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Effect of Dielectric Thickness on the Performance of Pentacene-Based Phototransistor with Field-Effect Transistor

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Abstract

In this paper, Pentacene thin film field effect phototransistors were fabricated and the influence of changing the thickness of bi-layer dielectric materials Polyvinylpyrrolidone (PVP) / Zirconium Oxide (ZrO_2) on the performance of the phototransistor was studied. By changing the thickness (t) of (PVP/ZrO_2) layer from 100 nm to 200 nm & 300 nm the electrical characteristics current (I_d) & transconductance (g_m) values were calculated by MATLAB software simulation, and the influence showed decreasing of these values by increasing the thickness (t) where the best value of current I_d = -1.25A and transconductance g_m = -1.3A/V was at thickness t = 100 nm. Photoresponsivity (R) also was calculated by different values of incident power (P) (20, 40, 60, 80 & 100) mW/cm^2 which decreasing Photoresponsivity by increasing the incident power.

Keywords: Organic field-effect transistor (OFET), Organic phototransistor, Pentacene thin film, Photoresponivity

1. Introduction

Due to the advantages of organic semiconductors (OSCs), such as easy preparation, low cost, light weight, and compatibility with soft substrates, researchers combined the photoconductive effect of OSCs with the field effect of OFETs to fabricate field-effect transistor (FET)-based photodetectors [1]–[4] with excellent photosensitive properties and easy integration into electronic circuits.(yang)

Among these OSCs, pentacene with high air stability, high carrier mobility, and Bon/off[current ratio ًIon=Ioffق has exhibited highly electrical and photosensitive characteristics, and it is an ideal candidate as the active layer in the organic photodetector with FET configuration [2]–[4], [11](yang)

The thin film transistors based on p-type organic semiconductors have showed the high-performance and high mobility of the order of 1 $cm^2/V\ s$ [12–14], organic solar cells (OSCs) [15], organic light emitting diodes (OLEDs) [16] and organic photodiodes (OPDs) and phototransistors (OPTs) [17].(article)

Different kinds of organic semiconducting materials were tried by various researchers around the world with different dielectric materials and device architectures in order to enhance and optimize the performance of organic phototransistors. P-Type organic semiconductors have been extensively used in organic thin film transistors applications and furthermore, high performance OTFTs can be improved by use of derivatives of pentacene, rubrene, anthracene, or thiophene[13, 14, 18, 19]. On the other hand, organic phototransistors which are type of optical transducer in which light detection and signal amplification are one of three terminal optoelectronic devices in which light can be used as an external stimulus to create photogenerated carriers in addition to the carriers induced by the gate voltage [20-23]. Organic phototransistors (OPTs) are considered to be one of the feasible applications of OTFTs because of their large absorption properties in visible light and the excellent photo current generation [24–27].(article)

2. Device Structure

Figure 1 shows the schematic diagram of the Pentacene thin film phototransistor structure**.** verticalOFET where structure a top contact /bottom gate configuration was chosen. and the gate dielectric materials used were PVP/ZrO_2. The organic semiconductor was Pentacene with gold electrodes for source and drain connections. And by applying the equation (2.18) MATLAB software was used to plot the I-V characteristics of PVP/ZrO_2-Pentacene thin film phototransistor.

