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Analysis of Series Resistance's (R_S) Impact on Ag/Perylene/n-Si Schottky Barrier Diode (SBD) in Various Techniques

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Keywords

Ag/Perylene/n-Si SBD
Series Resistance
Ohm’s Law
Modified Norde Function
Cheungs’ Methods

Abstract

The purpose of this research is to experimentally examine how R_s affects the I-V curves of *Ag/Perylene/n-Si* SBD. Various plots of the experimental I-V measurements with the forward voltage are wielded in order to determine the parameter R_s. The I-V properties of *Ag/Perylene/n-Si* SBD was evaluated at room temperature (RT) based on Thermionic-Emission (TE) model. We specified the R_s values using Ohm law, Cheungs’, and modified Norde functions. We compared the R_s values utilized various techniques. Modified Norde functions apply to the ln I-V graph's all forward voltage region. On the other hand, Cheung's approaches are just feasible in the non-linear section in the high voltage region. The R_s values obtained from various techniques are distinct and are dedicated in the table. The reason for this inconsistency is shown in our research. It is evident that the values of the R_s determined using various approaches are in good accordance with one another. The Ohm's law derived from sufficiently high forward voltages is the one among them that is the most straightforward, precise, and dependable. It was demonstrated by the I-V data that the dispersion of R_s is a key factor affecting the electrical properties of diodes.

Cite

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1. INTRODUCTION

Schottky barrier diodes, which are significant electronic devices in semiconductor technology, play a major role in metal-semiconductor technology because they feature an interface layer made of an insulator, ferroelectric, polymer, or composite materials. Metal-semiconductor-type SBDs transform into MIS/MFS/MPS-kind of SBDs when an interface is formed among metal and semiconductors. But, the inter-layer is higher than at about 4-5 hundred nanometers, this structures act a capacitor which storage more electrons or energy (Sze & Ng, 2007; Gencer Imer et al., 2019; Altındal et al., 2022). However, the used an interlayer can be considerably affect both the basic electrical parameters and conduction mechanism of these a structures. The performance or quality of these devices also depends on many parameters, such as the R_s, shunt-resistances (R_{sh}), barrier inhomogeneity, interface thickness and homogeneity, surface states (N_{ss}), and high-voltage (Norde, 1979; Cheung & Cheung, 1986; Sze & Ng, 2007; Rajagopal Reddy et al., 2014). According to Zeyrek et al. (2013) and Okur et al. (2019) the electrical features of these structures can be altered by using interfacial layers such as perylene, and DNA.

The prominence of MPS-type SBDs has increased because they have features like easy growth on the semiconductor, flexibility, and low cost in the last three decades (Sağlam et al., 2004; Yakuphanoglu, 2007; Özden et al., 2022). Among the conductive-polymers, the more important ones are the polythiophene, polyaniline, polyacetylene, PPy, and perylene because of they can easy to synthesize by chemical or electrochemical oxidation (Greene, 2009; Zeyrek et al., 2013). Therefore, we intended to build *Ag/Perylene/n-*

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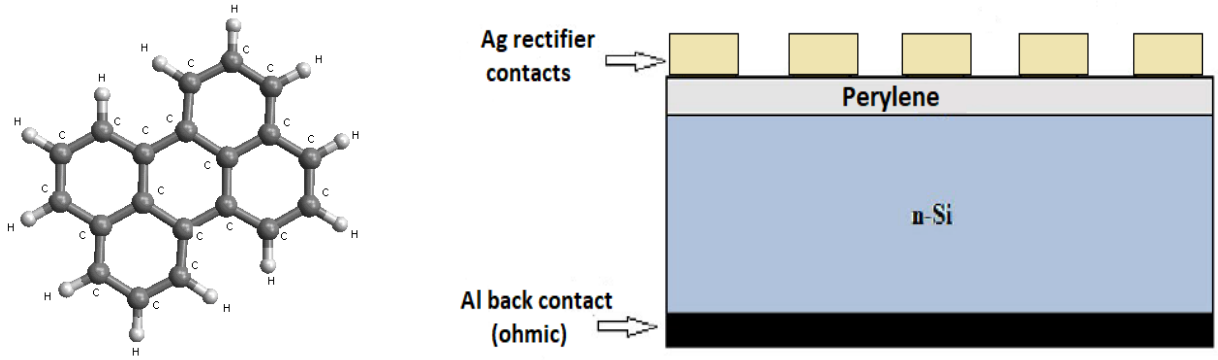
Si MPS-type SBDs rather than traditional MS or MIS. Then utilizing the I-V plots at RT, the electronic parameters n, Φ_B, R_s, R_{sh}, and rectification ratio (RR) was determined. Three linear regions with varying intercept points and slopes are depicted on the experimental I-V plot and correspond to low, moderate, and higher voltages. The I-V curve in the forward voltage shows the model of a multiple parallel diode.

