

Electrical characteristics of a high rectification ratio organic Schottky diode based on methyl red

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In this paper, the study of electrical properties of Au/methyl-red/Ag surface type Schottky diode by current-voltage (I-V) characteristics is reported. The I-V characteristics of the Schottky diode showed the very high rectifying behavior. The rectification ratio was found in order of 10^5 . The values of ideality factor n and barrier height ϕ_b of Au/methyl-red/Ag Schottky diode were calculated. The average values of n and ϕ_b were found about 1.58 and 0.24 V, respectively. The effect of series resistance was also investigated. The average value of R_s values was calculated about 1.1 k Ω .

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1. Introduction

Very recently, the fabrication and study of electronic devices using organic semiconducting materials have attracted considerable interest [1-5]. This is mainly due to low cost, ease of device fabrication and their successful application in electronic and photonic devices.

Schottky barrier diodes are one of the simplest electronic devices in semiconductor industry. The main advantage of these diodes is their high current density and low forward voltage drop [6]. Primarily the current flow in these diodes is due to the majority carriers having an inherently fast response. The current-voltage characteristics of Schottky diodes are similar to ordinary p-n junction diodes. These diodes are commonly used in switching circuits and high-frequency applications [6] because it can switch from one state to another much faster than ordinary p-n junction diodes. The behavior of organic Schottky diode depends on characteristics of the metal/organic semiconductor junction. Therefore, the understanding of electrical and electronic properties of interface between metal and organic semiconductor is important for device applications. There are more than a few possible reasons due to which the diodes show non-ideal behavior. These reasons include the effect of series resistance (R_s), formation of barrier height, insulating layer between metal and semiconductor and interface states. The series resistance is an important parameter which can lead the properties of Schottky diodes to be non-ideal [7, 8].

Methyl-red is a PH indicator dye in the form of dark red crystalline powder that turns red in acidic solutions. Moreover it is an organic semiconductor and has potential application for electronics devices. The hetero-junctions of methyl-red with silicon [9, 10] showed diode behavior.

In this work, Au/methyl-red/Ag surface type Schottky diode was fabricated. Methyl-red (MR) was chosen as organic semiconductor for the fabrication of the Schottky diode due to its conjugated structure and richness in 16- π -electron system [11]. The aim of this work was to determine the electronic parameters of Au/methyl-red/Ag Schottky diode. The parameters that control the device performance, such as ideality factor, barrier height and series resistance were calculated.

2. Experimental

Methyl-red with molecular formula $C_{15}H_{15}N_3O_2$ purchased from Sigma Aldrich was used without further purification for the fabrication of the Au/methyl-red/Ag surface type Schottky diode. The molecular structure of the methyl-red is shown in Fig. 1.

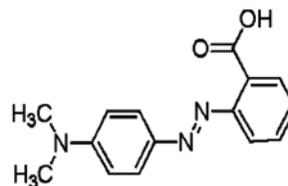


Fig. 1. Molecular structure of methyl-red.

The 10 wt% solution of methyl-red was prepared in benzene. The solution was stirred for 2 hours at room temperature. The substrate was cleaned for 10 min. using distilled water in ultrasonic cleaner and after drying the substrate was plasma cleaned for 5 minutes followed by the thermal deposition of Au and Ag electrodes by using shadow mask. During thermal deposition the chamber

pressure was 5.5×10^{-5} mbar while the deposition rate was kept at 0.1nm/s. The thickness of the electrodes was 100nm and gap between the electrodes was $30\mu\text{m}$. After that the thin film of MR was deposited by spin casting with angular rotation of 2000 RPM. A 300 nm thick film of methyl-red was deposited. The fabricated device was kept at 50°C for 1 hour to let the moisture in the film evaporate. Cross sectional view of Au/methyl-red/Ag surface type Schottky diode is shown in Fig. 2.

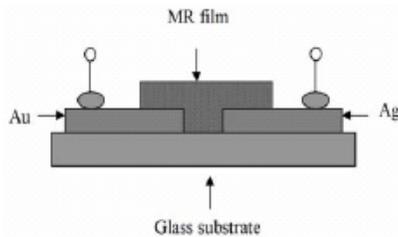


Fig. 2. Cross-sectional view of Au/methyl-red/Ag surface type Schottky diode.

