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High Rectifying Organic Device Based P3HT Molecule

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Abstract. In this study, organic material P3HT has grown via the Spray Pyrolysis technique on p-Si and the Metal/ Semiconductor /Polymer hetero-junction. The electrical measurements of Al/p-Si/P3HT/Ag are realized in the dark and at room temperature. The well-known parameters of the MSP type SBDs such as barrier height (ΦB), ideality factor (n), series resistance (Rs), are obtained via Current-Voltage (I–V) plot based on Thermionic Emission (TE) theory. The conduction mechanism of the MSP hetero-junction exhibits two different behaviors with two distinct regions on the plot.

Keywords. P3HT; Ultrasonic Spray Pyrolysis; MSP hetero-junction Thermionic Emission; Conduction mechanism.

INTRODUCTION

The interest in studies related to organic-based electronic and photoelectrical devices has been enlarged during the last years due to low cost and easy preparation methods, the possibility of synthesis for different purposes, and at the same time because of their semiconducting properties that are similar to inorganic materials.

A conductive polymer, poly (3-hexylthiophene) or P3HT is one of the famous polymers and its structure is shown in figure 1.

Recently, it has been the subject of several experimental and theoretical studies (Yakuphanoglu and Farooq, 2011; Alahmed et al., 2013; Benhaliliba et al., 2017).
It consists of thiophene aromatic rings carrying a hexyl group. Due to its side chains, it dissolves easily in organic solvents. As a thin film, polymer chains tend to organize with each other (Benhaliliba et al., 2019).
Its HOMO and LUMO levels are located at -5.2 eV and -3.5 eV respectively (Zhang et al., 2016). However, P3HT has the disadvantage of degrading very quickly in the presence of oxygen, which induces poor stability for device design (Ershov et al., 1998).
The present study exhibits the electrical behavior of Al/p-Si/P3HT/Ag MSP hetero-junction beside the conduction mechanism of our device.

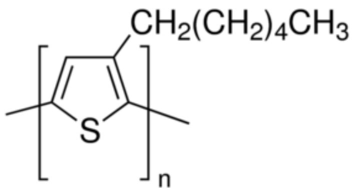

Fig. 1. The chemical structures of the P3HT organic semiconductor (Misiakos et al., 1997).

STRUCTURE OF THE MSP HETERO-JUNCTION

Bothe the organic material P3HT that is used and, the solvent chlorobenzene are purchased from Sigma Aldrich Company.
The silver used for electrodes, distilled water, toluene, and ethanol is provided by Kurt J. Lesker company.
The organic material is deposited onto a p-type silicon substrate of 406-457 µm with an orientation of (111) and a resistivity of 0.01-0.02Ω. cm.
Ultrasonic Spray pyrolysis technique is a low-cost and simple route for the production of high-quality thin layers intended for several optoelectronic applications.
Such a technique is a method of depositing a thin coating on a heated surface by spraying a solution over it, where the ingredients react to generate a chemical compound.
Those parameters are substrate temperature is between 97 and 55° C, and the deposition time is held for 19 min. The sample is then annealed temperature of 150°C on a hot plate inside the glove box for our samples.

ELECTRICAL CHARACTERIZATION OF MSP HETEROJUNCTION BASED ON P3HT

Thermionic Emission

The electrical parameters such as n, R_S, ϕ_B of the MSP hetero-junction were extracted by different methods at room temperature and in dark conditions.
The semi-log reverse and forward bias of the current-voltage experimental characteristics of the Al / p-Si / P3HT / Ag hetero-junction diode in the dark and at room temperature is shown in figure 2.
The current is expressed as a function of the theoretical thermionic emission. Throughout the experiment, the values of n, R_S, ϕ_B of the organic heterojunction diode are evaluated and determined by various techniques at room temperature and in dark conditions.

Figure 2 displays the profile of reverse and forward of the current-voltage characteristics in the semi-logarithmic scale of the Al / p-Si / P3HT / Ag heterojunction diode in the dark and at room temperature.

