Modeling of conduction properties of Schottky diodes in Polymer

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This work has been supported by :

- le comité Franco-Marocain 'Action Intégrée', N° MA/03/78,
- le Programme Thématique d'Appui à la Recherche Scientifique (PROTARS III), N° D43/06.

This work deals with the modeling of experimental current-voltage (I-V) characteristics according to the temperature of P type Schottky diode in polymers. The results obtained show that conduction in the fabricated structures depends on temperature and bias the mode (forward or reverse).

Under reverse bias, current increases significantly with temperature. This is due to the thermoionic conduction, affected by the lowering of the potential barrier at the metal /polymer interface due to the image charge effect. The analysis of current-voltage characteristics has enabled us to derive the saturation current and, also, the potential barrier at the metal/polymer interface according to temperature. It has been shown that the value of this barrier without image charge effect, is in the order of 0. 3eV.

Under forward bias, current increases with temperature. It is of the thermoionic type at low voltage (-0.4 Volt<V< 0 Volt). It has been shown that the values of the ideality factor depend very little on temperature: varying from 1.5 to 4. However, saturation current increases with temperature: when temperature increases by approximately 6%, current increases by 20%. The values of saturation current for temperatures in excess of 200°K are confirmed by the values found in reverse bias. For temperatures less than 200°K, saturation currents in reverse mode are important relative to that obtained in forward mode. This is attributed to the electrical properties of polymer at low temperatures in reverse mode.

At high voltages (V<-0.4 Volt), the current is attributed to the resistance effect of polymer. This resistance is evidenced by the high current and drops with temperature. Its analysis has allowed us to derive the mobility of the carrier charges: when temperature varies from 105°K to 425°K, mobility varies from 3 10^{-5} (cm^2 V^{-1} S^{-1}) to 7 10^{-5} (cm^2 V^{-1} S^{-1}).

I. Introduction

Over the last forty years, the semiconductor industry has developed on such materials as silicon (Si) and gallium arsenic (GaAs). More recently, other organic materials like polymer have become increasingly popular [1-4]. In addition to insulators and the photo-resin, another organic material, conductor polymer, is not well-known. Many potential applications can be envisaged.

Despite the popularity of these new materials based on economic factors, they may be considered as alternatives to classic materials for other reasons. The main advantage is their low manufacturing costs and ease of production.

In addition to products such as diodes and organic transistors (respectively OLEDs and OTFTs), other applications are worth investigating [5-7] : flexible color screens rolled on plastic, photovoltaic cells, field effect transistors (FETs), lasers, chips in plastics , etc…

In the literature, numerous polymers have been fabricated and characterized [8-14](P3OT, PET,...). The results obtained and their interpretations depend on the polymer preparation considered and the authors concerned. With respect to the Al (or In)/polymer/Au (or ITO) structures, it appears that when polymer is of the P type, the Al (or In)/Polymer contact is of the Schottky type [15] and the Polymer /Au (or ITO) contact of the ohmic type [15]. In forward bias, current is attributed to thermoionic conduction when the applied voltage |V| is less than 0.8 V [15]. The value the ideality factor is greater than that in the case of inorganic Schottky diode (Silicon). It varies from 1.4 to 7 [8,10,16,17] and does not depend on temperature [10]. When the applied voltage |V| is greater than 0.8 V, the current obtained is not governed by the thermoionic conduction. In this case, a few models have been proposed. In particular, in [10,18] conduction limited by space charge has been proposed. Under reverse regime, one observes a major current depending mainly on the applied voltage. The classic thermoionic conduction cannot model this current. In [18], this current has been modeled in terms of excess current assisted by traps in polymer. In other works [10], it is attributed to generation-recombination in the silicon forming the contact NiPc/Si(P).

With respect to polymer ageing, it has been shown that the injection of carriers creates charges in the polymer [19].

Electrical properties of polymer have been found to be similar to those of inorganic devices: conduction, ageing under carrier injection. As to current modeling, one observes the absence of a fine model, particularly in reverse mode. This enables us to propose an energy band diagram of the metal/polymer interface. Our work is focused on fabricating Al/P3OT/ITO structures and arriving at a fine modeling of current-voltage characteristics in forward and reverse modes. We consider the Poly (3-octylthiiophene) regioregular (P3OT) as a polymer layer. Based on the results obtained and those in the case of inorganic structures [20-23], we propose a conduction model for the fabricated structures, as well as their energy band diagram. Therefore, this study will allow us to better understand the mechanism of polymer conduction to improve the technological process of the new devices in polymer.

II. Experimental procedures

On a glass substrate coated with transparent conducting indium-Tin Oxide ITO (Fig. 1) a 1500 nm thick layer of P3OT using a solution of P3OT+ chloroforms (20g/l) is deposited by spin-coating. The polymer used is synthesized using Richard D. McCullough's method. It features a regioregular structure which noticeably improves its electrical performance compared to a regiorandom P3OT [28]. A layer (D_{poly}) of 200 nm thick Aluminum is deposited on P3OT by vacuum evaporation. The active surface (S) of the organic Schottky structure is in the order of 0.785 cm^2.

We verified that the ITO/polymer contact is ohmic when the schottky diode is biased in forward and reverse modes. Also, based on capacitance-voltage measurements, we were able to see that the deposited polymer is of the P type, with a doping level 10^{16} cm^{-3}.

Electrical measurements were carried out using current-voltage according to temperature with 'BIORAD 8000'. We biased the structures in a voltage ramp from -2 V to 2.5 V by fixing a 0.15 V measurement step. The 'COM' is connected to the metal of higher work (ITO). Current-voltage characteristics are obtained for several temperatures varying from 105°K to 425°K.