The current-voltage characteristics were measured at room temperature. The measurements of the Schottky diode were taken using a KARL SUSS PM5 probe station.

3. Results and discussion

The forward and reverse bias current-voltage characteristics of Au/methyl-red/Ag junction were performed at room temperature as shown in Fig. 3. These characteristics indicate that Au/methyl-red/Ag junction behave as a Schottky junction. The forward bias corresponds to the positive potential to the Au with respect to Ag. The current-voltage characteristics of the Schottky junction are nonlinear, asymmetric and show the rectification behavior with very small leakage current of 2×10^{-9} A at reverse bias voltage of 2.5 V, which gives the indication of formation of the depletion regions at interfaces of the junction.

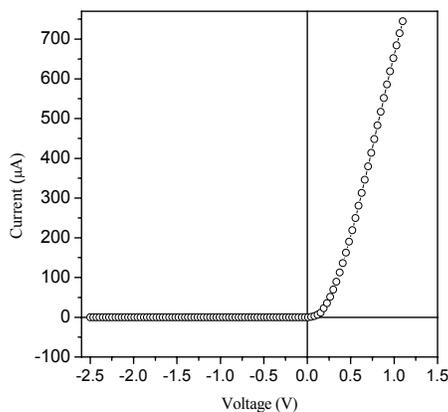


Fig. 3. Current-voltage characteristics of Au/methyl-red/Ag surface type Schottky diode.

From Fig. 3, it is observed that current-voltage characteristics of Au/methyl-red/Ag junction show the

rectification behavior. This behavior is due to the fact that a space charge layer is formed at the Au/methyl-red/Ag interfaces. The current-voltage characteristics of Au/methyl-red/Ag junction under the forward bias condition show the exponential increase in current at low voltage due to the decrease in the depletion layer width at the interfaces. At higher voltages the current-voltage characteristics are almost linear because the depletion layer is minimized at the interfaces and methyl-red film acts as series resistance. While in the reverse bias the depletion layer width increases and almost all the current is just due to the minority carriers of methyl-red. The equation, which describes the current as a function of the applied voltage for Schottky junction is written as:

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

where I_o is the reverse saturation current and is given as:

$$I_o = A^* T^2 \exp\left(\frac{-q\phi_b}{kT}\right) \quad (2)$$

The reverse saturation current is determined by interpolation of exponential slope of I at $V = 0$ and the value of ideality factor is calculated by using Eq. 1. The value of reverse saturation current is found to be 1×10^{-9} A. The value of ideality factor is found about 1.4. The value of ideality factor greater than unity can be attributed to the recombination of electrons and holes in the depletion region and it is also associated with Fermi-level pinning at the interface, or with a relatively large voltage drop in the interface region. The value of barrier height (ϕ_b) was estimated from the forward bias current-voltage characteristics and found to be 0.23 V. The Richardson's constant (A^*) has been determined from Eq. (2), which is about $5.4 \times 10^3 \text{ Am}^{-2}\text{K}^{-2}$. It is observed that the Schottky barrier effect disappears at higher voltage further than which the current is mainly contributed from bulk resistance of the methyl-red film. The rectification ratio (RR) is determined as the ratio of the forward current to the reverse current at a certain applied voltage (I_F/I_R). It is well known that the RR is subjective to applied voltage. The Au/methyl-red/Ag junction shows very high value of RR. The value of RR is found in order of 10^5 . Such high value of RR was also reported in [12, 13]. The RR value at different voltages is plotted in Fig. 4.

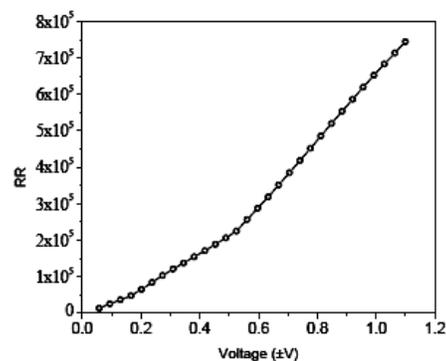


Fig. 4. RR plot of Au/methyl-red/Ag Schottky junction.

