New Materials, Compounds and Applications
Vol.3, No.1, 2019, pp.15-22

A NOVEL DEVICE BEHAVIOR OF Al/Coronene/n-GaAs/In ORGANIC BASED SCHOTTKY BARRIER DIODE

Ümmühan Akın[1], Ömer F. Yüksel[1], Osman Pakma[2], Haluk Koralay[3]
Şükrü Çavdar[3], Nihat Tuğluoğlu[4*]

[1]Department of Physics, Faculty of Science, Selçuk University, Konya, Turkey
[2]Department of Physics, Science and Art Faculty, Batman University, Batman, Turkey
[3]Department of Physics, Faculty of Science, Gazi University, Ankara, Turkey
[4]Department of Energy Systems Engineering, Faculty of Engineering, Giresun University, Giresun, Turkey

Abstract. A new Schottky barrier diode of Al/Coronene/n-GaAs/In was successfully prepared using spin-coating method. The interface state and electrical properties of Al/Coronene/n-GaAs Schottky barrier diode have been studied by current– voltage (*I–V*) data in dark and light. The key diode parameters such as ideality factor, Schottky barrier height, rectification ratio, series and shunt resistances were evaluated from *I–V* data. The effective forward conduction mechanisms were determined as the thermionic emission at low voltage. Results obtained at room temperature (300 K) showed highly rectifying devices under dark and light. The barrier height (Φ_B) of the diode was obtained as 0.901 eV and 0.842 eV under dark and light, respectively. The ideality factor (*n*) of the diode was calculated to be 1.49 and 1.82 under dark and light, respectively. The values of series resistance (R_s) obtained from Cheung-Cheung technique were determined to be 18 Ω and 16 Ω under dark and light, respectively. The interface states density (N_{ss}) of the Shottky device exhibits an exponential decrease with bias from 5.31×10^{10} eV^{-1} cm^{-2} and 7.24×10^{10} eV^{-1} cm^{-2} at (E_c-0.338) eV to 1.84×10^{10} eV^{-1} cm^{-2} and 2.17×10^{10} eV^{-1} cm^{-2}at (E_c-0.640) eV under dark and light, respectively.

Keywords: *Coronene, Schottky diode, barrier height, ideality factor, series resistance*

Corresponding Author: *Nihat Tuğluoğlu, Department of Energy Systems Engineering, Faculty of Engineering, Giresun University, Giresun, Turkey, Tel:+90 454 310 10 00; Fax: +90 454 310 10 1, e-mail: tugluo@gmail.com*

Received: *04 March 2019;* ***Accepted:*** *27 March 2019;* ***Published:*** *10 April 2019.*

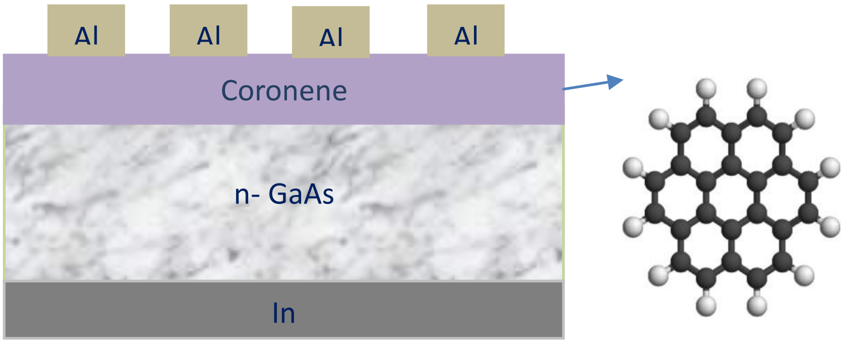
1. Introduction

Recently, many researchers have introduced on the improvement or development in the metal–semiconductor contact by using organic interfacial layer (i.e., rubrene, Rhodamine-101, perylene monoimide, polymer P2ClAn, PTCDA, MgPc, CuPc) deposited on GaAs wafer with different technique (Kampen *et al.*, 2002; Karimova *et al.*, 2005; Missouma *et al*., 2015; Özdemir *et al.*, 2017; Şimşir *et al.*, 2012; Tuğluoğlu *et al*., 2015; Vural *et al*., 2010). The presence of an organic interfacial thin film can have a powerful effect on the diode parameters as well as the barrier height (Φ_b), interface state density (N_{ss}) and ideality factor (*n*) (Brutting, 2005; Tuğluoğlu *et al*., 2015; Sun *et al.*, 2005). For this reason, it is important to obtain the interface properties and series resistance of such a organic based Schottky contact (Mekki *et al.*, 2016;Tuğluoğlu *et al.*, 2015). In additionally, the utility of organic interfacial layer can not only acts a passivation effect but also have the inter-diffusion between semiconductor and metal (Missouma *et al*., 2015; Vural *et al*., 2010).