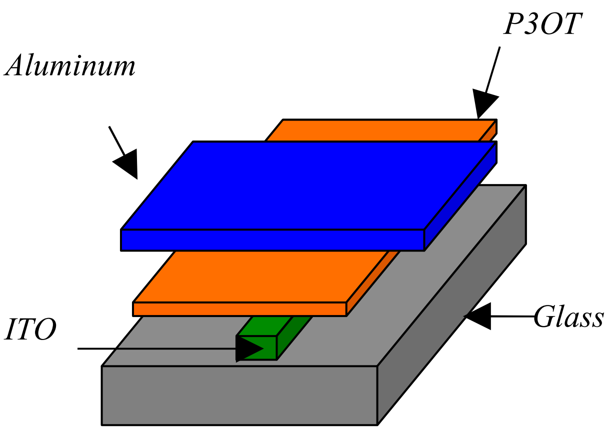

Figure 1: *Structure of Schottky diode in polymer.*

III. Results & discussions

III.1. Experimental current-tension characteristics

III.1.1. Electrical stability of Schottky diode in polymer

Fig. 2, shows several passages of current-voltage characteristics at room temperature (300°K) from the forward (V<0) to reverse (V>0) regime, and from reverse to forward regime. We can derive electrical stability of the Schottky diode without hysterisis: the characteristics obtained follow the same curve. We checked this stable behavior by varying temperature from 105 °K to 425 °K.

Also, Fig. 2 shows that the trapped charges are practically negligible during the current-voltage acquisition.

Therefore, these results demonstrate that the properties of the structure conduction are not degraded by the current-voltage characteristics.

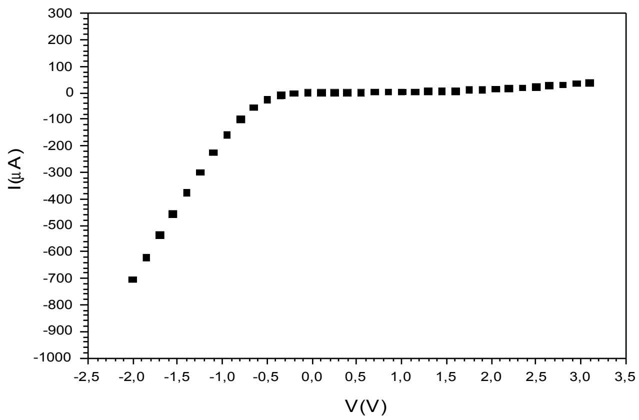

Figure 2 : *Several crossings, at room temperature (T = 300 °K), of current-voltage characteristics of Schottky diodes in polymer.*

III.1.2. Temperature Influence on the current-voltage characteristics

In Fig. 3, we have plotted the current-voltage characteristics of Schottky diodes according to temperature. Behavior is found to depend on temperature and bias. From these characteristics, we have plotted in Fig. 4 the temperature influence on the current that crosses the Schottky diode in forward and in reverse regimes for several voltages (V). It appears that in forward regime, the influence of temperature is significant for the low voltage: current increases one decade when

the temperature increases by 100°K. In reverse, the current is very sensitive to temperature: current increases linearly with temperature. When temperature increases by 100°K, the current can reach a decade. These results show that the dependence of current on temperature remains the same in forward (for low voltage (-0.4 Volt <V<0)) and reverse regimes. This allows us to conclude that the physical mechanism for the current remains the same in forward and reverse regimes.

In Fig. 5, the rectifier factor (relationship between forward and reverse current) has been plotted according to temperature and voltage (V). It appears that:

- the influence of temperature on the rectifier factor is more important at higher voltages;
- for a given temperature, the rectifier factor increases with voltage;
- at high voltage, this factor is hardly dependent on voltage and decreases with temperature. At room temperature, it is in the order of 150. At 100 °K, this factor is in the order of 2 10^3 and can reach 10 at temperature of 425 °K;
- at low temperature (|V| =0.2V) this factor is in the order of 3 at room temperature. From 105°K to 425°K, it varies from 40 to 12.

The degradation of the rectifier factor with temperature is attributed to the significant increase in reverse current with temperature (Fig. 3).

Each current-voltage characteristic will now be modeled according to temperature.

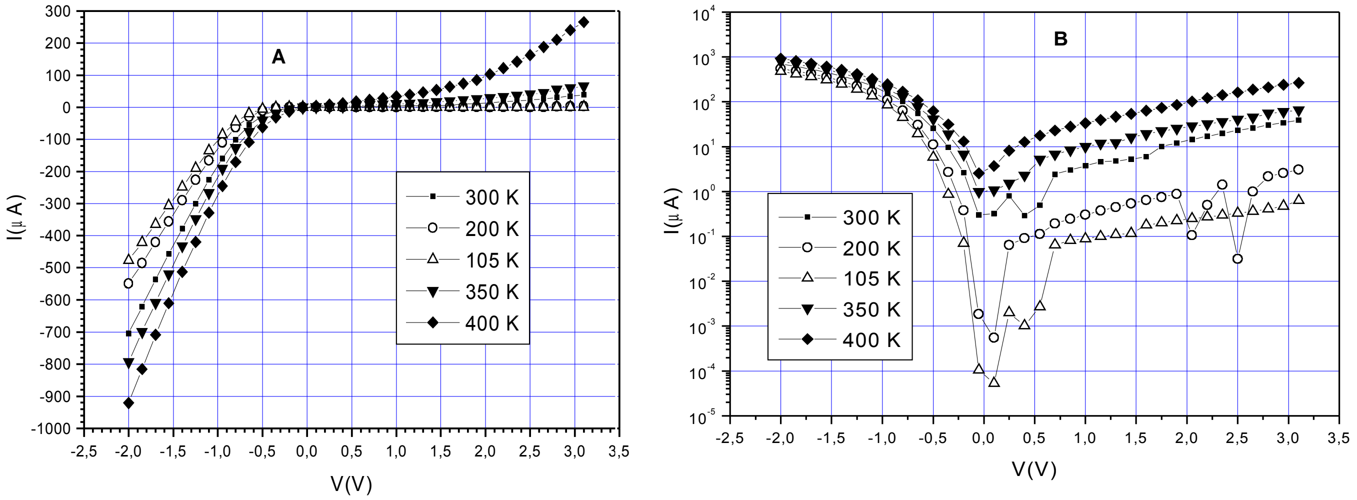

Figure 3 : *Current-voltage characteristics of Schottky diode in polymer as a function of temperature :*
A) Current (I) with respect to voltage (V),
B) Log(I) with respect to voltage (V).

