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The analysis of current-voltage characteristic of organic semiconductor diode with anthracene-imine fabricated by spin coating method

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Anthracene-imine (dimethyl (E)-3-(anthracene-9-ylmethylene)amino)benzoate, the compound containing an anthracene-imine group) thin film was deposited on n-Si crystal by spin coating method. In this work, Au/ Anthracene-imine /n-Si/In diode with Schottky barrier were prepared and electrical characteristics were investigated in dark and 300 K. The characteristic diode parameters such as ideality factor and barrier height were determined by the current–voltage (I–V) measurement. The values of the rectifying ratio, ideality factor (n) and barrier height (Φ_b) values were determined as 160, 2.44, and 0.662 eV, respectively. The series resistance (R_s) values were determined using Cheung and Norde functions as 440 Ω for dV/d(lnI)-I graph, 413 Ω for H(I)-I graph and 1849 Ω for F(V)-V graph. As a results, the results revealed that the Schottky barrier height of the diode can be modifed by Anthracene-imine organic interfacial layer, and the Au/Anthracene-imine/n-Si/In Schottky diode can be used in electronic applications

Keywords: *Anthracene-imine, Spin coating, Schottky diode, ideality factor, barrier height, series resistance*

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1. Introduction

In recent, organic semiconductor-based structures have gained expanded attention in optoelectronic and electronic applications [1, 2]. Organic semiconductor materials provide some advantages such as broad area applications, fabrication flexibility and low cost manufacturing.[3]. These materials are needed as essential elements in the manufacture of semiconductor electronic devices such as Schottky barrier diodes, rechargeable batteries, organic photovoltaic devices, and organic light-emitting diodes (OLEDs)[4-6].

Many researchers design new organic materials in order to gain new performances comparable to those of silicon structures [7-10]. Some researchers have reported the diode parameters of organic material/Si Schottky diodes [11-15]. Immer et al. [11] have fabricated Au/Sunset Yellow/n-Si Schottky diode by using the spin coating method. The ideality factor and barrier height values of the diode were determined as 1.23 and 0.73 eV, respectively. Tezcan et al. synthesized BOD-Z-EN organic material and fabricated Au/BOD-Z-EN/n-Si Schottky diode [12]. They studied using (photo) electrical properties of diode in detail by using I–V characteristics. They have determined that the ideality factor and barrier height values of the diode as 2.33 and 0.86 eV, respectively. This results revealed that the construction of the physical barrier between the semiconductor and metal owing to the organic material to exclude the directly contacting of the Si crystal with metal [16].

Herein, we report new organic semiconducting (Anthracene-imine) containing both active imine and anthracene units in the macromolecular backbone. This organic semiconductor material investigated with diode production was examined by various theoretical process to study its diode parameter properties. In particular, diode parameters were explained by the current-voltage (I-V) measurements in order to determine the electrical properties. The rectifying ratio, series resistance, ideality factor and barrier height behavior of the fabricated diode are revealed.

2. Experimental

In this work, the n-type Si crystal has phosphor doped, (1 0 0) surface orientation, 525 µm thickness, and 1–20 Ω-cm resistivity. First, the n-type silicon semiconductor purchased from University Wafer was chemically cleaned by RCA method to remove impurities. [17]. Thermal evaporation method was used to deposite the indium (In, 99.99% purity, 200 nm) ohmic contact and gold (Au, 99.99 % purity, 200 nm) rectifying contact to n-Si crystal. To prepare the aqueous solution of Anthracene-imine for use in the spin coater, 10 mg of Anthracene-imine organic material was dissolved in 10 ml of chloroform. After that Anthracene-imine aqueous solution was used to deposite Anthracene-imine organic thin film on the polished surface of n-Si by spin coating technique at 2000 rpm, for 60 s, and allowed it to dry in a thermal evaporation system (5 x10^{-5} Torr) for 3 h. As a result, Au/Anthracene-imine/n-Si/In Schottky diode was produced. Figure 1 shows the 3D presentation of Au/ Anthracene-imine/n-Si/In diode. In order to investigate the ideality factor, barrier height and series resistance characteristics of the fabricated diode, current-voltage (*I-V*) measurement was taken in the vary from -2 V to +2 V in dark and at room temperature. The I-V measurement of Au/ Anthracene-imine/n-Si/In diode was taken by means of a Keithley 2400 Sourcemeter. An Nano Magnetics atomic force microscope (AFM) were used to analyze the surface morphology of the Anthracene-imine thin film.