In this work, Coronene was used as an organic interfacial layer for modification of Al/n-GaAs diode. Coronene has six-fold symmetrical aromatic molecule. It is a molecular semiconductor and blue fluorescent material , which have been used to set up solar cells, organic transistors, etc. Coronene is known to be electron rich. The reverseand forward bias current–voltage (*I*–*V*) characteristics of Al/Coronene/n-GaAs diodes have been performed in dark and under light. These results of photoelectric and electric properties of organic-on-inorganic Al/Coronene/n-GaAs/Indiodesin dark and under light are reported.

2. Experimental details

In this work, we used that the n-type GaAs (100) wafer has a 500 μm thickness and 20 Ω cm resistivity. The substrate cleaned in acetone and methanol with ultrasonic agitation for 5 min and rinsed in de-ionized water. The GaAs wafer is cleaned using the RCA cleaning method (Tuğluoğlu *et al.*, 2015; Şimşir *et al.*, 2012). Ohmic and rectifying contacts are deposited with indium (99.99%, In) metal and aluminum (99.99%, Al) metal by using thermal evaporation method in 10^{-6} Torr, respectively. The thicknesses of the metals are 150 nm. The GaAs wafer in vacuum has exposed by annealing at 500^{o}C for 2 min to form ohmic contact. A coronene film (100 nm) is deposited on the GaAs wafer with a Spin Coater (Laurell) by the spin coating method. The molecular structure of Coronene is given in Fig. 1(a). The schematic representation of the Al/Coronene/n-GaAs/In diode is demonstrated in Fig. 1(b). The *I-V* characteristics with a Source Meter (Keithley 2410) were measured in dark and light (daylight) at room temperature.



(b) (a)

Figure 1. a) The organic structure of Coronene
b) the schematic representation of the Al/Coronene/n-type GaAs/Indevice

3. Results and discussion

3.1. Al/Coronene/n-GaAs/In device characteristics

Fig. 2 represents the dark and light current–voltage (*I-V*) behaviors of the Al/Coronene/n-GaAs/In device under reverse and forward -bias voltages. It is seen that the characteristics of *I–V* is nonlinear, showing rectification ratio (RR). RR from Fig. 2 is determined as 68200 and 1800 at ±2V under dark and light, respectively. We assumed that the thermionic emission is the effective treatment of Schottky devices and the current-voltage characteristics of such a device can be expressed as (Rhoderick *et al.*, 1988; Tuğluoğlu *et al*., 2015; Sze, 1981).

$$I = I_0\left[exp\left(\frac{qV}{nkT}\right) - 1\right] \tag{1}$$

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

where I_0 is the saturation current, n is the diode quality factor, q is the electronic charge, $A^{*}$is equal to 8.16 A/cm^{2}K^2 effective Richardson constant for n-type GaAs (Vural *et. al.,* 2010), A is the Schottky contact area, Φ_b is the device barrier height and T is the absolute temperature in Kelvin. Φ_b values are determined from extrapolated I_0. n values are determined the slope of the straight-line region of the forward-bias characteristics of Fig. 2 according to the following equations (Bobby *et al*., 2016; Tuğluoğlu *et al*., 2015; Yüksel *et al*., 2013).

$$\Phi_b = \frac{kT}{q}ln\left(\frac{AA^{*}T^{2}}{I_0}\right) \quad \text{and} \quad n = \frac{q}{kT}\left(\frac{dV}{dlnI}\right) \tag{3}$$