2. MATERIAL AND METHOD

Ag/Perylene/n-Si MPS-type SBD was produced onto the n type Si. Before the processing, it was cleaned in trichloroethylene and ethanol, etched by CP4 (HNO3: HF: COOH C2H5: H2O =3:1:2:2 weight ratio) solution 30 s rinsed by propylene glycol. Following that, it washed with deionised-water (DW) and desiccated with N_2 gas. The wafer form tempered at 400°C to provide decent ohmic-contact. Here, Al was used as ohmic contact and Ag was used as rectifies contact. 1.26 mg of Perylene of 99% purity, branded Alfa Aesar, code L03047, was taken. It was mixed in 10 ml of Sigma-Aldrich brand 34856 coded Dichloromethane at 30°C for 2 hours on a magnetic stirrer. 0.5 mM (millimolar) solution was prepared. Afterward, Si wafers with ohmic contacts were coated with a layer of perylene using the spin coating method. The coating process was carried out at a rotation speed of 2000 rpm for 2 minutes. The processed was completed by thermally growing the rectifier contact on perylene at 10^{-6} Torr. The 3D structure diagram of perylene and schematic diagram of the sample were given in Figure 1. The measurements were realized at RT using Keithley-2400 SourceMeter.



(a) **(b)**

Figure 1. a)*The 3D structure diagram of perylene ($C_{20}H_{12}$) (Zeyrek et al., 2013),*
b) *The schematic illustration of the SBD.*

3. RESULTS AND DISCUSSION

The I-V curves of *Ag/Perylene/n-Si* SBD results examined at RT are shown in Figure 2. The I-V curve of the forward voltage increases exponentially. Furthermore, as illustrated in the inset of Figure 2, the I-V curve of the forward voltage has three different linear regions with distinct slopes, called region-1, 2 and 3 respectively. These multi-linear regions are referred to as the multi parallel diode model in the literature (Güçlü et al., 2016).

The rectification rates ($RR=I_{Forward}/I_{Reverse}$) were calculated in 0.5 V steps from ± 0.5 V to ±5 V and presented in Figure 3. The RR at V= ±0.5 V was even less than 1 ($5.25x10^{-2}$) (Figure 3), and especially reaching ~10^3 for ±5 V. This indicates that the *Ag/Perylene/n-Si* SBD could also be defined as a good diode as well as has being a high RR, good ohmic performance. Many investigations have demonstrated that a high rate of rectification is achieved by reducing the leakage current. Besides, it is also cognized that the RR, a crucial factor in diode efficiency, is affected by the interface quality and the impurities in the SiO_2/Si substrate. RRs are one of the most features for metal-semiconductor structures in electronic device technologies (Jaffery et al., 2020).

The I-V curve shows a linear behaviour but divergence from linearity owing to the impact of R_s under forward bias. The fundamental diode parameters such as n, Φ_{Bo}, I_o were derived using the TE equations for whole three regions based on the findings of I-V plot (Sze & Ng, 2007).

$$I_t = \mathrm{I}_{01}\left[\exp\left(\frac{\beta(\mathrm{V}\text{-}IR_S)}{n_1}\right)-1\right]+\mathrm{I}_{02}\left[\exp\left(\frac{\beta(\mathrm{V}\text{-}IR_S)}{n_2}\right)-1\right]+\mathrm{I}_{03}\left[\exp\left(\frac{\beta(\mathrm{V}\text{-}IR_S)}{n_3}\right)-1\right]+\left(\frac{V-IR_S}{R_{sh}}\right) \tag{1}$$

