decreased after irradiation. Depletion layer width, built in potential, effective barrier height and carrier concentration were obtained from *C-V* measurements. Depletion layer width increased and carrier concentration decreased after irradiation.

Keywords: $Cd_{1-x}Zn_xS$ thin films, Schottky barrier diode, irradiation, current-voltage and capacitance-voltage measurements.

1. INTRODUCTION

Cadmium zinc sulphide ($Cd_{1-x}Zn_xS$) is a chalcogenide ternary direct bandgap semiconductor and its bandgap can be controlled between the bandgap of CdS and ZnS by changing the value of x. $Cd_{1-x}Zn_xS$ has found wide range of applications in optoelectronic devices such as photodetectors, heterojunction solar cells, light emitting diodes [1] etc. In heterojunction solar cells, $Cd_{1-x}Zn_xS$ is used as window layer in place of the widely used CdS, this leads to the reduction in window absorption loses and an increase in the short circuit current of the solar cells [2]. Due to the importance of $Cd_{1-x}Zn_xS$, many studies have been undertaken by various researchers in order to study the properties of $Cd_{1-x}Zn_xS$ thin films and its application in semiconductor devices [2-5].

The SBDs find wide application in modern electronic and optoelectronic devices [6]. It was found that the reliability and the performance of Schottky barrier diodes are significantly influenced from the metal-semiconductor interface quality [7]. For example, the devices used in space environments are continuously exposed to various energetic particles such as electrons, neutrons, protons and alpha particles having energy ranging from a few keV to hundreds of MeV. These energetic radiations produces large number of lattice defects in the SBDs and it results in gradual decrease in the diode performance, affecting the reliability and the lifetime of the electronic systems in space environments.

The study on the radiation effects on SBDs have been attracted the attention of the researchers and various studies have been performed by various researchers during the recent years [8,9]. It was found that the radiation damage is directly related to the amount of energy and the total dose of radiation received by the device. The experimental methods like current-voltage (*I-V*) and capacitance-voltage (*C-V*) can be used to determine the radiation induced damages in the performance of SBDs. An *I-V* plot gives information about the diode parameters such as ideality factor (n), barrier height (ϕ_b), series resistance (R_S) etc. *C-V* plots gives an information about the depletion layer width (W), built in potential (V_{bi}), carrier concentration (N_d), and barrier height (ϕ_b) of SBDs.

In the present study, $Al/Cd_{0.8}Zn_{0.2}S$ SBD was exposed to 8 MeV electrons for various doses ranging 10 kGy-75 kGy at room temperature. Room temperature *I-V* characteristics were recorded both before and after exposing the diodes for various radiation doses. Room temperature *C-V* measurements were performed on unirradiated and irradiated $Al/Cd_{0.8}Zn_{0.2}S$ SBD at 1 MHz frequency. The Mott-Schottky analysis was adopted to determine the built in potential (V_{bi}) and the carrier concentration (N_d) of $Al/Cd_{0.8}Zn_{0.2}S$ SBD. The analysis of the *I-V* and *C-V* measurements done on $Al/Cd_{0.8}Zn_{0.2}S$ SBD before and after electron irradiation are presented and discussed in this paper.

2. EXPERIMENTAL TECHNIQUES

The $Cd_{0.8}Zn_{0.2}S$ thin film was deposited on ITO coated glass substrate using spray pyrolysis. Aqueous solutions of 0.15M $CdCl_2$, 0.15M $ZnCl_2$, 0.15M $(NH_2)_2CS$ were

