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Electrical characterization of ZnO/organic semiconductor diode

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The electrical characterization of IZO/FSS/Al diode has been investigated current-voltage method. The ideality factor of the diode was found to be 2.84, which confirm that the IZO/FSS/Al device indicates a non-ideal I-V behaviour. The effect of series resistance was evaluated using a method developed by Cheung. The R_S and n values were determined from the dV/dln(I)-I plot and were found to be 8.00 kΩ and 2.84, respectively. The barrier height and R_s values were calculated from H(I)-I plot and were found to be 0.86 eV and 7.83 kΩ. At higher voltages, I-V characteristics of the diode are affected by the electrical properties. This suggests that at higher voltages, the current flow in the diode is controlled by the space limited current mechanism.

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1. Introduction

Transparent conductive oxide (TCO) films are used, for example, as transparent electrodes in flat panel displays, solar cells, and other optoelectronic devices[1-3]. Among the TCO materials available, zinc oxide films doped with appropriate impurities, usually the group-III elements such as B, Al, Ga and In, is attractive alternative materials due to their good electrical and optical properties as transparent conducting electrode because they are nontoxic and inexpensive compared with indium tin oxide (ITO). An outstanding characteristic of ZnO thin film is that its electrical properties can be changed from insulator through n-type semiconductor to metal by controlling the doping level. These properties of ZnO which is a II–VI compound have received considerable attention, and various n-ZnO based single heterojunction devices have been fabricated using different p-type materials [4]. There are several methods for producing ZnO films: chemical vapor deposition, ionized cluster-beam deposition, pulsed-laser deposition, dc sputtering, magnetron sputtering and spray pyrolysis [5-9]. Among these techniques, spray pyrolysis has proved to be a simple and inexpensive method, particularly useful for large area applications.

Zinc oxide, a direct band gap (E_g=3.3 eV at 300 K) semiconductor with large exciton binding energy of 60 meV is a promising material for fabrication of high efficiency ultraviolet light-emitting devices [4]. Many of the advantages of ZnO can also be realized by the fabrication of ZnO-based heterojunction and metal–insulator–semiconductor (MIS) diodes. For example, several heterojunction devices comprising n-type ZnO grown on various p-type materials have been recently reported. On the other hand, there are no recent reports on ZnO/FSS diode.

Apart from our work and to best of our knowledge no other information on semiconductor organic compound /inorganic semiconductor structure (IZO/FSS/Al) has been reported any study in the literature. This paper reports the electrical characterization of IZO/FSS/Al diode by current-voltage characteristics.

2. Experimental

The indium zinc oxide IZO film was deposited onto glass substrate, chemically cleaned, using the spray pyrolysis method at 350^{o}C substrate temperature. 0.1M solution of zinc acetate dihydrate ($Zn(CH_3COO)_2.2H_2O$) diluted in methanol and deionized water (3:1) was used for the film, and indium chloride ($InCl_3$) was added to starting solution for indium doping. The In/Zn ratio was 1 at.%. A few drops of acetic acid were added to improve the clarity of solution. Nitrogen was used as the carrier gas, pressure at 0.2kgcm^{-2}. The ultrasonic nozzle to substrate distance was 28cm and during deposition, solution flow rate was held constant at 4mlmin^{-1}. After this process fluorescein sodium salt (FSS) which is an organic semiconductor material was performed on the IZO. The solution of the fluorescein sodium salt (FSS) was prepared in methanol. The solution of the FSS was homogenized for 1 hour by mixing with rotation before the deposition. Then, the film of the FSS was prepared by casting the solution on IZO with subsequent drying [10]. Al metal was evaporated onto FSS by thermal evaporation system. The standard geometry of the Au/IZO/FSS/Al diode is the sandwich, as shown in Fig.1. The diode contact area 0.196 cm^2. The current–voltage (I-V) measurements were performed by a Keithley 2400 sourcemeter and data of current-voltage measurements are recorded to a PC computer using an GPIB data transfer card.

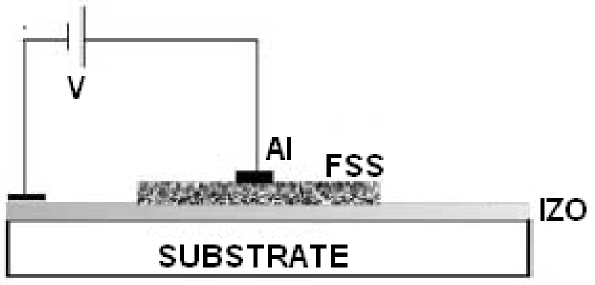


Fig. 1 Au/IZO/FSS/Al diode structure.