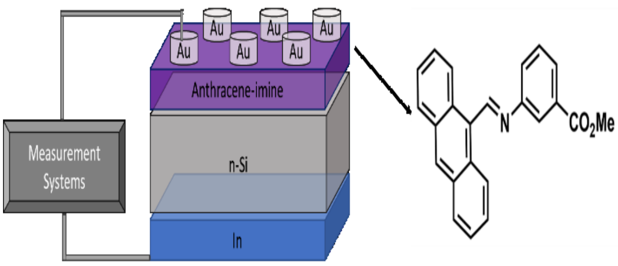


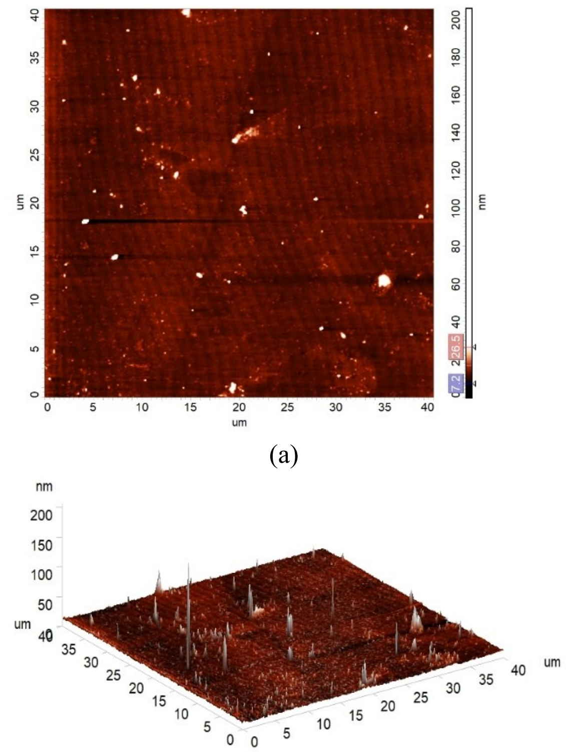
Figure 1: 3D view of Au/Anthracene-imine/n-Si/In Schottky diode structure

3. Results

The formation of uniform organic thin films is crucial for any diode applications [32]. The surface morphology of the spin coated thin film of Anthracene-imine was observed using atomic force microscopy (AFM) analysis. The AFM analysis (Fig. 2) displayed a average roughness value of 0.94 nm, peak to peak value of 205.7 nm, ten point height of 75.8 nm, average value of 12.7 nm, root mean square value of 2.3 nm. These results indicate that Anthracene-imine is a proper functional material for diode production with possibly decreased of leakage current.

To calculate the characteristic parameters such as saturation current, ideality factor and Schottky barrier height of the diode according to the thermionic emission theory, the current-voltage (I–V) relation might be expressed by [18]:

$$I = I_0\left[exp\left(\frac{q(V-IR_S)}{nkT}\right)-1\right] \quad (1)$$



(a)

(b)

Figure 2: a) 2D and b) 3D AFM topographic surface images of Anthracene-imine on n-Si substrate.

where I_0 is the saturation current, R_s is the series resistance, q is the electron charge, and T is the temperature in K.

$$I_0 = AA^*T^2 exp\left[\frac{-q\Phi_b}{kT}\right] \quad (2)$$

where A^* is Richardson constant for n-Si semiconductor (112 A.cm^{-2} K^{-2}) and k is Boltzmann's constant. After determining the value of I_0, the parameters of barrier height (Φ_b) and ideality factor (n) can be rewritten as follows [19]:

$$\Phi_b = \frac{kT}{q} ln\left(\frac{AA^*T^2}{I_0}\right) \quad (3)$$

$$n = \frac{q}{kT}\frac{dV}{d(lnI)} \quad (4)$$

A typical semi-logarithmic I–V plots of the Au/Anthracene-imine/n-Si Schottky diode are presented in Fig. 3. The calculated diode parameters are given in Table 1. The rectification ratio at ±2 V from Fig. 3 is also determined as 160. It is observed that the n fromTable 1 is bigger than 1, showing that the fabricated diode is non-ideal. Some potential reasons for this occurrence include interfacial states, series resistance, and leakage current [20].