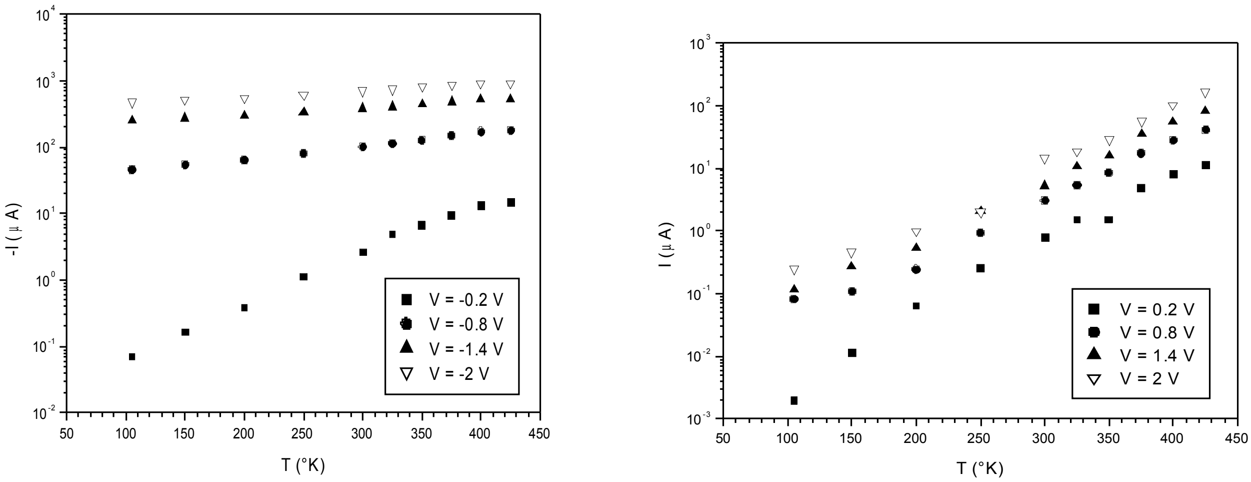

Figure 4 : *Influence of temperature on the current in forward (V<0) and reverse (V>0) regimes for different voltages.*

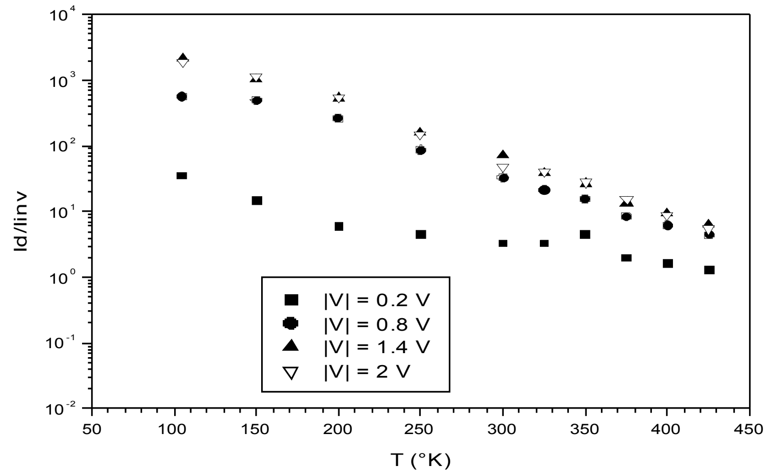

Figure 5 : *Influence of temperature on the rectifier factor (Relationship between the current in forward and reverse regimes) for different voltage .*

III.2. Current-voltage characteristics in forward regime

In the literature [24-26], most authors analyze the current at low voltage (0<-V<1Volt). Based on Log(I) plot according to voltage (V), they derive a linear behavior showing that the current of the Schottky diode in Polymer is of the thermoionic type. In our case, as shown in Fig. 3, the linear behavior appears only at the start of conduction (-0.4 Volt <V<0 Volt). In the voltage range (-2 Volt<V<-0.4 Volt), the current does not vary linearly with voltage.

III.2.1. Modeling of the linear part (-0.4 Volt< V< 0 Volt)

At low voltages (-0.4 Volt<V<0), the linear behavior of Log(I) according to voltage V (Fig. 3 - B) could be modeled by the following thermoionic model [15] :

$$I_{Ther} = - I_s \exp\left(- \frac{V}{\eta U_T} - 1\right) \qquad \text{-8-}$$

where ;

I_s : saturation current which is a function of the temperature.

U_T : thermodynamic voltage. It is given, for an inorganic Schottky diode, by the following relation:

$$U_T = \frac{q}{K_B T} ,$$

where,

K_B : Boltzmann constant,

q : electron charge ,

η : ideality factor.

It should be pointed out that within in the framework of our experiment, we set a high measurement step in order not to degrade the Schottky diode, particularly the polymer layer. At low voltages (-0.4 Volt<V<0) some measurement points appear in the beginning of the current-voltage characteristics. To ascertain that, in this voltage range, the Log(I) plot according to voltage V is practically linear by decreasing the measurement step.

From the Log (I/S) plot according to the voltage (V), we derived the value of the ideality factor (η) from the slope and saturation current (or current density $J_S=I_S/S$) from the intercept of the linear curves with the Log (I/S) axis. The values obtained show that the ideality factor depends very little on temperature: it varies from 1.5 to 4. Also, as shown in Fig. 6, the saturation current density varies with temperature (in °K) in accordance with the expression :

$$J_s = \beta \cdot T^{\alpha} \qquad \text{-9-}$$

where,

β : pre-factor (of the order of $6.33\ 10^{-24}$ SI),

α : factor (of the order of 7).

