Temperature dependent current-voltage (I-V) characteristics of Al/n-Cadmium Selenide-Polyvinyl alcohol (Al/n-CdSe-PVA) Schottky diode

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The paper reports the fabrication and characterization of Al/n-Cadmium Selenide -Polyvinyl Alcohol (Al/n-CdSe-PVA) Schottky diode. I-V characteristics have been measured at different temperatures in the forward and reverse bias. The different parameters like ideality factor (n), the effective barrier height (Φ_b), the Richardson constant (A^*) has been calculated. Temperature dependent barrier height and ideality factor is also studied. The series resistance (R_S) is calculated by using the Cheung's method. The reverse biased leakage current with the temperature have played important role in inhomogeneity of the barrier height. The recombination - tunneling mechanism is used to explain the conduction process in Schottky diode.

1. Introduction

Polymer nanocomposites have attracted much attention due to their unique size dependent magnetic, optical and electrical properties [1-5]. However, the exploitation of these properties requires a homogeneous dispersion of the inorganic particles in the polymer matrix. Recently, polymer/semiconductor structures of these materials became attractive for applications in electronic and optoelectronic devices [6] such as all polymer integrated circuits [7], sensors [8], field effect transistors [9], Schottky diodes (SDs) and light emitting diodes[10] etc. Here, author considers Cadmium selenide as semiconducting materials and polyvinyl alcohol (PVA) as matrix. Cadmium Selenide (CdSe) is an attractive material due to their important nonlinear optical properties, luminescent properties, quantum-size effect and other important physical and chemical properties [11]. Polyvinyl alcohol (PVA) is of great attractive research topic because of their potential applications and interesting properties by chemists, physicists, and electrical engineers as well. In recent years, PVA nanofabrics have attracted much attention due to its unique chemical and physical properties as well as its industrial applications. PVA have normally a poor electrical conductivity and become conductive upon doping with some dopants.

The analysis of forward bias *I–V* characteristics of the Schottky barrier diodes (SBDs) structures only at room temperature cannot provide us with detailed information regarding their current conduction mechanisms or the nature of barrier formation at the metal/semiconductor interface. However, the temperature dependence of the *I–V* characteristics could allow us to gain insight into different aspects of the characteristics of these devices [12]. With this aim in mind, the forward bias *I–V* characteristics of the Al/*n*-CdSe-PVA (MS) structures have been studied at different temperature. The importance of the series resistance influence on the evaluated barrier parameters has been demonstrated in experimental structures [13-14]. The studies on the series resistance influence show that the forward bias *I–V* characteristics are linear in the semilogarithmic scale at intermediate voltages, but deviate considerably from linearity due to the effect of series resistance of the devices when the applied voltage is sufficiently large. It has often been observed that the ideality factor was found to decrease, while the zero-bias barrier height increases with increasing temperature.

2. Experimental details

The selenium source chosen for study is sodium selenosulphate (Na_2SeSO_3). The sodium selenosulphate aqueous solution (0.50 M) is prepared by adding 1.0 M of sodium sulphite and 0.05 mol of selenium powder in 50 ml of double deionized water. The solution has been stirred for 7 hours at 70 ^{0}C and kept overnight. Upon filtration, sodium selenosulfate solution is sealed and stored in the dark at 60 ^{0}C to prevent decomposition. PVA solution is obtained by adding 6.0 gram PVA to 100 ml double deionized water and stirring at 60 ^{0}C until a viscous transparent solution is achieved. 0.1 M of cadmium acetate has been dissolved in 20 ml of double deionized water. Sodium hydroxide solution (2.0 M) is used to turn metal ions into complex ions and to reduce the free metal ion concentration. In a 50 ml flask, 20 ml PVA solution has been taken. Sodium hydroxide solution is then slowly added drop wise until a clear solution is obtained. The pH