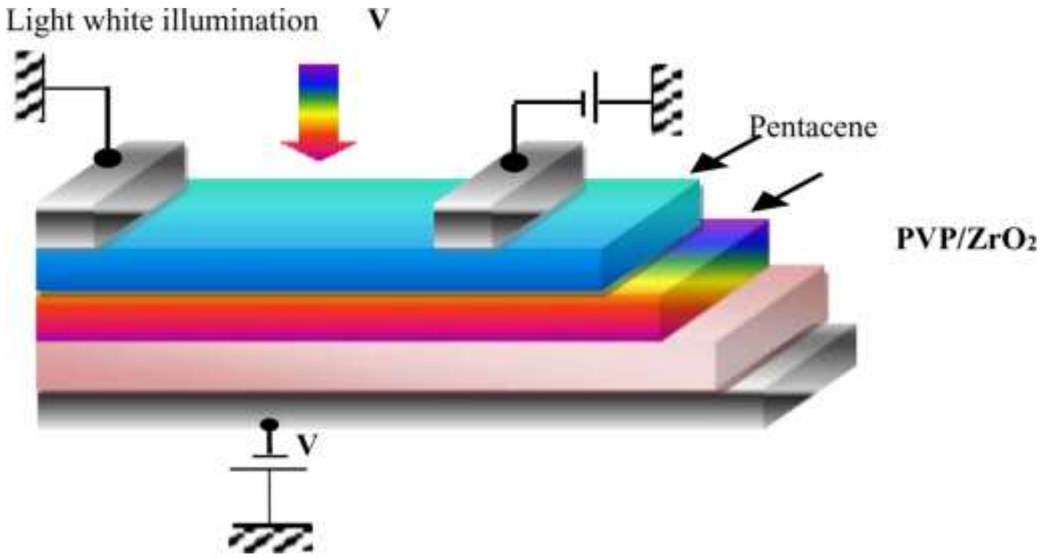

Figure (2.1): The schematic diagram of the Pentacene thin film phototransistor structure.[28]

Mathematical Approach

A typical model of field-impact transistors gives Id in the direct regime [29].

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

With $V_d < V_g - V_T$

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

While the transconductance of in direct and the immersion locale of the OFET is given by [30]

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

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.

The photocurrent can be written as a direct photocurrent $I_{ph,direct}$ multiplied by the optical-to-electrical gain G.[31]

$$I_{ph} = I_{ph,\text{ direct}} \cdot G = \eta_{IQE}\frac{qP_{ill}}{h\nu} \cdot G \quad (5)$$

Where:

η_{IQE}: is the internal quantum efficiency representing the number of charge carriers photogenerated per photon.

I_{ph}The direct photocurrent represents the photocurrent without any gain.

The responsivity depends on the wavelength of the illumination source. To avoid this the external quantum efficiency η_{EQE} can be used.

$$\eta_{EQE} = \frac{\frac{I_{ph}}{q}}{\frac{P_{ill}}{h\nu}} \quad (6)$$

Where:

η_{EQE}: the external quantum efficiency.

I_{ph}: is the photocurrent through the photodetector.

q:the charge of electron.

P_{ill}: the incident illumination power.

$h\nu$: photons energy.

An important parameter of photoresponsive organic thin filmtransistors is photoresponsivity and it is expressed by the following relation [32]:

$$R = \frac{I_{ph}}{P_{opt}} = \frac{(I_{ill} - I_{dark})}{P.A}$$

Where Iph is the drain-source photocurrent, Popt is the incidentoptical power, P is the power of the incident light per unit area, Iill is the drain–source current under illumination, Idarkis the drain-source current under dark and A is the effective device area.

3. RESULTS AND DISCUSSION

To investigate the influence of the dielectric layer thickness on the FET-based organic photodetectors, we used device with PVP/ZrO_2 at thickness 100 nm, 200 nm, and 300 nm, respectively. The capacitance of the dielectric layer varies with its thickness, which determines the electrical property of the device.

Figures(3.6-3.11) shows the output and transfer characteristics of FET-based pentacene photodetectors. In Figures (3.6),(3.7) and (3.8) the linear and saturation regions of all the devices can be observed clearly with increasing negative gate voltages, exhibiting a typical p-channel accumulation-type FET behavior. At lower voltages, drain-source current-voltage (IDS_VDS) curves exhibit good linearity.

This confirms that a good ohmic contact was established between the pentacene and gold electrodes [33]. It can be seen that thinner dielectric layer exhibits higher saturation current and larger Ion/Ioff, and the highest Ion/Ioff of 10^{-4} is obtained at 100 nm because the capacity for storing charges decreases with increasing the thickness of the dielectric layer.

From the transfer characteristics in Figures. (3.9),(3.10) and (3.11) one can see that IDS decreases by two orders of magnitude as the thickness of the dielectric layer increases from 100 nm to 300 nm. In organic field-effect phototransistors (organic photoFETs), the transconductance of the field-effect transistor is used to amplify the photocurrent.

All electrical parameters of FET-based organic photodetectors were summarized in Table 1.