In Fig. 7, the typical plots of experimental and simulated current-voltage characteristic (following the thermoionic model) are given. Therefore, at the beginning of conduction of Schottky diodes in polymer, current density is governed by the following relation:

$$J_{Ther} = - J_S(T) \cdot \exp\left(- \frac{V}{\eta(T) \cdot U_T} - 1\right) \qquad \text{-10-}$$

also : $$J_{Ther} = - \beta \cdot T^{\alpha} \cdot \exp\left(- \frac{V}{\eta(T) \cdot U_T} - 1\right) \qquad \text{-11-}$$

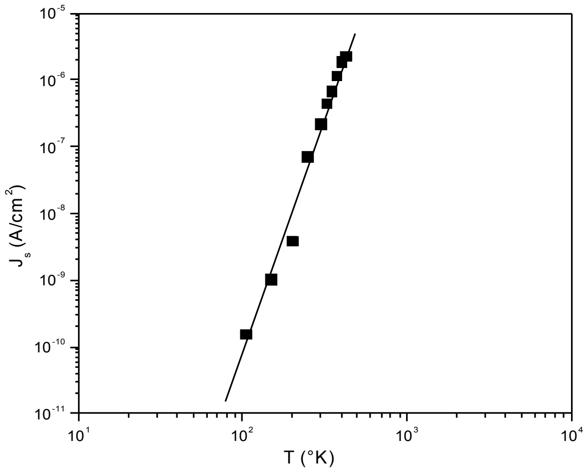

***Figure 6 :** Saturation current densities of Schottky diode in polymer as function of temperature.*

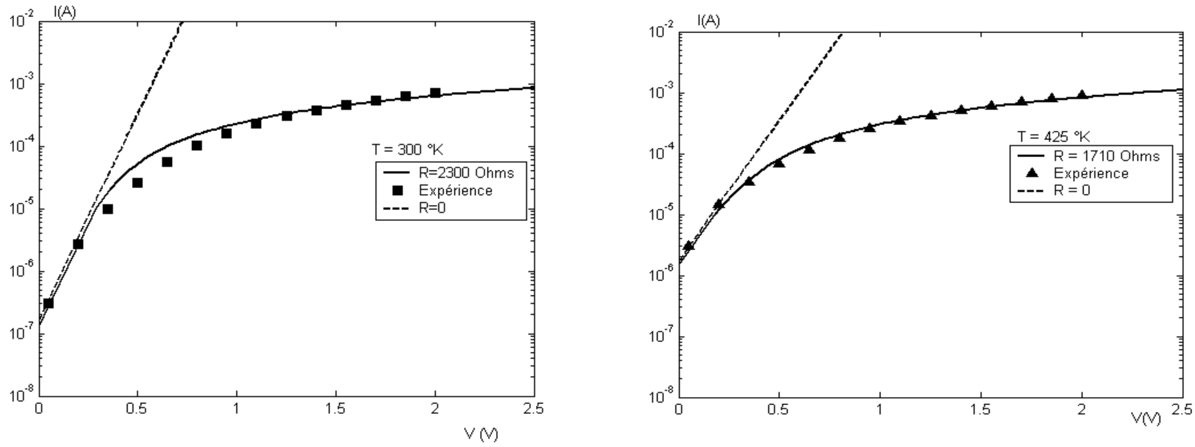

***Figure** 7 : Typical experimental and simulated (--- : equation 8 (without out resistance R), — : equation 12 (with resistance R)) current-voltage characteristics for two temperatures.*

III.2.2. Modeling of the no linear part (-2 Volt<V< -0.4 Volt)

III.2.2.1. Polymer resistance

The nonlinear part of current-voltage characteristics (Fig. 3 - B) can be observed when the applied voltage varies from -0.4 V to -2V. This behavior cannot be attributed to the thermoionic conduction mechanism. It is observed at a higher voltage similar to that observed for the inorganic Schottky diode where we take account of the semiconductor's series resistance [15]. The Schottky diode could be equivalent to an ideal diode (without resistance) connected in series with a resistance (R). Our current-voltage characteristics can be modeled by this behavior, since we use relatively thick polymers (in the order of 1500 nm). We have modeled the current-voltage characteristics following the thermoionic model by taking into account this resistance (R) :

$$I = -I_s \exp\left(-\frac{V + R \cdot I}{\eta U_T} - 1\right) \qquad \text{-12-}$$

where :

η, I_S : ideality factor and saturation current previously determined according to temperature (paragraph III.2.1)

The typical results obtained are given in Fig. 7. Thus, a very good agreement can be engineered between the experiments and the simulated current-voltage characteristics

(Eq. 12). Therefore, the currents obtained at higher voltages are attributed to the series resistance of polymer. At a low voltage, the influence of this resistance becomes negligible because the current that crosses the structure is very low.

In table 1, the resistance values R that allow modeling of the current-voltage characteristics according the temperature are listed. It can be concluded that the current decreases with temperature. We verified that these values are identical to those obtained by computing the slopes of current-voltage characteristics at higher voltages (-0.4 Volt <V< -2 Volt) (Fig. 3 -B).

It should be pointed out that the current obtained at a higher voltage can also be modeled qualitatively using Fowler-Nordheim (FN) model [22,23,27] :

$$I = S \cdot K_1 \cdot E^2 \exp\left(\frac{-K_2}{E}\right)$$

where,

K_1 et K_2 : conduction parameters,

E : electrical field in the polymer. It is expressed according to the voltage and the polymer thickness by :

$$E = \frac{V}{D_{poly}}$$

The typical FN plot ($Log\left(\frac{I}{S \cdot E^2}\right)$ as a function of ($\frac{1}{E}$) yields a linear behavior (Fig. 8) followed by a current saturation at a high voltage. Linear curves show that the current can
by modeled by the FN model. Saturation can be attributed to the resistance series of the polymer or as in the case of the inorganic MOS diodes [20], to the current limitation by the bulk of the semiconductor (polymer).

