

# The dependence of electrical properties of Al/NphAOEMA/PEDOT-PSS/ITO structures on temperature

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The capacitance-voltage-temperature (*C-V-T*) and conductance-voltage-temperature (*G/w-V-T*) characteristics of the Al/NphAOEMA/PEDOT-PSS/ITO heterojunction structures have been investigated by taking into account the effect of the series resistance ( $R_s$ ) and interface states ( $N_{ss}$ ) in the temperature range of 120-400 K. The values of  $R_s$  and  $N_{ss}$  were calculated by using Nicollian and Goetzberger and Hill-Coleman methods, respectively, and both the values of  $R_s$  and  $N_{ss}$  decrease with increasing temperature. Experimental *C-V-T* and *G/w-V-T* characteristics confirm that the  $N_{ss}$  and  $R_s$  of the diode are important parameters that strongly influence the electric parameters of Al/NphAOEMA/PEDOT-PSS/ITO heterojunction structures. While the  $R_s$  are significant only in the downward curvature of the forward bias *C-V* characteristics and accumulation region,  $N_{ss}$  are significant in both the inversion and depletion region. Such behavior of  $R_s$  may be attributed to particular distribution of  $N_{ss}$ , restructure and reordering surface atoms with temperature and excess capacitance resulting from the  $N_{ss}$  in equilibrium with the semiconductor which can follow the ac signal.

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## 1. Introduction

Semiconductor polymers have attracted a great deal of interest in recent years and they can be used as active components in the electronic devices due to their excellent electrical characteristics. These materials have a great potential advantage on account of easy processing in low cost manufacturing and large area electronic and optoelectronic devices applications (field effect transistors (FETs), Schottky barrier diodes (SBDs), light emitting diodes (LEDs), polymeric voltaic cells (PVCs), memory, sensors, etc.) [1-6]. There are a lot of polymers that can be used for the fabrication of microelectronic devices due to their unique electrical, optical and dielectric properties but among them methacrylic copolymers have gained great importance in various industrial fields. Because copolymers containing the naphthyl group with a methacrylic monomers have good thermal stability [7].

The performance and reliability of these devices depend on various parameters such as the process of fabrication, the barrier height between metal and polymer, the density of surface states at interface, device temperature and voltage, and the stability of the polymer used. The existence of a polymer (NphAOEMA) between Al/PEDOT-PSS can have a strong influence on the electrical properties of structure. There are currently a vast number of reports of experimental studies on metal/polymer structure [1-6], but very limited experimental information is available on their temperature

dependent electrical characteristics in the literature. The dependence of electrical properties on temperature and bias voltage are of great important to get accurate and reliable results for semiconductor devices [9]. Because the analysis of electrical characteristics of these devices measured only at room temperature does not give detailed information about their conduction process and interface characteristics.

In our previous work we studied the frequency dependence of the electrical characteristics of Al/NphAOEMA/PEDOT-PSS/ITO heterojunction structures by the use of the I-V and C-V method [10]. In the present study, for further research, the forward and reverse bias C-V and *G/w-V* characteristics of Al/NphAOEMA/PEDOT-PSS/ITO heterojunction structures were measured over the temperature range of 120-400 K by considering both the  $N_{ss}$  and  $R_s$  effects. The distribution profile of  $N_{ss}$  and  $R_s$  were obtained from the *C-V-T* and *G/w-V-T* measurements by using Hill-Coleman [8] and Nicollian and Goetzberger [9] methods, respectively.

