Effects of two different solvents on Schottky barrier of organic device

Sudipta Sen and N B Manik
Condensed Matter Physics Research Centre, Department of Physics Jadavpur University, Kolkata-700032, India
E-mail: sagnike000@gmail.com

Keywords: chlorobenzene solvent, fullerene nanoparticles, metal-organic (M/O) interface, methyl red dye, Schottky barrier, toluene solvent

Abstract
In this paper, the effects of two different solvents on the Schottky barrier of ITO/ blend of methyl red dye—fullerene nanoparticles/Al - M electrode have been studied. We have taken chlorobenzene solvent and toluene solvent. Three different devices have been made by taking three different weight ratios of the dye—nanoparticles blend which is 1:1, 1:2, and 2:1. The estimation of the interfacial Schottky barrier at the junction of metal-organic dye is estimated using the device’s dark I—V plot. Interfacial Schottky barrier at the metal-organic junction is least for 2:1 weight ratio of dye—nanoparticle blend in chlorobenzene solvent but for toluene solvent, the Schottky barrier is least for 1:2 weight ratio of dye—nanoparticle blend. The lowering of barrier height at 2:1 and 1:2 ratios in Schottky barrier contacts prepared with chlorobenzene and toluene solvents can be attributed to the filling up of traps at the metal-organic layer interface. The Norde method is also used to check the consistency of the obtained value of the Schottky barrier measured from I—V plots. Reduction in Schottky barrier results in improved current injection process at the metal-organic interface.

1. Introduction

Organic thin-film devices have gained substantial consideration in recent years as they are flexible, cost-effective and they are also easy to tune, and have large area solution-processable fabrication techniques [1–4]. Though there are many advantages of these organic devices, there are few limitations also, which are required to be addressed. One of the limitations is when these organic dye-based thin films are sandwiched in between two metal electrodes, a high Schottky barrier occurs at one of the metal–organic (M/O) interfaces which lowers the injection of majority charge carriers [5, 6]. To understand the charge injection mechanism at M/O contact, a carrier injection-based device is designed to investigate the mechanisms [7]. Basically, organic dye-based devices consist of π-conjugated bonds, which lead to delocalized filled and empty π-orbitals that affect the electrical behavior of the material. Charge injection at the metal–organic layer interface plays a major role in the performance of organic devices [8]. Organic semiconductors differ significantly from their inorganic counterparts, as they are amorphous in nature [9]. Their electronic states are highly localized, and the charge injection process is described as thermally assisted tunneling from the delocalized states of the metal into the localized states of the organic semiconductor. The charge injection process is described as thermally assisted tunneling from the delocalized states of the metal into the localized states of the organic semiconductor and it plays a crucial role in the electrical properties of organic dye-based devices and is sometimes even more dominant than charge transport within the organic semiconductor [10].

Earlier, in our works [11, 12], we have incorporated different nanoparticles in the organic dye devices such as single-walled carbon nanotubes (SWCNT), different sized multiwalled carbon nanotubes (MWCNT) to improve the Schottky barrier at junction interface which has also resulted in improved charge injection in these devices. We have also reported a decrease in the Schottky barrier and trap energy due to changes in the back electrode [13].

