

# The electrical properties of Au/GaN and PEDOT: PSS/GaN diodes

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## Abstract –

*In the present paper, using a numerical simulator, the simulation of Au/n-GaN and PEDOT: PSS/GaN structures were performed in a temperature at room temperature. The electrical parameters: barrier height, ideality factor, shunt resistance series, and resistance have been calculated using different methods: conventional I-V, Norde, Chattopadhyay, and Mikhelashvili. Statistical analysis showed that the Au/GaN structure has a barrier height of (0.6 eV) which is higher compared with the PEDOT: PSS/GaN structure (0.72 eV) and ideality factor (1.88 and 2.26) respectively. The values of resistance shunt were increased from 77150.056  $\Omega$  to 11207586  $\Omega$ . It is observed that the leakage current increased from 6.64E-5 to 4.98926E-5A at -0.85 V.*

**Keywords:** Schottky diode; Au/n-GaN; PEDOT: PSS/GaN; (I-V), Norde, Cheung and Chattopadhyay methods; Leakage current; Resistance shunt.

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## I. Introduction

In the development of electronic components such as Schottky diode, MOS, transistor and metal-isolate-semiconductor, GaN's are commonly used (MIS). et cetera. [1-3]. Gallium nitride is a very promising material for semiconductor materials with high strength, high-frequency and wide-bandgap and high electron velocity saturation. The Gallium nitride binary compound is a semiconductor direct bandgap with a lattice parameter = 4.52 Å and  $E_g = 3.22$  eV and 300 K belonging to the III-V family [4]. This binary compound (LEDs), photodetectors (MSM), laser diodes, solar cell application, and field-effect microwave transistors[5-9] is the promising material in light-emitting diodes. GaN's high-frequency characteristics make it suitable for high-frequency and high-power applications. [10, 11]. Many theoretical and experimental studies on the production of devices for Schottky diodes have been carried out (Metal-GaN). Projects have investigated the electronic parameters and frequency dependent properties of Au / NiO / GaN Schottky diodes in the range 1 kHz-1 MHz at different frequencies.

A group of researchers have studied the effect of the hafnium dioxide layer on the electrical properties of the diode (Pd / GaN) in a wide temperature range (270 - 390K), they have also treated the effect of temperature (400-600 K) on the electrical properties of the Au / Ta2O5 / n-GaN structure. Another group have studied the electric transport and transport properties of the rare earth oxide intercalary diode Au / Y2O3 / n-GaN [13,14]. The same group of researchers studied the effect of annealing temperature on the electrical properties of Au / Ta2O5 / n-GaN of the metallic insulating semiconductor structure (MIS) [12].

In this paper, we present a theoretical analysis of the effects of PEDOT: PSS is given using forward I-V bias measurements on the electrical properties of the Schottky diode (M / n-GaN) at a temperature (300 K). We studied the evolution of ideality factor ( $n$ ), barrier height ( $\Phi_b$ ), shunt resistance, and series resistance ( $R_s$ ) using (I-V), Norde, Chattopadhyay and Mikhelashvili methods.

## II. Method

The band gap ( $E_g=3.40\text{eV}$ ), electron affinity ( $\chi =4.10$ ), Relative permittivity  $\epsilon=9.50$ ), Effective density of states in the conduction band ( $N_c =2.3.10E17 \text{ cm}^{-3}$  ) and Effective density of states in the valence band ( $N_v =4.7.10E17 \text{ cm}^{-3}$  ) parameters used in the simulation for Au/n-GaN and PEDOT: PSS/GaN SBDs, , The simulator is based on a mathematical model [13, 14].

- Bandgap model [15].
- Mobility model [16].
- Shockley–Read–Hall model [16].
- Auger recombination [17].
- Impact ionization [18].
- Thermionic emission [19].
- Universal Schottky tunneling [20].
- Image force lowering [21].

