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Pentacene Based Organic Field Effect Transistor Using Different Gate Dielectric

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HIGHLIGHTS

- Modeling of Organic field effect transistors were conceded.
- Focusing on the effect of dielectric materials on the OFET performance.
- Comparison between two different dielectric materials (PVP, ZrO2) was considering.
- I-V characteristics were analyzed and studied.

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ABSTRACT

This paper presents the electrical behavior of the top contact/ bottom gate of an organic field-effect transistor (OFET) utilizing Pentacene as a semiconductor layer with two distinctive gate dielectric materials Polyvinylpyrrolidone (PVP) and Zirconium oxide (ZrO_2) were chosen. The influence of the monolayer and bilayer gates insulator on OFET performance was investigated. MATLAB software was used to simulate and determine the electrical characteristics of a device. The output and transfer characteristics were studied for ZrO_2, PVP and ZrO_2/PVP as an organic gate insulator layer. Both characteristics show a high drain current at the gate dielectric ZrO_2/PVP equal to -0.0031A and -0.0015A for output and transfer characteristics respectively, this can be attributed to an increase in the dielectric capacitance. Trans conductance characteristics also studied the gate dielectric materials and show the ZrO_2/PVP gate dielectric having a higher value from the monolayer, indicating the effect of dielectric capacitance.

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 ($C_{22}H_{14}$) 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 cm^2/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 $cm^2V^1s^1$[10]. Numerous inorganic metal oxides of high-k concentrated to date incorporate HfO_2 [11], TiO_2 [12], Zirconium oxide (ZrO_2) [13]. This work aims to enhance the performance of Pentacene-based OFET depending on two different gate dielectric materials ($ZrO_2$and PVP) by using it as monolayer and bilayer.

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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.

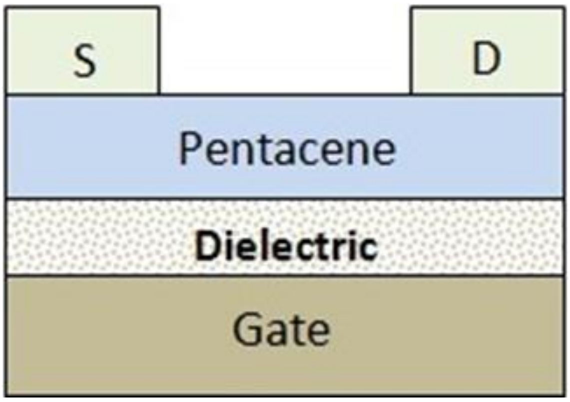

Figure 1: Schematic of OFET

Table 1: Physical parameter for simulation structure

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

3. Simulation

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

$$I_d = \frac{WC_i}{L}\mu \times \left[(V_g - V_T) \times V_d - \frac{V_d^2}{2}\right] \quad (1)$$

With $V_d < V_g - V_T$

$$I_d = \frac{WC_i}{2L}\mu_{sat.} \times (V_g - V_T)^2 \quad (2)$$

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

The Linear region $$g_m = \frac{\partial I_d}{\partial V_g} = \mu C_i \frac{W}{L} V_d \quad (3)$$

The saturation region $$g_m = \frac{\partial I_D}{\partial V_g} = \mu C_i \frac{W}{L}(V_g - V_T) \quad (4)$$

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 µ 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.

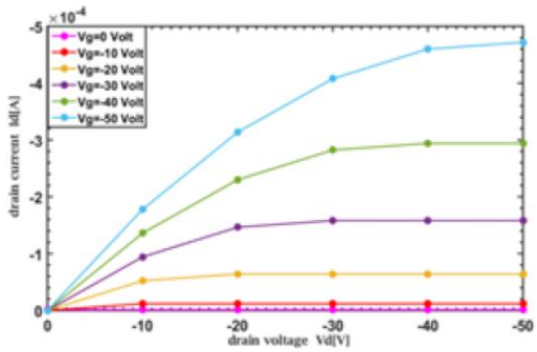

Figure 2: Output Characteristics of gate insulator PVP

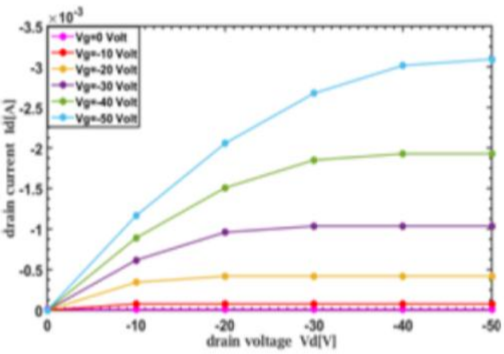

Figure 3: Output Characteristics of gate insulator ZrO2

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 Ci, which is defined as Ci, which is defined as [16]:

$$C_i = \boldsymbol{k}_{\circ}\varepsilon/t \qquad (5)$$

Which the carriers charge density increasing too

$$Q = Ci\ (Vg-VT) \qquad (6)$$

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):

$$C_{total} = CPVP + CZrO_2 \qquad (7)$$

The highest current that can be obtained for ZrO_2/PVP of OFETs is I_d = -0.0031A at V_g =-40V. These high values of the drain current can be associated with the high capacitance of the ZrO_2/PVP layer.