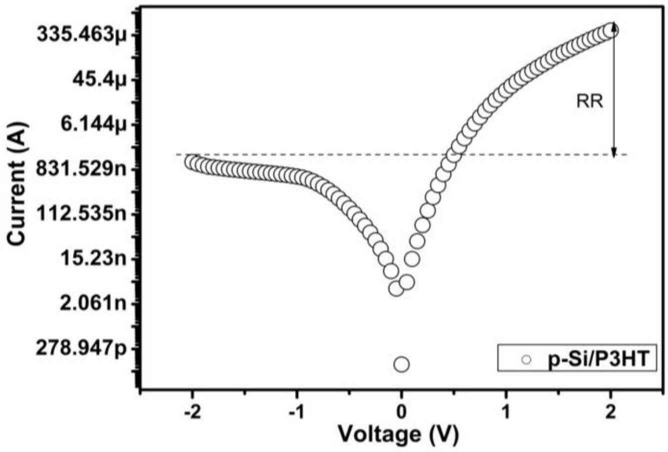

Fig. 2. Current-voltage characteristics of the Al/p-Si/P3HT/Ag organic MSP diode in dark, at room temperature condition, the rectifying ratio RR is displayed.

Based on the theoretical thermionic emission, the current against voltage is expressed as (Kavasoglu et al., 2010);

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

Where I and V are the measured currents and applied voltage of the diode and I_0 is the reverse saturation current given by (El Tayyan, 2015);

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

Where A is the effective diode area, A^* is the effective Richardson constant which equals 32 $A.cm^{-2}.K^{-2}$ for the p-type Silicon used for deposition, T is temperature expressed in Kelvin, q is the electron charge, n is the ideality factor, ϕ_B is the zero-bias barrier height. The plot presenting a linear segment is deducted from the previous equation and by injection in equation 1, the ϕ_B value is extracted.

The barrier height is expressed as (Karataş et al., 2013):

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

The n is the ideality factor which is greater than 1 for experimental electrical characteristics can be extracted using equation 8, as follows (Gupta and Yakuphanoglu, 2013) ;

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

Where k is the Boltzmann constant, T is the absolute temperature (300 K) and q is the electron charge. The parameter n is equal to unity in the ideal diode case. However, due to the density of the interface and the series resistance, n is usually higher than 1.

The great value of the ideality factor can also be assigned to different influences, such as the uneven thickness of the organic layer, the effect of the organic layer, etc. (Ahmad et al., 2020). The RR rectification ratio of organic MSP devices is calculated from figure 2 and is about 355.3. Series resistance is a significant parameter that marks the electrical characteristics of MSP hetero-junction. We use the functions which are developed by Cheung and Cheung defined as Eq.(5) as an efficient method to evaluate n, R_S andϕ_B (Gholami and Khakbaz, 2011);

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

$$\boldsymbol{H(I) = V - \left(\frac{nkT}{q}\right) ln\left(\frac{I}{AA^{*}T^{2}}\right)} \qquad (1)$$

And H(I) is written as follows ;

$$\boldsymbol{H(I) = IR_S + n\phi_B} \qquad (7)$$

The experimental plots of $dV/dLnI$ vs I and H(I) vs I for our organic hetero-junction are shown in figures 3 and 4. From equations 5, 6, and 7, different values of R_s and $n\phi_B$ are determined using intercepts of slops from the electrical plots. Correspondence the Cheung's approach is verified, R_s values are 6.11 $K\Omega$ and 4.96 $K\Omega$ and are in good agreement with an average value of 5.54 $K\Omega$.

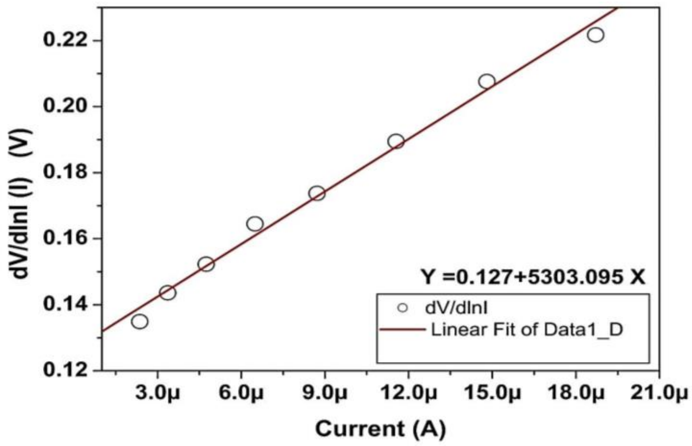

Fig. 3 The experimental dV/d(lnI) vs. I plot for Al/p-Si/P3HT/Ag organic MSP diode in dark, at room temperature condition.