## III. Result and discussions

### 3.1 Current-voltage (I-V) method

The electrical characterization of Schottky diode devices was carried out at the temperature 300 K. Figure 1 shows the results of semi-log forward and reverse bias (current-voltage) characteristics of the Au/n-GaN and PEDOT: PSS/GaN. The current-voltage characteristics of an ideal SBD are given by thermionic emission theory[24, 25] [7,8]. Equation (1) can be written as an equation for the forward voltage applied ( $V > 3kT/q$ ) (1). [24-26]:

$$I = I_0 \exp\left(\frac{-qV}{kT}\right) \quad (1)$$

We could find the value of ( $I_0$ ) by the plot  $\ln(I)$  versus ( $v$ ) at  $v = 0$  volts. Then, by replacing the calculated ( $I_0$ ) value in the equation (2), we could find the Schottky barrier height. You can extract the value of the ideality factor ( $n$ ) from the linear curve area ( $\ln(I) -v$ ) .

$$I_0 = AT^2A^* \exp\left(\frac{q\Phi_{b0}}{kT}\right) \quad (2)$$

Where  $A$  is the rectifier contact area,  $\Phi_b$  is the Schottky barrier height [24].  $A^*$  is the Richardson constant ( $A^* =26.4 \text{ A/cm}^2 \text{ K}^2$  for n-GaN).

The values of barrier height and ideality factor, these values can be determined using the equation (3):

$$n = \frac{q}{kT} \frac{d(V - IR_s)}{d(\ln I)} \quad (3)$$

And the barrier height  $\Phi_{bn}$  is given by:

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

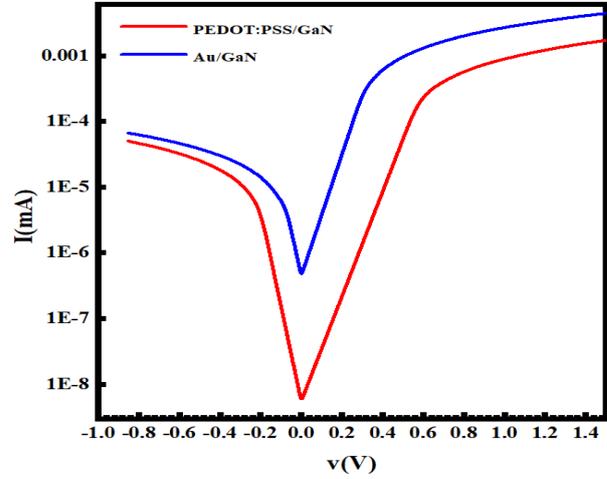


Figure 1. The semi-logarithmic reverse and forward bias current-voltage characteristics for Au/n-GaN and PEDOT: PSS/GaN SBD in the temperature (300K)

### 3.2. Method of Norde

The Norde approximation method is defined by equation (5)[27]. This estimate is based on adjusted forward plots (I-V) that can be used to measure the height barrier:

$$F(v) = \frac{v}{\gamma} - \frac{kT}{q} \ln\left(\frac{I(v)}{AA^*T^2}\right) \quad (5)$$

Where  $\gamma$  is an integer (dimensionless) greater than  $n$  and  $I(V)$  present the current which is acquired from the (I–V) curve. In this approximation, height barrier values can be determined using the equation (6) [27, 28]:

$$\Phi_b = F(v_0) + \left[\frac{v_0}{\gamma} - \frac{kT}{q}\right] \quad (6)$$

Where ( $n$ )value is obtained from the  $\ln(I)$ -V curve,  $F(v_0)$  is the minimum point of  $F(V)$  as a function of  $V$ .

From Figure 2, we can determine values barrier heights, at the temperature of 300 K. was obtained and collected in Table 1.