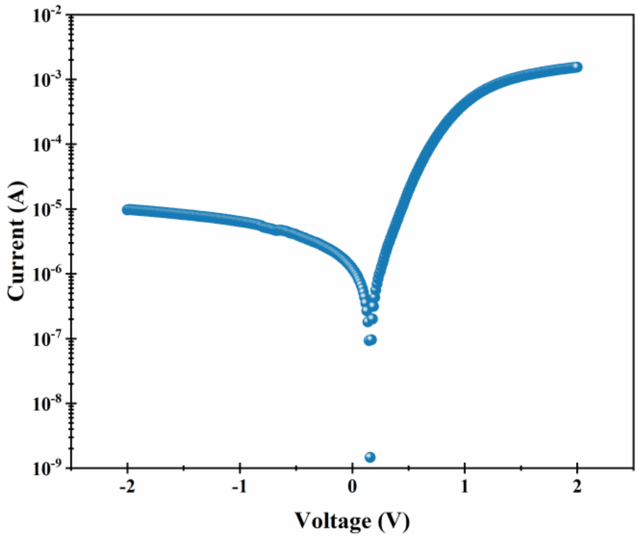


Figure 3: Plot of $lnI-V$ of the Au/Anthracene-imine/n-Si diode in dark and at room temperature.

Table 1. n, Φ_b and I_0 values determined from $lnI-V$ graph of Au/Anthracene-imine/n-Si diode.

	n	I_0 (A)	Φ_b(eV)
Au/Anthracene-imine/n-Si	2.44	2.44x10^{-6}	0.662

The other method used to calculate the characteristic parameters of Schottky barrier diodes is the Cheung&Cheung method. In this method, two functions are defined, one is $dV/d(lnI)$ and the other is $H(I)$. These functions are defined as follows [21]:

$$\frac{dV}{d(lnI)} = n\frac{kT}{q} + IR_s \quad (5)$$

$$H(I) = V - \left(\frac{nkT}{q}\right) ln\left(\frac{I}{AA^*T^2}\right) \quad (6)$$

$$H(I) = n\Phi_b + IR_s \quad (7)$$

The current-dependent plots of these functions in the series resistance region are plotted and given in Fig. 4 and Fig. 5. The diode parameters calculated from these plots are presented in Table 2.

Table 2. n, Φ_b and R_s values determined from Cheung graphs of Au/Anthracene-imine/n-Si diode.

	dV/dln(I)-I		H(I)-I	
	n	$R_s(\Omega)$	Φ_b(eV)	$R_s(\Omega)$
Au/Anthracene-imine/n-Si	4.3	440	0.721	413

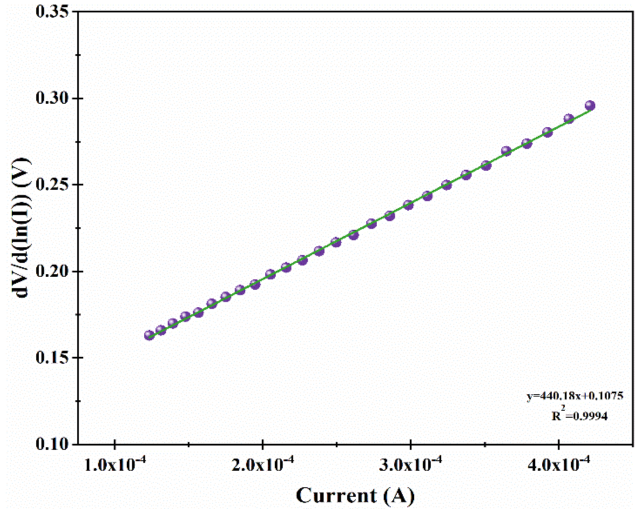


Figure 4: Plot of $dV/d(lnI)-I$ of the Au/Anthracene-imine/n-Si diode.