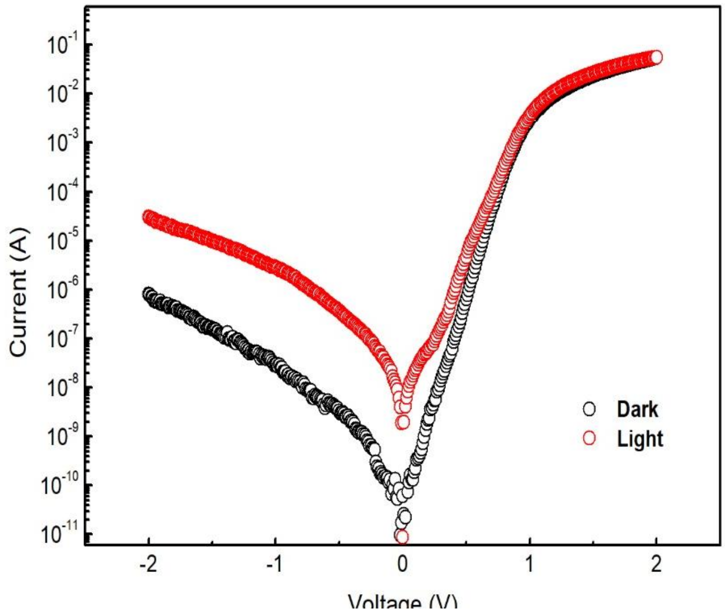


Figure 2. The*I-V*data of Al/Coronene/n-GaAs/In diodes according to dark and under light

Using Eq. (2), Eq. (3) and Fig. 2, the ideality factor, the Schottky barrier height, and saturation current values of the device under dark and light were found to be $n =$ 1.49 and 1.82, Φ_b = 0.901 eV and 0.842 eV, I_0 =1.76 x 10^{-11} A and 1.72x10^{-10} A, respectively. The high ideality factor value of Al/Coronene/n-GaAs Schottky device under dark is referred to the series resistance, the interface state density effects and the existence of the coronene layer on n-GaAs. Tuğluoğlu et al. have fabricated Al/rubrene/n-GaAs Schottky diode and obtained the device electrical parameters such as barrier height and ideality factor (Tuğluoğlu *et al*., 2015). The determined values of n and Φ_b for the Al/rubrene/n-GaAs diode are 1.918 and 0.870 eV, respectively. Vural et al. have prepared Al/Rhodamine-101/n-GaAs Schottky diodes and obtained the common device parameters (Vural *et al.*, 2010). The values of I_0, n and Φ_b were obtained as 1.74x10^{-8} A, 2.63, and 0.68 eV for Al/Rhodamine-101/n-GaAs, respectively. Furthermore, Vandenbroucke et al. (1987) and Hirose et al. (1988) reported that the ideality factor and barrier height values are 1.12-1.02 and 0.74-0.78 eV for Al/n-GaAs diode without interfacial layer, respectively. Our results represent that Coronene organic layer increased barrier height in Al/n-GaAs diode. This shows that organic layer improved the quality of diode compared to conventional Al/n-GaAs diodes.

3.2. Series resistance characteristics

Also, it is interpreted that the dark and light *I–V* characteristics of the device are influenced from series resistance (R_s) and shunt resistance (R_{sh}). R_{sh} and R_s are obtained by using *I-V* measurements according to diode resistance $R_d = \partial V / \partial I$ relation and the plot of R_d vs. *V* was indicated in Fig. 3. The values of R_s from high forward bias and R_{sh} from the reverse bias are determined as 14.07 Ω and 8.51 MΩ under dark and 17.92 Ω and 1.41 MΩ under light, respectively. Such values of R_s and R_{sh} is a powerful finding of performance improvement of Al/Coronene/n-GaAs device.

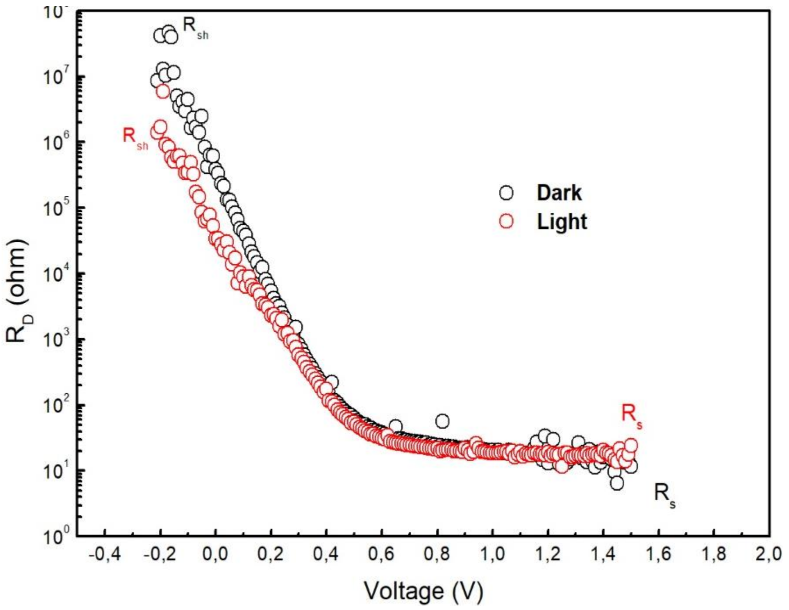


Figure 3. Plots of structure resistance (R_D) versus voltage (V_i) of Al/Coronene/n-GaAs/In device in dark and under light at room temperature

