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Electrical behaviour of Ag/n-CdS thin film Schottky diode irradiated with 8 MeV electron beam

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Abstract

In this study Ag/n-CdS Schottky diode was prepared by thermal evaporation of Ag metal film on spray deposited CdS thin film. The prepared Ag/n-CdS thin film Schottky diode was exposed to 8 MeV electron beam with radiation dose ranging from 10 kGy to 75 kGy. *I-V* and *C-V* measurements were used to study the irradiation induced changes in the electrical characteristics of the diode. The irradiation with 8 MeV electrons leads to a considerable change in the electrical properties of the Ag/n-CdS thin film Schottky diode. The ideality factor and the series resistance increased and the Schottky barrier height decreased with the increase in radiation dose. The diode reverse current increases with increase in irradiation dose. The carrier concentration was found to decrease after irradiation. The observed irradiation induced changes in the diode electrical properties may be attributed to the creation of irradiation induced defects/trapping centres in the n-CdS thin film.

Keywords: Cadmium sulphide, Schottky diodes, Irradiation, Schottky barrier height.

INTRODUCTION

CdS is a wide band gap II-VI semiconductor material having band gap energy of about 2.42 eV at room temperature. It is an n-type semiconductor due to native donors resulting from sulphur vacancies. CdS is an important semiconductor material for applications in electronic and optoelectronic devices such as heterojunction solar cells

[1], non-linear integrated optical devices [2], photodetectors [3], photodiodes [4], thin film transistors [5], etc. Recently, there are several reports on the experimental studies on metal-CdS semiconductor rectifying contacts. Metal-semiconductor rectifying contact also known as Schottky diode is one of the simplest and widely used electronic devices. The electrical properties of the Schottky diode are significantly influenced by the metal-semiconductor surface and interface properties [6]. Any mechanism, such as particle radiations, which affects the interface properties will also leads to changes in the device performance. The devices used in radiation environment like in outer space applications are always subjected to radiation effects [7]. For the application of a particular electronic device in radiation environments, it is important to know the effect of radiation on the device and the semiconductor material comprising of the device. There are several reports on the effect of electron irradiation on Schottky diodes [8-11]. It was found that the irradiation leads to changes in the diode parameters such as Schottky barrier height, series resistance, and depletion layer width.

To the best of our knowledge there are no reports on the effect of electron irradiation on Ag/n-CdS Schottky diodes. Therefore, in the present study, the investigation on the effect of 8 MeV electron irradiation on the *I-V* and *C-V* properties of the Ag/n-CdS Schottky diode was undertaken. The Ag/n-CdS Schottky diode was prepared using spray pyrolysis grown CdS thin film and the prepared diode was exposed to 8 MeV electrons for various doses ranging 10 kGy - 75 kGy. Room temperature *I-V* and *C-V* characteristics were recorded before and after irradiation of the sample and were analysed to find the effect of irradiation on diode parameters such as series resistance, Schottky barrier height, ideality factor, depletion layer width, carrier concentration etc. *C-V* measurements were performed at 1 MHz frequency. The Mott-Schottky analysis is adopted to determine the built in potential (V_{bi}) and the carrier concentration (N_d) of Ag/n-CdS Schottky diode from the C-V data.

EXPERIMENTAL DETAILS

CdS thin film was deposited on ITO coated glass substrate using spray pyrolysis technique. Aqueous solutions of 0.15M $CdCl_2$ and 0.15M $(NH_2)_2CS$ were used as sources of Cd^{2+} and S^{2-} and 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 using a magnetic stirrer 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 Ag/n-CdS Schottky diode was prepared by depositing Ag metal film of 125 nm in thickness and 0.014 cm^2 area using a shade mask on the CdS film at a pressure of 2×10^{-5} mbar using a HINDHIVAC vacuum coating unit - Model 12A 4. Indium metal was used to make Ohmic contact on ITO. The prepared Ag/n-CdS Schottky diode was irradiated with 8 MeV electron beam 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 [12].