## 2. Experimental procedure

A naphthylamino group containing methacrylate based on monomer 2-(2-naphthylamino)-2-oxo-ethyl methacrylate (NphAOEMA) was synthesized by reacting 2-chloro-N-2-naphthylacetamide (NphA) with sodium methacrylate in acetonitrile. (NphA) was prepared by reacting 1-

naphthylamine dissolved in benzene with chloroacetylchloride. The free-radical-initiated polymerization of (NphAOEMA) was carried out in dimethylsulphoxide (DMSO) solution at 65 °C using 2,2'-azobisisobutyronitrile (AIBN) as an initiator. The poly (NphAOEMA) was characterized and described elsewhere [7]. Al/Polymer/PEDOT-PSS/ITO was prepared as follows; ITO glass was etched and cleaned. The [poly (NphAOEMA)] having amorphous structure was prepared as 75 nm thickness. Before the application of the polymer, PEDOT-PSS was spin coated on the ITO substrate. PEDOT-PSS is a synthetic metal and known as hole injection material. The speed of the spinner was 5000 rpm for 30 s and this speed gave 70 nm thick layer on the ITO substrate. 200 µm aluminium as cathode was evaporated on top of the [poly (NphAOEMA)] layer by using an evaporator from West Technology Systems. The structure of Al/Polymer /PEDOT-PSS/ITO heterojunction structures and details of fabricated procedures have been given in our previous study [7, 10].

The  $C$ - $V$  and  $G/w$ - $V$  measurements were carried out with a HP 4192A LF impedance analyzer meter at 500 kHz. Small sinusoidal signal of 50 mV peak to peak from the external pulse generator is applied to the sample in order to meet the requirement [9]. The sample temperature was always monitored by using a copper-constantan thermocouple and a Lakeshore 321 auto-tuning temperature controller with sensitivity better than  $\pm 0.1$  K. All measurements were carried out with the help of a microcomputer through an IEEE-488 ac/dc converter card.

### 3. Results and discussion

In order to extract the series resistance, several methods have been suggested in the literature [9, 11-13] Among them the most important one is the conductance technique ( $C$ - $V$  and  $G/w$ - $V$  measurements), developed by Nicollian and Goetzberger [9]. In this technique, both the reverse and forward bias  $C$ - $V$  and  $G/w$ - $V$  measurements give the important information about the  $R_s$  of device and the distribution of interface states ( $N_{ss}$ ) at metal/semiconductor interface. To obtain the real  $C$  and  $G/w$ , the high frequency  $C$  and  $G/w$  measurements under both reverse and forward bias can be corrected for the effect of  $R_s$ . Also, at high frequencies ( $f \geq 500$  kHz), the charges at interface states cannot follow the external ac signal and thus, the  $N_{ss}$  do not contribute to  $C$  and  $G/w$ . On the other hand, the Cheung [11], Norde [12] and Sato and Yasamura [13] techniques are related only the forward bias current-voltage ( $I$ - $V$ ) characteristics at high bias voltage and the effect of  $N_{ss}$  cannot fully eliminate. The measured capacitance  $C_m$  ( $V$ ,  $T$ ) and conductance  $G_m/w$  ( $V$ ,  $T$ ) plots are shown in Fig. 1 and Fig. 2 respectively. As seen in Fig. 1, the values of capacitance give a pike in each temperature, the magnitude of pike increases with increasing temperature. Contrary to the values of  $C$ , the values of conductance (Fig. 2) decreases with increasing temperature. Such behavior of  $C$  and  $G/w$  are mainly attributed to the molecular restructuring and reordering of the interface states.

The real series resistance of the Al/NphAOEMA/PEDOT-PSS/ITO heterojunction structures can be subtracted from the  $C_m$  and  $G_m/w$  in strong accumulation region at 500 kHz. At the same time, the values of  $R_s$  can be subtracted voltage dependent for each temperature. When the device is biased into strong accumulation, the admittance ( $Y_{ma}$ ) can be given as [9],