In addition, we have also calculated that the value of R_s from Cheung functions (Cheung *et al.*, 1986). The values of R_s and other parameters of the diodes can be determined from the following equations (Rhoderick *et al.*, 1988; Tuğluoğlu *et al.*, 2015; Sze, 1981):

$$I = I_0 \left[exp\left(\frac{q(V - IR_s)}{nkT} \right) \right], \tag{4}$$

$$V = IR_s + n\Phi_b + \frac{nkT}{q} ln\left(\frac{I}{AA^* T^2} \right), \tag{5}$$

$$\frac{dV}{dln\,(I)} = \frac{nkT}{q} + IR_s, \tag{6}$$

$$H(I) = V - \left(\frac{nkT}{q}\right) ln\left(\frac{I}{AA^{*}T^{2}}\right) = n\Phi_b + IR_s. \tag{7}$$

In Fig. 4 and 5, the values of *dV/d(ln(I))* vs. *I* and *H(I)* vs. *I* are plotted for Al/Coronene/n-GaAs in dark and light, respectively. The values of the series resistance and ideality factor from the slope and intercept of the solid line shown in curve of *dV/d(ln(I))* vs. *I* are determined as 18.72 Ω and 2.72 in dark and 16.46 Ω and 2.66 under light, respectively. Further, the values of the series resistance and barrier height from the slope and intercept of the solid line shown incurve of *H(I)* vs. *I* are calculated as 14.70 Ω and 0.957 eV in dark and 12.35 Ω and 0.966 eV under light, respectively. It is seen that the values of R_s obtained by Eqs. (6) and (7) are in good agreement with each other. These values also are in good agreement with the values of R_s determined from Ohm law (R_d, diode resistance).

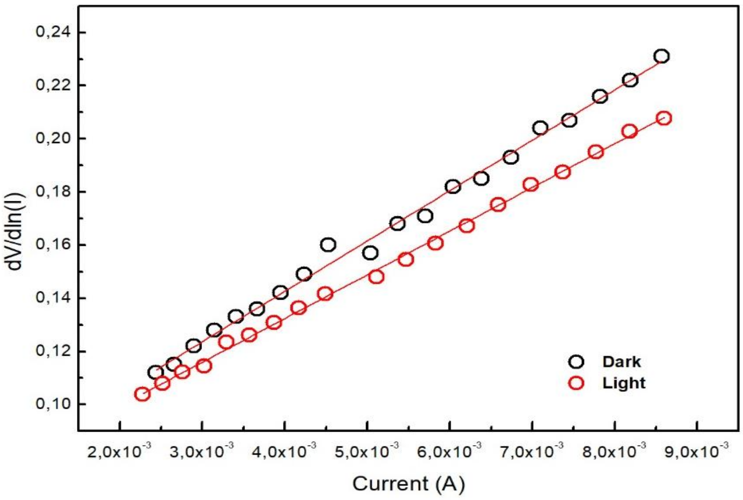


Figure 4. *dV/d(ln(I))* vs. *I* data of Coronene/n-GaAs contacts in dark and under light

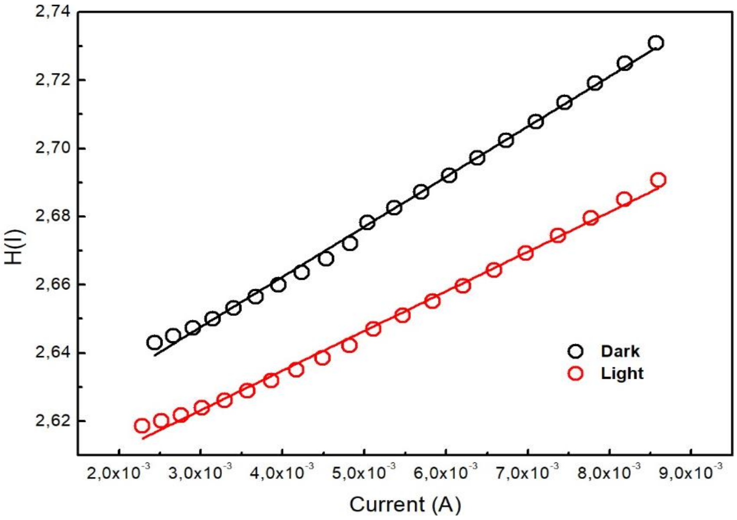


Figure 5. *H(I)* vs. *I* data of Coronene/n-GaAs contacts in dark and under light