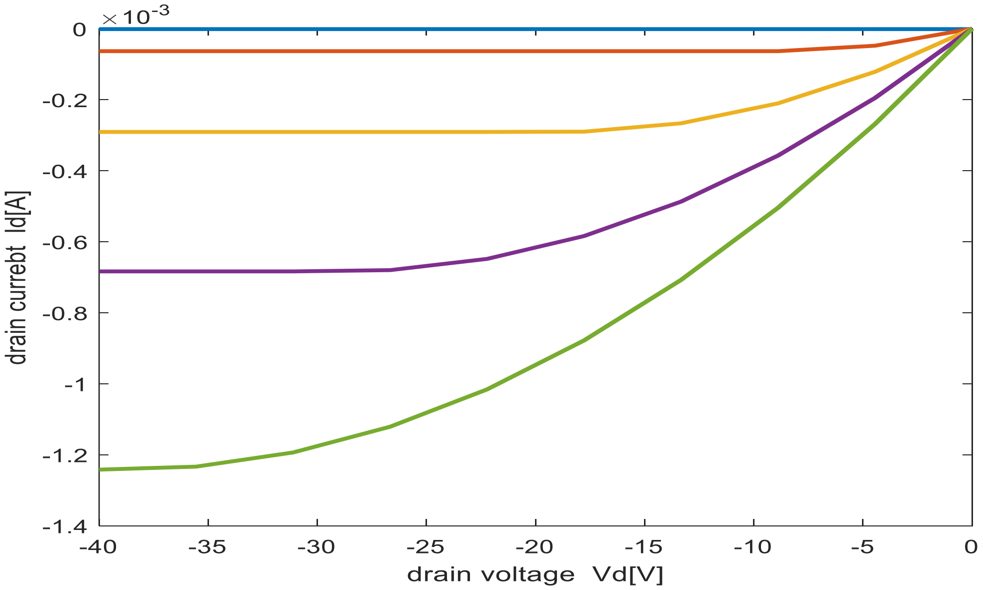

Fig.(3-1): Output characteristics of FET-based pentacene phototransistor of PVP/ZrO_2 t=100

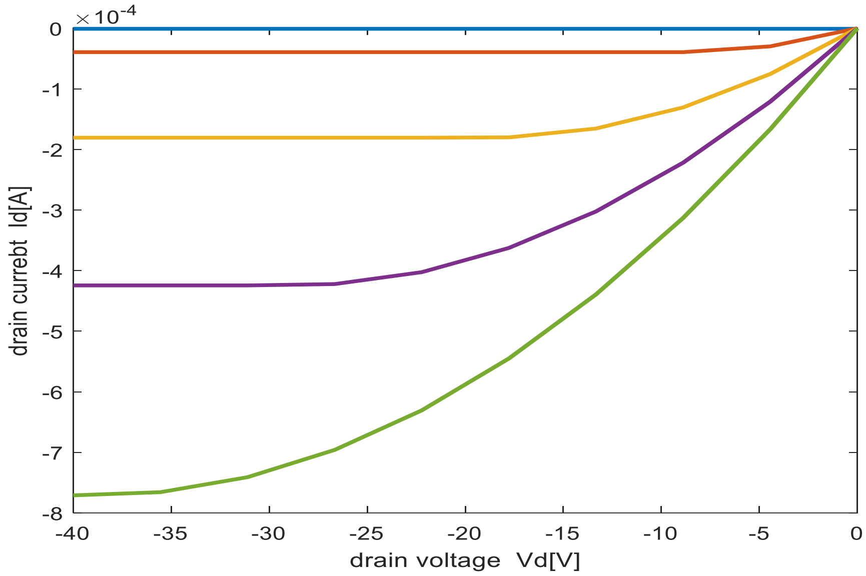

Fig.(3-2): Output characteristics of FET-based pentacene phototransistor of PVP/ZrO_2 t=200