In the present work, we have used methyl red dye and fullerene nanoparticles as a blended structure. We have tried to show the effect of different solvents on the Schottky barrier of these organic dye-based blended
structured thin-film devices. We have taken two different solvents namely chlorobenzene and toluene solvents as both methyl red dye and fullerene nanoparticles are soluble in both of these solvents. In our earlier works [14, 15], we have reported that with fullerene nanoparticles, the Schottky barrier gets improved in organic devices resulting in improved charge injection as fullerene nanoparticles are highly electronegative carbon nanoparticles and they act as electron acceptors. The existence of low lying excited states (0.2–0.4 eV) with respect to vacuum level makes fullerene a suitable material to increase the mobile charge carrier flow by reducing the loss of mobile charge carriers. The blended structure of methyl red dye and fullerene nanoparticles is sandwiched in between ITO and Al—M electrodes. Although nowadays, there are several processes of making the electrodes flexible and this flexible electrode can be fabricated by a simple rolling method and then pressed on a self-standing SWCNT film [16], in this work, we have not used flexible electrodes. We have observed the change in the Schottky barrier of this organic device in these two different solvents. Subsequently, we have also varied the weight ratio of the composite to study its influence on the Schottky barrier at the interface. Charge flow at the metal-organic layer interface exhibits behavior relating to thermionic emission. The interfacial barrier at metal-organic contact is generally described by the mechanism of metal to semiconductor contact. This provides the explanation that a potential barrier is caused by the energy difference between the Fermi level of the metal and the energy band of the organic material [17]. In this work, calculation of the Schottky barrier is done by the Richardson—Schottky (RS) model of thermionic emission [18]. We have estimated the Schottky barrier by analyzing I—V plots for different solvents and also for different weight ratios of the composite. The Schottky barrier is also estimated by the Norde method to check the consistency of the obtained result from I—V plots. The estimated barrier height at metal-organic layer interface is always greater than 0.30 eV and due to this, we have considered only injection limited current (ILC) and we have not considered space charge limiting current (SCLC) effect on the current mechanism [19].
2. Materials and sample preparation

Methyl Red (4-dimethylamino benzene-2-carboxylic acid) is a typical aromatic anionic azo compound with the molecular formula \((\text{CH}_3)_2\text{N}^+\text{C}_6\text{H}_4\text{N} = \text{N}_2\text{C}_6\text{H}_4\text{COOH}[20]\). \(\text{N} = \text{N}\) group constitutes azo group, and the \(R\) and \(R'\) groups of azo compounds are aromatic which stabilizes \(\text{N} = \text{N}\) group by making it part of an extended delocalized system [21]. Its conjugated structure and richness in 16 \(\pi\) electrons make methyl red an interesting material for producing Schottky contact at metal-organic interface. Fullerene nanoparticles are a class of novel carbon allotropes [22]. Both materials have been obtained from Sigma—Aldrich. Structures of MR dye and Fullerene nanoparticles are represented in figures 1(a) and (b) respectively.

Chlorobenzene and Toluene, both were obtained from Merck Specialities, India. Chlorobenzene is an aryl halide in which a halogen atom is directly attached to the benzene ring and they are non-reactive compared to toluene as a methyl group is attached to it [23]. Structures of chlorobenzene and toluene are represented in figures 2(a) and (b) respectively.

A 75 mm \(\times\) 25 mm \(\times\) 1.1 mm ITO coated glass slide (surface resistivity \(\sim\) 20 \(\Omega\) sq\(^{-1}\)) and Aluminium coated on mylar (Al—M) are used as front and back electrodes respectively in forming organic device. The effective area of the prepared organic device is 1.5 cm\(^2\).

At first, 10 ml chlorobenzene and 1 mg of Polymethyl methacrylate (PMMA) are mixed to form a PMMA solution. Methyl red dye and fullerene nanoparticles are added to this solution to form methyl red dye—fullerene nanoparticles composite. Three different solutions are being made by varying composite weight ratios. The prepared composite weight ratios are 1:1, 1:2, and 2:1. For the same composite weight ratio, 1 mg MR dye and 1 mg fullerene nanoparticles are mixed. For two other concentrations, weight ratios are accordingly adjusted. When MR dye and fullerene nanoparticle composite weight ratio is 2:1, then, amount of MR dye and fullerene nanoparticle is 2 mg and 1 mg respectively. For the 1:2 weight ratio of MR dye and fullerene nanoparticle composite, the amount of MR dye and fullerene nanoparticle is 1 mg and 2 mg respectively.

The prepared solutions are well stirred by a magnetic stirrer and left for 12 h for a well-prepared solution. The solution is spin-coated separately on both electrodes at 1200 rpm speed and dried at 3000 rpm speed. Then both these electrodes are sandwiched together to prepare an organic device. The prepared device is vacuum dried for 12 h. Similarly, two other devices are being prepared in the same solvent by the above-mentioned technique.