3.3. Characteristics of interface states of Coronene/n-GaAs contact

Finally, the values of interface states density (N_{ss}) is calculated according to (Akkılıç *et al.*, 2008; Card *et al.*, 1971)

$$N_{ss} = \frac{1}{q}\left(\frac{\varepsilon_i}{\delta}\left(n(V)-1\right)-\frac{\varepsilon_s}{W_D}\right), \tag{8}$$

where δ is the thickness of the organic thin film, W_D is the width of the space charge region, $\varepsilon_i = 3\varepsilon_0$ and $\varepsilon_s = 12.9\varepsilon_0$ (Sze, 1981) are the permittivity of coronene and gallium arsenide semiconductor, respectively.

For n-type inorganic semiconductor, the interface state energy, E_{ss} with respect to the bottom of the conduction band is presented by (Akkılıç *et al.*, 2008; Card *et al.*, 1971):

$$E_c - E_{ss} = q(\Phi_e - V), \tag{9}$$

where E_c is the conduction band edge. Figure 6 indicates the resulting dependence of N_{ss} as a function of $E_c - E_{ss}$ at room temperature in dark and under light. It is obvious from Fig. 6 that the increasing of N_{ss} toward the bottom of the conduction band is open. This status represents the interface state continuum. In the range from $E_c - 0.338$ eV to $E_c - 0.640$eV, the N_{ss} values are in the range from 5.31 x 10^{10}to1.84 x 10^{10} $\text{eV}^{-1}\text{cm}^{-2}$ in dark and from 7.24 x 10^{10} to 2.17 x $10^{10}$$\text{eV}^{-1}\text{cm}^{-2}$ under light, respectively.

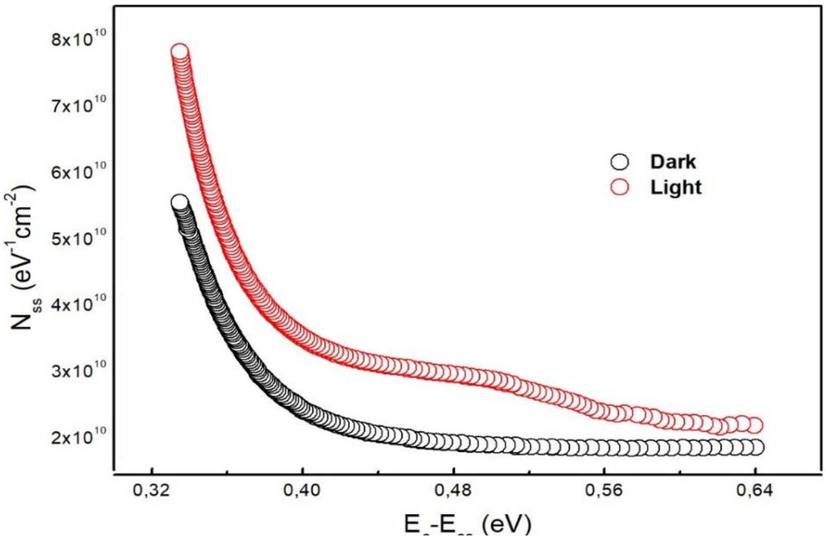


Figure 6. The $N_{ss} - (E_c - E_{ss})$measurements of Al/Coronene/n-GaAs/In Schottky diodes in dark and under light.

4. Conclusions

For the first time, anovel n-type diode have been successfully prepared, based entirely on Al/Coronene/n-GaAs/In using spin coating method. The forward and reverse bias *I–V* characteristics of Al/Coronene/n-GaAs/ In devices were measured at room temperature and in dark and under light. It was observed that our diode showed high rectifying behavior and yielded several barrier height and ideality factor in comparison to Al/n-GaAs diode. This is referred to the organic interfacial layer. The current value of the diode for light is higher than the current value for dark at the same reverse bias (-2V). This shows that the Al/Coronene/n-GaAs/In Schottky diode exhibits photovoltaic behavior. It is interpreted that the Al/Coronene/n-GaAs/In device can be used as a photo sensor for electronic applications.