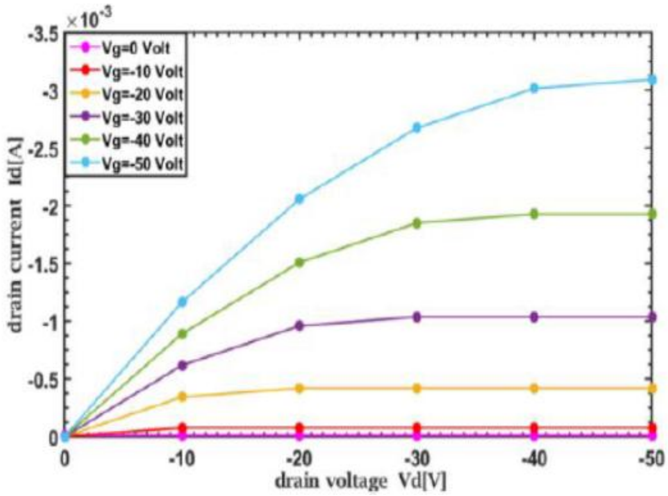

Figure 1: Output Characteristics of gate insulator PVP/ZrO_2

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 = -50V 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 = -40V. A diminishing in the channel current for all gate voltages contrasting and the most elevated estimation of the channel current at V_g = -50V, 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 ZrO_2, PVP and ZrO_2/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 ZrO_2 insulator against PVP insulator, while the best values of the Trans conductance were obtained for dielectric material (ZrO_2/PVP) comparing with PVP and ZrO_2. These results show an improvement of the trans conductance by using ZrO_2 insulator against PVP insulator, while the best values of the trans conductance are obtained for dielectric material (ZrO_2/PVP) comparing with PVP and ZrO_2, 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].

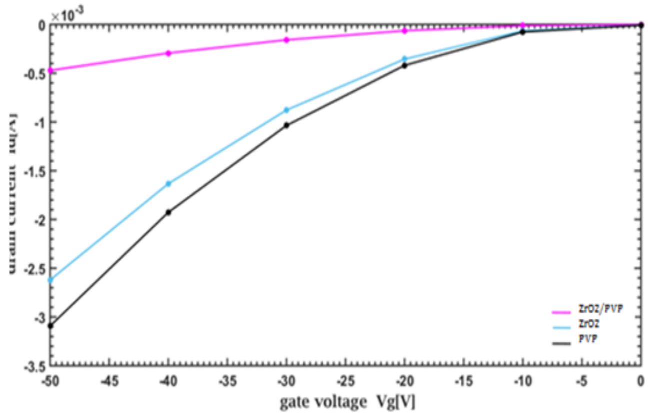

Figure 2: Transfer characteristics of gate insulator ZrO_2/PVP

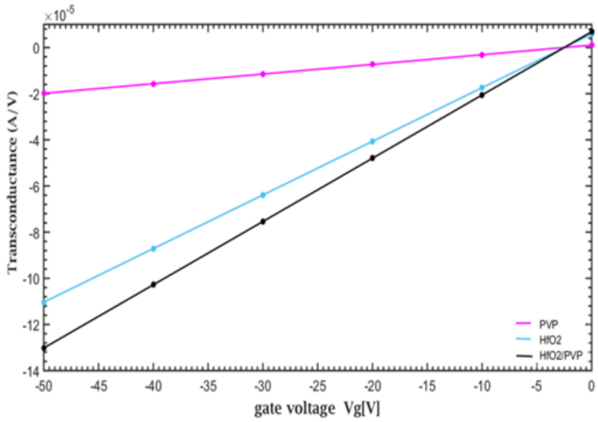

Figure 3: Trans conductance of gate insulators PVP, ZrO_2 and ZrO_2/PVP

5. CONCLUSIONS

Top contact/ bottom gate Pentacene-based OFETs having a monolayer and bilayer of PVP and ZrO_2 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 ZrO_2/PVP than the monolayer PVP and ZrO_2 for I-V characteristics and trans conductance.

Author contribution

All authors contributed equally to this work.

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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.

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