The toluene solvent is also being made by mixing 10 ml of toluene and 1 mg of PMMA in a clean test tube and stirred. In this solution, methyl red dye and fullerene nanoparticles are added to form a methyl red dye—fullerene nanoparticle composite. The prepared composite weight ratios in this toluene solvent are similar to that of chlorobenzene solvent. The process which is mentioned above by which the three organic devices are being prepared in chlorobenzene solvent, the same technique has been followed to form another three organic devices in toluene solvent. The organic device structure is displayed in figure 3.

The thickness of ITO-coated glass substrate, MR dye with fullerene nanoparticles, and Aluminium coated Mylar sheet is 1.5 \(\mu\)m, 5.3 \(\mu\)m, and 1.7 \(\mu\)m respectively.

3. Measurements

Dark current-voltage (I-V) characteristics of the cells have been measured with a Keithley 2400 source measure unit. The same measurement technique is followed as mentioned in one of our earlier works [24]. During I-V measurement, the front electrode is connected to the positive terminal of the battery and the negative terminal of the battery is connected to the back electrode of the device. The voltage range is between 0 to 6 V in steps of 0.5 V with a delay of 500 ms. The room temperature was kept at 25 °C.
4. Results and discussions

SEM images are taken for methyl red dye-based organic devices consisting of fullerene nanoparticles in both chlorobenzene solvent and toluene solvent respectively. The SEM analysis is done using JSM—6700 F whose accelerating voltage is 5 kV. Figures 4(a) and (b) display SEM images of methyl red dye and fullerene nanoparticles composite in chlorobenzene solvent and toluene solvent respectively. Figures 4(c) and (d) show the TEM images of methyl red dye and fullerene nanoparticles composite in chlorobenzene solvent and toluene solvent respectively.

SEM images of MR dye—fullerene nanoparticle composite in toluene solvent have a higher grain size (90 nm) compared to the grain size (50 nm) of MR dye—fullerene nanoparticles composite in chlorobenzene solvent. Due to large clusters, the mobile charge carriers are incapable to reach the electrodes and hence they recombine before reaching the electrodes which lead to a smaller amount of current for MR dye -fullerene nanoparticles composite in toluene solvent but for small clusters of MR dye -fullerene nanoparticles composite in chlorobenzene solvent, the charge carriers do not recombine and can reach the specific electrodes leaving a higher amount of current. High current flow will improve the charge injection process resulting in the lowering of the interfacial barrier at metal-organic semiconductor contact.
The following equations (1)–(3) describe the current flow at the metal-organic interface

\[
I = AA^*T^2 \exp \left(- \beta \phi_b \right) \left( \exp \left( \frac{qV}{nKT} \right) - 1 \right)
\]

(1)

\[
I_0 = AA^*T^2 \exp \left(- \beta \phi_b \right)
\]

(2)

Where, \( \beta = \frac{q}{kT} \) and \( q \) is the charge of an electron, \( V \) is the voltage that is applied to the device, \( A \) is the device area, \( k \) is the Boltzmann’s constant, \( T \) is the absolute value of room temperature, \( A^* \) is the effective Richardson constant, \( n \) is the ideality factor and \( \phi_b \) is the Schottky barrier and \( I_0 \) is the saturation current [25–30]. The value of \( I_0 \) is determined by the intersection point of the straight portion of the curve of \( I \) at \( V = 0 \) from the semi-log forward bias I-V characteristics. By putting the value of \( I_0 \), Schottky Barrier can be estimated at room temperature by using equation (3) which is as follows

\[
\phi_b = \frac{1}{\beta} \ln \left( \frac{AA^*T^2}{I_0} \right)
\]

(3)