From Fig. 8, the factors K_1 and K_2 has been derived. The values obtained show that K_1 hardly depends on temperature. It is of the order
of 10^{-12} A/V^2. K_2 decreases with temperature particularly at high temperatures: when temperature varies from 105°K to 425 °K, it varies from 3 10^4 (V/cm) to 6 10^2 (V/cm).

In our case, the effect of series resistance is preeminent relative to other mechanisms likely to affect the conduction of the Schottky diode in Polymer. To validate this hypothesis, future studies will be devoted to the effect of polymer resistance, by greatly reducing polymer thickness, and by investigating FN conduction at high voltages.

III.2.2.2. Charge carrier mobility

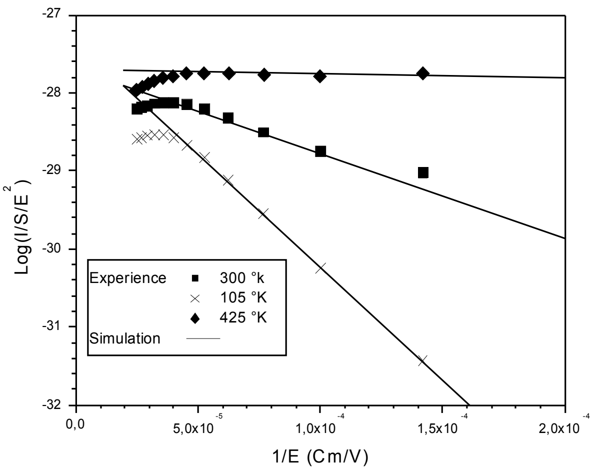

Figure 8 *: Typical experimental and simulated FN current-voltage characteristics for different temperatures.*

By using the conventional equation of resistance (R) according to mobility of the charge carriers (μ_p) and doped polymer ($N_A = 10^{16}$ cm^{-3}), mobility values versus temperature can be expressed as follows:

$$\mu_p = \frac{D_{poly}}{q \cdot N_A \cdot R \cdot S}$$

The values obtained, according to temperature, are given in Table 1. Low values are listed relative to those found in the case of the inorganic Schottky structures [15]. However, they are in good agreement with those reported in the literature. Also, the mobility of charge carriers tends to increase with temperature, showing that the positive charge mobility in polymers might have been activated thermally.

III.2.3. Energy band diagram

For Schottky diode in polymers, current due to free carriers cannot occur (absence of free carriers) [15]. According to the results reported in the literature and in this work, conduction mechanisms in the polymer Schottky diode are attributed to the thermoionic current. This current is controlled by the potential barrier in the depletion zone situated in the polymer layer at the metal/polymer interface. Using the experimental results obtained, it is possible to postulate when the organic diodes are forward -biased:

- in polymers, charge carriers are the polarons with energies in the band gap [8]. Polarons move in the polymer through a hopping process [15]. At the metal/polymer interface, the polymer being of the P type, a positive charge moves from the metal (polymer) to polymer (metal) by thermoionic effect (Fig. 9).
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▪the energy band diagram of the structure can be similar to that of the inorganic Schottky diode : charges in the depletion zone at the polymer interface followed by a quasi neutral region (Fig. 9). The potential barrier in this depletion zone depends primarily on the applied voltage (or electrical field). For a given voltage, the electrical field at the depletion zone ($\vec{E}_{dep}$) is significant compared to that fixed by the bias ($\vec{E}_{pol}$);

●the resulting current is of the thermoionic type for low voltages and effected by the series resistance of the polymer at high voltage;

●the thermoionic current density J_{TMPOLY} (J_{TPOLYM}) is due to crossing of the positive charge from the metal (polymer) to the polymer (metal) under the potential barrier at the metal/polymer interface by thermoionic effect (Fig. 9).

T (°K)	R (Ω)	$\mu_p N_A$ ($cm^{-1}V^{-1}S^{-1}$)	μ_p ($cm^2V^{-1}S^{-1}$)
105	3650	$3.26\ 10^{11}$	$3.26\ 10^{-5}$
150	2400	$4.95\ 10^{11}$	$4.95\ 10^{-5}$
200	2350	5.0610^{11}	$5.06\ 10^{-5}$
300	2300	$5.19\ 10^{11}$	$5.15\ 10^{-5}$
400	1800	$6.61\ 10^{11}$	$6.61\ 10^{-5}$
425	1710	$6.98\ 10^{11}$	$6.98\ 10^{-5}$

Table 1*: Influence of temperature on the resistance (R) of polymer, and on the mobility (μ_p) of charge carriers.*

At low voltages, as the potential barrier in the depletion zone decreases when the applied voltage increases, the current density J_{TPOLYM} is preeminent relative to that of J_{TMPOLY}. Consequently, the global current density is attributed to positive charges crossing from the polymer to the metal by thermoionic effect (Fig. 9).

At high voltages, current increases so that the voltage over the series resistance becomes considerable. At room temperature, when the applied voltage is equal to -2 V, the current is about 7 10^{-4} A and the voltage applied over the ideal diode (resp resistance) is therefore of the order of 0,39V (resp 1.61 V). In our study, it assumed that the voltage applied over the ideal diode induces the energy band diagram shown in Fig. 9.

Under negative voltage, the potential barrier in the depletion zone is greatly diminished. At the metal /polymer interface, band curvatures in opposite to that of Fig. 9. This may cause tunnel conduction (Fowler-Nordhiem) in the polymer. To better understand this, new devices are being investigated.

