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Flexible Spray Coated TIPS-Pentacene Organic P-N Junction Diode

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Abstract – *A p-n junction diode fabricated onto flexible substrates using 0.1wt% 6,13-bis(triisopropylsilylethynyl) (pentacene) (TIPS-pentacene) as p-type semiconductor by spray coating techniques. Electrical properties of ITO/p-TIPS-Pentacene/n-ZnO/Au investigated using current-voltage graph and Cheung and Cheung's function. The ideality factor n, barrier height ϕb, shunt resistance Rsh and series resistance Rs were found to be 11.60, 13.02eV, 7.82 x 105Ω and 6.71 x 104Ω, respectively. Ideality factor for the organic diode is more than the unity value of a Schottky diode that shows existence of other elements between semiconductor and metal surface.*

Keywords: Diode, TIPS-pentacene, Spray coating, Thin film

1.0 INTRODUCTION

Organic semiconductor raises intense attention by researchers in producing a thin film semiconductor. Organic materials developed its own advantages by easy fabrication, low cost, large area electronic applications and low temperature process [1-2]. Schottky diodes are known to be the most straightforward device as it has the advantages of high current density and low voltage drops. With these advantages, it is easier for the diode to have fast response compared to the conventional diodes [3]. Schottky diodes are formed with the presence of metal and semiconductor interface [6, 7]; therefore it is crucial to understand the characteristics for both layers as it will affect the device's performance [10].

2.0 METHODOLOGY

Samples were prepared with four different stages that consist of: solution preparation, substrate cleaning, samples depositions and samples characterization.

2.1 Solution Preparation

TIPS-pentacene (purchased from Ossila) in powdered form were diluted in toluene to form a 0.1wt% solution, then stirred overnight for 12 hours.

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2.2 Substrate Cleaning

Mylar plastics were cut into 2.7cmx1.5cm in size and went through simple cleaning process.. Plastics were soaked for 2hours before undergo sonication with three solution of distilled water, ethanol, and acetone. Then the substrates were blown using Nitrogen gas to remove any excess residue on the surface.

2.3 Samples Deposition

Figure 1 shows the schematic diagram of an organic diode on flexible substrates. TIPS-pentacene was used as the diode's p-type semiconductor and deposited using spray coating techniques. Spray coating parameters for TIPS-pentacene were done with an airbrush spray system with the nozzle distance of 10cm from ITO surface with total of 10 Pa pressure control. The samples were covered with a clean petri dish as soon as sprayed to control the evaporation rate for TIPS-pentacene. Then it is baked in furnace for 1 hour with the temperature of 60°C.

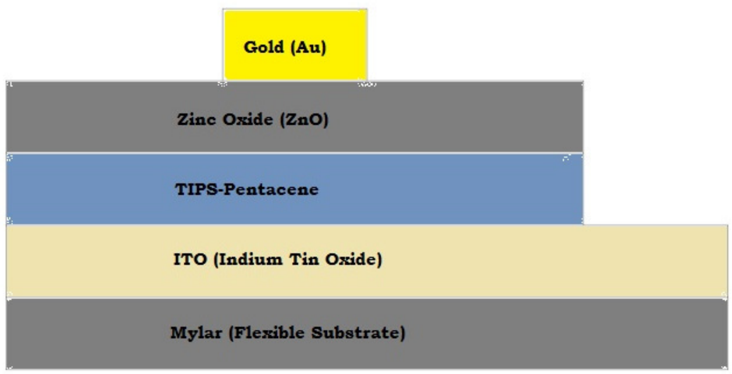

Figure 1: Organic diode architecture on flexible substrate

Zinc oxides (ZnO) as n-type layer for the organic diode were deposited using DC sputtering system with controlled thickness of 175nm. Lastly, gold (Au) coated on top of ZnO to perfectly form a Au/n-ZnO/p-TIPS-pentacene/ITO/plastic Schottky barrier diode.

2.4 Samples Characterization

The electrical characterization were done in a room temperature using a Keithley 2400 sourcemeter interfaced with PC using USB-to-GPIB interface adapter. Conventional I-V characteristics and Cheung and Cheung's functions were used to extract ideality factor (n), barrier height ($\emptyset_b$), shunt resistance (R_{sh}) and series resistance (R_s) for the organic diode. Schottky junction current-voltage characteristics were analyzed using this equation [3]:

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

Where I_0 is the saturation current that can be extracted as:

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

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As V is the applied voltage, T is the temperature, A indicates diode effective area, A* for effective Richardson constant and *k* is for Boltzmann constant. Ideality factor (n) for the organic diode can be calculated from this equation (3) using a semi-log scale [6, 9]:

