

# Investigation of the Electronic Properties of Au/methyl-red/Ag Surface type Schottky Diode by Current-Voltage Method

Zubair Ahmad and Muhammad Hassan Sayyad

**Abstract**—In this paper, fabrication and study of electronic properties of Au/methyl-red/Ag surface type Schottky diode by current-voltage ( $I$ - $V$ ) method has been reported. The  $I$ - $V$  characteristics of the Schottky diode showed the good rectifying behavior. The values of ideality factor  $n$  and barrier height  $\phi_b$  of Au/methyl-red/Ag Schottky diode were calculated from the semi-log  $I$ - $V$  characteristics and by using Cheung functions. From semi-log current-voltage characteristics the values of  $n$  and  $\phi_b$  were found 1.93 and 0.254 eV, respectively, while by using Cheung functions their values were calculated 1.89 and 0.26 eV, respectively. The effect of series resistance was also analyzed by Cheung functions. The series resistance  $R_s$  values were determined from  $dV/d(\ln I)$ - $I$  and  $H(I)$ - $I$  graphs and were found to be 1.1 k $\Omega$  and 1.3 k $\Omega$ , respectively.

**Keywords**—Surface type Schottky diodes, Methyl-red, Current-voltage method

## I. INTRODUCTION

VERY recently, the fabrication and study of electronic devices using organic semiconductor 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 [7]. 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 [8]. 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 [9],[10].

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 heterojunctions of methyl-red with silicon [11],[12] showed diode behavior.

In this work, Au/methyl-red/Ag surface type Schottky diode was fabricated. Methyl-red was chosen as organic semiconductor for the fabrication of the Schottky diode due to its conjugated structure and richness in 16- $\pi$ -electron system [13]. The aim of this work was to analyze the electronic properties of Au/methyl-red/Ag Schottky diode and to determine its important parameters. The parameters that control the device performance, such as ideality factor, barrier height and series resistance were calculated by current-voltage method.

## II. 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. 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  $5.5 \times 10^{-5}$  mbar while the deposition rate was kept at 0.1 nm/s. The thickness of the electrodes was 100 nm and gap between the electrodes was 30  $\mu$ 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  $^{\circ}$ 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

Manuscript received June 27, 2008.

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Fig. 2. The current-voltage characteristics were measured at room temperature. The measurements of the Schottky diode were taken using a KARL SUSS PM5 probe station.

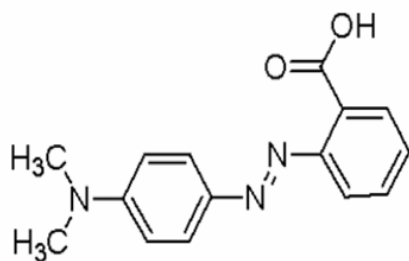


Fig. 1 Molecular structure of methyl-red

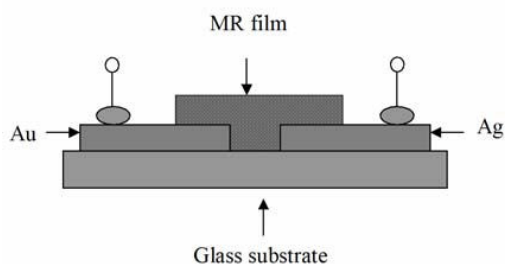


Fig. 2 Cross-sectional view of Au/methyl-red/Ag surface type Schottky diode

### III. RESULTS AND DISCUSSION

The forward and reverse bias current-voltage characteristics of the Au/methyl-red/Ag surface type Schottky diode at room temperature are shown in Fig. 3. It can be seen from Fig. 3 that the current-voltage characteristics of the Schottky diode are nonlinear, asymmetric and show good rectification behavior with very small leakage current of 0.002  $\mu\text{A}$  at reverse bias voltage of 2.5 V. The value of turn on voltage was estimated from the forward bias current-voltage characteristics and its value was found to be 0.23 V.

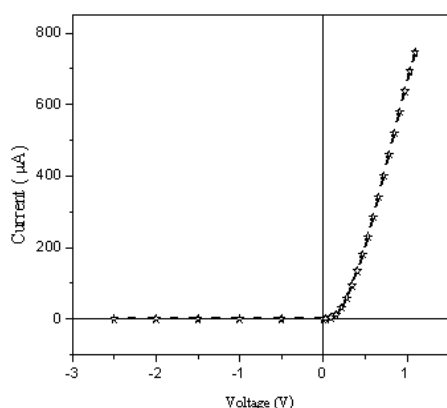


Fig. 3 Current-voltage characteristics of Au/methyl-red/Ag surface type Schottky diode

Semi-log current-voltage characteristics of Au/methyl-red/Ag surface type Schottky diode are exhibited in Fig. 4. It

is assumed that the current in the Schottky contact is due to thermionic emission. The current-voltage characteristics of the Schottky junction can be analyzed by the following relation [14]:

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

where  $I_o$  is the saturation current and can be given as:

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

where  $V$  is the applied voltage,  $T$  is the temperature,  $A$  is the effective diode area,  $A^*$  is the effective Richardson constant,  $\phi_b$  is the zero-bias barrier height,  $n$  is the ideality factor and  $k$  is the Boltzmann constant. The value of ideality factor  $n$  can be calculated as:

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

The value of ideality factor of Au/methyl-red/Ag surface type Schottky diode was calculated as 1.93 from the slope of the linear region of forward bias Semi-log current-voltage characteristics shown in Fig. 4. The value of barrier height was calculated by using Eq.(3) and its value was found to be 0.254 eV.