of final solution is 10. 1 ml of selenosulphate solution and 16ml of cadmium acetate solution is added in order to achieve the Cd: Se :: 16: 1 ratio. The mixture is stirred for 6-7h in room temperature to obtain a reddish brown colour solution. The Al substrate is washed with KOH pellets to remove native alumina layer and other soluble salts on the Al substrate. The CdSe-PVA material is deposited on Al substrate by casting method. Upon solvent evaporation, a CdSe-PVA nanocomposite film has been obtained. The as prepared film is finally washed with double deionized water to remove any soluble salts and kept for drying. The Schottky junction Al/n-CdSe-PVA has prepared using a proper masking arrangement so as to form a square type device having an active area of 1 cm^2. The aluminium metal film about 1000^0A thickness has been deposited by direct evaporation on CdSe-PVA films. The vacuum of the order of 10^{-4} Pa is maintained during the evaporation. The films are kept in the deposition chamber in the dark for 24 h before mounting them in the metallic sample holder to attain thermodynamic equilibrium. The area of diode is 4.7×10^{-3} cm^2. The schematic diagram of the Al/n-CdSe-PVA Schottky diode is shown in Fig. 1. A vacuum of about 10^{-3} mbar is maintained throughout these measurements. The temperature dependence I–V measurements are taken with Keithley's electrometer 6517A from temperature range 273 K to 333 K.
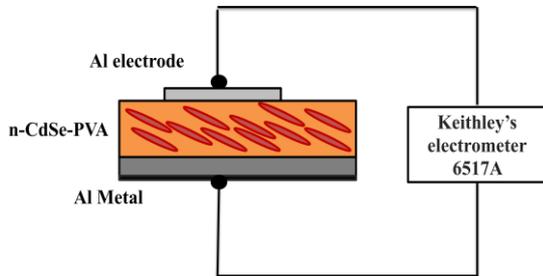
Fig. 1. Diode structure.

3. Results and discussion

3.1 Characterization

XRD spectra of CdSe-PVA nanocomposite show the mixed cubic as well as hexagonal structure. With addition of CdSe into PVA matrix, nanocrystalline peak of CdSe-PVA nanocomposites are observed. The average crystallite size is 4.3 nm as calculated by using the Debye-Scherrer formula. TEM provides information regarding morphology and size distribution of selenide particles. The morphology of CdSe-PVA nanocomposites is of nanorods type. The well dispersed single nanorods of CdSe particles have an average diameter of 2.65 nm, 157 nm in length. The FTIR spectra of CdSe/PVA nanocomposite show good interaction between PVA and CdSe nanorods. [15].

3.2 Forward Bias I-V characteristics as function of temperature

When the Schottky Barrier Diode (SBD) with a series resistance and an interfacial layer, the I-V relation based on thermionic emission (TE) theory is given by [16]

$$I = I_o \left(\frac{q(V - IR_S)}{nkT}\right)\left(1 - \exp\left(\frac{q(V - IR_S)}{kT}\right)\right) \quad (1)$$

where V, n, q, IR_S, and T are the applied bias voltage, the ideality factor, the electronic charge, the voltage drop across series resistance of SBD, and the temperature in Kelvin, respectively. I_o is the reverse saturation current extracted from the straight line intercept of lnI-V plot at zero bias and is given by,

$$I_o = AA^*T^2 \exp(\frac{-q\Phi_b}{kT}) \quad (2)$$

where A, A*, Φ_b are the contact area, the effective Richardson constant (14A/cm^{2}K^2 for CdSe), and the zero bias barrier height, respectively. The zero-bias barrier height $\Phi_{B0} = \Phi_B(I–V)$ and ideality factor (n) is determined from the extrapolated I_0 and is given by

$$\Phi_b = \left(\frac{kT}{e}\right) ln\left(\frac{AA^*T^2}{I_s}\right) \quad (3)$$

$$\frac{1}{\eta} = \frac{kT}{q}\frac{d(V)}{d(lnI)} \quad (4)$$

The φ_b and n is obtained from the slope and intercept of the linear region of the forward-bias ln(I) versus V plot at each temperature by using equation (4) and (5). Fig. 2 shows the semi logarithmic forward current-voltage characteristics of Al/n-CdSe-PVA Schottky diode at temperature range 268K to 343K. I-V characteristics of Al/n-CdSe-PVA show an appreciable increase in the forward bias conditions.