$$\mathrm{n}_i = \beta\left(\frac{dV}{d(lnI)}\right) \tag{2}$$

$$\Phi_{B0i} = \frac{1}{\beta}ln\left[\frac{AA^{*}T^{2}}{I_0}\right] \tag{3}$$

where β is a variable that changes with temperature and is calculated using the equation β=q/kT (q, k, and T are well-known values in the literature). n, A, A*, and Φ_{Bo} are the ideality factor, contact-area of the diode, Richardson-constant of the semiconductor (for n-Si, it is equal to 112 A/(cm^2.K^2), and zero-bias BH, respectively. I_o is the saturation current, and $I{\cdot}R_S$ denotes the voltage drop across the series resistor. The n_i, I_{oi}, and Φ_{Boi} values were found from the slope and intercept of the linear part ln(I)-V plot for three linear regions as 5.947, 4.37x10^{-7} A, 0.661 eV (for Region-I), 8.433, 4.64x10^{-6} A, 0.600 eV (for Region-II), and 7.593, 2.00x10^{-6} A, 0.621 eV (for Region-III), respectively. It is clear that these parameters are different in different voltage regions due to the voltage dependent of them.

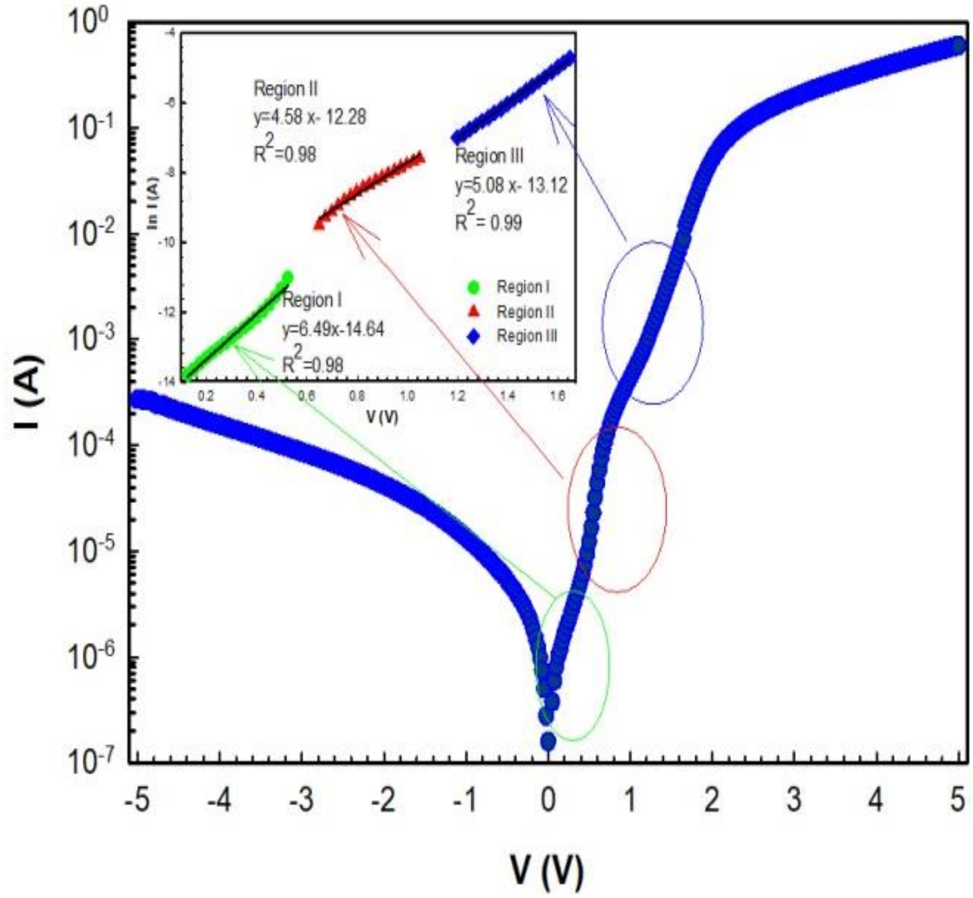


Figure 2. *I–V graph of the Ag/Perylene/n-Si SBD (inset the Region I, II, and III)*

Ohm's law ($R_i=V_i/I_i$) was used to calculate the measurements due to the significant influence of R_S. I-V plots for the samples were used and the results were shown in Figure 4. R_i values are constant in both the high forward and high reverse bias regions, and R_i corresponds to R_{sh} and R_s values in these regions. The R_{Sh} and R_S values were determined to be 18.45 kΩ and 8.347 Ω at (-5 V) and (+5V) voltage values, respectively.