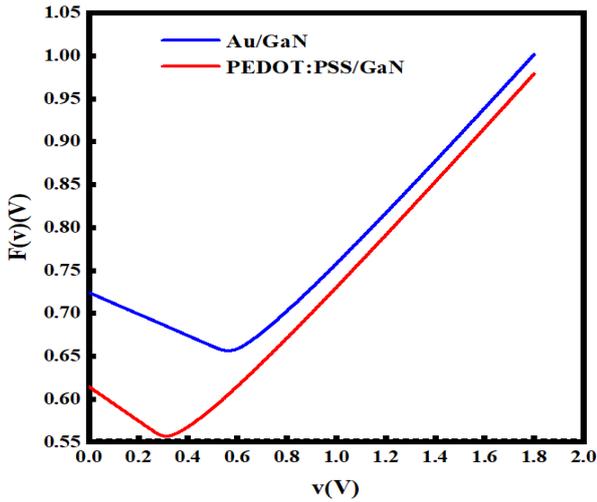


Figure 1.  $F(v)$  as a function of  $V$  of Au/n-GaN and PEDOT: PSS/GaN structures

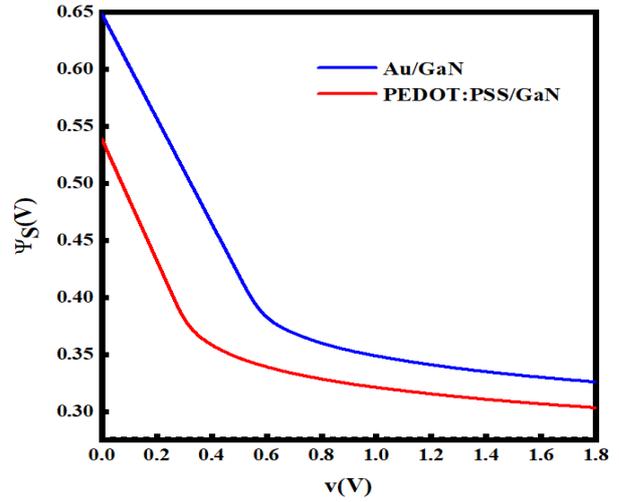


Figure 2. Surface potential-forward voltage curves of the Au/n-GaN and PEDOT: PSS/GaN structures at  $T = 300\text{K}$

### 3.3. Model of Chattopadhyay

The Chattopadhyay model is defined by equation (6) this approximation can be used to determine heights barrier and the ideality factor this values, can be calculated from the equation (7) :

$$\phi_b = \Psi_s(JC, VC) + C_2VC + V_n - KT/q \quad (7)$$

The inverse of the ideality factor ( $C_2$ ) can be calculated by equation (8):

$$C_2 = \frac{1}{n} = \left( \frac{d\Psi_s}{dV} \right)_{Jc, Vc} \quad (8)$$

Where  $V_n$  is the potential difference between the Fermi level and the bottom of the conduction band ( $(E_F) - E_c$ ), which can be calculated from equation (9):

$$V_n = \frac{kT}{q} \ln\left(\frac{N_c}{N_d}\right) \quad (9)$$

Where, ( $N_c$  and  $N_d$ ) present the effective conduction band density of states and the carrier concentration, respectively.

The value of surface potential  $\Psi_s$  can be determined from equation (10):

$$\Psi_s = \frac{KT}{q} \ln\left(\frac{AA^*T^2}{I}\right) - V_n \quad (10)$$

With the aid of equations (9) and (10), the values of ideality factor ( $n$ ) and barrier height were obtained and collected in Table 1.

### 3.4. Mikhelashvili method

Mikhelashvili's method for determination of the barrier height, ideality factor, and the series resistance. This method is based on the equation (11):

$$\theta(v) = \frac{d(\ln(I))}{d(\ln(v))} \quad (11)$$

The barrier height and the ideality factor are obtained from equations (12) and (13)

$$\Phi_b = \frac{kT}{q} \left[ \theta_m + 1 - \ln\left(\frac{I_m}{AA^*T^2}\right) \right] \quad (12)$$

$$n = \frac{qv_m(\theta_m - 1)}{kT\theta_m^2} \quad (13)$$

Where ( $\theta_m$  and  $V_m$ ) are the coordinates of the maximum point in  $\theta(V)$  versus  $V$  plot. at temperatures (300 K). The series resistance ( $R_s$ ) is obtained from equation (14):