mixed in an appropriate quantity in order to get the composition $Cd_{0.8}Zn_{0.2}S$ with [Cd+Zn]/[S] = 0.5. The solution mixture was then stirred well and sprayed on the ITO coated glass substrate 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. Al/$Cd_{0.8}Zn_{0.2}S$ SBD was fabricated by depositing Al metal film of 125 nm in thickness with contact area of 0.014 cm^2 through a mask on the $Cd_{0.8}Zn_{0.2}S$ thin film at a pressure of 2 x 10^{-5} mbar using a HINDHIVAC vacuum coating unit - Model 12A 4. The fabricated Al/$Cd_{0.8}Zn_{0.2}S$ SBD was irradiated with 8 MeV electron beam at room temperature using Microtron accelerator at Mangalore University. The features of Microtron accelerator has been defined elsewhere [10]. The diode was exposed to 8 MeV electrons of various doses ranging 10 kGy-75 kGy.
The *I-V* measurements were performed both before and after each irradiation dose using Keithley 236 source/measure unit at Microtron centre, Mangalore University. The *C-V* measurements were done on unirradiated SBD and the SBD exposed to 75 kGy at 1 MHz frequency using Agilent 4294 A precision impedance analyser at CENSE, IISc, Bangalore.

3. RESULTS AND DISCUSSION

3.1 Current-voltage measurements

The I-V characteristics of Al/$Cd_{0.8}Zn_{0.2}S$ SBD exposed to various doses of 8 MeV electrons are shown in the Figure 1. It was observed that the forward current decreased and the reverse current increased with the increase of irradiation dose. As shown in Figure 1, the forward ln*I* versus *V* plot varied somewhat linearly for the forward voltage up to around 0.4 V, and this linear region is labelled as Region I. Above 0.4 V, the forward ln*I* versus *V* plot showed a non-linear behaviour with a downward trend in the slope. This nonlinear region of the forward ln*I* versus *V* plot is labelled as Region II.
The current flow through the fabricated Al/$Cd_{0.8}Zn_{0.2}S$ SBD can be explained using the thermionic emission theory [11] and the corresponding expression for linear portion of the *I-V* characteristics is given by

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

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, ϕ_b is the Schottky barrier height and I_s is the saturation current. The saturation current I_S is given by the equation

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

Equation (1) can also be expressed as

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

The saturation current (I_s) and the ideality factor (n) can be obtained respectively from the intercept and slope of semilog forward *I-V* plot. The ideality factor of the SBD obtained for various irradiation doses are given in the Table 1.

Table 1. Ideality factor (n), Series resistance (R_S) and barrier height (ϕ_b) variation of $Al/Cd_{0.8}Zn_{0.2}S$ Schottky barrier diode 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<2 V		
Unirradiated	6.84	3.34	180.74	0.462
10	6.97	3.41	317.46	0.446
25	7.08	3.58	386.10	0.413
50	7.22	3.67	534.75	0.402
75	7.35	3.85	769.23	0.385

Ideality factor was found to increase with the increase of irradiation dose, which may be due to the increase in the density of interface states with radiation dose [12]. The Schottky barrier height (ϕ_b) can be calculated using the equation (2) as

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

The values of the Schottky barrier height obtained by taking A** equal to 76.33 $AK^{-2}cm^{-2}$ for n-CdZnS [13] are given in the Table 1. The Schottky barrier height was found to decrease with increase in electron irradiation dose. Similar kind of decrease in Schottky barrier height with 8 MeV electron beam irradiation was also observed by Rao et al. [14] and Krishnan et al. [12] for Au/n-Si and Al/p-Si SBDs, respectively. The decrease in the Schottky barrier height with increase of irradiation dose may be due to the increase in the irradiation induced interface defects [12, 14]. For a Schottky barrier diode having series resistance R_S, the *I-V* relation based on thermionic theory can be rewritten as

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

Equation (5) can be written as

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

The Series resistance and the ideality factor were obtained from the slope and intercept of dV/dln$I$ vs. I plot using equation (6). Figure 2. shows the plot of dV/dln$I$ against current (I) for the Al/$Cd_{0.8}Zn_{0.2}S$ SBD exposed to various doses of 8 MeV electrons. The R_S and n values obtained from the dV/dln$I$ versus current (I) plot are given in the Table 1. It was observed that ideality factor obtained in the nonlinear region (Region II) was considerably smaller than that obtained in the linear region (Region I). It was also observed that the ideality factor increased with the increase of radiation dose, which can be related to the increase in the density of interface states with radiation dose [12]. In addition to this, it was also observed that the series resistance increased with the increase of radiation dose. This can be explained as; radiation induces defect centres in the Schottky junction, which act as scattering centres leading to the decrease in mobility. Defect centres also results in the decrease of free carrier concentration. Thus the product of free carrier concentration and the mobility decreases resulting in the increase of series resistance.

