Pentacene Based Organic Field Effect Transistor Using Different Gate Dielectric

Ayat J. Kadhima, Estabraq T. Abdullah, Abdulhadi K. Judranc

1 Laser and Optoelectronic Engineering Dept., University of Technology-Iraq, Alsina’a Street, 10066 Baghdad, Iraq.
2 College of Science Department of Physics, University of Baghdad, Baghdad, Iraq.

*Corresponding author Email: jkadhim950@gmail.com

1 A R T I C L E  I N F O

Handling editor: Jawad K. Oleiwi

Keywords:
Dielectric materials
Organic field effect transistors
PVP
ZrO2

1. Introduction

Small molecular organic semiconductors have a great interest because of their good facilities, lightweight, and easy fabrication under the ambient condition at low cost [1]. The importance of organic semiconductors appears in devices such as transistors[2], solar cells [3], sensors [4], light-emitting diode [5]. Although, these materials typically exhibit low charge carrier mobility, poor environmental stability and a short operational lifetime comparing with inorganic counterparts [6]. Among these small semiconductors, Pentacene is a promising material for a modern application, it is an organic semiconductor molecule (C22H14) with high mobility and carrier and the most promising p-type materials to use in the fabrication of organic field-effect transistor (OFET) devices, typically its charge carrier mobility’s ranging between 0.1 – 0.7 cm²/V.s. [7]. The gate dielectric materials and the interface between the gate dielectric materials and the active region are very effective in OFET performance. The organic-inorganic dielectric materials will play a significant role because of their features including low leakage current, decreases in threshold voltage and power dispersion with good thermal stability [8] [9]. Polymer dielectrics show several advantages against inorganic dielectric materials including transparent transistors and flexible display. One of the most interesting polymers is poly vinyl pyro linen (PVP), it is transparent, cross-linkable flexibility which has a great dielectric properties and a high transporter versatility of 3–5 cm²/V.s[10]. Numerous inorganic metal oxides of high-k concentrated to date incorporate HfO2 [11], TiO2 [12], Zirconium oxide (ZrO2) [13]. This work aims to enhance the performance of Pentacene-based OFET depending on two different gate dielectric materials (ZrO2 and PVP) by using it as monolayer and bilayer.
2. Device Structure

Pentacene-based OFET with bottom-gate/top contact with 50nm thickness; the parameters used in this work are listed in Table 1. The schematic structure of the Pentacene-based OFETs has appeared in Figure 1.

![Schematic of OFET](image)

**Figure 1:** Schematic of OFET

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel length, L</td>
<td>1 μm</td>
</tr>
<tr>
<td>Thickness, t</td>
<td>100 nm</td>
</tr>
<tr>
<td>Channel width, W</td>
<td>2.1 μm</td>
</tr>
<tr>
<td>Dielectric constant for PVP, k</td>
<td>4.5</td>
</tr>
<tr>
<td>Dielectric constant for ZrO2, k</td>
<td>23</td>
</tr>
<tr>
<td>Mobility, μ</td>
<td>5 Cm2/V.S</td>
</tr>
<tr>
<td>Threshold voltage, Vth</td>
<td>360</td>
</tr>
</tbody>
</table>

Table 1: Physical parameter for simulation structure

3. Simulation

A typical model of field-impact transistors gives $I_d$ in the direct regime [14].

$$I_d = \frac{W}{L} \frac{C_i}{\mu} \times \left[ (V_g - V_T) \times V_d - \frac{V_d^2}{2} \right]$$  \hspace{1cm} (1)

With $V_d < V_g - V_T$

$$I_d = \frac{W}{2L} C_i \mu_{\text{sat.}} \times (V_g - V_T)^2$$ \hspace{1cm} (2)

While the trans conductance of indirect and the immersion locale of the OFET is given by [15]

The Linear region

$$g_m = \frac{\partial I_d}{\partial V_g} = \mu C_i \frac{W}{L} V_d$$ \hspace{1cm} (3)

The saturation region

$$g_m = \frac{\partial I_d}{\partial V_g} = \mu C_i \frac{W}{L} (V_g - V_T)$$ \hspace{1cm} (4)

Where $W$ and $L$ are the channel width and length, individually. $C_i$ the geometric capacitance of the dielectric layer, $V_g$ is the voltage applied to the entryway contact, $V_d$ is the voltage applied to the channel contact, and $\mu$ is the mobility. MATLAB recreation was utilized to extricate parameters, for example, portability from the electrical portrayal of Pentacene-based OFETs.