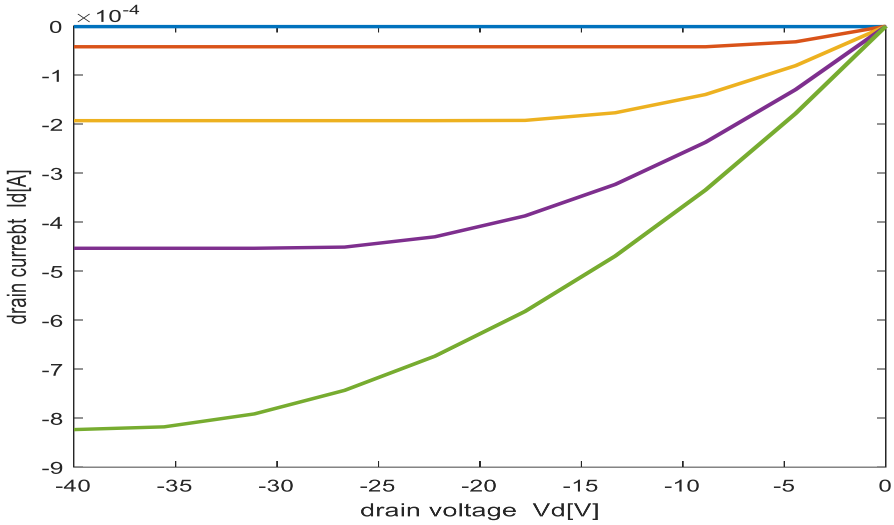

Fig.(3-3): Output characteristics of FET-based pentacene phototransistor of PVP/ZrO_2 t=300

Transfer characteristics

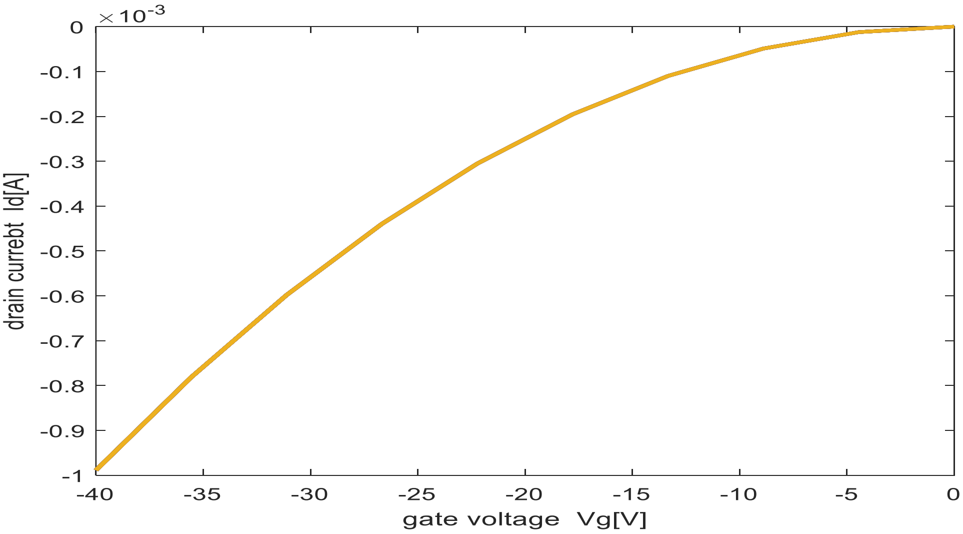

Fig.(3-4): transfer characteristic for PVP/ZrO2 at thickness 100nm(photo)