We can determine values barrier heights and series resistance, at the temperature of 300 K and presented in Table 1

$$R_s = \frac{V_m}{I_m \theta_m^2} \quad (14)$$

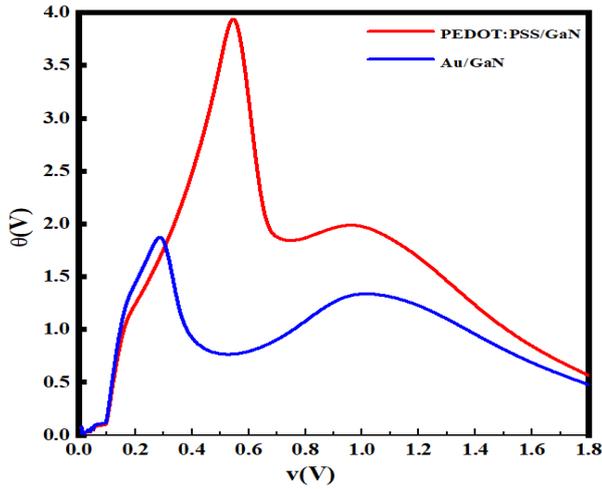


Figure 3. Mikhelashvili's plots for (a) the Au/n-GaN and PEDOT: PSS/GaN structures at T = 300K

We computed values of ideality factor, barrier height and series resistance and reported it in Table 1. The obtained results using the I-V approach in temperatures 300 K shows an increase of barrier height (from 0.6 to 0.72 eV), an increase of ideality factor (n) (from 1.88 to 2.26) and an increase of series resistance (RS) (from 318 to 608.5 Ω). We observed that an increase in (T=300K) is accompanied by a decrease in the ideality factor and an increase in the barrier height for all methods [20]. The shunt resistance and series resistance are the other two important parameters for the SBD.

Table 1. The obtained values of saturation current, barrier height, ideality factor, and series resistance for Au/n-GaN and PEDOT: PSS/GaN structures

	ideality factor		saturation current		barrier height		series resistance	
	A1	A2	A1	A2	A1	A2	A1	A2
V-I	1.88	2.26	4.4E-7	5.55E-9	0.66	0.72	318	608.5
Norde	--	--	--	--	0.68	0.94	--	--
Chattopadhyay	2.22	1.78	--	--	0.60	0.85	--	--
Mikhelashvili	2.17	2.10	--	--	0.59	0.82	401	432

Figure 5 represents Resistance  $R_{Sh}$  as a function of voltage V and it is noted that the  $R_{Sh}$  values are found to be 77150.056Ω and 11207586Ω Au/n-GaN and PEDOT: PSS/GaN structures, respectively.

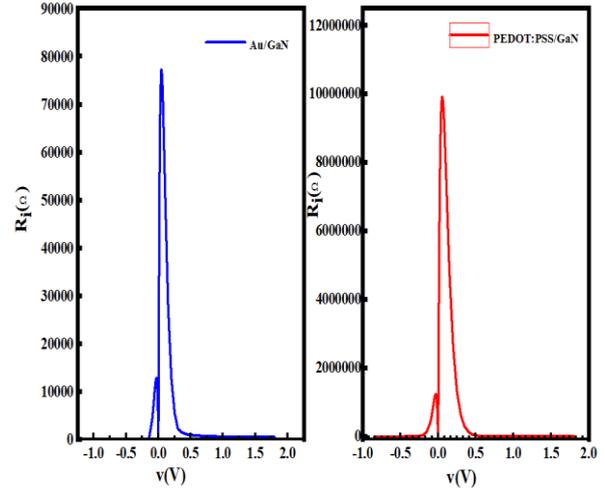


Figure 5. voltage reliant device resistance

### IV. Conclusion

We reported in this paper the electrical characterization of Au/ GaN and PEDOT: PSS/GaN structures. We demonstrated that the I-V curves of these diodes. A low barrier height and the leakage current were obtained. The barrier height, ideality factor, and series resistance are also estimated by (I-V), Norde's, Chattopadhyay's, and Mikhelashvili's methods. Results show that the Schottky emission is the dominant conduction mechanism. The statistical analysis is employed to extract the barrier Heights were 0.6 eV and 0.72 eV from I-V measurements respectively. It is observed that the leakage current increased from 6.64E-5 to 4.98926E-5A at -0.85 V.

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