Acknowledgements. This study was financially supported by Scientific Research Projects Unit of Giresun University under Project number: FEN-BAP-A-160317-48.

References

Akkılıç, K., Ocak, Y.S., İlhan, S. & Kılıçoğlu, T. (2008). Effect of the binuclear Cu(II) complex interface layer on the calculation of electronic properties of Au/Cu(II) complex/n-Si organic–inorganic hybrid heterojunction. *Synthetic Metals*, *158***,** 969-972.

Bobby, A., Shiwakoti, N., Gupta, P.S. & Antony B.K. (2016). Barrier modification of Au/n-GaAs Schottky structure by organic interlayer, *Indian Journal of Physics*, *90*, 307-312.

Brutting, W. (2005). *Physics of Organic Semiconductors*, Wiley-VCH Verlag GmbH and Co. KGaA, Weinheim.

Card, H.C. & Rhoderick, E.H. (1971). Studies of tunnel MOS diodes I. Interface effects in silicon Schottky diodes. *Journal of Physics D: Applied Physics*, *4***,** 1589-1595.

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

Hirose, K., Tsuda, H. & Mizutani, T., (1988). Al/n-GaAs Schottky barrier modified with rare-earth metal interlayer. *Journal of Applied Physics, 64*, 6575-6577.

Kampen, T.U., Park, S. & Zahn, D.R.T. (2002). Barrier height engineering of Ag/GaAs(100) Schottky contacts by a thin organic interlayer. *Applied Surface Science*, *190*, 461–466.

Karimova, Kh. S., Ahmed M.M., Moiz, S.A. & Fedorov, M.I. (2005). Temperature-dependent properties of organic-on-inorganic Ag/p-CuPc/n-GaAs/Ag photoelectric cell. *Solar Energy Materials & Solar Cells*, *87*, 61–75.

Mekki, A., Ocaya, R.O., Dere, A., Al-Ghamdi, A.A., Harrabi, K. & Yakuphanoğlu, F. (2016). New photodiodes based graphene-organic semiconductor hybrid materials, *Synthetic Metals*, *213*, 47–56.

Missouma, I., Benhalilibab, M., Chakera, A., Ocak, Y.S. & Benouis, C.E. (2015). A novel device behavior of Ag/MgPc/n-GaAs/Au-Ge organic based Schottky diode. *Synthetic Metals*, *207*, 42–45.

Özdemir, A.F., Salari, M.A., Kökçe, A. & Uçar, N. (2017). The Role of Hydrostatic Pressure in Electrical Properties of Au/n-GaAs Schottky diodes with Substituted Polyaniline Interfacial Layer. *Acta Physica Polonica A, 132*, 1118-1121.

Rhoderick, E.H. & Williams, R.H. (1988). *Metal–Semiconductor Contacts* 2nd edn. Oxford: Claredon.

Şimşir, N., Şafak, H., Yüksel, Ö.F. & Kuş, M. (2012). Investigation of currentevoltage and capacitanceevoltage characteristics of Ag/perylene-monoimide/n-GaAs Schottky diode. *Current Applied Physics*, *12*, 1510-1514.

Sun, S. & Sariciftci, N.S. (2005). *Organic Photovoltaics: Mechanisms, Materials and Devices*, CRC Press, Boca Raton, Florida, United States.

Sze, S.M. (1981). *Physics of Semiconductor Devices*, New York: Wiley.

Tuğluoğlu, N., Çalışkan, F. &Yüksel, Ö.F. (2015). Analysis of inhomogeneous barrier and capacitance parameters for Al/rubrene/n-GaAs (100) Schottky diodes. *Synthetic Metals*, *199*, 270-275.

Vandenbroucke, D.A., Van Meirhaeghe, R.L., Laflere, W.H.,& Cardon, F. (1987). Sputter-induced damage in Al/n-GaAs and Al/p-GaAs Schottky barriers. *Semiconductor Science and Technology*, *2*, 293-298.

Vural, Ö., Şafak, Y., Altındal, Ş.,& Türüt, A. (2010). Current–voltage characteristics of Al/Rhodamine-101/n-GaAs structures in the wide temperature range. *Current Applied Physics, 10,* 761–765.

Yüksel, Ö.F., Tuğluoğlu, N., Şafak, H. & Kuş, M. (2015). The modification of Schottky barrier height of Au/p-Si Schottky devices by perylene-diimide, *Journal of Applied Physics, 113,* 044507-044511.