3. Results and discussion

3.1. Current-voltage characteristics of the Au/IZO/FSS/Al diode

The current-voltage (I-V) characteristics of the Au/IZO/FSS/Al diode are shown in Fig. 2a and b. The forward bias I-V characteristic of the diode is exponential at low bias voltages. But, at higher voltages, a deviation in I-V characteristic is observed due to series resistance and interfacial layer. The current transport of the diode studied is governed by the following relation [11-12],

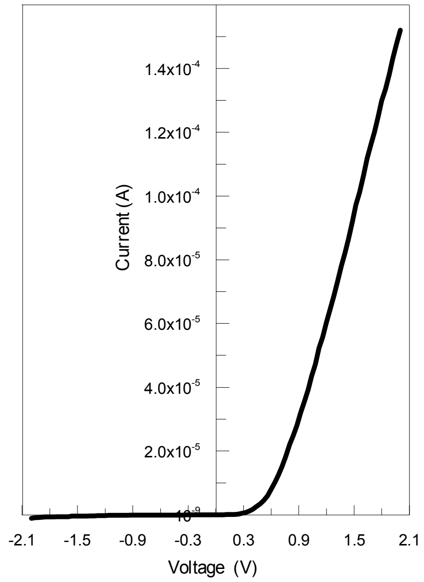
$$I = I_S \exp\left(\frac{q(V - IR_S)}{nkT}\right) \quad \text{for } V>3kT/q \qquad (1)$$

where n is the ideality factor and V is the applied voltage, R_S is the series resistance and I_S is the saturation current given by [11],

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

where k is the Boltzmann constant, q is the electronic charge, A is the contact area, T is the temperature and ϕ_B is the barrier height. The saturation current is obtained from the linear portion intercept of lnI at V=0. A^* is the Richardson constant given by $A^* = 120x\frac{m}{m_e}$ A.cm^2. K^{-2} and m=0.38m$_e$ for the ZnO [13]. Thus, A^*=45.6 A.cm^2. K^{-2}. The ideality factor of Au/IZO/FSS/Al diode was calculated using the following equation,

$$n = \frac{q}{kT}\frac{dV}{d(\ln I)} \qquad (3)$$



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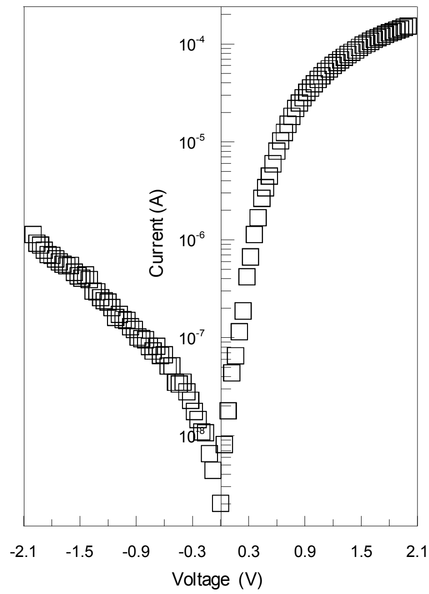

B

Fig. 2 I-V characteristics of the Au/IZO/FSS/Al diode a) linear scale b)logarithmic scale.

The n value was calculated from the Fig. 2 and was found to be 2.52. The n value is higher than unity. This suggests that the diode exhibits a non-ideal behaviour. This effect can be due to the organic semiconductor, interface oxide layer and series resistance. The series resistance is significant in the non-linear region of the I-V characteristics. The series resistance can be evaluated using a method developed by Cheung [14] to determine the barrier height, ideality factor and series resistance. Cheung's functions are expressed as,

$$\frac{dV}{d\ln(I)} = n\frac{kT}{q} + IR_s \qquad (4)$$

$$H(I) = V - n\frac{kT}{q}\ln\left(\frac{I_o}{AA^*T^2}\right) \quad (5)$$

and

$$H(I) = IR_s + n\phi_B \quad (6)$$

Fig. 3 show the plots of dV/dlnI-I and H(I)-I. The R_S and n values were determined from the slope and intercept of dV/dlnI-I plot and were found to be 8.00 kΩ and 2.84, respectively. The barrier height ϕ_B and R_s values were calculated from the H(I)-I using obtained n value and were found to be 0.86 eV and 7.83 kΩ, respectively. Interfacial layer causes a voltage drop across the interface. The bias dependence on the voltage drop V_i across interfacial layer is expressed by [15-16],