In figure 5, dark I—V plots of methyl red dye and fullerene nanoparticles blend in chlorobenzene solvent for three different weight ratios have been shown. It has been found out that in chlorobenzene solvent, the weight
ratio 2:1 of the organic dye—fullerene nanoparticles blend shows the highest current flow compared to that of the other two weight ratios of the blend. The current flow is least for the 1:1 ratio of methyl red dye and fullerene nanoparticles blend. It can be said that whenever dye content in total blend content increases or the content of the nanoparticle in the total content of the blend increases rather than the same ratio of both the component in the blend, the current flow at the junction improves. From figure 5, the estimated values of turn-on voltages for weight ratio of MR: C60 = 1:1, 1:2, and 2:1 in chlorobenzene solvent are 3 V, 2 V, and 1.5 V respectively. These results can be ascribed to the filling up of traps as we all know that these devices contain many recombination centers, known as traps. When the number of recombination centers reduces, the charge flow also gets improved in these devices.

In figure 6, dark I—V characteristics of methyl red dye and fullerene nanoparticles blend in toluene solvent for three different weight ratios have been shown. In toluene solvent, the similar weight ratio of 2:1 of the organic dye—fullerene nanoparticles blend shows the highest current flow compared to that of the other two weight ratios of the blend. For toluene solvent also, it can be said that whenever the charge trapping effect reduces, the charge flow increases. From figure 6, the respective values of turn-on voltages for weight ratio of MR: C60 = 1:1, 1:2, and 2:1 in toluene solvent are 2.5 V, 1.5 V, and 2 V.

In figure 7, ln I—V plots of methyl red dye and fullerene nanoparticles blend in chlorobenzene solvent for three different weight ratios have been shown. This plot has been done to calculate the Schottky barrier variation

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure7.png}
\caption{In I—V plots of all three concentrations of Methyl Red (MR) dye and fullerene nanoparticles in chlorobenzene solvent.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure8.png}
\caption{In I—V plots of all three concentrations of Methyl Red (MR) dye and fullerene nanoparticles in toluene solvent.}
\end{figure}
of dye nanoparticles blend using the equation (3). The respective values of \( I_0 \) for weight ratio of MR: \( C_{60} = 1:1 \), 1:2, and 2:1 in chlorobenzene solvent obtained from linear fitting of the curve are 3.829 \( \mu A \), 4.457 \( \mu A \), and 5.736 \( \mu A \). It has been found out that the barrier height for the 2:1 ratio of dye-nanoparticle blend is 0.37 eV, which is the least compared to the other two compositions.

In figure 8, ln \( I-V \) plots of methyl red dye and fullerene nanoparticles blend in toluene solvent for three different weight ratios have been shown. For the weight ratio of MR: \( C_{60} = 1:1 \), 1:2, and 2:1 in toluene solvent, the values of \( I_0 \) are 3.485 \( \mu A \), 5.357 \( \mu A \), and 4.236 \( \mu A \) respectively. The barrier height for the 1:2 ratio of dye-nanoparticle blend is 0.39 eV, which is showing the lowest value compared to the other two compositions.

From the ln \( I-V \) plots for three different weight ratios of the blend in two different solvents, that the barrier height at M/O interface, it has been observed that Schottky barrier is least for 2:1 weight ratio of dye-nanoparticle blend in chlorobenzene solvent but for toluene solvent Schottky barrier is least for 1:2 weight ratio of dye—nanoparticle blend. In chlorobenzene solvent, when the dye content is more compared to the nanoparticle in the blend composition, the device shows a reduced Schottky barrier. In toluene solvent, the opposite happens i.e. when the content of the fullerene nanoparticle is more compared to the dye in blend composition, the device shows better performance as the Schottky barrier reduces.

In the case of light I-V study, the photonic emission mechanism may be explained by the well-known Bremsstrahlung radiation if the depletion region at the interface is approximately treated as gas micro-plasma [31]. But, in this present study, only the dark I-V characteristics of the prepared organic device have been analyzed.

