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Electrical Characterization of Metal–Semiconductor Au/Alpc-H/P-Si/Al Organic Diode

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Abstract. The Au/AlPc-H/p-Si/Al organic diodes based on Al-phthalocyanine diodes are fabricated by the spin coating process onto p-type silicon substrate. The Au/AlPc-H contact is thermally evaporated in vacuum at 10^{-6}Torr. Here, we investigate the electronic parameters obtained from the current-voltage (I-V) characteristics achieved at room temperature under dark conditions within the -1V, +1V bias voltage range. The Cheung's and Norde approximations are used for the calculation of the electronic magnitudes. The obtained values, such as ideality factor (n), barrier height (Φ_b) series resistance (R_S), are approximately similar which approve the consistency of Cheung's and Norde methods. The I–V forward bias in log scale has been investigated to explore the dominated conduction mechanism. The AlPc Hydroxide/ p-Si contacts exhibit high rectification ratio (RR) in order of 2.73×10^4 and large ideality factor of 7.37.

Keywords. AlPc Hydroxide; Organic diode; Spin-coating; Electrical parameters; Current-voltage measurement.

INTRODUCTION

These days, the organic semiconductor materials are investigated by many researchers due to their different applications. In this ambitious filed, the metal-phthalocyanine semiconductors are used as diodes for optoelectronics (Honeybonme and Ewen, 1983)**,** solar cells, liquid crystals, photovoltaic cell, gas sensors and optical data storage (Orti, 1990).

In order to fabricate organic diodes with such appropriate characteristics. Metal-phthalocyanine (M-Pc) where M=Zn, Cu, Al, Mg and Ni has been used as layers in the device fabrication (Benhaliliba et al., 2014; Mutabar, 2010). Organic diodes are fabricated by using several methods, which are mostly spin-coating and thermal evaporation. In this study, the AlPc-H material is deposited by spin-coating technique on p-Si substrates as well as the Au electrode is formed by thermal evaporation technique in vacuum as shown in figure 1.

The current-voltage (I-V) characteristics of the fabricated ZnPc and AlPc-chloride organic diodes are measured and the rectification ration (RR) are extracted and calculated for studying the microelectronic and the electronic behavior parameters of AlPc-H organic diode.

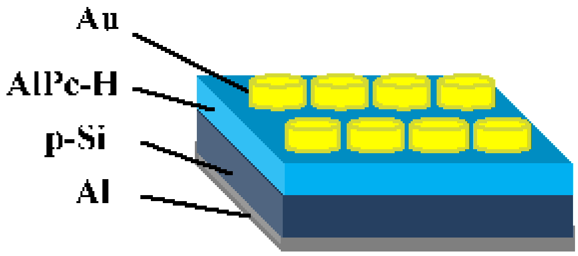

Fig .1. The cross sectional of AlPc-H organic diode.

EXPERIMENTAL DETAILS

The Au/AlPc-H/p-Si/Al organic diode is fabricated by spin coating system at 2000 rpm for 1 min and dried at 115 °C for 3 min; the process was repeated 2 times to get suitable films. The Au front contact is formed by thermal evaporation process in vacuum at pressure of 10^{-6} T. The metallic (Au) contacts have a diameter of 1.5 mm.

The current-voltage measurement of Au/AlPc-H/p-Si/Al organic diodes was performed from –3V to +3 V bias voltages by using Keithely 2400 source meter under dark conditions.

RESULTS AND DISCUSSION

It is crucial to study the behavior of organic diode for that reason we plot I-V characteristics measurement. Figure 2 shows the I-V semilog plot of Au/AlPc-H/p-Si/Al organic diodes within (– 3V, + 3 V) voltage range under dark conditions.