$$V_i = (1 - \frac{1}{n})V \quad (7)$$

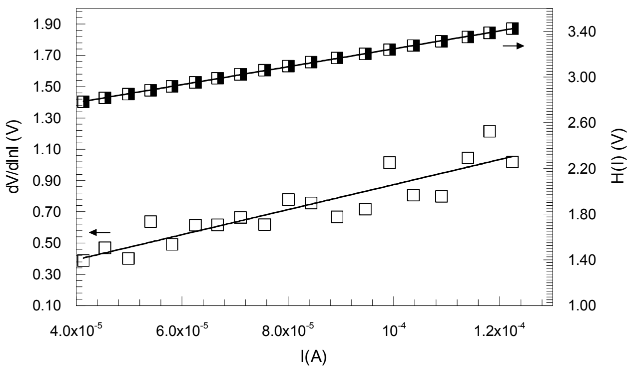

Fig. 3. Plots of dV/dln(I)-I and H(I)-I of Au/IZO/FSS/Al diode.

The effect of series resistance is taken into account by substituting V in Eq. 7 with ($V-IR_S$). After arranging the Eq.7, it gives,

$$V_i = (1 - \frac{1}{n})(V - IR_S) \quad (8)$$

The values of V_i were calculated using Eq.8. In order to obtain the voltage drop across depletion layer V_D, voltage obtained from Eq.7 should be subtracted from the total value of applied forward voltage,

$$V_D = V - V_i \quad (9)$$

The curves of lnI v.s V were reported for obtained V_i and V_D values (Fig. 4) to indicate effect of interface layer on parameters of the diode. The n and ϕ_B values of Au/IZO/FSS/Al diode were calculated from the lnI-Vi plot and were found to be 1.63 and 0.76 eV, respectively. The obtained values are lower than equivalent values obtained previously without considering effect of the presence of interfacial layer.

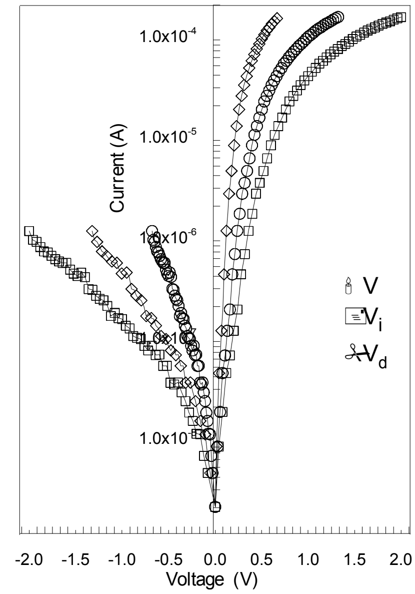

Fig. 4 Plots of lnI v.s V for obtained V_D and V_i values of Au/IZO/FSS/Al diode.

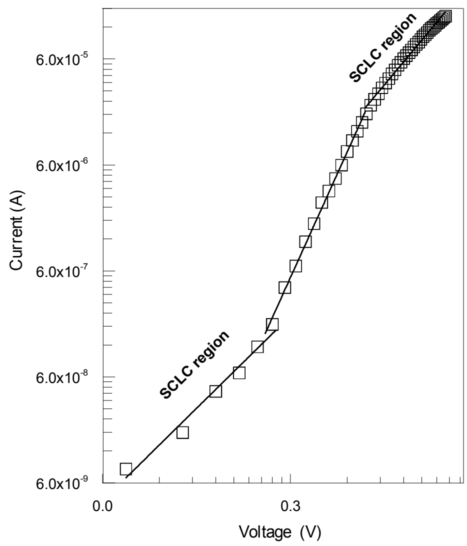

Fig. 5. I-V characteristics of the Au/IZO/FSS/Al diode in double logarithmic scale.

At higher voltages, the charge transport mechanism of the diode can be changed due to the electrical properties of FSS organic semiconductor. In order to check the transport mechanism, we plotted current-voltage characteristics in logarithmic and is shown in Fig. 5. As seen in Fig. 5, the curves exhibit three regions having different slopes. Thus, the current-voltage characteristics can be analyzed using $I=bxV^m$ relation. Here, V is the voltage, b and m are constants. The m values for regions I, II and III were found to be 2.07, 3.93 and 2.12, respectively. The obtained m values for region I and III indicate the presence of the space charge limited current mechanism [17], whereas, 3.93 value for the second region satisfies trap-charge-limited current (TCLC) mechanism.

4. Conclusions

The electrical characterization of IZO/FSS/Al MIS diode has been investigated current-voltage method. The IZO/FSS/Al device is a metal-insulator-semiconductor diode. The ideality factor and barrier height of the diode are 2.84 and 0.86 eV. At higher voltages, the charge transport mechanism of the diode is controlled by space limited current mechanism.

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