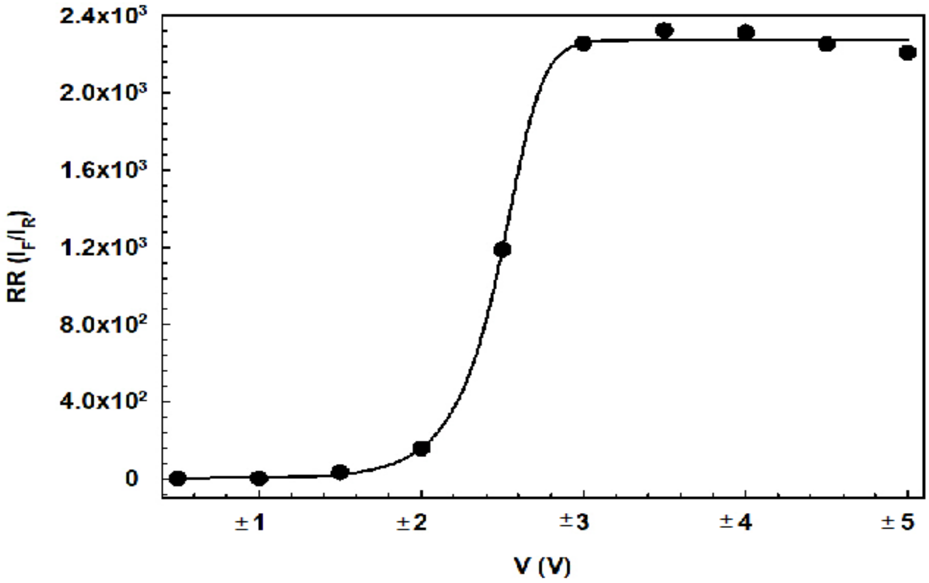


Figure 3. *Rectification Rates of the Ag/Perylene/n-Si SBD*

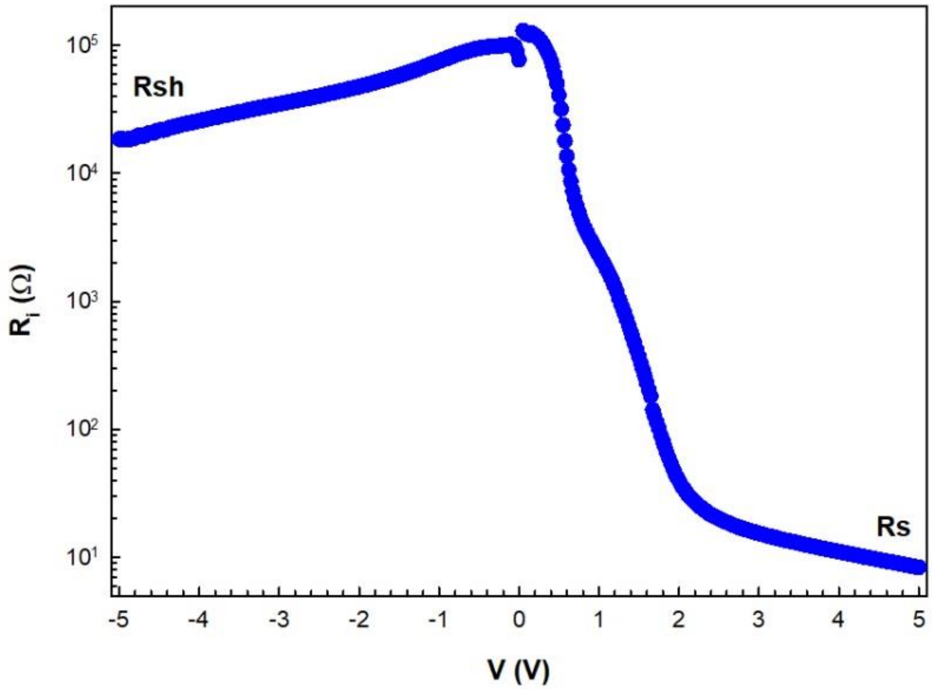


Figure 4. *Resistance values of the Ag/Perylene/n-Si SBD as a voltage dependent*

The R_S values are one of the major parameters influencing the electrical characteristics of *Ag/Perylene/n-Si* SBD. R_S is the significant source of minor signal loss in semiconductor devices. R_{sh} has a high value, making it ideal for an electronic device. R_{sh} could be caused by leak currents across the insulator among the front and rear contacts. Furthermore, R_{sh} might be caused by the shunt routes from the prob cable to the grounding, as well as the shunt resistance in the measurement device. The R_S is more influential in regions with sufficient forward voltage, whereas the R_{sh} is more potent in regions with reverse bias.

n and Φ_B values be determined only from the rectilinear section of the forward voltage region with TE theory. It is necessary to determine these parameters for the other bias region as well. The Cheungs' and modified Norde's functions can be used to do these computations in other regions (Norde, 1979; Bohlin, 1986; Cheung & Cheung, 1986).