To estimate the Schottky barrier in a different method, the Norde method is used. This function interrelates function \( F(V) \) and the current \( I(V) \). The expression has been shown in equation (4) given below where all symbols carry their usual meaning [32].

\[
F(V) = \left( \frac{V}{\gamma} \right) - \frac{kT}{q} \ln \left( \frac{I(V)}{AA'T^2} \right)
\]  

(4)

where \( \gamma \) is the first integer greater than \( n \) [33–35].

By taking derivative of the function \( F(V) \) with respect to \( V \) and putting \( \frac{dF(V)}{dV} = 0 \), will thus give the current \( I_0 \) at the minimum point of \( F(V) \). The minimum voltage \( V_0 \) is obtained as shown in equation (5)

\[
V_0 = \frac{kT}{q} + \ln \left( \frac{I_0}{AA'T^2} \right)
\]  

(5)

and the minimum value of \( F(V) \) becomes \( F(V_0) \) which is shown in equation (6)

\[
F(V_0) = \frac{V_0}{\gamma} - \frac{kT}{q} \ln \left( \frac{I_0}{AA'T^2} \right)
\]  

(6)

The Schottky barrier height is estimated by using the following expression (7) where \( V_0 \) is the minimum voltage and \( F(V_0) = \) minimum value of the Norde function.
For the weight ratio of MR: C₆₀ = 1:1, 1:2, and 2:1 in chlorobenzene solvent, the values of γ are considered to be 2, 3, and 3 as the ideality factors are found out to be 1.67, 2.23, and 2.87 respectively. The values of γ for weight ratio of MR: C₆₀ = 1:1, 1:2, and 2:1 in toluene solvent are 2, 3, and 2 respectively as the ideality factors are estimated to be 1.43, 2.47, and 1.91 respectively. F (V)—V plot of the blend of methyl red dye and fullerene nanoparticles in chlorobenzene and toluene solvent for three different weight ratios have been shown in figures 9 and 10 respectively. In figure 9, the values of V₀ for weight ratio of MR: C₆₀ = 1:1, 1:2 and 2:1 in chlorobenzene solvent are 0.28 V, 0.25 V and 0.21 V respectively. In figure 10, the values of V₀ for weight ratio of MR: C₆₀ = 1:1, 1:2 and 2:1 in toluene solvent are 0.31 V, 0.24 V and 0.27 V respectively. These figures represent the same Schottky barrier lowering for the particular weight ratio of dye nanoparticles blend which is consistent with the value obtained from I-V plots.

The estimated values of the Schottky barrier for three different weight ratios of Methyl Red dye and Fullerene Nanoparticle blend in both solvents are displayed in tables 1 and 2 respectively.

![Figure 10. F (V)—V plots of all three concentrations of Methyl Red (MR) dye and fullerene nanoparticles in toluene solvent.](image)

**Table 1.** Schottky Barrier Estimation for three different weight ratios of Methyl Red dye and Fullerene nanoparticle blend in chlorobenzene solvent.

| Device | Schottky Barrier From steady-state I—V Plots (eV) | Schottky Barrier From norde function (eV) |
|--------|-----------------------------------------------|----------------------------------------|
| MR: C₆₀ = 1:1 | 0.42 | 0.45 |
| MR: C₆₀ = 1:2 | 0.40 | 0.42 |
| MR: C₆₀ = 2:1 | 0.37 | 0.38 |

**Table 2.** Schottky Barrier Estimation for three different weight ratios of Methyl Red dye and Fullerene Nanoparticle blend in Toluene Solvent.

| Device | Schottky Barrier from steady-state I—V plots (eV) | Schottky Barrier from norde function (eV) |
|--------|-----------------------------------------------|----------------------------------------|
| MR: C₆₀ = 1:1 | 0.44 | 0.48 |
| MR: C₆₀ = 1:2 | 0.39 | 0.41 |
| MR: C₆₀ = 2:1 | 0.41 | 0.44 |

\[
\phi_b = F(V_0) + \frac{V_0}{\gamma} - \frac{kT}{q} \quad (7)
\]
5. Conclusions