The *I-V* characteristics of the Ag/n-CdS thin film Schottky diode was 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 on the Ag/n-CdS thin film Schottky diode, both before and after irradiation, at 1 MHz frequency using Agilent 4294 A LCR meter at CENSE, IISc, Bangalore.

RESULTS AND DISCUSSION

Current - voltage characteristics

The *I-V* characteristics of Ag/n-CdS thin film Schottky diode before and after irradiation with 8 MeV electron beam for various doses ranging 10 kGy - 75 kGy are shown in Figure 1.

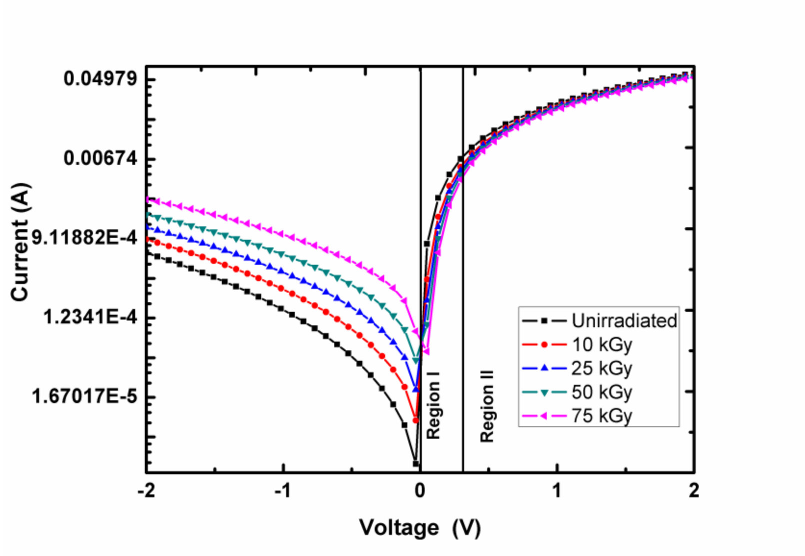

Figure1. *I-V* characteristics of Ag/n-CdS Schottky diode irradiated with different electron doses.

The current flow through a Schottky contact may be described by the thermionic emission of majority carriers over metal-semiconductor interface barrier [13]. Based on thermionic emission theory, the *I-V* relationship for metal-semiconductor rectifying contact is given by the relation

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

with saturation current I_S is given by the relation

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

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 zero bias Schottky barrier height. Equation (1) can also be expressed as

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

The saturation current and the ideality factor values are obtained from the intercept and slope of the linear region of ln*I* vs. *V* plot using the equation (3). The zero bias Schottky barrier height (ϕ_b) can be calculated using the equation (2) by rearranging it as

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

As shown in Figure 1, the forward ln*I* versus *V* plot varied somewhat linearly with increase in voltage up to around 0.3 V and this linear region is labelled as Region I. Above 0.3 V, the forward ln*I* versus *V* plot shows a nonlinear behaviour with large decrease in slope and this region is labelled as region II. The observed decrease in the slope of the ln*I* versus *V* plot above 0.3 V may be due to the increase in the series resistance and metal-semiconductor interfacial layer defects due to electron irradiation [14, 15]. Based on thermionic emission theory, the *I-V* relation for a Schottky diode with series resistance R_S is given by the relation [10]

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

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 can be obtained from the slope and intercept of d*V*/dln*I* vs. *I* plot using the equation (6).

As shown in Figure 1, electron irradiation shows a slight decrease in forward current with increase in irradiation dose. The reverse current shows relatively a large increase with increase in electron irradiation dose. For region I, the saturation current and the ideality factor values are obtained from the intercept and slope of the linear region of ln*I* vs. *V* plot using equation (3) and are shown in table 1. As shown in table 1, the ideality factor increased with the increase in radiation dose. S. Krishnan et al. [11] also observed similar trend in the ideality factor for Al/p-Si SBDs exposed to 8 MeV electron beam for various doses. The zero bias Schottky barrier height (ϕ_b) was calculated using the equation (4) by taking the value of the Richardson constant A^{**} to be equal to 12 $AK^{-2}cm^{-2}$ for n-CdS [16, 17]. The obtained values of ϕ_b decreased with the increase in irradiation dose as shown in Table 1.