The linear fit is displayed by a dashed line and its equation is written.

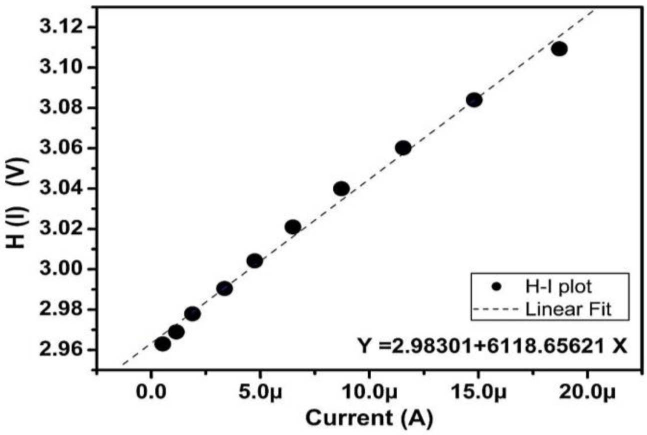

Fig. 4 The experimental H(I) vs. I plot for Al/p-Si/P3HT/Ag organic MSP diode in dark, at room temperature condition.

The linear fit is displayed by a dashed line and its equation is written.

Conduction mechanism

Due to the low mobility of carriers in organic semiconductors, the measured I-V characteristics usually deviate from Ohm's Law (i.e., the linear relationship between current and voltage). This is illustrated in figure 4. In this case, if an efficient charge injection from the metal electrode is achieved by choosing an appropriate metal, the IV characteristics will follow the equation of current limited by space charge, as indicated by the following formula:

$I\alpha\, V^{m+1}$ (8)

Where m is related to the distribution of trapping canters and varies within injection levels (Ershov et al., 1998). By measuring the I-V characteristics, the mobility and density of the traps can be determined.

Region 1 In the first region, the Ohmic regime is the most dominant mechanism at low voltage and the current is proportional to the voltage for our organic material P3HT (Sinha et al., 2020; Benhaliliba and Ayeshamariam, 2016).

Region 2 Further, for the second region for P3HT, the TSCLC process is mainly governed. The latter is characterized by the energy distribution of the trap levels in the forbidden band (Gunduzb et al., 2012; Yakuphanoglu et al., 2007). Consequently, the effects of Schottky and Poole-Frenkel are the dominant mechanisms translated by good injection properties (good connectivity between the Ag contact and the P3HT layer) (Kumar et al., 2020). Thus, SCLC measurement is a very useful technique reflecting the conduction mechanisms in organic semiconductors.

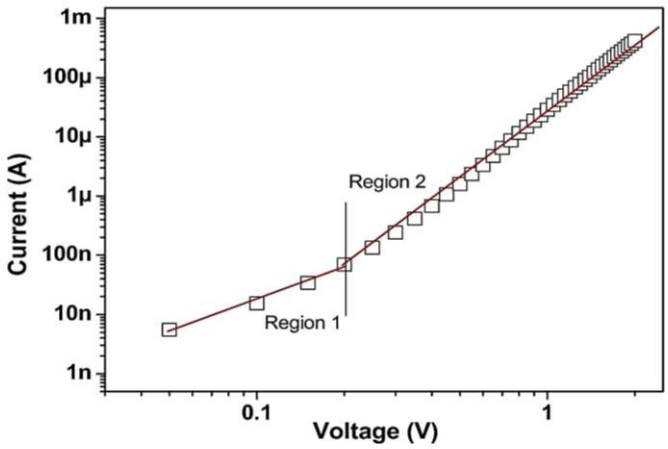

Fig. 5 . log vs. log obtained by plotting the forward bias I–V characteristics of Al/p-Si/P3HT/Ag MSP diode at room temperature.

The red solid line defines the different linear portions of the I–V curve and two regions are then indicated.

CONCLUSION

The electrical characteristics of MSP heterojunction organic devices have been investigated in detail in the dark and at room temperature. It is concluded that the ideality factor (*n*) increased and deviated from ideality with a value of barrier height (ϕ_B), 0.72 V, and average series resistance (R_S) of 4.69 KΩ with different Cheung's methods. Moreover, the Al/p-Si/P3HT/Ag conduction mechanisms are also investigated.

As a result, it is believed that the P3HT material and the resulting structural interface MSP type device may provide insight into future electrical qualities.

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