In this paper, the effects of two different solvents namely, chlorobenzene and toluene solvents on the Schottky barrier of the blend of methyl red—fullerene nanoparticles have been studied. It has been found out that Schottky barrier height is least for the 2:1 ratio of dye - nanoparticles blend in chlorobenzene solvent and for the 1:2 ratio of dye - nanoparticles blend in toluene solvent. The reduction of the Schottky barrier can be ascribed to the filling of traps. Overall better charge injection of the device has been observed in chlorobenzene solvent compared to that of toluene solvent. As we have mentioned earlier, the formation of a small cluster of the blend of methyl red—fullerene nanoparticles in chlorobenzene solvent compared to large cluster formation in toluene solvent allow more free charge carriers to flow at the M/O interface, resulting in more filling of traps and lowering of Schottky barrier of the devices. The Schottky barrier has been estimated from both devices’ I–V plots and by using the Norde function. Norde function remains in good agreement with the device’s I–V plots in estimating the Schottky barrier. A further detailed study is required on the thin film morphology on its effect on current injection at the M/O interface.

Acknowledgments

Financial support under Grant No.3482/(NET-JULY2016) from UGC, India is gratefully acknowledged by Sudipta Sen.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Conflicts of interest

Both the authors declare that there is no conflict of interest regarding this present work.