Table 1: Ideality factor (n), Series resistance (R_S) and barrier height (ϕ_b) variation of Ag/n-CdS Schottky diodes with radiation dose.

Dose (kGy)	Ideality factor		Series resistance (Ω)	Barrier height (eV)
	0 V <V<0.3 V	0.3 V <V<2 V	0.3 V<V<2 V	
Unirradiated	5.05	3.12	30.60	0.338
10	5.21	3.28	30.86	0.330
25	5.29	3.42	31.18	0.329
50	5.38	3.59	31.56	0.322
75	5.56	3.64	31.75	0.321

The decrease of ϕ_b with increase in radiation dose can be related to the increase of irradiation induced defects at the Ag/n-CdS interface with increase in radiation dose [11, 18]. The slight decrease in the forward current observed with increase in electron irradiation dose may be related to the increase in series resistance of the diode due to the irradiation induced defects.

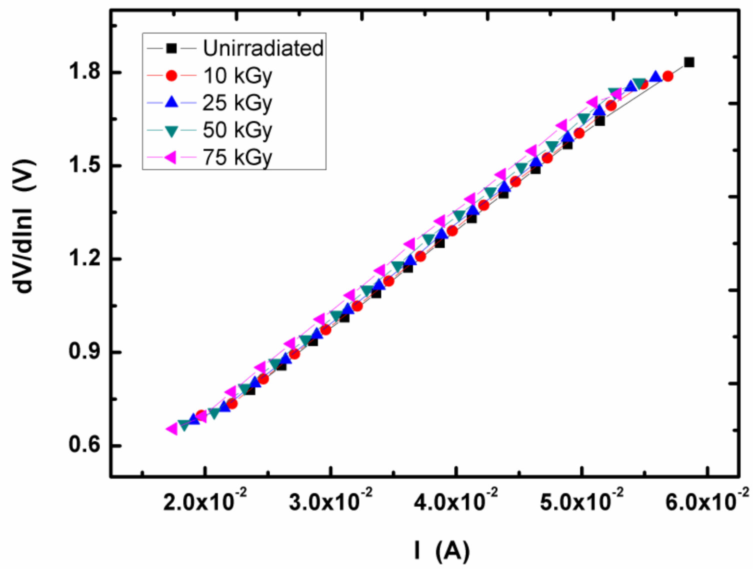

Figure 2. dV/dln$I$ vs. I plot for Ag/n-CdS Schottky diode irradiated with different electron doses.

Figure 2 shows d*V*/dln*I* vs. *I* plot for the Ag/n-CdS Schottky diode irradiated with different electron doses. As per equation (6), the series resistance and the ideality factor for the Ag/n-CdS SBD were calculated from the slope and intercept of d*V*/dln*I* vs. *I* plot. Both the series resistance and the ideality factor increased with the increase of radiation dose as shown in Table 1. A similar trend in ideality factor and series resistance was observed by Rao et al. [18] for Au/n-Si and Krishnan et al. [11] for Al/p-Si Schottky diodes irradiated with 8 MeV electron beam for various doses. The irradiation induces defect centres, which act as scattering centres that increases with the increase of radiation dose resulting in the lowering of carrier mobility [11, 18]. An increase in defect centres also leads to a reduction in the free carrier concentration, thus, decreasing the product of free carrier concentration and mobility with the increase of radiation dose, resulting in an increase of series resistance. The increase in the series resistance may be the main cause for the nonlinear behaviour and drastic decrease in the observed slope of the forward bias ln*I* vs. *V* plot of Ag/n-CdS thin film Schottky diode with the increase of radiation dose. The observed lowering of the Schottky barrier height with increase in electron irradiation dose may be related to the increase in irradiation induced interface states. Therefore, the observed increase in Ag/n-CdS thin film Schottky diode reverse current with increase in irradiation dose may be attributed to the irradiation induced lowering of the Schottky barrier height.