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

Barrier height from equation (2) can be further extract as in equation (4):

$$\emptyset_b = \frac{kT}{q}\ln\left(\frac{AA^*T^2}{I_0}\right) \qquad (4)$$

Using the slope and current axis intercept of linear region at I-V plotted graph, we can obtain n and $\emptyset_b$ for the organic diode I-V characteristics. Using Cheung's function, junction resistance at V > 3kT/q of the forward bias I-V characteristics were written as in equations below [4-5, 8]:

$$\frac{dV}{d\ln I} = n\frac{kT}{q} + IR_s \qquad (5)$$

$$H(I) = V - n\frac{kT}{q}\ln\left(\frac{I_0}{AA^*T^2}\right) \qquad (6)$$

$$H(I) = IR_s + n\emptyset_b \qquad (7)$$

Value of n obtained from equation (5) were replaced into equation (6) in order to find the value for H(I). H(I) versus I graph were plotted to find the y axis intercept and slope of the graph that represents $\emptyset_b$ and value of R_s.

3.0 RESULTS AND DISCUSSION

I-V characteristics is the easiest way to characterize a diode in order to find basic parameters of diodes such as series resistance, ideality factor and barrier height [3, 5]. As shown in figure 2, the figure shows a nonsymmetrical and rectifying behavior, indicating that the junction formed is a non-ohmic junction [3]. A straight line in the forward region curve is drawn to find the turn on voltage $V_{turn\ on}$ which values at 0.8V.

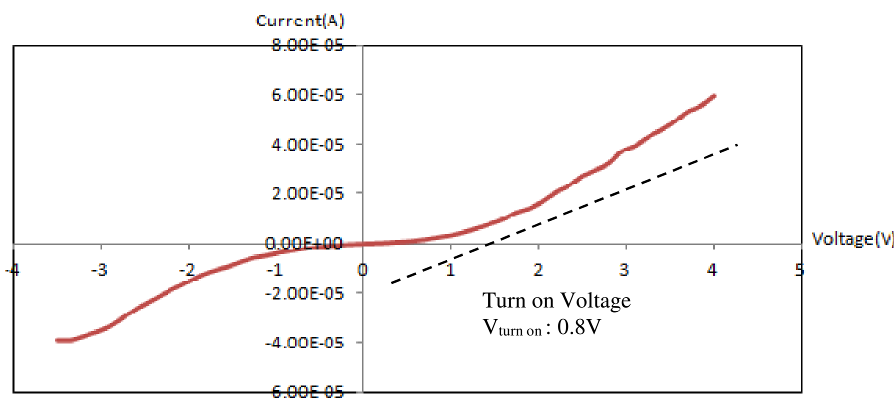

Figure 2 : Current-voltage (I-V) characteristics of Au/n-ZnO/p-TIPS-pentacene/ITO/plastic Schottky barrier diode

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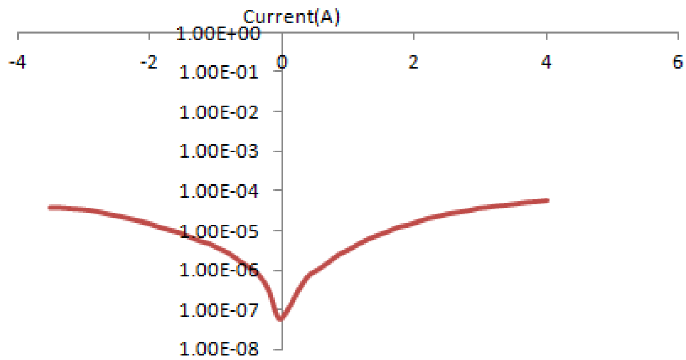
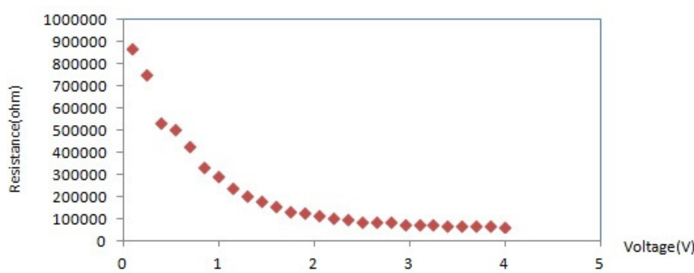
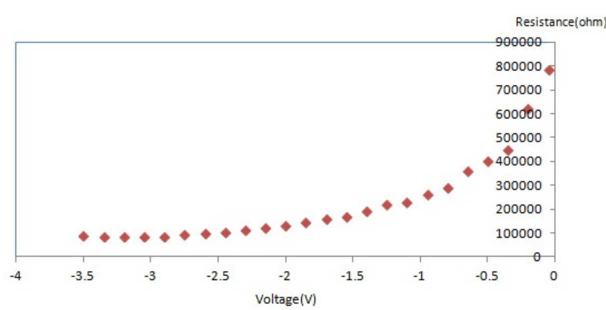