ORCID iDs

Sudipta Sen https://orcid.org/0000-0002-0008-633X

References

[1] Kamedulski P, Kedziera A K and Lukaszewicz J P 2018 Influence of intermolecular interactions on the properties of carbon nanotubes Bull. Mater. Sci. 41 1–14
[2] Salem G F, El Shazly E A A, Farag A A M and Yahia I S 2018 Optical and microelectronic analysis of rhodamine B—based organic Schottky diode: a new trend application Appl. Phys. A 124 1–12
[3] Esalamian M 2017 Inorganic and organic solution-processed thin-film devices Nano-Micro Lett. 9 1–23
[4] Haneef H F, Zeidell A M and Jurchescu O D 2020 Charge carrier traps in organic semiconductors: a review on the underlying physics and impact on electronic devices J. Mater. Chem. C 8 759–87
[5] Antohe S, Ilimier S, Hrostea L, Antohe V A and Girtan M 2017 A critical review of photovoltaic cells based on organic monomeric and polymeric thin film heterojunctions Thin Solid Films 642 1–48
[6] Ang Y S and Ang L K 2019 Theory of thermionic carrier injection in graphene/organic schottky interface Frontiers in Materials 6 1–7
[7] Xu K, Huang L, Zhang Z, Zhao J, Zhang Z, Snyman L W and Swart J W 2018 Light emission from a poly-silicon device with carrier injection engineering Materials Science & Engineering B 231 28–31
[8] Scott J C 2003 Metal—organic interface and charge injection in organic electronic devices J. Vac. Sci. Technol. A 21 521–31
[9] Hiszpanski A M, Khlyabich P P and Loo Y L 2015 Tuning kinetic competitions to traverse the rich structural space of organic semiconductor thin films MRS Commun. 5 407–21
[10] Kumatani A, Li Y, Darmawan P, Minari T and Tsukagoshi K 2013 On practical charge injection at the Metal/Organic semiconductor interface Sci Rep. 3 1–6
[11] Sen S and Manik N B 2019 Effect of carboxyl-functionalized single walled carbon nanotubes on the interfacial barrier height of malachite green dye based organic device Phys. Int. 10 1–7
[12] Sen S and Manik N B 2020 Study on the effect of 8 nm size multi walled carbon nanotubes (MWCNT) on the barrier height of malachite green (MG) dye based organic device Int. J. Adv. Sci. Eng. 6 23–7
[13] Sen S and Manik N B 2020 Effect of back electrode on trap energy and interfacial barrier height of crystal violet (CV) dye based organic device Bull. Mater. Sci. 43 1–4
[14] Sen S and Manik N B 2019 Effect of fullerene nanoparticles on barrier height of crystal violet dye based organic device proceedings of 3rd IEEE Int. Conf. on Electronics, Materials Engineering & Nano-Technology 1–6
[15] Sen S and Manik N B 2020 Effects of fullerene nanoparticles and fullerite nanoparticles on the charge injection mechanism of methyl red dye based organic device AIP Adv. 10 1–5
[16] Wu H, Meng Q, Yang Q, Zhang M, Lu K and Wei Z 2015 Large—area polyimide/SWCNT nanocable cathode for flexible lithium-ion batteries Adv. Mater. 27 6504–10
[17] Ishii H, Sugiyama K, Ito E and Seki K 1999 Energy level alignment and interfacial electronic structures at organic/metal and organic/organic interfaces Adv. Mater. 11 605–25
[18] Sze S M and Ng K K 2007 Physics of Semiconductor Devices 3rd (New York: Wiley) 159–81
[19] Arkhipov V I, Seggern H V and Emelianova E V 2003 Charge injection versus space—charge limited current in organic light-emitting diodes Appl. Phys. Lett. 83 5074–6
[20] Salem A 2019 Conduction mechanism under DC and AC fields of methyl red dye as a new organic semiconductor Acta Phys. Pol. A 136 952–6
[21] Kılıç T, Aydin M E and Ocak Y S 2007 The determination of the interface state density distribution of the Al/methyl red/p-Si Schottky barrier diode by using a capacitance method Physica B 388 244–8
[22] Speller E M 2017 The significance of fullerene electron acceptors in organic solar cell photo-oxidation Mater. Sci. Technol. 33 924–33
[23] Saha S and Manik N B 2012 Study of solvent dependence of Methyl Red and C60 based organic photovoltaic devices Thin Solid Films 520 6274–81
[24] Sen S and Manik N B 2020 Effect of Zinc Oxide (ZnO) nanoparticles on interfacial barrier height and band bending of phenosafranin (PSF) dye-based organic device J. Electron. Mater. 49 4647–52
[25] Sen S, Das P K and Manik N B 2021 Study on the effect of single walled carbon nanotubes on junction properties of safranin–T dye-based organic device J. Phys. Commun. 5 1–9
[26] Al-Ta’ii H M, Amin Y M and Periasamy V 2015 Calculation of the electronic parameters of an Al/DNA/p-Si Schottky barrier diode influenced by alpha radiation Sensors 15 4810–22
[27] Svensson J and Campbell E E B 2011 Schottky barriers in carbon nanotube-metal contacts J. Appl. Phys. 110 1–16
[28] Sen S and Manik N B 2020 Correlation between barrier potential and charge trapping under the influence of titanium dioxide nanomaterials in organic devices Results in Materials 8 1–6
[29] Parameshwari P M, Shrisha B V, Bhat P S and Naik K G 2016 Electrical behavior of CdS/Al Schottky barrier diode at low temperatures Mater. Today Proc. 3 1620–1626
[30] Yıldırım M 2017 Determination of contact parameters of Au/n-ge schottky barrier diode with rubrene interlayer J. Polym. Tech. 20 165–73
[31] Xu K 2021 Silicon electro-optic micro—modulator fabricated in standard CMOS technology as components for all silicon monolithic integrated optoelectronic systems J. Micromech. Microeng. 31 1–11
[32] Norde H 1979 A modified forward I-V plot for Schottky diodes with high series resistance J. Appl. Phys. 50 5052–5053
[33] Yakuphanoğlu F, Shah M and Farooq A W 2011 Electrical and interfacial properties of p-Si/P3HT organic-on-inorganic junction barrier Acta Phys. Pol. A 120 358–62
[34] Türtüt A 2012 Determination of barrier height temperature coefficient by Norde’s method in ideal Co/n-GaAs Schottky contacts Türk. J. Phys. 36 235–244
[35] Güllü Ö and Türtüt A 2015 Electronic parameters of MIS Schottky diodes with DNA biopolymer interlayer Materials Science-Poland 33 593–600