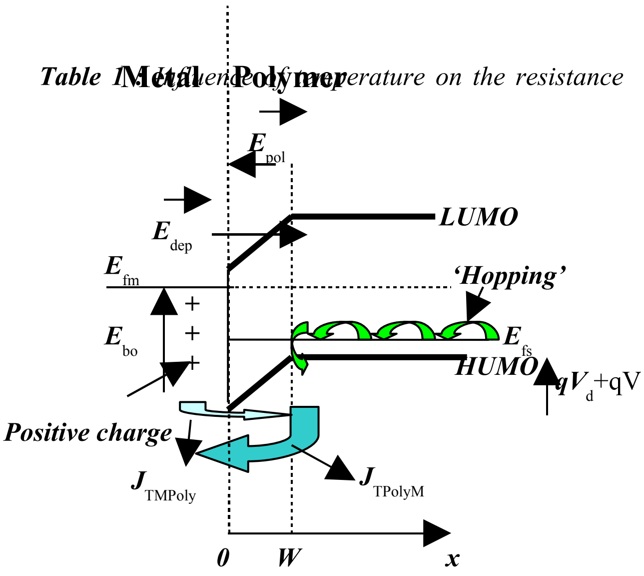

Figure 9 : Energy band diagram of Schottky diode in polymer polarized in forward (V<0).

x : abscissa in the polymer, E_{bo} : potential barrier metal/polymer interface, V_d : diffusion potential, LUMO (HUMO) : bottom (top) conduction (valence) band,E_{fm} : Fermi metal level, E_{fS} : polymer Fermi level, W : depletion extension, J_{TPolyM} : Thermoionic current density resulting from passage of positive charge from polymer to metal, J_{TMPoly} : Thermoionic current density resulting from passage positive charge from metal to polymer, $\vec{E}_{dep}$ ($\vec{E}_{pol}$) : electrical field set by depleted zone (polarization)

III.3. Current-voltage characteristics in reverse regime

III.3.1. Modeling of current – voltage characteristics

Under reverse regime, the current measured cannot be modeled by the classical thermoinic model (relation 9) [19]:

$$Inv = I_s = S \cdot \beta \cdot T^{\alpha} \qquad \text{-16-}$$

also,

$$I_S = S \cdot A \cdot T^2 \exp\left(- \frac{E_{b0}}{KT} \right) \qquad \text{-17-}$$

where,

β et α : parameters determined in forward regime (parag III.2.1),

E_{bo} : potential barrier at metal/Polymer interface (Fig. 9),

A : Richardson constant.

By using this model (Eqs 16 and 17), the theoretical reverse currents vary from 10^{-11}A to 10^{-6} A when temperature varies from 105°K to 425°K. Experimentally, when temperature varies from 105°K to 425°K, the current varies from 10^{-5}A to 10^{-4}A. By comparing these currents, it can be seen that experimental currents are very important compared to the theoretical one: when temperature varies from 105°K to 425°K, the ratio varies from 10^6 to 10^2. Therefore, the behavior of the current-voltage characteristic in reverse regime cannot be modeled by the thermoionic model (Eqs 9, 16 and 17).

Also, by comparing the values of the currents obtained in reverse regime to those obtained in forward regime, it can be seen that the series resistance fails to affect currents in the reverse regime. This has been checked this by the Log(I) plot according to the voltage V; a linear behavior can be found on all current-voltage characteristics.

To account for the physical mechanism of experimental current in inverse regime, we have plotted Log(I/S) according to $\sqrt{V}$ (Fig. 10). A linear behavior can be found on practically all characteristics. This enables us to model the current obtained in reverse regime by taking into account a lower barrier, in the depletion zone, by the image charge effect [15] :

$$Inv = S \cdot A \cdot T^2 \exp\left(- \frac{E_{b0} - B' \sqrt{V}}{KT} \right) \qquad \text{-18-}$$

also,

$$Inv = I_S \exp\left(\frac{B' \sqrt{V}}{KT} \right) \qquad \text{-19-}$$

with,

B' : pre-factor. For inorganic Schottky diodes, it is given by :

$$B' = \sqrt{\frac{q}{16\pi\varepsilon_o\varepsilon_r} \cdot \frac{1}{D_{poly}}} \qquad \text{-20}$$

$$I_S = S \cdot A \cdot T^2 \exp\left(- \frac{E_{b0}}{KT} \right)$$

The slope of this curve (Log(I/S) according to $\sqrt{V}$) allows us to derive the B' constant, and the intercept of the linear curves with Log (I/S) axis allows us to derive the saturation current I_S. The results obtained are listed in table 2. Thus, under reverse bias, the saturation current increases with temperature. In paragraph III.4, these results are reviewed.

It is worth noting that the image charges effect has not effect on the forward current. For a given voltage, the electrical field in the depletion zone decreases and the lowering of the potential barrier is practically negligible.

Therefore, in reverse regime the current obtained can be modeled by taking into account a lower potential barrier in the depletion zone by the image charge effect. In the next section, we determine the Richardson constant (A) and the potential barrier at the metal/polymer interface (E_{bo})

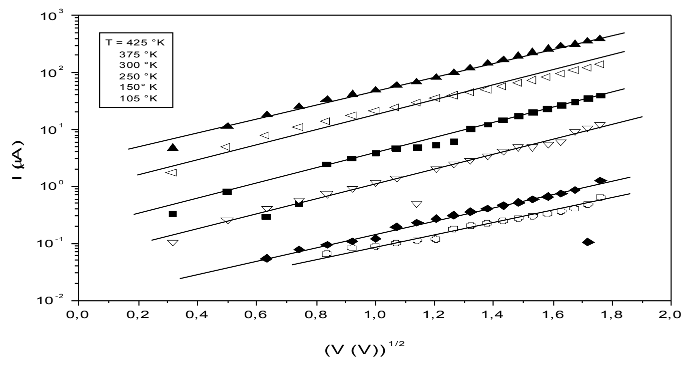

Figure 10 : *Typical experimental and simulated (——) values, following thermoionic model taking into account the charge image effect, current-voltage characteristics at several temperatures .*

T (°K)	B'/KT (SI)	Log(I_S)	I_S (A)	J_S (A/cm^{-2})
105	2.23	-18.344	1.079 10^{-8}	1.375 10^{-8}
150	2.606	-18.297	1.131 10^{-8}	1.441 10^{-8}
250	2.826	-16.485	6.928 10^{-8}	8.826 10^{-8}
300	3.10	-15.592	1.69 10^{-7}	2.154 10^{-7}
375	2.937	-13.909	9.104 10^{-7}	1.159 10^{-7}
425	3.104	-13.187	1.874 10^{-6}	2.388 10^{-6}