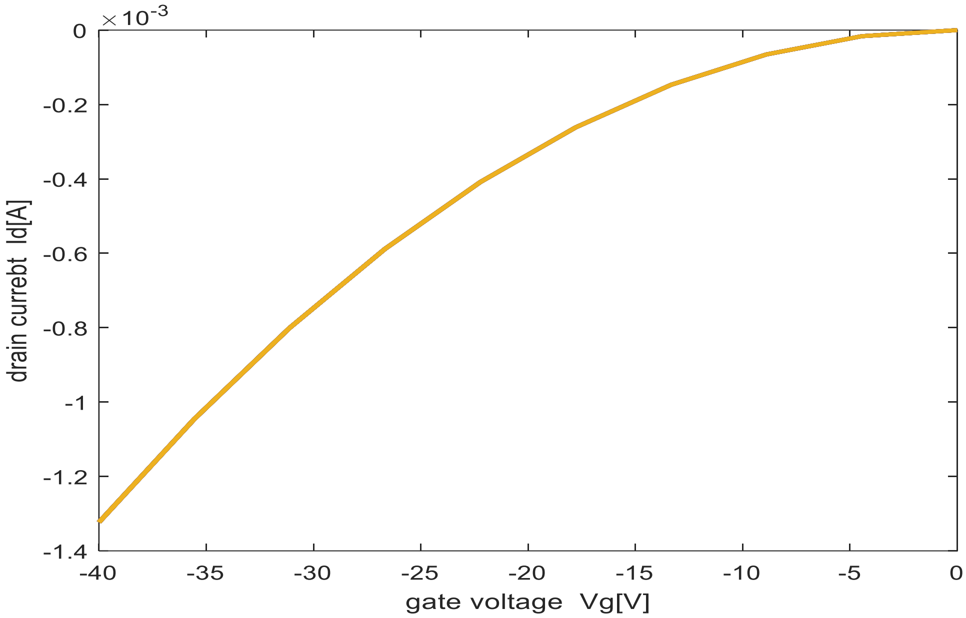

Fig.(3-5): transfer characteristic for PVP/ZrO2 at thickness 200nm(photo)

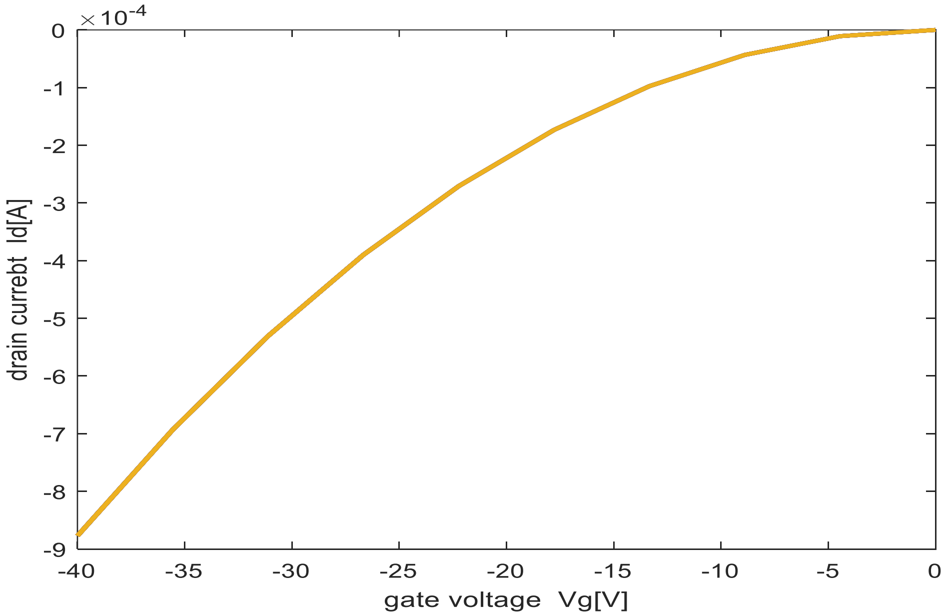

Fig.(3-6): transfer characteristic for PVP/ZrO2 at thickness 300nm(photo)