$$Y_{ma} = G_{ma} + j\omega C_{ma} \quad (1)$$

$$R_s = \frac{G_{ma}}{G_{ma}^2 + \omega^2 C_{ma}^2} \quad (2)$$

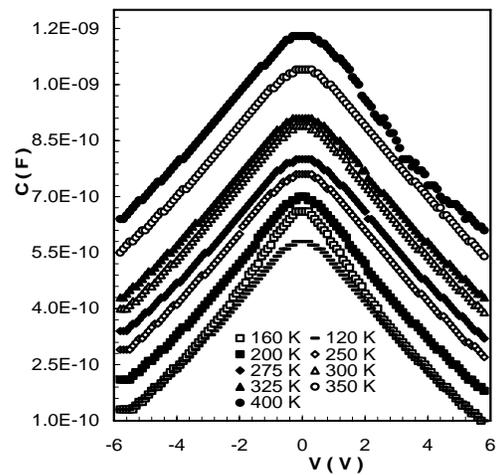


Fig. 1. The temperature dependent  $C_m$ - $V$  characteristics of Al/NphAOEMA/PEDOT-PSS/ITO heterojunction structure.

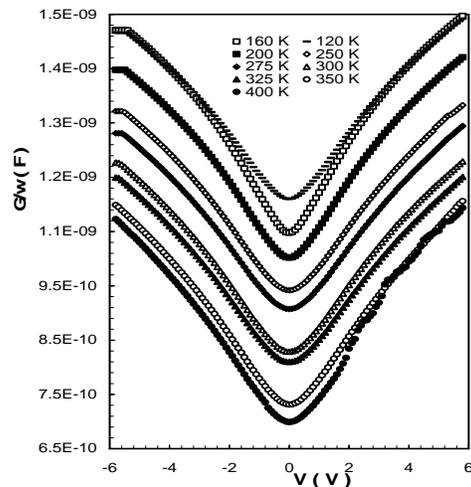


Fig. 2. The temperature dependent  $G_m/w$ - $V$  characteristics of Al/NphAOEMA/PEDOT-PSS/ITO heterojunction structure.

The values of  $R_s$  calculated as a function of voltage at various temperatures and are shown in Fig. 3. It can be seen in

Fig. 3 that, series resistance have a minimum value about zero bias region where the interface states are intensive. These very significant values demanded that special attention be given to effects of the series resistance in the C-V and G/w-V measurements. Similar results are reported in literature [14-17]. As can be seen from Fig. 1 and Fig. 2, the peak value of the capacitance depends on the value of series resistance. While the values of  $R_s$  are increased, the value of capacitance at the peak is decreased. As seen in Fig. 3, that the series resistance is strongly dependent of voltage. We considering that the trap charges have enough energy to escape from the traps located metal/polymer interface especially at high temperatures.

Also, according to the Hill-Coleman method [8], density of interface states is given by

$$N_{ss} = \left( \frac{2}{qA} \right) \frac{(G_m/\omega)_{\max}}{(G_m/\omega)_{\max} C_{ox}^2 + (1 - C_m/C_{ox})^2} \quad (3)$$

where,  $A$  is the area of the diode,  $\omega$  is the angular frequency,  $C_{max}$  and  $(G_m/\omega)_{\max}$  are the measured capacitance and conductance which correspond to peak values, respectively, and  $C_{ox}$  is the capacitance of oxide layer. The values of various parameters for Al/NphAOEMA/PEDOT-PSS/ITO heterojunction structure determined from C-V and G/w-V characteristics in the temperature range of 120-400 K are given in Table 1.

The temperature dependence of interface states density was obtained from the C-V and G/w-V measurements by using the Hill-Coleman method [8] and shown in Fig. 4. As can be seen from Fig. 4 and Table 1, both the values of  $N_{ss}$  and  $R_s$  should decrease with increasing temperature. Such results indicated that both the values of  $N_{ss}$  and  $R_s$  are important parameters that strongly influence electrical characteristics of these devices.

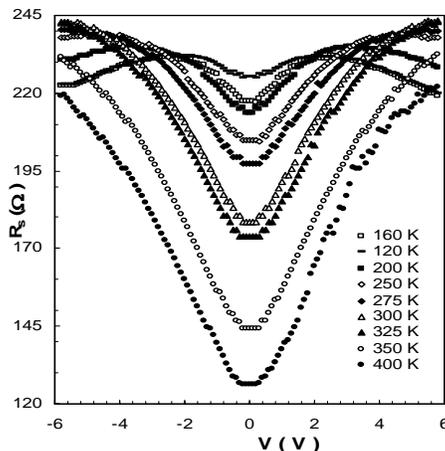


Fig. 3. The  $R_s$  vs  $V$  plots at various temperatures Al/NphAOEMA/PEDOT-PSS/ITO heterojunction structure.