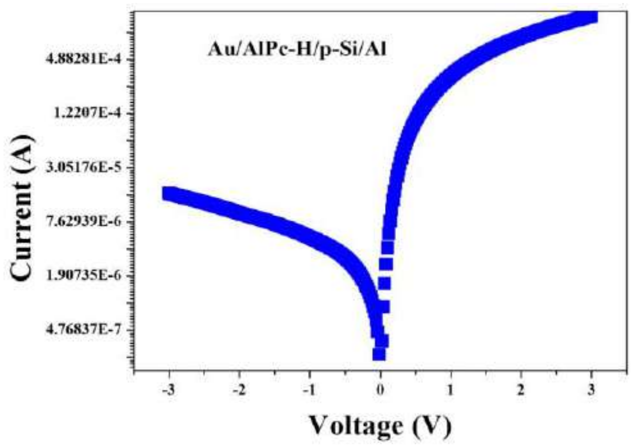

Fig. 2. The current-voltage characteristics plotting (semilog scale) of Au/AlPc-H/p-Si/Al diodes, in dark conditions.

Here, the I-V characteristics were investigated by means of the thermionic emission (TE) theory given as follow (Rhoderick and Williams, 1988);

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

The parameters I, V and I_0 are the current, voltage and saturation current of organic diode respectively; the saturation current is given by (Sze and Ng Kwok, 2007):

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

A is the effective diode area, A^* is Richardson constant which equal 32 A/K^{2}cm^2 (Missoum, 2016) for the p- Si, T is absolute temperature in Kelvin, q is the electron charge, n is ideality factor and Φ_b represents the barrier height that can calculate by using the following equation :

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

The *I-V* calculation of organic diode based on the TE theory shows that the plot of current versus voltage gives linear curve and the value of I_0 can extract it from the y-axis intercept of this curve and injected in equation 3 to calculate Φ_b.

The *n* represent the ideality factor, which is greater than the unity and shown, the deviation of the *I-V* characteristics of the diode from the ideal to non-ideal behavior that can calculate by using the following equation (Missoum, 2016).

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

The constant *K*, *T*, *q* are Boltzmann constant, absolute temperature (300 K) and the electron charge respectively. The parameter *n* is equal 1 in the ideal case.

To explore the deviation from the ideal case we used the equation 4 to determine the ideality factor of our Au/AlPc-H/p-Si/Al fabricated diode from the slope of the linear part of the bias forward of ln*I*-*V*.

The ideality factor n is very important parameter that decides the amount of contribution of tunneling on the recombination process and the change of performance of the device (Dalapati et al., 2015).

In order to calculate the series resistance, barrier height and ideality factor, we are used the functions of the method developed by Cheung and Cheung (Cheung and Cheung, 1986):

$$\frac{dV}{d(\ln I)} = IR_S + n\left(\frac{kT}{q}\right) \quad (5)$$

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

and H(I) is given as follows:

$$H(I) = IR_S + n\phi_b \quad (7)$$

The equation 5 of dV/dlnI vs current is represented in figure 3a. By using a linear fit of these curves we can obtain the series resistance and ideality factor values from (nkT/q) + IR$_s$ plots. The R$_s$ takes the value of 3809 Ω and n of 7.35 for AlPc-H organic diode.

From the equation 6, shown in figure 3b, we calculate the barrier height and series resistance by using linear fit as $IR_S + n\phi_b$.The ϕ_b takes the value of 0.14 eV and R_S of 3839.16 Ω for AlPc-H organic diode.

In order to compare and to emphasize the accuracy of the calculated values by Cheung method, we used the functions developed by Norde as follows (Norde, 1979);

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

Where γ is the first integer number greater than ideality factor of Au/AlPc-H/p-Si/Al; *I* and *V* are taken from the *I-V* characteristics in forward bias region. The barrier height of as-fabricated diode is defined as:

$$\Phi_b = F(V_0) + \frac{V_0}{\gamma} - \frac{kT}{q} \quad (9)$$

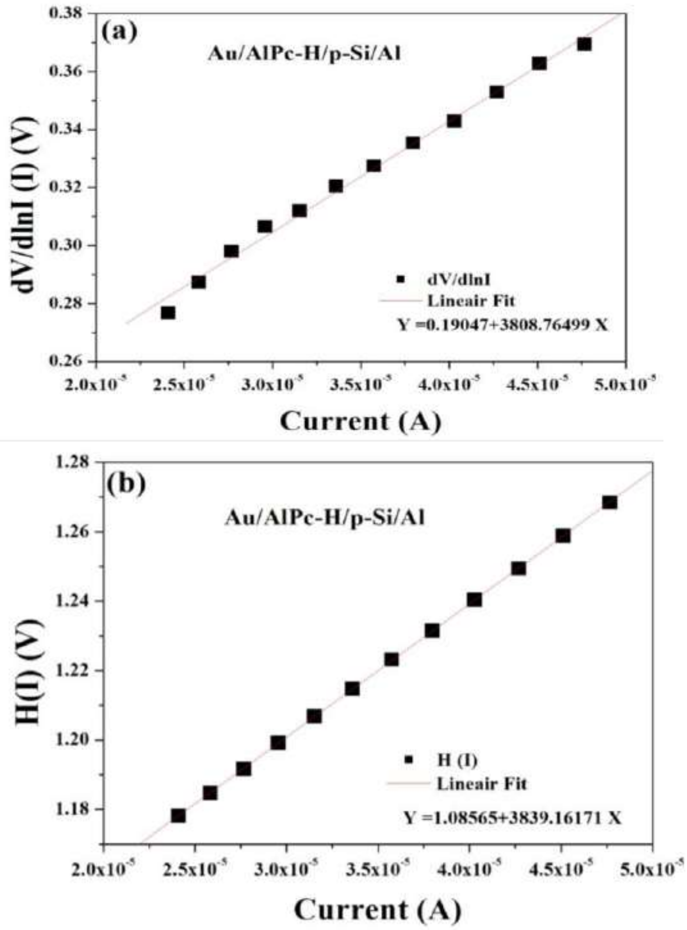

Fig. 3. The plotting of dV/dlnI and H(I) as function of current of Au/AlPc-H/p- Si/Al organic diodes, in dark conditions.

Where $F(V_0)$ is the minimum value taken from the plot of $F(V)$ vs V curve as depicted in figure 4 and V_0 is the corresponding value of voltage.

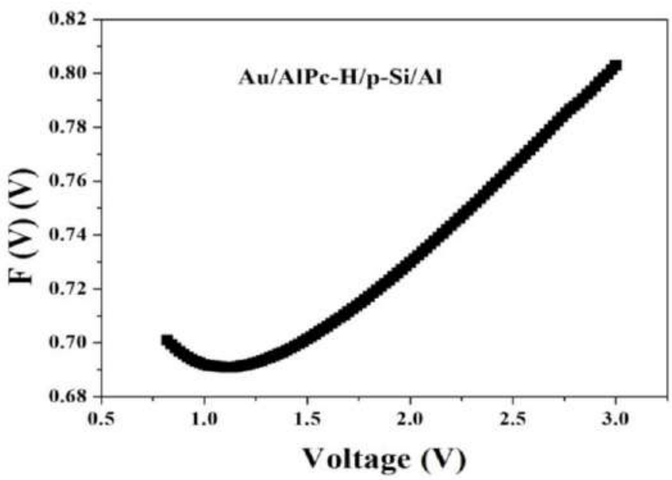

Fig. 4. F(V) vs. Voltage of Au/AlPc-H/p-Si/Al organic diodes, in dark conditions.

Besides, from the Norde method we calculated R_S using the following equation:

$$R_s = \frac{kT(\gamma - n)}{qI_{\min}} \quad (1)$$

In this case, the I_{min} value is the minimum value of current corresponding to the value of V_0. The calculated values of R_S and ϕ_b from Norde method were determined. The R_S take the value of 3657.57 Ω and ϕ_b of 0.75 eV for AlPc-H organic diode.

The values of ideality factor, series resistance and barrier height are calculated from Cheung method and are compared with those reported in literature as listed in table 1.

Table1. Comparison of microelectronic parameters of various organic diodes in dark conditions.