Table 2 : *Influence of temperature on saturation current (or saturation current density) and on constant B' due the charge image effect.*

III.3.2. Energy band diagram

The results of the preceding paragraph show that in reverse regime, the energy band diagram could have been represented by that of the Fig. 11. For a given voltage, the potential barrier increases in the polymer: the electric field $\vec{E}_{dep}$ due to the depletion zone is added to that $\vec{E}_{pol}$ fixed by the applied voltage. According to the results obtained in the case of inorganic Schottky diode, the extension of the depletion zone (W) increases with respect the applied voltage [20]. Since the electrical field in the depletion zone is important, a lower potential barrier due to the image charge effect in the polymer could become significant [20,23]. In our case, these degradations can involve a considerable increase of the reverse current: when the voltage increases, the potential barrier at the metal/polymer interface decreases and favors the increase of the thermoionic current J_{TMPOLY} (Fig. 11) according to Eqs. 18 to 20. These results, show that the current due to positive charges crossing from the polymer to the metal is weak. This is due to the higher potential barrier in the polymer (Fig. 11) under the reverse bias.

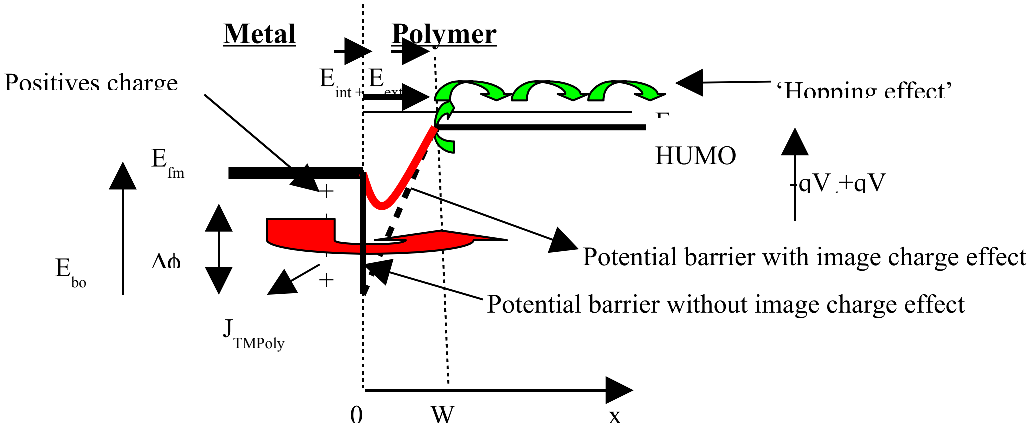

Figure 11 : *Energy band diagram of Schottky diode in polymer biased in reverse regime (V>0).*

x : abscissa in polymer,
E_{bo} : Potential barrier metal/polymer interface,
$\Delta\phi$: Potential barrier lowering by image charge effect,
W : Depletion zone extension,
V_d : Diffusion potential, LUMO (HUMO) : bottom (top) conduction (valence) band,
E_{fm} : metal Fermi level, E_{fS} : polymer Fermi level,
J_{TMPoly} : Thermoionic current density due to passage of positive charge from the metal to the polymer,

III.3.3. Determination of Richardson constant A

In paragraph III.4.1, it has been shown that the expression of the current in the reverse regime can also be written as:

$$Log\left(\frac{Inv}{T^2}\right) = Log(S \cdot A) - \left(E_{b0} - B'\sqrt{V}\right) \cdot \frac{1}{KT}$$

This shows that the plot of $Log\left(\frac{Inv}{T^2}\right)$ according to $\frac{1}{KT}$, for a given voltage, yields a linear behavior that allows us to derive the Richardson constant (A) from the intercept of

the linear curves with the $Log\left(\frac{Inv}{T^2}\right)$ axis. We can also derive the potential barrier $\left(E_{b0} - B'\sqrt{V}\right)$ at the metal/polymer interface from the slope of the same plot. The obtained Fig. 12 shows this behavior for several voltages at a temperature in excess of 250°K. The values of constant A and the potential barrier $\left(E_{b0} - B'\sqrt{V}\right)$ are listed in table 3. It appears that constant A hardly depends on voltages (5-9 10^{-8} A cm^2 K^{-2}) and is in good agreement with values found in the literature in the forward mode [8]. The potential barrier decreases with voltage: when the voltage increases by 45 % around the 1V, the barrier decreases by 5 %.

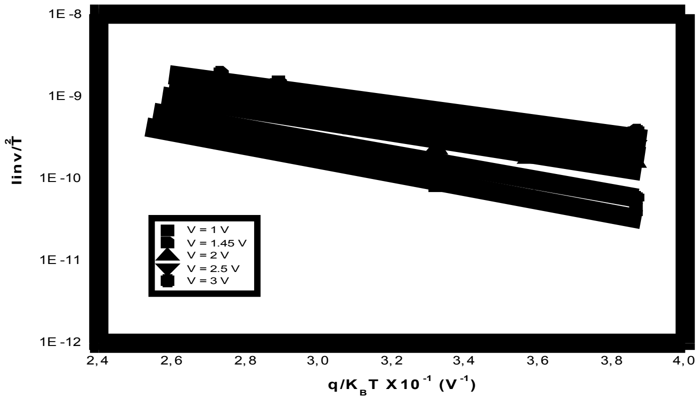

Figure 12 : *Typical trace of* $Log\left(\frac{Inv}{T^2}\right)$ *with respect to* $\frac{1}{KT}$ *for several voltages.*

V (V)	Pente = $\left(E_{b0} - B'\sqrt{V}\right)$ (V)	Log(A*S)	A (A cm^2 K^{-2})
1	0.193	-16.683	7.24 10^{-8}
1.45	0.1832	-16.469	8.90 10^{-8}
2	0.1472	-17.032	5.10 10^{-8}
2.5	0.1401	-16.883	5.92 10^{-8}
3	0.1308	-16.799	6.44 10^{-8}