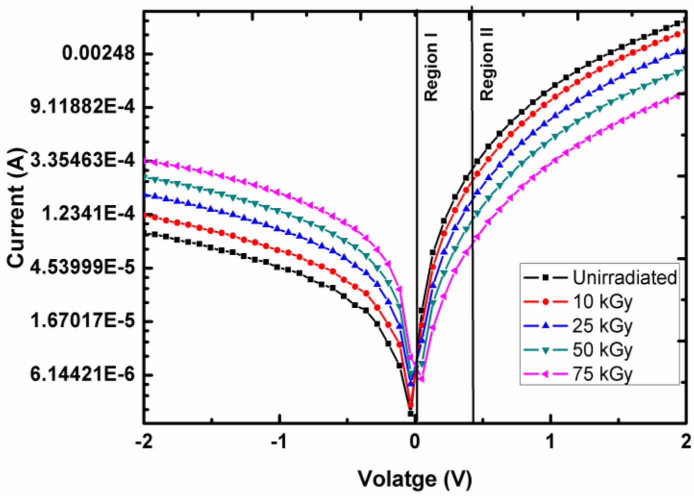

Figure 1. *I-V* characteristics of Al/$Cd_{0.8}Zn_{0.2}S$ SBD irradiated with different electron doses.

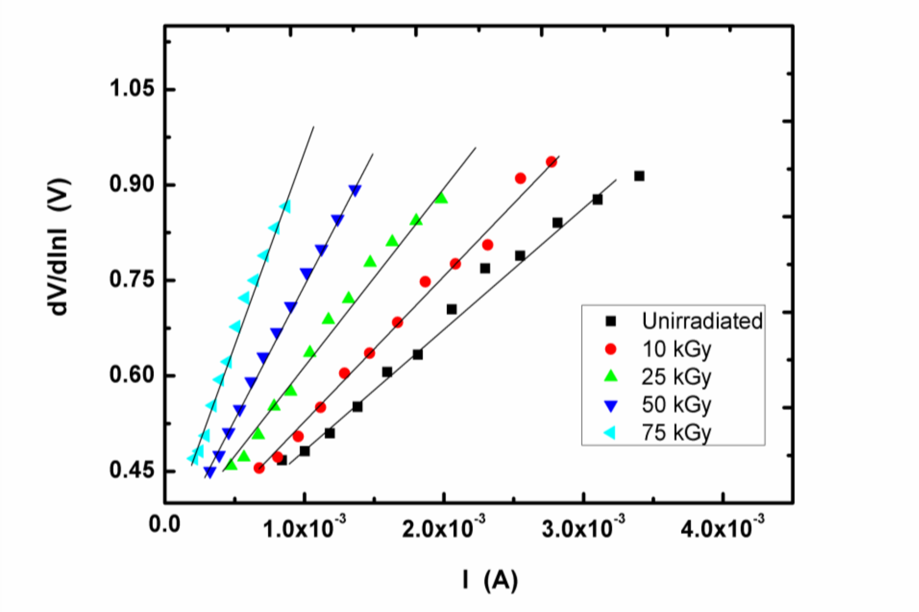

Figure 2. dV/dln$I$ vs. I plot of Al/$Cd_{0.8}Zn_{0.2}S$ SBD irradiated with different electron doses.