The φ_b and n is found to be 0.7eV and 2.4 at 273K. The larger n value may be due to generation recombination currents due to deep levels in CdSe-PVA. The tunnelling mechanisms probably provide a greater contribution to both the high device currents and device nonideality. Another possibility for greater value of ideality factor is existence of high leakage current is due to polymer layer on the CdSe-PVA. The conduction mechanism involve in Schottky diode is tunnelling mechanism. The nonideality in ln(I) vs. V curves and larger value of n is clearly caused by the interfacial layer and surface states [17].
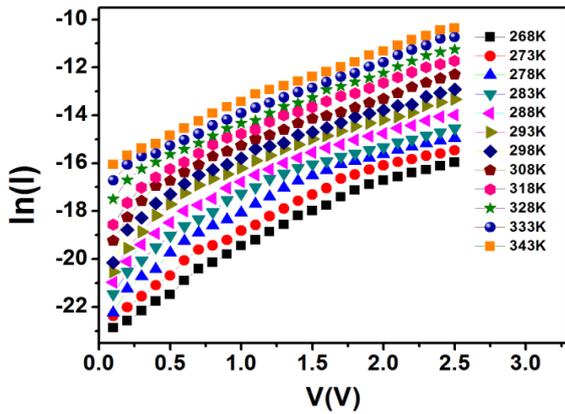
Fig. 2. Temperature dependence ln(I) vs.V plot of Al/n-CdSe-PVA Schottky Diode.

3.3 Barrier height and ideality factor

The values of barrier height (Φ_{B0}) increase and ideality factor decrease with increase in temperature as shown in Fig. 3. Such temperature dependence is in obvious disagreement with the reported negative temperature coefficient of the Schottky barrier height. Since the current transport across the metal semiconductor interface is a temperature-activated process, electrons are able to surmount the lower barriers.
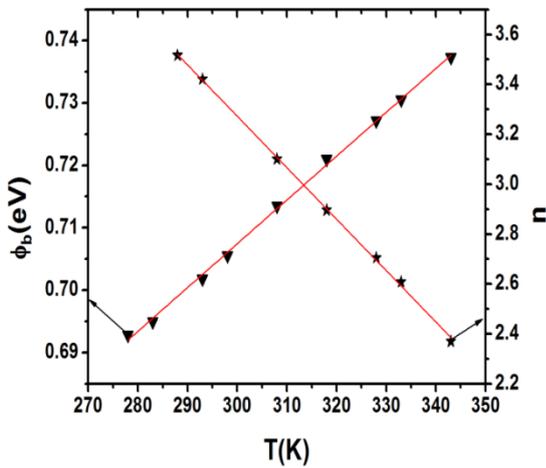
Fig. 3. Temperature dependence barrier height and ideality factor of Al/n-CdSe-PVA Schottky Diode.

Therefore, the current flow through the lower SBH and a larger ideality factor will dominate current transport. In other words, more and more electrons have gain sufficient energy to overcome the higher barrier so barrier height increases with temperature and bias voltage [18].