Table 3 : *Richardson constant (A) and potential barrier* $\left(E_{b0} - B'\sqrt{V}\right)$ *(at metal/polymer interface taking into account the image charge effect) for several voltages from the eq. 21.*

III.3.4. Determination of potential barrier E_{bo}

The experimental plot of the slope $\left(E_{b0} - B'\sqrt{V}\right)$ (table 3) as a function of $\sqrt{V}$ yields a linear behavior (Fig. 13). Therefore, the value of the potential barrier (E_{bo}), which is not affected by the image charge effect, can be derived from the intercept of the linear curves with the $\left(E_{b0} - B'\sqrt{V}\right)$ axis. The results obtained (table 4) show that it is in the order of 0.3 eV. In the literature, values greater than 0.3 V have been reported. This could be attributed to the deposited polymer or to the method used to determine this barrier (E_{bo}). Generally, one determines it (E_{bo}) in forward regime for a narrow voltage range (-V<0.3V). In reverse, relationships are simple and used over a large voltage range.

Also, the slope of the characteristic plotted in Fig. 13 allows us to derive constant B' and consequently, the lowering of barrier ($B'\sqrt{V}$) by the image charge effect according to the voltage. The results obtained are given on the same table 4. It increases with the applied voltage: when the voltage increases by 45 % around 1 V, the barrier lowering increases by 20.5 %. This variation can cause a major current increase in reverse regime.

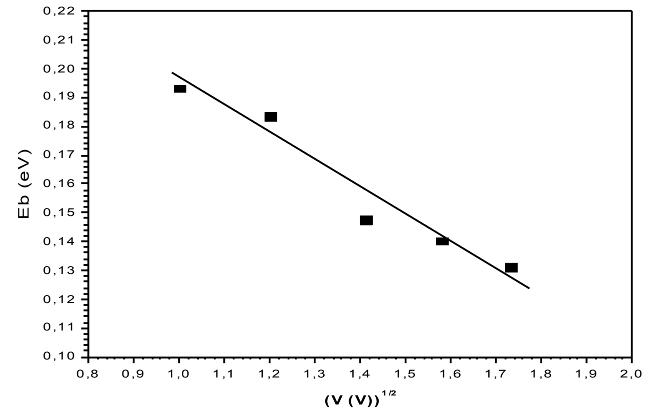

***Figure 13** : Typical value of $\left(E_{b0} - B'\sqrt{V}\right)$ as a function of $\sqrt{V}$.*

V (V)	B'	E_{bo} (V)	$B'\sqrt{V}$ (V)
1	9.71 10^{-2}	0.2944	0.0971
1.45			0.1169
2			0.1372
2.5			0.1535
3			0.1681

***Table 4 :** Potential barrier (E_{bo}) at metal/polymer interface without image charge effect, potential barrier lowering ($B'\sqrt{V}$) by image charge effect according to voltage.*

III.4. Validation of results

To validate the results obtained in forward and reverse regimes, the values of saturation current densities under forward ($J_S\left(Forward\right)$) (Fig. 6) and reverse ($J_S\left(reverse\right)$) (Table 2) regimes have been listed in table 5 along with the ($\frac{J_S\left(Forward\right)}{J_S\left(reverse\right)}$) ratio versus temperatures. A good agreement is found between both bias regimes when temperature is greater than 250°K. When it is less than 250°K, the values under reverse regime are as important as those obtained in forward regime. This is due to the electrical properties of polymer at low temperatures in reverse. To get a better understanding of this phenomenon, studies are underway.

Thus, in reverse regime the current measurement is governed by the thermoionic model affected by a lower of the potential barrier by the image charge effect. This favors the positive charge crossing from metal to polymer (Fig.11).

T (°K)	$J_S\left(reverse\right)$ (A)	$J_S\left(forward\right)$ (A)	$\frac{J_S\left(forward\right)}{J_S\left(reverse\right)}$
105	1.375 10^{-8}	1.52 10^{-10}	1.11 10^{-2}
150	1.441 10^{-8}	1.01 10^{-9}	7.0 10^{-2}
250	8.826 10^{-8}	7.086 10^{-8}	0.802
300	2.154 10^{-7}	2.15 10^{-7}	0.998
375	1.159 10^{-7}	1.14 10^{-6}	0.983
425	2.388 10^{-6}	2.24 10^{-6}	0.938

***Table 5 :** Saturation current obtained in forward and reverse regimes, as well as their relationship according to temperature.*

IV. Conclusion

In this work, on the modeling of current-voltage characteristics of Schottky diodes in polymer (P3OT), it has been shown that current depends on bias and temperature. Based on the results obtained and those of an inorganic Schootky diode, it can be stated that:

●in forward regime, the measurement current is due to the thermoionic current at a low voltage

(-0.4Volt<V<0 Volt). We have derived the ideality factor in the order of 1.5 - 4, which hardly depends on temperature.

●At high voltage (V<-0.4 Volt), current is attributed to the series resistance of polymer. It has been shown that this resistance decreases with temperature thus, allowing the value of the mobility of charge carriers in polymers to be obtained according to temperature.

●In reverse regime, the measurement current is due to the thermoionic current effect affected by the lowering of the potential barrier by the image charge effect. From the modeling of the characteristics, we have shown that:

-the potential barrier at the metal/polymer interface, without of the image charge effect, is in the order of 0.3 eV.

-saturation currents in reverse regime are almost identical to those obtained in forward regime when temperature is greater than 250°K. This makes it possible to validate the results obtained in this work for temperatures in excess of 250 °K. However, for temperatures less than 250 °K, saturation currents in reverse regime are important compared to these obtained in forward regime.

These results show the feasibility of the polymer Schottky diodes and support a better understanding of their conduction mechanisms and properties.

VI. Bibliography

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