4. Results and Discussion

4.1 Output Characteristics

Figures 2 and 3 show OFET-based Pentacene for PVP and ZrO$_2$ as natural protector layers individually. It shows a regular yield bend of a field-impact transistor (FET) which demonstrates that solitary gaps are gathered at the semiconductor-dielectric interface and flow stream from the source to the channel through the channel area when negative entryway voltages are applied. In this way, the OFET is working in the p-direct activity in aggregation mode with expanding negative channel current.
The drain current increases with increasing the negative drain voltage till arises saturation region and this is because of the channel pinch-off. It can be the observed improvement of the drain current by using ZrO$_2$ insulator against PVP insulator such behavior can be attributed to the differences in dielectric constant for the two materials which leads to an increase in the effective capacitance $C_i$, which is defined as $C_i$, which is defined as [16]:

$$C_i = \frac{\varepsilon}{t}$$ (5)

Which the carriers charge density increasing too

$$Q = C_i (V_g - VT)$$ (6)

Figure 4, shows more increase in the $I_d$ for ZrO$_2$/PVP comparing with PVP and ZrO$_2$, because of the increase of the total dielectric capacitance $C_{total}$, which is given by Eq. (7):

$$C_{total} = C_{PVP} + C_{ZrO_2}$$ (7)

The highest current that can be obtained for ZrO$_2$/PVP of OFETs is $I_d = -0.0031$A at $V_g = -40$V. These high values of the drain current can be associated with the high capacitance of the ZrO$_2$/PVP layer.

4.2 Transfer Characteristics

Figure 5 shows the ordinary exchange qualities of OFET dependent on PVP, ZrO$_2$ and ZrO$_2$/PVP dielectric with $V_g$ clearing from 0V to -50V and $V_d = -50$V and thickness =100nm. Obviously, as the channel inclination expanded the channel field brings down the source to channel hindrance which builds the charge bearer Q, towards the start of the channel; they will cross the boundary, which in the end will prompt an increment of the channel current. The best estimations of the channel flow are gotten for dielectric material (ZrO$_2$/PVP) contrasting and PVP and ZrO$_2$. The most noteworthy estimation of the channel flow for the ZrO$_2$/PVP dielectric of OFETs was acquired right now 0.0015A at $V_g = -40$V. A diminishing in the channel current for all gate voltages contrasting and the most elevated estimation of the channel current at $V_g = -50$V, is identified with the edge voltage move as it were.
4.3 Trans conductance Characteristics

Figure 6 represents Trans conductance as a function of gate voltage for Pentacene OFET. At Vg= 0V for gate insulator ZrO₂, PVP and ZrO₂/PVP high Trans conductance is estimated to equal gm. =-0.5517x10^-4A/V, -0.9931x10^-5A/V, and -0.6511 x10^-4A/V respectively. It can be observed an improvement of the Trans conductance by using ZrO₂ insulator against PVP insulator, while the best values of the Trans conductance were obtained for dielectric material (ZrO₂/PVP) comparing with PVP and ZrO₂. These results show an improvement of the trans conductance by using ZrO₂ insulator against PVP insulator, while the best values of the trans conductance are obtained for dielectric material (ZrO₂/PVP) comparing with PVP and ZrO₂, and that is because the increase in the capacitance will induce more charge carriers by the same gate voltage, this behavior is in agreement with Demur et al. [17].

5. CONCLUSIONS

Top contact/ bottom gate Pentacene-based OFETs having a monolayer and bilayer of PVP and ZrO₂ as gate dielectric was studied. The electrical characteristics were calculated by using the MATLAB program in order to study the effect of gate dielectric on the device performance. The results show the best performance was bilayer ZrO₂/PVP than the monolayer PVP and ZrO₂ for I-V characteristics and trans conductance.

Author contribution

All authors contributed equally to this work.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

References