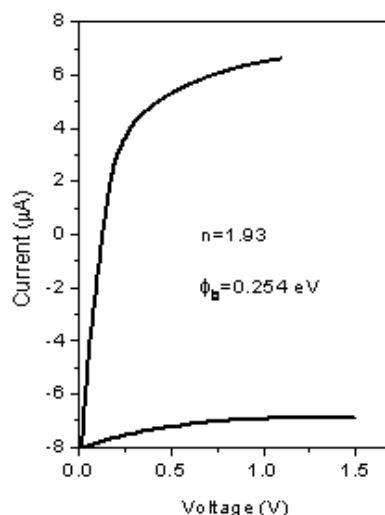


Fig. 4 Semi-log current-voltage characteristics of Au/methyl-red/Ag Schottky diode

Forward bias current-voltage characteristic at low voltage are linear in semi-log scale, but at higher voltages the characteristics deviate from linear behavior due to effect of series resistance. To determine the effect of series resistance on the Schottky diode characteristics, the following Cheung functions were used [15]:

$$dv / d(\ln I) = n(kT / q) + IR_s \quad (4)$$

and

$$H(I) = V - n(kT / q) \ln(I / AA^* T^2) \quad (5)$$

$$H(I) = IR_s - n\phi_b \quad (6)$$

The factor  $IR_s$  is the voltage drop across the series resistance of the Schottky diode. The graphs of  $dV/d(\ln I)$  vs  $I$  and  $H(I)$  vs  $I$  are shown in Figs. 5 and 6, respectively. The values of series resistance and  $n(kT/q)$  are obtained from the slope and y-axis intercept of the graph  $dV/d(\ln I)$  vs  $I$ . Similarly, the plot of  $H(I)$  vs  $I$  gives a straight line with the y-axis intercept equal to  $n\phi_b$ . The slope of this plot also gives the value of series resistance by which the consistency of Cheung's approach can be checked. The determined values of series resistance from the plots of  $dV/d(\ln I)$  vs  $I$  and  $H(I)$  vs  $I$  and were found to be 1.1 k $\Omega$  and 1.3 k $\Omega$ , respectively. The average value of series resistance for the diode was calculated 1.2 k $\Omega$ . As it can be seen that the values of series resistance from the plot  $dV/d(\ln I)$  vs  $I$  and  $H(I)$  vs  $I$  are in good agreement with each other.

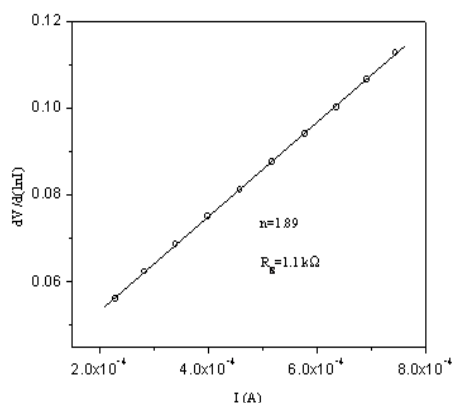


Fig. 5  $dV/d\ln I$  plot of Au/methyl-red/Ag Schottky diode

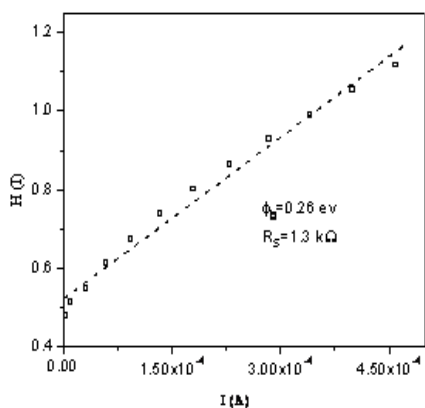


Fig. 6  $H(I)$ - $I$  plot of Au/methyl-red/Ag Schottky diode

#### IV. CONCLUSIONS

The electronic properties of Au/methyl-red/Ag surface type Schottky diode have been analyzed in this work by current-

voltage method at room temperature. The values of ideality factor and barrier height are calculated about 1.9 and 0.26 eV, respectively, from forward bias current-voltage characteristics and by using Cheung functions. The  $n$  value is higher than unity that reflects the effect of series resistance due to which the behavior of diode is non-ideal. The curvature at higher voltages is due to the effect of series resistance  $R_s$ . The value of the  $R_s$  has been calculated from the higher voltage region by using Cheung functions. It has been seen that there is a good agreement between the values of the series resistance obtained from two Cheung plots.

#### ACKNOWLEDGMENT

The authors are thankful to the Ghulam Ishaq Khan Institute of Engineering Sciences and Technology ([www.giki.edu.pk](http://www.giki.edu.pk)) for its support during this work. We are pleased to acknowledge the Higher Education Commission (HEC) Pakistan for providing PhD scholarship to Mr. Zubair Ahmad.

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