Semi-log current-voltage characteristics of Au/methyl-red/Ag Schottky junction at forward and reverse bias are shown in Fig. 5. The characteristics show an increase in the forward current with applied voltage for the junction at low voltage range. This increase at lower voltage can be attributed to the formation of depletion layer. From Fig. 5, the junction parameters can also be easily calculated. The value of reverse saturation current from Fig. 5 is found to be 0.911×10^{-9} A.

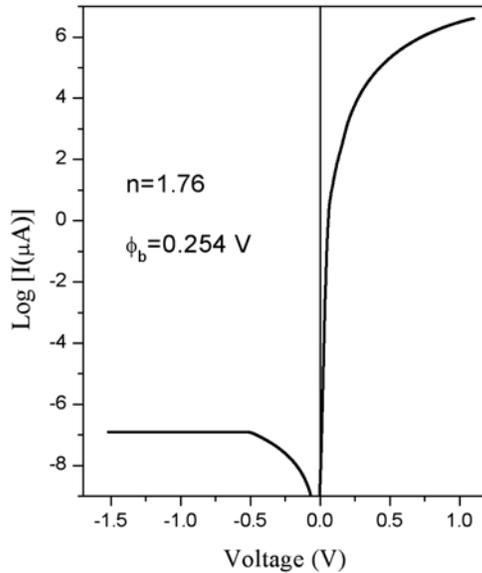


Fig. 5. Semi-log current-voltage characteristics of Au/methyl-red/Ag diode.

The value of barrier height was found to be 0.254 V. The value of ideality factor of Au/methyl-red/Ag surface type Schottky diode is calculated as 1.76 from the slope of the linear region of forward bias Semi-log current-voltage characteristics by using the following equation [14]:

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

where V is the applied voltage, T is the temperature in Kelvin. Forward bias current-voltage characteristic at low voltage are linear in semi- logarithmic scale, but at higher voltages the characteristics deviate from linear behavior due to effect of series resistance. For non-ideal diodes, the characteristics often present a more complex behavior than the ideal diodes due to the presence of various conduction mechanisms [15]. For such non-ideal diodes the following modified Schottky equation can be used [16]:

$$I = I_{o1} \left[\exp \left(\frac{qV - IR_s}{n_1 kT} \right) - 1 \right] + I_{o2} \left[\exp \left(\frac{qV - IR_s}{n_2 kT} \right) - 1 \right] + \frac{V - IR_s}{R_{sh}} \quad (4)$$

where R_s is the series resistance and R_{sh} is the shunt resistance. The equation also includes the effects of parasitic series and parallel resistance, which can obscure the intrinsic parameters of the device. The values of R_s , and R_{sh} , are found from the the junction resistance (RJ) vs. voltage (V) plot where $RJ = \delta V / \delta I$. A plot of RJ vs.V is shown in Fig. 6.

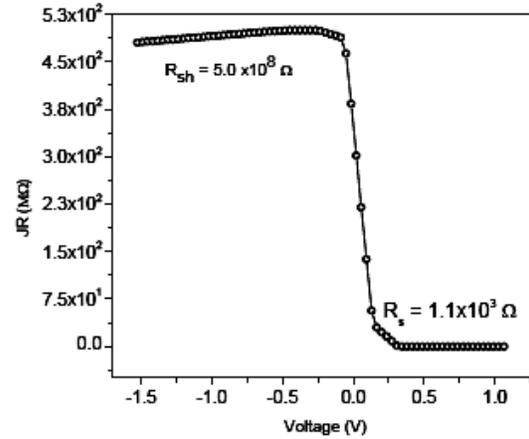


Fig. 6. Junction resistance plot of Au/methyl-red/Ag Schottky junction.

It is observed at higher voltage in forward bias the junction resistance approaches about to a constant value, this value is taken as R_s while in reverse bias the maximum value of junction resistance is equal to diode R_{sh} . The values R_s and the R_{sh} are found $5.0 \times 10^8 \Omega$ and $1.1 \times 10^3 \Omega$, respectively.

4. Conclusions

The electronic parameters of Au/methyl-red/Ag surface type Schottky diode have been calculated in this work by current-voltage method at room temperature. The average values of ideality factor and barrier height are calculated about 1.55 and 0.24V, respectively, from forward bias current-voltage characteristics. From high RR value it is concluded that this junction has potential to be used as a good rectifier.

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