Cheung's methods allow us to calculate the parameters n, Φ_B, and R_S in the region of descending curve of the I_F-V_F graphs. The n, $\Phi_{B0,}$ and R_s values are computed utilizing the given equations and presented in Table 1.

$$\frac{dV}{dln(I)} = \frac{nkT}{q} + R_s I \tag{4a}$$

$$H(I) = V - \frac{nkT}{q} \ln\left[\frac{I}{T^2 A^* A}\right] = R_s I + \Phi_{B0} n \tag{4b}$$

***Table 1.** Various electronic parameters computed with diverce approaches from the I-V plot at RT*

TE Theory (For Region-III)				**Ohm's-Law**		**Norde's-Function**		**Cheungs'-Methods**			
								dV/dln (I)		**H(I)**	
n	**I_0 (A)**	**Φ_{B0} (eV)**	**RR at ± 5 V**	**R_s at +5V (Ω)**	**R_{sh} at -5V (kΩ)**	**Φ_{B0} (eV)**	**R_s (Ω)**	**n**	**R_s (Ω)**	**Φ_{B0} (eV)**	**R_s (Ω)**
7.59	2.00x10^{-6}	0.621	2.21x10^{3}	8.34	18.45	0.739	0.541	24.17	4.094	0.415	3.814

The Cheung functions determined as dV/dLn(I) which is known Cheung's 1st function and H(I) which is known as Cheung's 2nd function were plotted versus current. From Cheung's 1st functions. slope and intercept, it is possible to determine the n and R_s of a diode. Figure 5 and Eq. 4a are refered for this. Similarly, the slope and intercept of Cheung's 2nd functions may be used to derive the Φ_{B0} and R_s of a diode using Figure 6 and Eq. 4b. According to Cheung's 1st and Cheung's 2nd functions, the values of n, $\Phi_{B0,}$ and R_s were worked out, Table 1 shows them.

The results in Table 1, Figures 5 and 6 indicate that the R_S values acquired Cheung's methods concur. The calculated R_s values using the H(I)- I and dV/d(ln I)- I graphs demonstrate the Cheung method's consistency.

The modified Norde Function is an alternate approach for computing values such as R_s and Φ_B. The modified Norde function considers all forward voltage region of the curve, in which the current changes exponentially. The conventional TE method was utilized to determine the ideality factor employed in the R_s value computation. The Φ_{B0} and R_s values may be computed using the below formulas according to this function.

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

$$\Phi_{B0} = F(V_{min}) + \frac{V_{min}}{\gamma} - \frac{kT}{q} \tag{5b}$$

$$R_S = \frac{kT(\gamma - n)}{qI_{min}} \tag{5c}$$

In Eq. 5a, F(V) and γ is an arbitrary constant and must be greater than n, which is derived from Eq. 2, respectively. In Eq. 5b and 5c, I_{min} is the current value matching the F(V)'s minimum. Likewise, V_{min} is the voltage value matching the F(V)'s minimum. The values of R_S and Φ_B were figured out by substituting the values of F (V_{min}), V_{min}, and I_{min} corresponding to F (V), V, and I values of the determined minimum F (V)-V graph (Figure 7), in Eq. 5b and 5c, and recorded in Table 1. The values of F(V_{min}), V_{min}, I_{min} was found as 0.593 V, 1.97 V, and 0.0463 A. Thus, the values of and Φ_B and Rs were calculated from Eq. 5b and 5c as 0.740 eV and 0.541 Ω by using the value of γ (1.5*n=11.385).