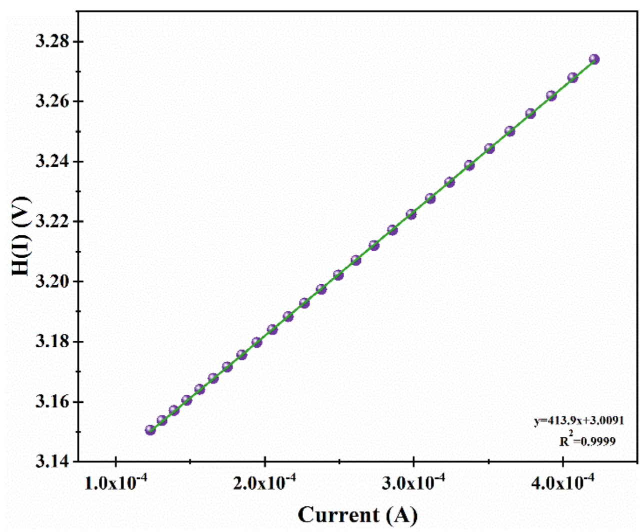


Figure 5: Plot of $H(I)-I$ of the Au/Anthracene-imine/n-Si diode.

In this work, another method is used to determine diode parameters is Norde method [22]. Using this method barrier height and series resistance values can be calculated as following equations [22]:

$$F(V) = \frac{V}{\gamma} - \frac{kT}{q} ln(\frac{I(V)}{AA^*T^2}) \quad (8)$$

$$\Phi_b = F(V_{min}) + \frac{V_{min}}{\gamma} - \frac{kT}{q} \quad (9)$$

$$R_s = \frac{kT(\gamma - n)}{qImin} \quad (10)$$

where V_{min} and I_{min} are the minimum voltage and current and F(V_{min}) is the corresponding minimum value of $F(V)$. γ is the first integer number greater than n of Anthracene-imine/n-Si diode. $F(V)-V$ plot of the Au/Anthracene-imine/n-Si Schottky diode are presented in Fig. 6. The diode parameters calculated from this plot are presented in Table 3.

Table 3. $\Phi_b$and R_s values determined from Norde graph of Au/Anthracene-imine/n-Si diode.

	$F(V_{\min})$ (V)	V_{min} (V)	I_{min} (μA)	Φ_b (eV)	R_s (Ω)
Au/Anthracene-imine/n-Si	0.805	0.23	0.84	0.806	1849

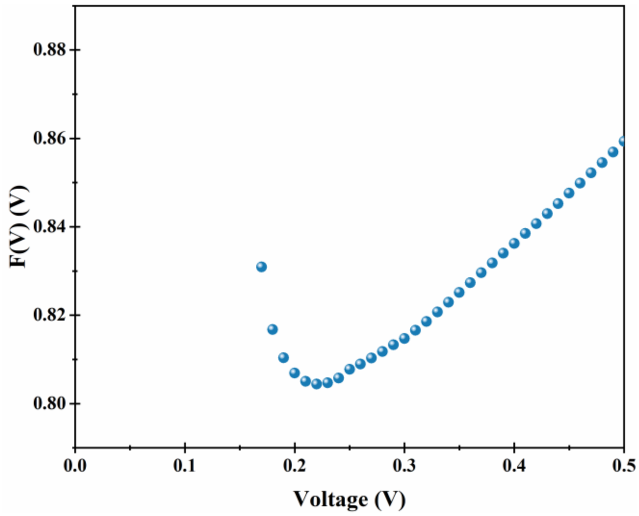


Figure 6: Plot of $F(V)-V$ of the Au/Anthracene-imine/n-Si diode.

4. Conclusion

In the presented study, it was investigated to develop the efficiency of the diode by depositing theAnthracene-imine organic layer between n-Si and Au by spin coating method method. The forward and reverse bias *I-V* characteristic of Au/Anthracene-imine/n-Si diode was measured in the voltage vary from -2V to 2V. The ideality factor, barrier height, and saturation current values have been determined from *I-V* measurement. Series resistance values determined from functions of different methods. This work could highlight the understanding of organic Anthracene-imine diode on n-Si substrate Schottky diode for the usage in organic electronic applications.

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