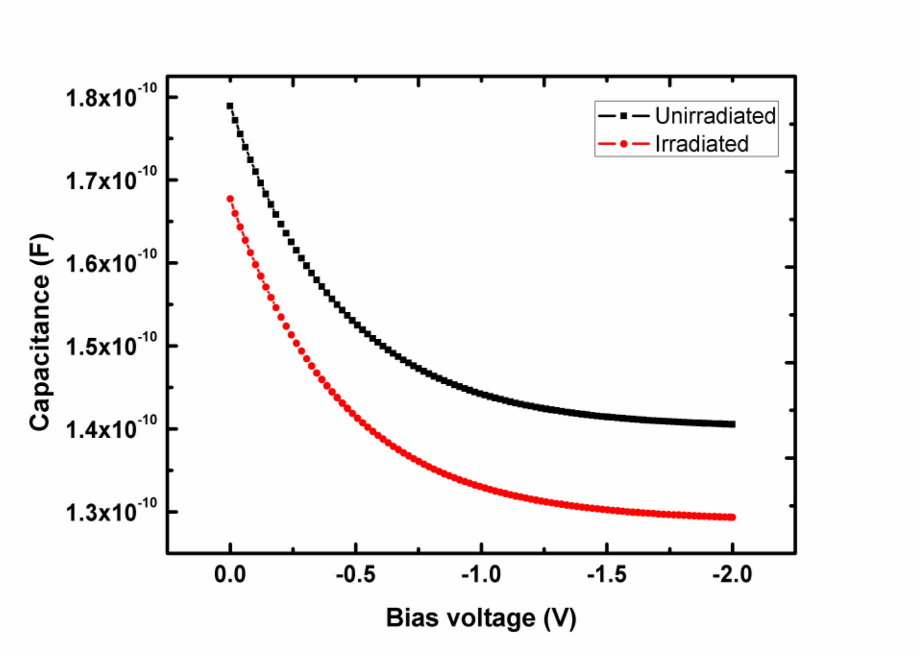

Figure 3. C-V characteristics of Al/$Cd_{0.8}Zn_{0.2}S$ SBD irradiated with electron beam.

3.2 Capacitance-voltage measurements

Figure 3 shows the *C-V* characteristics of Al/$Cd_{0.8}Zn_{0.2}S$ SBD before and after exposing to 8 MeV electron beam for a dose of 75 kGy. The C-V relation for a n-type semiconductor SBD is given by a relation [15]

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

where C is the capacitance, ε_r is dielectric constant of the semiconductor material which is equal to 5.4 for n-CdZnS [16], ε_0 is the vacuum permittivity, A is the area of the diode, N_D is the doping concentration, V_{bi} is the built in potential, W is the depletion layer width, and V is the applied bias voltage. The depletion layer width for the unirradiated Al/$Cd_{0.8}Zn_{0.2}S$ SBD was found to be 0.374 µm at zero bias and 0.476 µm at -2 V bias. After irradiation the depletion width was found to be equal to 0.399 µm at zero bias and 0.518 µm at -2 V bias.

Equation (7) can be rewritten as

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

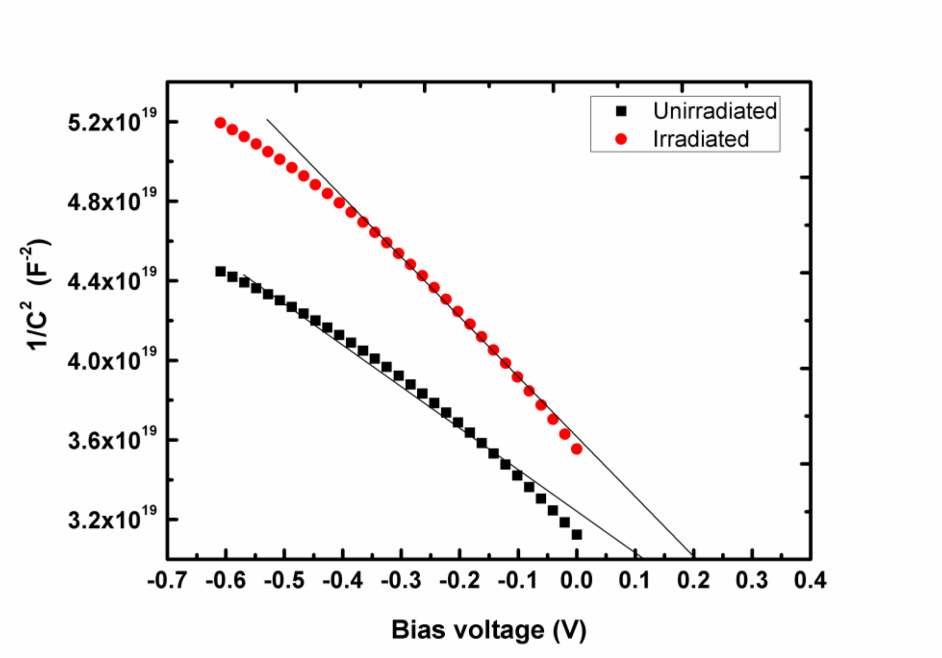

Figure 4. $1/C^2$ vs. V plot of Al/$Cd_{0.8}Zn_{0.2}S$ SBD irradiated with electron beam.