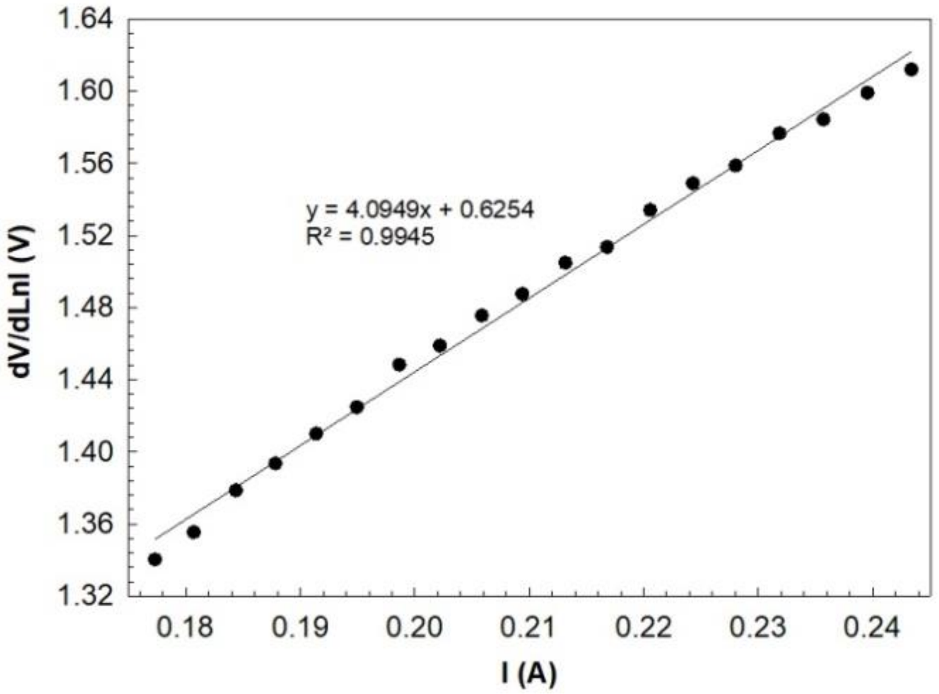


__Figure 5.__ The dV/dln(I)-I plot of Ag/Perylene/n-Si SBD

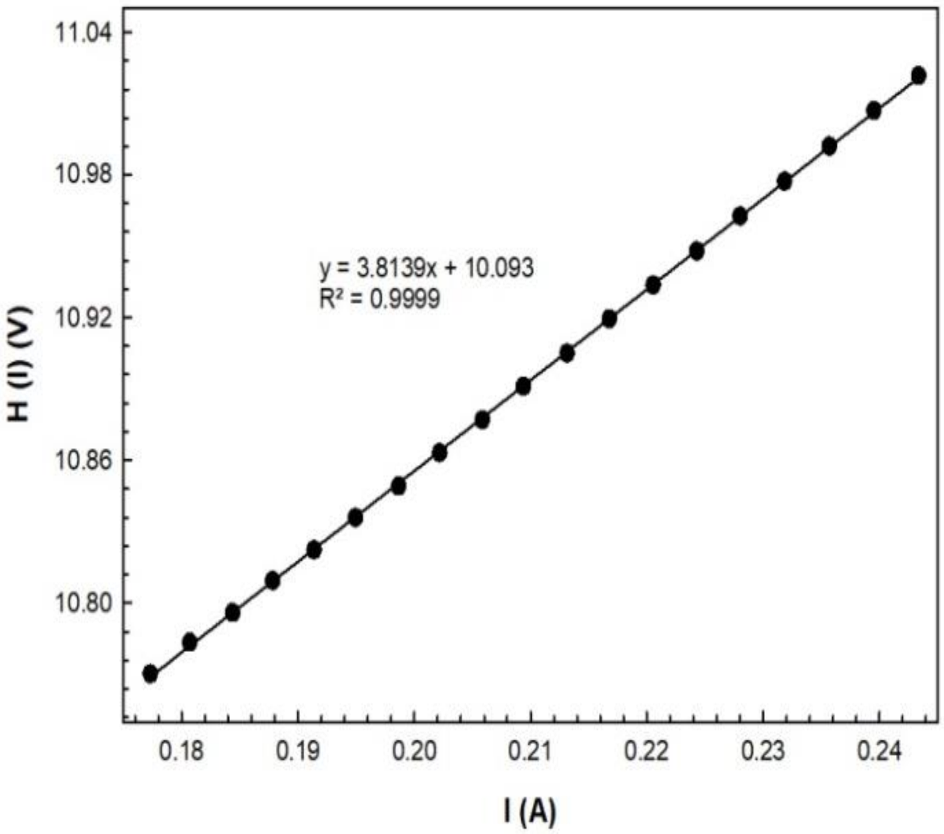


__Figure 6.__ The H(I)-I plot of Ag/Perylene/n-Si SBD

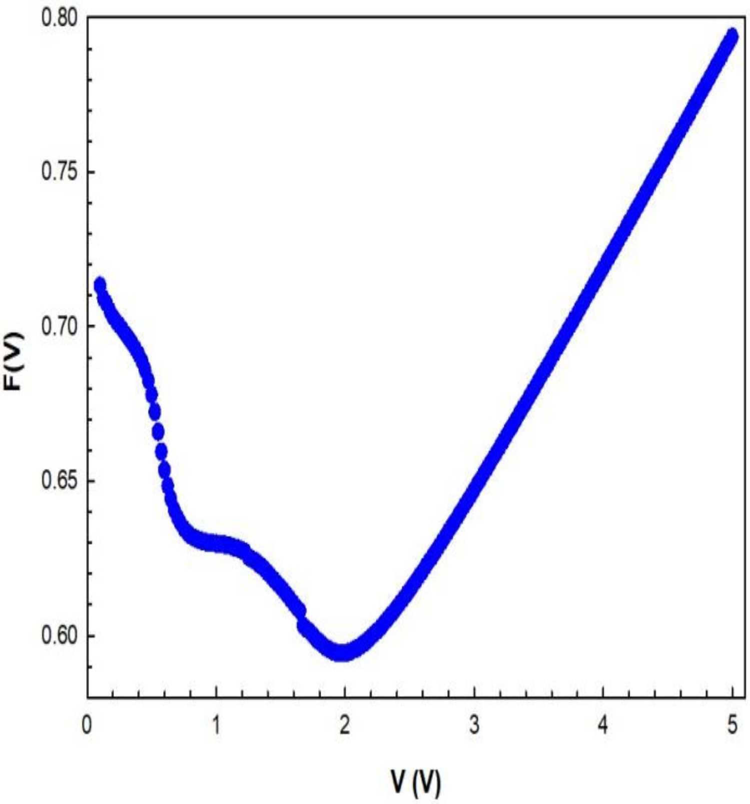


Figure 7. *F(V)-V plot for Ag/Perylene/n-Si SBD*

It is seen that the R_S values in Table 1 determined using *Ohm law*, *Cheung's methods* and *modified Norde function* are distinct from each other (Turut et al., 2020). These approaches relate to various voltage region, which explains why the results obtained using these methods varies. The TE theory places emphasis on the linear portion, while Cheung's methods center on the downward curvature of the LnI-V graph. The Norde's function also emphasizes on the entire forward bias area. As a result, it describes how the value of R_s is impacted by changes in the applied voltage.

4. CONCLUSION

In this study, the influence of R_S on the I-V plot of the *Ag/Perylene/n-Si* SBD was investigated experimentally at RT. The values of R_S have been studied via various technics, including the theorem of TE and the functions of Cheung and Norde. The R_S values of *Ag/Perylene/n-Si* SBD were found as 8.34 Ω, 4.094 Ω and 3.814 Ω and 2.125 Ω using Ohm's-Law, Cheungs'-methods and Norde-function, respectively. It was noted that some inconsistencies were attributed to the limitations of the method, specifically due to the range of voltage used. The R_{sh} value was found from I-V data in the reverse voltage region using Ohm's law as 18.45 kΩ at -5 V. R_{sh} has a high value it appropriate for an electronic device. The RR was determined from I-V data as~10^3 at V= ±5 V. This indicates that the *Ag/Perylene/n-Si* SBD has a very high RR, good ohmic behavior and is also as a good diode. As a result, the basic diode parameters such as I_o, n, Φ_{Bo} and Rs values were obtained by using TE, Norde and Cheungs methods. When these results were compared, it is clear that all these parameters are depended on bias voltage or the studied voltage range.

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CONFLICT OF INTEREST

The writer states that there is no competing interest or affiliation.