It is clear that Al/Polymer/PEDOT-PSS/ITO heterojunction structures have been controlled by the interface states and series resistance, which are responsible for the non-ideal behavior of both the C-V and G/w-V characteristics.

Table 1. The experimental values of parameters obtained from C (V, T) and G/w (V, T) characteristics of Al / NphAOEMA / PEDOT - PSS/ITO heterojunction structure at different temperatures.

T (K)	$V_m$ (V)	$C_m$ (F)	$G_m/w$ (F)	$N_{ss}$ ( $eV^{-1}cm^{-2}$ )	$R_s$ ( $\Omega$ )
120	0,1	$5,8 \times 10^{-10}$	$1,1 \times 10^{-9}$	$1,9 \times 10^{11}$	217
160	0,1	$6,6 \times 10^{-10}$	$1,0 \times 10^{-9}$	$1,8 \times 10^{11}$	225
200	0,1	$7,0 \times 10^{-10}$	$1,0 \times 10^{-9}$	$1,7 \times 10^{11}$	214
250	0,1	$7,6 \times 10^{-10}$	$9,4 \times 10^{-10}$	$1,6 \times 10^{11}$	205
275	0,1	$8,0 \times 10^{-10}$	$9,1 \times 10^{-10}$	$1,5 \times 10^{11}$	197
300	0,1	$8,9 \times 10^{-10}$	$8,3 \times 10^{-10}$	$1,4 \times 10^{11}$	178
325	0,1	$9,1 \times 10^{-10}$	$8,1 \times 10^{-10}$	$1,4 \times 10^{11}$	174
350	0,1	$1,0 \times 10^{-9}$	$7,3 \times 10^{-10}$	$1,2 \times 10^{11}$	144
400	0,1	$1,1 \times 10^{-9}$	$7,0 \times 10^{-10}$	$1,2 \times 10^{11}$	126

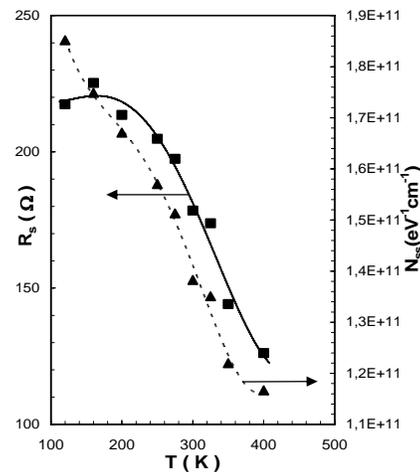


Fig. 4. The variation of  $R_s$  and  $N_{ss}$  as a function of temperature for Al/NphAOEMA/PEDOT-PSS/ITO heterojunction structure.

#### 4. Conclusions

The forward and reverse bias C-V-T and G/wV-T characteristics of the Al/NphAOEMA/PEDOT-PSS/ITO structures were measured in the temperature range of 120-400 K. The C-V and G/w-V characteristics confirm that the  $N_{ss}$  and  $R_s$  are important parameters that strongly influence the electrical and dielectrical parameters in the examined structure. It has been found that both capacitance and conductance were quite sensitive to temperature, especially at high temperatures. The values of  $N_{ss}$  and  $R_s$  decrease with increasing temperature. Such behaviour of C and G/w are mainly attributed to the molecular restructuring and reordering at the metal-polymer interface. This effect of  $N_{ss}$  can be eliminated

when these C-V and G/w-V curves are obtained at sufficiently high frequency ( $f \geq 500$  kHz). The C-V and G/w-V characteristics confirm that the  $N_{ss}$  and  $R_s$  are important parameters that strongly influence the electrical parameters in Al/NphAOEMA/PEDOT-PSS/ITO heterojunction structures.

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