3.4 Richardson plot

Fig. 4 shows the Richardson plot of ln (I_0/T^2) against $1000/T$. The dependence of $\ln(I_0/T^2)$ versus $1000/T$ is found to be linear. To determine the barrier height in a different way, equation (2) can be rewritten

$$ln\left(\frac{I_0}{T^2}\right) = \ln(AA^*) - \frac{q\Phi_b}{kT} \qquad (5)$$

The experimental data is straight line fit yielding activation energy~0.54eV and Richardson constant (A^*)~2.5×10^{-2}Acm^{-2}K^{-2} for the Al/CdSe-PVA Schottky barrier diode was determined from slope and intercept of Fig. 4. This value is lower than the known value of 14.6Acm^{-2} K^{-2} for n-CdSe. This lesser value of the Richardson constant may be due to the spatial inhomogeneous barrier heights and potential fluctuations at the interface that consist of low and high barrier areas. In other words, the current of the diode will flow preferentially through the lower barriers in the potential distribution. Furthermore, the value of the Richardson constant obtained from the *I-V* characteristics as a function of temperature may be affected by the lateral inhomogeneity of the barrier [12].
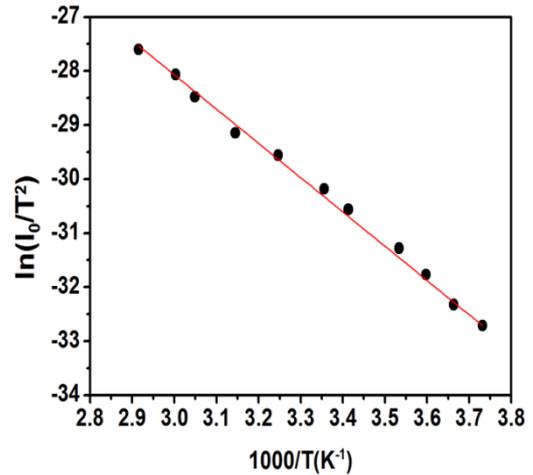
Fig. 4. Richardson plot for Al/n-CdSe-PVA Schottky Diode.
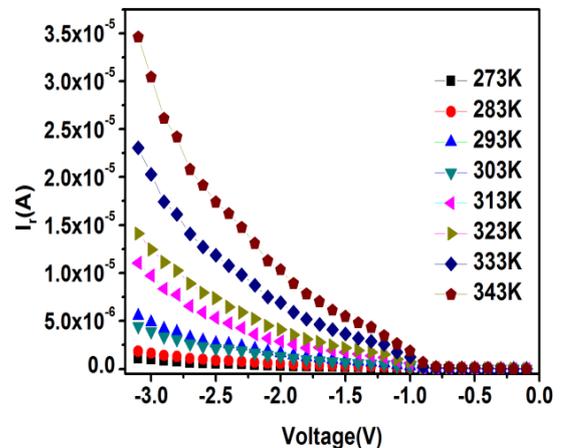
Fig. 5. Temperature dependence reverse bias I-V characteristics of Al/n-CdSe-PVA Schottky Diode.

3.5 Leakage current

Fig. 5 shows the reverse bias semi-logarithmic I-V characteristics (up to -3.1V) for this diode at various temperatures. For V= -1V, the measured leakage current of the Al/CdSe-PVA SBD is 6.1×10^{-8} A at 273 K while it is 1.87×10^{-6} A at 343 K as shown in Fig. 6. The increase of the leakage current with temperature is due to the tunneling through the surface and bulk states. The existence of large leakage current also plays an important role in device performance. The possibility for the high leakage current is due to oxide layer on the CdSe, even though the removal of oxide layer during Schottky diode fabrication has been conducted, the exposure from the atmosphere was unavoided resulting a native oxide on CdSe surface. This can be explained on basis of tunneling mechanism assisted by some CdSe-PVA interface states such as dislocations or/and possibly oxygen vacancies in polyvinyl Alcohol [19,20].