Figure 4 shows the $1/C^2$-V plot for Al/$Cd_{0.8}Zn_{0.2}S$ SBD before and after exposing to 8 MeV electron beam for 75 kGy. The $1/C^2$ versus V plot is linear only for low bias voltages, and as the bias voltage increases, the $1/C^2$ versus V plot deviates from this linearity. This may be due to a high leakage current in this Schottky barrier diode as shown in the *I-V* characteristics in Section 3.1.

The carrier concentration and built-in potential of the diode was obtained from the slope and intercept of $1/C^2$–V plot, respectively. The carrier concentration and the built in potential before irradiation were found to be 6.26 x 10^{21} m^{-3} and 0.117 V, respectively. The values of carrier concentration and built in potential after irradiation were found to be 4.72 x 10^{21} m^{-3} and 0.203 V, respectively. Decrease in the carrier concentration after irradiation can be related to the irradiation induced electron capture levels or acceptor like defects in n-$Cd_{0.8}Zn_{0.2}S$ film [17].

The effective Schottky barrier height (ϕ_b) was calculated from *C-V* measurements using the well known equation [17]

$$\phi_b = V_{bi} + V_P \tag{9}$$

The potential difference between the Fermi level and the top of the valence band (V_P) in $Cd_{0.8}Zn_{0.2}S$ was calculated using the relation [18],

$$V_P = kT \ln\left(\frac{N_C}{N_D}\right) \tag{10}$$

where N_C is the density of states in the conduction band of n-CdZnS, equal to 2.1 x 10^{24} m^{-3} [19]. The value of V_P for the Al/$Cd_{0.8}Zn_{0.2}S$ SBD was found to be 0.0054 eV before irradiation and 0.0052 eV after irradiation, respectively. The effective barrier height (ϕ_b) was calculated from *C-V* measurements using equation (9). Schottky barrier height of Al/$Cd_{0.8}Zn_{0.2}S$ SBD was found to be 0.122 eV before irradiation and 0.208 eV after irradiation, respectively. There was a noticeable difference in the value of ϕ_b obtained from *I-V* and *C-V* measurements. Similar kind of result was reported by E. Ugurel et al. [17] for Au/n-Si/Al SBD exposed to 6 MeV electron beam. This can be attributed to the presence of interface layer or spatial inhomogeneities at the MS interface of Schottky contact.

4. CONCLUSIONS

$Cd_{0.8}Zn_{0.2}S$ thin film was deposited on ITO coated glass substrate by spray pyrolysis. Al/$Cd_{0.8}Zn_{0.2}S$ SBD was fabricated by depositing Al metal contact on $Cd_{0.8}Zn_{0.2}S$ film by thermal evaporation. *I-V* and *C-V* measurements were carried out on Al/$Cd_{0.8}Zn_{0.2}S$

Schottky barrier diode both before and after exposing to 8 MeV electron beam for various doses. The ideality factor and the series resistance of Al/$Cd_{0.8}Zn_{0.2}S$ SBD was found to be increased with the increase of radiation dose which may be due to the creation of interface states/defects in the Schottky junction that increases with the increase of radiation dose. Schottky barrier height of Al/$Cd_{0.8}Zn_{0.2}S$ SBD was found to be decreased after irradiation. Also, the carrier concentration was found to be decreased from 6.26 x 10^{21} m^{-3} to 4.72 x 10^{21} m^{-3} after irradiation, which can be attributed to the irradiation induced electron capture levels or acceptor like defects in $Cd_{0.8}Zn_{0.2}S$ film.

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