Capacitance – Voltage characteristics

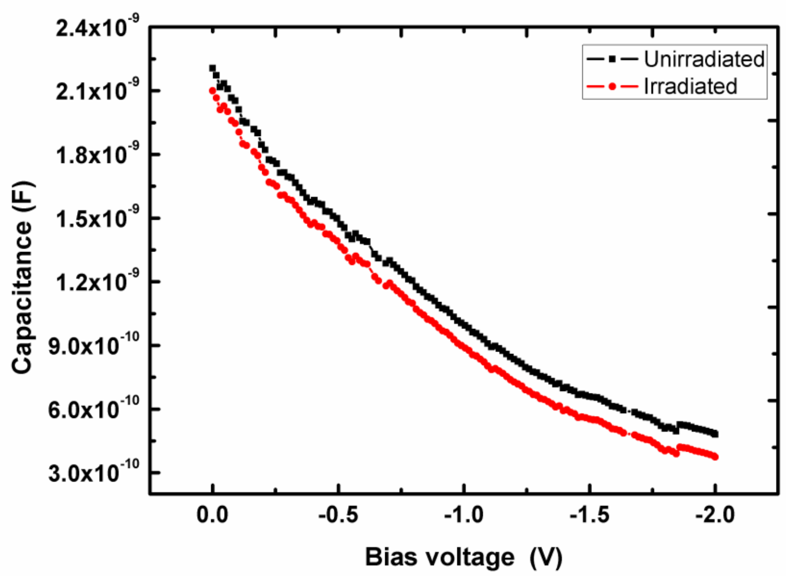

Figure 3. *C-V* characteristics of 8 MeV electron beam irradiated Ag/n-CdS Schottky diode.

Figure 3 shows the *C-V* characteristics of the Ag/n-CdS Schottky diode before and after irradiation with 8 MeV electron with dose of 75 kGy. It was observed that the capacitance decreased slightly with irradiation. The *C-V* characteristic of the Ag/n-CdS Schottky diode has been analysed using the equation [13]

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

where ε_s is the permittivity of the semiconductor material, ε_0 the vacuum permittivity, A is the area of the diode, N_d is the density of ionized donors, V_{bi} is the built in potential, W is the depletion layer width, and V is the applied bias voltage. The depletion layer width obtained from *C-V* measurements using equation (7) before irradiation of the Ag/n-CdS thin film Schottky diode was found to be 32 nm at zero bias and 0.147 μm at -2 V bias. The depletion width for same Ag/n-CdS thin film Schottky diode after irradiation with 8 MeV electrons with a radiation dose of 75 kGy was found to be 33.7 nm at zero bias and 0.189 μm at -2 V bias. Equation (7) can be rewritten as

$$\frac{1}{C^2} = \frac{2}{A}\frac{1}{q\varepsilon_0 \varepsilon_r N_d}\left[V_{bi}+V\right] \tag{8}$$

As per equation (7), the built in potential and doping concentration N_d or ionized donor concentration can be obtained by making a $1/C^2$ versus V plot.