Organic diode	n	ϕ_b(eV)	R_S (Ω)	Reference
Au/AlPc-H/p-Si/Al	7.3	0.14	3.81×10^3	Current study
Au/CoPc/p-Si/Al	1.3	0.90	314.5	Yakuphanoglu et al., 2008
Ag/CuPc/a-Si/p-Si/Ag	5.7	0.93	28.6	Tatar and Demiroglu, 2013
Ag/MgPc/p-Si	2.2	0.98	2.73×10^4	Karataş, 2010

Table 1 displays the results of microelectronic parameters of some organic diodes based on Metalphthalocyanine (MPc where M= Al, Co, Cu and Mg) deposited on p-type Si substrates. We have noted that the deposited material has significant influence on the behavior of diode, the AlPc-H showed very high n of 7.35 and very small ϕ_b of 0.14 eV compared to others diodes (CoPc, CuPc and MgPc).

The high ideality factor suggests that the transport properties of the device could not be well defined by thermionic emission only. Higher ideality factor could be due to presence of secondary mechanism at the interface (Aydogan et al., 2010). Such as the recombination generation, image force effect and tunneling (Rhoderick and Williams, 1988), order to survey the behavior deviation of the as-fabricated AlPc-H/p-Si organic diode we determined the dominant transport charge mechanism by plotting the forward bias log I versus log V and that's shows a power law behavior of the current $I \propto V^{m+1}$ with different exponents (m+1). Where (m+1) varies with the injection level and is related to the distribution of trapping centers (Missoum et al., 2016; Soylu and Abay, 2010; Aydogan, 2009). After that, we distinct the linear regions and fit to calculate the (m +1) slopes as shown in figure 4.

At low voltage (0.06 < log V < 0.14), the Au/AlPc-H/p-Si/Al organic diode is controlled by the trapped-charge-limited current (TCLC) in the band gap of the AlPc-H layer (Aydogan et al., 2010). In intermediate voltages range, (0.16 < log V < 0.34) the dominant mechanism in the device is space charge limited current (SCLC) which is controlled by an exponential distribution of traps (Zubair and Sayad, 2009).

Obviously in the high voltages (0.36 < log V < 1.00) the slope decrease which means that most traps are filled (TFL) and the contribution of free charge carriers in the electric field becomes important (Aydogan et al., 2010; Soylu, and Abay, 2010).

As result we can say that there is significant influence of recombination in the deviation of Au/AlPc-H/p-Si/Al organic diode from the ideal behavior.

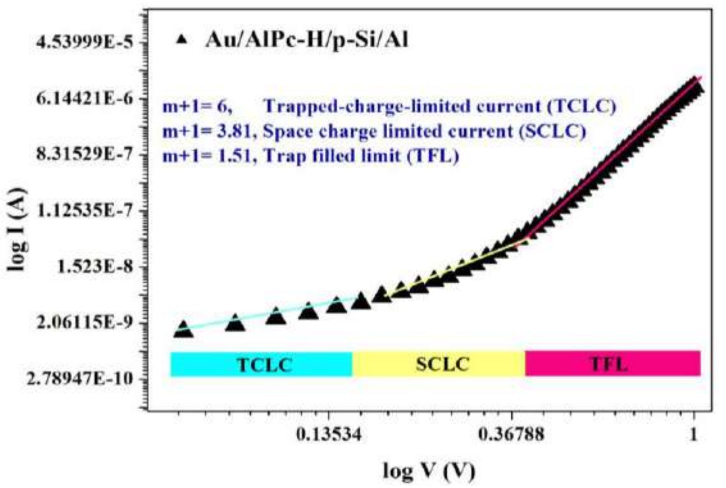

Fig. 4. The forward bias I–V characteristics of Au/AlPc-H/p-Si/Al organic diodes at room temperature.

CONCLUSION

The Au/AlPc-H/p-Si/Al organic diode is fabricated by spin-coating and thermal evaporation techniques. The I-V characteristics were meseaured and used in the calculation of the electrical parameters by Cheung and Norde methods. The Au/AlPc-H/p-Si/Al revealed high RR value of 2.73×10^4 which proves that this structure is suitable candidate to be used as a good rectifier device. Here the strong dependence of the microelectronic parameters on the deposited material is revealed. Besides the AlPc-H showed three conduction mechanisms such as: TCLC, SCLC and TFL. The current study gives us more understanding of the Aluminum phthalocyanine hydroxide (AlPc-H) organic diode for the use in organic microelectronics applications.

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