REFERENCES

Altındal, Ş., Özdemir, A. F., Aydoğan, Ş., & Türüt, A. (2022). Discrepancies in barrier heights obtained from current–voltage and capacitance–voltage of Au/PNoMPhPPy/n-GaAs structures in wide range of temperature. *Journal of Materials Science: Materials in Electronics*, *33*(15), 12210-12223. doi:10.1007/s10854-022-08181-1

Bohlin, K. E. (1986). Generalized Norde plot including determination of the ideality factor. *Journal of Applied Physics*, *60*(3), 1223-1224. doi:10.1063/1.337372

Cheung, S. K., & Cheung, N. W. (1986). Extraction of Schottky diode parameters from forward current-voltage characteristics. *Applied Physics Letters*, *49*(2), 85-87. doi:10.1063/1.97359

Gencer Imer, A., Korkut, A, Farooq, W A, Dere, A, Atif, M, Hanif, A., & Karabulut, A. (2019). Interface controlling study of silicon based Schottky diode by organic layer. *Journal of Materials Science: Materials in Electronics*, *30*, 19239-19246. doi:10.1007/s10854-019-02282-0

Greene, M. (2009). Perylene Pigments. In: E. B. Faulkner & R. J. Schwartz (Eds.), *High Performance Pigments* (2nd ed.) (pp. 261-274). Wiley. doi:10.1002/9783527626915.ch16

Güçlü, Ç. Ş., Özdemir, A. F., & Altindal, Ş. (2016). Double exponential I–V characteristics and double Gaussian distribution of barrier heights in (Au/Ti)/Al_2O_3/n-GaAs (MIS)-type Schottky barrier diodes in wide temperature range. *Applied Physics A*, *122*(12), 1032. doi:10.1007/s00339-016-0558-x

Jaffery, S. H. A., Kim, J., Dastgeer, G., Hussain, M., Ali, A., Hussain, S., Eom, J., Hong, S., & Jung, J. (2020). Thickness-Dependent, Gate-Tunable Rectification and Highly Sensitive Photovoltaic Behavior of Heterostructured GeSe/WS_2 p–n Diode. *Advanced Materials Interfaces*, *7*(23), 2000893. doi:10.1002/admi.202000893

Norde, H. (1979). A modified forward I-V plot for Schottky diodes with high series resistance. *Journal of Applied Physics 50*(7), 5052-5053. doi:10.1063/1.325607

Okur, S., Yakuphanoglu, F., Ozsoz, M., & Kadayifcilar, P. K. (2009). Electrical and interface properties of Au/DNA/n-Si organic-on-inorganic structures. *Microelectronic Engineering*, *86*(11), 2305-2311. doi:10.1016/j.mee.2009.04.017

Özden, Ş., Avcı, N., Pakma, O., & Kariper İ. A. (2022). Influence of illumination intensity on the electrical properties of Al/NOA65/p-Si/Al heterojunction MPS device. *Journal of Materials Science: Materials in Electronics*, *33*(16), 12796-12807. doi:10.1007/s10854-022-08225-6

Rajagopal Reddy, V., Manjunath, V., Janardhanam, V., Kil, Y.-H., & Choi, C.-J. (2014). Electrical properties and current transport mechanisms of the Au/n-GaN Schottky structure with solution-processed high-k BaTiO3 interlayer. *Journal of Electronic Materials*, *43*(9), 3499-3507. doi:10.1007/s11664-014-3177-3

Sze, S. M., & Ng, K. K. (2007). *Physics of Semiconductor Devices* (3rd ed.). John Wiley & Sons, Inc. doi:10.1002/0470068329

Turut, A., Yıldız, D. E., Karabulut, A., & Orak, İ. (2020). Electrical characteristics of atomic layer deposited Au/Ti/HfO2/n-GaAs MIS-diodes in the wide temperature range. *Journal of Materials Science: Materials in Electronics*, *31*, 7839-7849. doi:10.1007/s10854-020-03322-w

Yakuphanoglu, F. (2007). The current-voltage characteristics of FSS/n-Si heterojunction diode under dark and illumination. *Physica B: Condensed Matter*, *388*(1-2), 226-229. doi:10.1016/j.physb.2006.05.430

Zeyrek, S., Acaroğlu, E., Altindal, Ş., Birdoğan, S., & Bülbül, M. M. (2013). The effect of series resistance and interface states on the frequency dependent C–V and G/w–V characteristics of Al/perylene/p-Si MPS type Schottky barrier diodes. *Current Applied Physics*, *13*(7), 1225-1230. doi:10.1016/J.CAP.2013.03.014