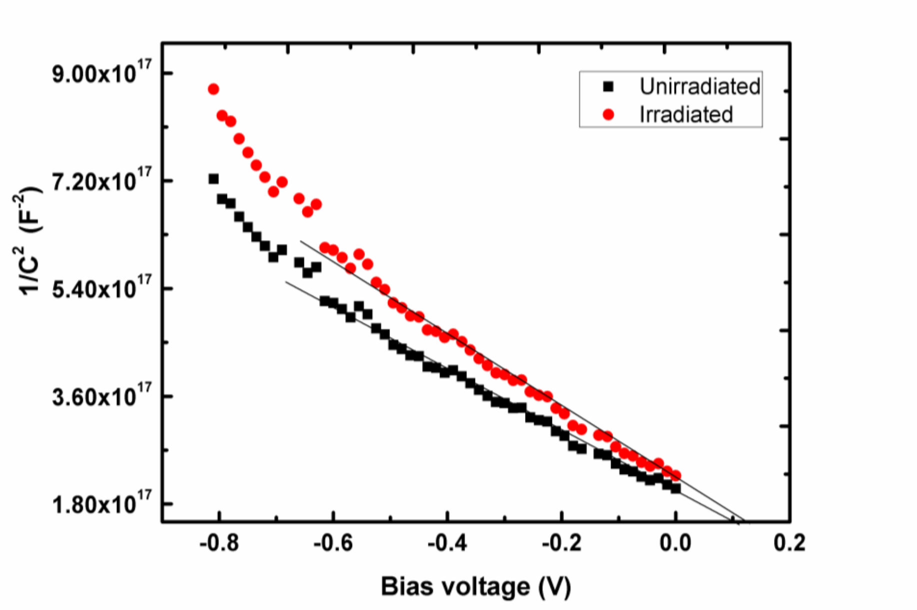

Figure 4. $1/C^2$ vs. V plot of 8 MeV electron beam irradiated Ag/n-CdS Schottky diode.

Figure 4 shows the $1/C^2$ versus V plot for Ag/n-CdS thin film Schottky diode before and after irradiation. 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 reverse leakage current of the Ag/n-CdS thin film Schottky diode as shown in Figure 1. The slope of $1/C^2$-V plot was used to calculate the carrier concentration, using the equation (8), (ε = 5.7 for n-CdS [19] and the built in potential was obtained from the extrapolation of intercept of $1/C^2$ with voltage axis. The ionized donor density or the free carrier concentration was found to be 2.36×10^{23} m^{-3} and 1.71×10^{23} m^{-3} before and after irradiation, respectively. The built in potential was found to be 0.106 V and 0.115V before and after irradiation, respectively. The observed decrease of the carrier concentration with irradiation may be due to the irradiation induced electron capture levels or acceptor - like defects in n-CdS film. Decrease in the carrier concentration was also reported by Ugurel et. al [10] for 6 MeV electron beam irradiated Au/n-Si/Al Schottky diode. The observed decrease in the capacitance of Ag/n-CdS thin film Schottky diode with irradiation may be related to the decrease of dielectric constant at metal-semiconductor interface or this may be due to the net ionized dopant concentration [20]. The effective Schottky barrier height (ϕ_b) was calculated from C-V measurements using the well known equation [10]

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

The potential difference between the Fermi level and the top of the valence band (V_P) in CdS was calculated using the relation [14],

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

where N_C is the density of states in the conduction band of CdS, equal to 2×10^{24} m^{-3} [21]. V_P was found to be equal to 0.00603 eV and 0.00553 eV before and after irradiation, respectively. The effective Schottky barrier height (ϕ_b) of Ag/n-CdS thin film Schottky diode increased from the value of 0.11 eV before irradiation to 0.12 eV after irradiation. The considerable difference in the value of ϕ_b obtained from I-V and C-V measurements may be due to the presence of interface layer or due to spatial inhomogeneities at the Ag/CdS interface [10].

CONCLUSIONS

Ag/n-CdS Schottky diode was prepared by depositing Ag metal by thermal evaporation on spray deposited CdS thin film. Effects of 8 MeV electron beam irradiation on the electrical parameters of Ag/n-CdS thin film Schottky diode was studied using I-V and C-V measurements before and after irradiation. The irradiation with 8 MeV electrons leads to a considerable change in the electrical properties of the Ag/n-CdS thin film Schottky diode. The ideality factor and the series resistance increased and the Schottky barrier height decreased with the increase in radiation dose. Carrier concentration of Ag/CdS Schottky barrier diode was found to be decreased from 2.36×10^{23} m^{-3} to 1.71×10^{23} m^{-3} after exposing to 8 MeV electron beam of dose 75 kGy. The degradation in the properties of Ag/n-CdS Schottky diode after irradiation is may be due to the irradiation induced electron capture levels or acceptor - like defects in n-CdS film with irradiation.

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