Transcountactance

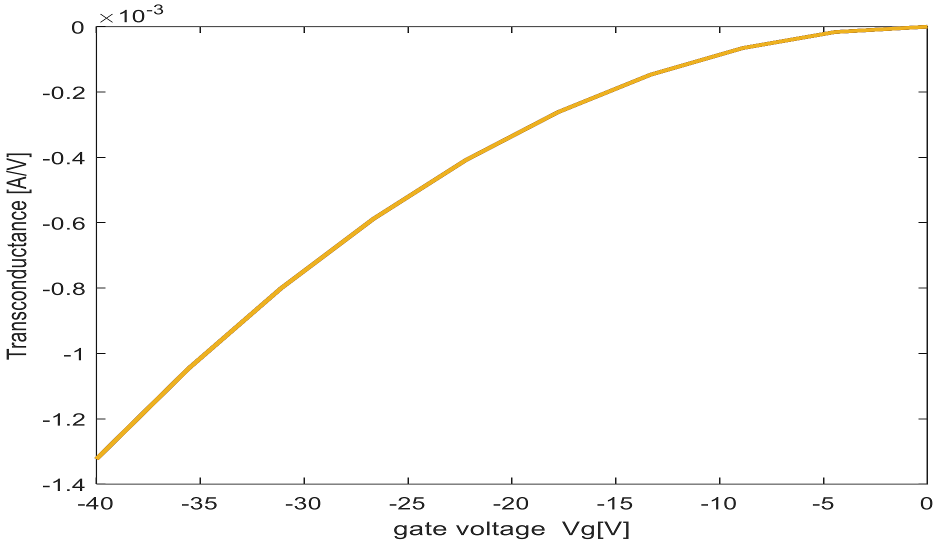

Fig.(3-7): transcorductance characteristic for PVP/ZrO2 at thickness 100nm

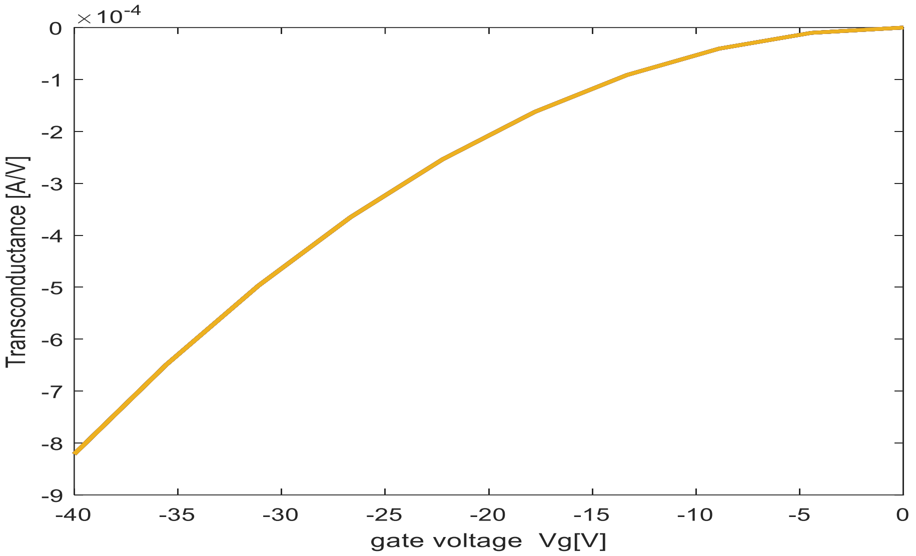

Fig.(3-8): Transconductance characteristic for PVP/ZrO2 at thickness 200nm

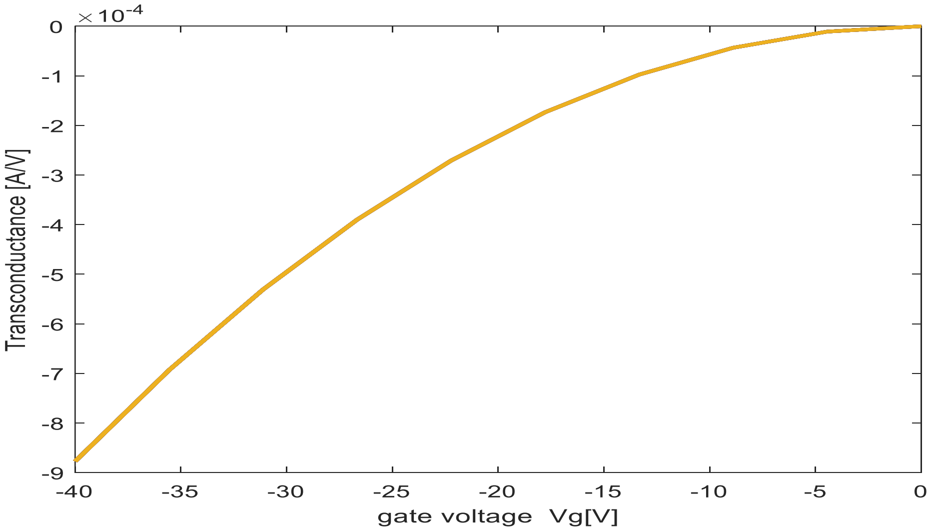

Fig.(3-9): Transconductance characteristic for PVP/ZrO2 at thickness 300nm

P	R
20 mW/ cm2	A/W 0.1250
40 mW/ cm2	A/W 0.0625
60 mW/ cm2	A/W 0.0417
80 mW/ cm2	A/W 0.0313
100 mW/ cm2	A/W 0.0250

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