Figure 3 : Semi-logarithmic I-V characteristics of Au/n-ZnO/p-TIPS-pentacene/ITO/plastic Schottky barrier diode



(a)



(b)

Figure 4: Graph of (a) Forward junction resistance (b) Reverse biased junction resistance vs voltage graph of Au/n-ZnO/p-TIPS-pentacene/ITO/plastic Schottky diode

Rectifying junction for I-V relationship are defined by thermionic emission model as shown equation (1); as V is the bias voltage across the junction, q is the electronic charge, n is the ideality factor, k is Boltzmann's contant, I_o is the saturation current and T is absolute temperature in Kelvin.

Based on figure 3, by using equation (3) and (4); values of $\emptyset_b$, n and I_o were extracted from semi-logarithmic I-V graph as13.02eV, 11.60 and 6.38 x 10^{-8}A, respectively. Value of n shows higher than one due to the unevenness thickness between organic film metal layers [3,5].

Existence of interfacial oxide layer between TIPS-pentacene and ZnO are also one of the factors that cause the diode to be non-ideal, this is caused by over exposure to air on the device's surface[10]. Values of $\emptyset_b$ obtained have large number because it is influenced by the non-uniform junction and irregularity of the Schottky diode's barrier heights. Barrier heights are also has great impact with how much bias voltage supplied across the junction.

Series resistance R_s of junction diodes can be extract from lower region of forward biased resistance R versus voltage V graph as shown in figure 4(a), value of R_s is equal to $6.71\text{x}10^{-4}$ Ω. While shunt resistance R_{sh} can be obtained from highest value of reverse biased resistance R versus voltage V as shown in figure 4(b), with the value of R_{sh} to be $7.83\text{x}10^5$ Ω.

Cheung and Cheung characterization used equation (5), (6) and (7) to obtain its ideality factor, barrier height and series resistance based on figure 5 of dv/d(lnI) vs I graph. Obtained values for y intercept is the series resistance and were substituted into equation (5) to obtain the ideality factor. The value of series resistance and ideality factor based on Cheung and Cheungs characterization was 6.06 x $10^4\Omega$ and 12.02, respectively. Graph H(I) vs I as shown in figure 6 were plotted to find its barrier height, that values 13.01eV.

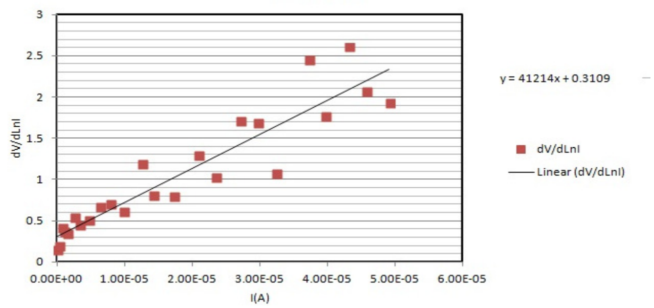


Figure 5: dV / dLnI graph

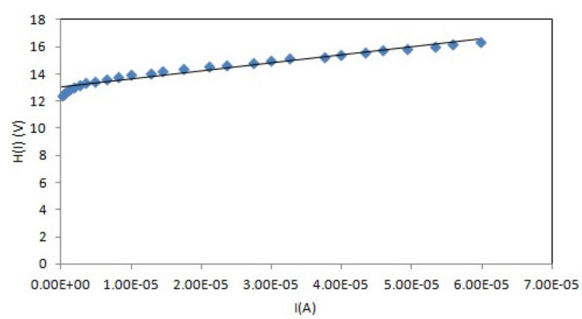


Figure 6: H(I) vs I graph

4.0 CONCLUSSION

The Au/n-ZnO/p-TIPS-pentacene/ITO/plastic Schottky diode has been fabricated and its electrical characteristics were calculated using conventional I-V characterization and Cheung

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and Cheung's function. The junction obtained shows a non-ohmic and rectifying character. Both calculation were compared between conventional I-Vcharacterization and Cheung-Cheung's method: as the ideality factor for conventional obtained were 11.6 while Cheung's method shows 12.02. Series resistance for conventional and Cheung's method were 6.71x10$^4\Omega$ and 6.06x10$^4\Omega$. For the barrier height calculated between conventional and Cheung method obtained were 13.02eV and 13.01eV.

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