3.6 Series resistance (R_s) calculation

The existence of R_s in the structure is responsible for the deviation of characteristics from linearity. The Chenug's function method is used to determine the n and R_s [21]. According to Cheung's function method, equation (3) and (4) can be expressed as

$$\frac{dV}{d(lnI)} = IR_s + \frac{nkT}{q} \qquad (6)$$
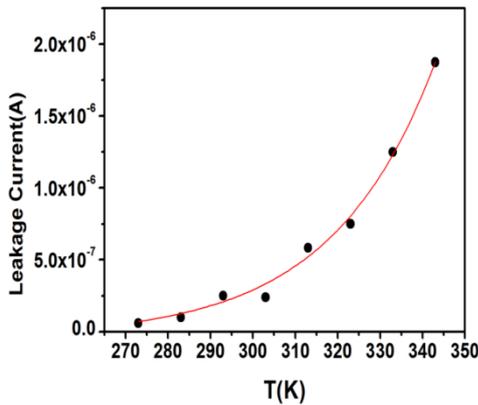
Fig. 6. Variation of leakage current with temperature.

and $H(I) = V + \frac{nkT}{q}\ln\left(\frac{I}{AA^*T^2}\right) = IR_s + n\Phi_{eff}$ $\qquad$ (7)

Equation (6) and (7) should give a straight line for the data of the forward-bias $I–V$ characteristics. R_s value is calculated from the slope of the dV/d(ln I) versus I plot and H(I) versus I plot . The equation (7) in addition with equation (6) is used to check the consistency of Cheung's approach in obtained R_s values. There is good agreement in value of R_s obtained from equation (6) and (7) as shown in figure 7. The series resistance increases with increasing

temperature [22-24]. The larger value of R_s is due to presence of polymer layer. Such temperature dependence is in obvious disagreement with the reported negative temperature coefficient of the resistance.
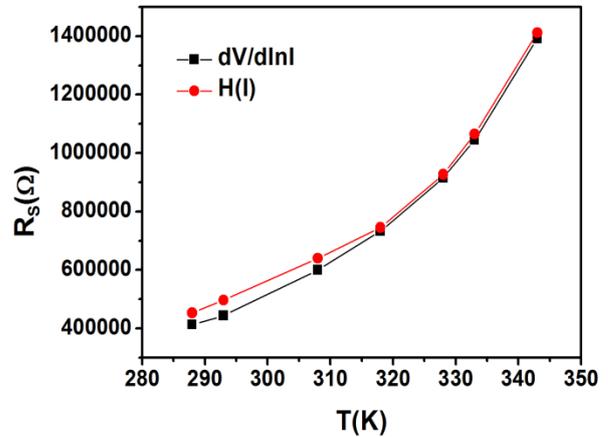
Fig. 7. Variation of Series Resistance with temperature as calculated by Chenug's Method.

The significant decrease of Φ_b and the increase of n are possibly caused by the barrier height inhomogeneities present at metal-semiconductor interface. Tung et al [25] has reported the existence of inhomogeneity at barrier interface by considering the variation of Φ_b with n. It is clear from the Fig. 8 that these two values are correlated linearly with each other in accordance with Tung's theory [25]. It justifies the presence of lateral inhomogeneities in the metal-semiconductor interface [26-27].
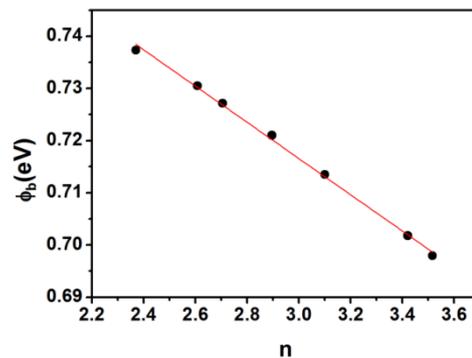
Fig. 8. Variation of barrier height with Ideality Factor.

4. Conclusions

The different parameters like ideality factor (n), the effective barrier height (Φ_b), the Richardson constant (A^*), leakage current has been calculated from I-V characteristics at different temperatures. Temperature dependence barrier height and ideality factor is also studied. The series resistance (R_S) is calculated by using the Cheung's method. The recombination - tunneling

mechanism is used to explain the conduction mechanism in Schottky diode.

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