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Review on Factors Influencing Performance of Organic Thin Film Transistors

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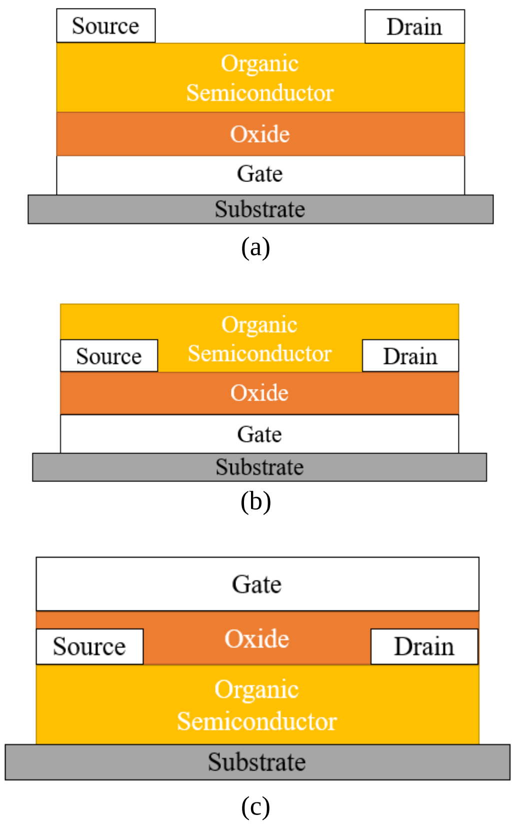
ABSTRACT: Organic semiconductor based organic transistors also known as organic thin film transistor (OTFT)are used in active matrix displays, integrated electronic circuits and low-cost radio-frequency identification(RFIDs). These organic compounds based electronic devices offers additional feature over conventional electronics such as mechanical flexibility, easily processible, low cost, etc. These transistors now exhibit good mobility comparable to amorphous silicon devices.As the technology is advancing at very fast pace there's need to enhance the various electrical characteristics of OTFT so that commercialization of such organic based devices can be done on large scale. In order to do that there's a need to understand various parameters that effect the behaviour of device so that proper optimization and enhancement of these devices can be done easily. This paper gives overview of variations observed in mobility, threshold voltage, maximum output current, and so on, by varying oxide material, device dimensions and electrode material.

Keywords: Mobility, on/off current ratio, organic transistor, contact resistance, short channel effects, channel length.

I. INTRODUCTION

Organic transistor or organic thin film transistortransistor (OTFT) are the devices consisting of organic compounds having good conductivity as an active material in which channel formation takes place at semiconductor and oxide interface, output current obtained can be controlled by applying variable gate voltage, thus it's also known as voltage controlled current device[1]. Earlier polythiophene was used as an insulator in the various packaging industries, but in 1978 Heeger et. al discovered charge transport phenomenon in organic compound for which they were awarded Nobel Prize later in 2000 [2],[3]. After this discovery electronic devices were made using organic semiconductors as an active layer material and these were known as organic devices. Organic electronics provides various benefits such as – low cost, lab processible, roll-to-roll printing, mechanical flexibility and so on. OTFT are used in various devices such as sensors, active matrix displays, electronic circuits, low cost RFIDs [4],[5],[6].

OTFT works in the accumulation mode of operation and based on the electrode placement with reference to the organic semiconductor material and also the gate electrode these can be classified into 4 different types as shown below [7],[8]–



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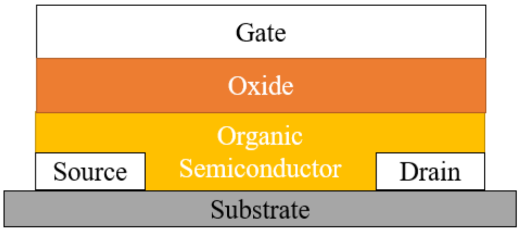

(d)

Figure 1. Various types of OTFT device structures – (a) Bottom gate top contact, (b) Bottom gate bottom contact, (c) Top gate top contact, (d) Top gate bottom contact.

In order to enhance the device performance of OTFTs such as obtaining higher on/off ratio, higher mobility, low threshold voltage, maximum output current, lower sub-threshold swing, etc. various device parameters need to be varied taking into consideration various effects such as charge injection mechanism, contact resistance, short channel effect and so on.

II. DISCUSSION

A. Organic semiconductor thickness Variation:

Through various experiments and simulations, it has been observed that organic semiconductor (OSC) thickness variation of OTFT devices effects – threshold voltage, mobility. This variation is observed due to increment in channel resistance and contact resistance [9].

Pentacene based OTFT was taken into consideration and OSC thickness was varied from 3nm to 50nm and the change in the mobility, threshold voltage and on/off current ratio was being observed. Table 1 shows the various results observed –

TABLE 1. PARAMETER VARIATION ACCORDING TO THE VARIATION IN SEMICONDUCTOR MATERIAL.

Parameters	**Values**		**Ref.**
Thickness of film (nm)	3	50	[10]
On/off ratio	76	640	
Threshold voltage (V)	19	9	
Mobility	0.055	0.046	

Form the above table 1 we can see that at lower oxide thickness threshold voltage was high and on/off ratio was low while at higher values of oxide thickness on/ ratio was increased and threshold voltage was decreased considerably. Contact resistance is increased on increasing thickness of OSC.

In another experiment Dibutylquaterthiophene (4QT4) was taken as active material for OFET and thickness of the device was varied from 20nm to 80nm and effects were observed on subthreshold slope and mobility. Table 2 shows various results observed-

TABLE 2. CHANGE IN PARAMETERS ACCORDING TO THE SEMOCONDUCTOR THICKNESS VARIATION.

Parameters	**Values**		**Ref.**
Thickness of film (nm)	20	80	[9]
Mobility (cm^2/Vs)	0.048	0.035	
Subthreshold slope	3.5	5	

From the above table 2 it can be clearly observed that subthreshold slope value has increased which is good for the better applications [7]. While in this case also it was observed that the mobility was reduced considerably.

So, from the above discussion it can be seen that on increasing the thickness of OSC mobility is reduced due to the increment in contact resistance, while there was improvement in other parameters - lowering of threshold voltage, higher slope value for subthreshold and improvement in on/off ratio.

B. Electrode material dependence –

Experimentally it has been observed that changing the material of source and drain electrode can enhance the performance of device.

Gold (Au) has high work function, good stability and is also compatible with p-type organic semiconductor such as pentacene, and gives good device performance when used as an electrode material for source and drain contact [11]. Silver (Ag) having low cost and good conductivity provides an alternative to be used in devices as an alternative of gold [12]. Poor performance of Copper (Cu) is due to low work function and it also causes large hole-injection barrier. On chemically treating this Cu with 7,7,8,8-tetracyanoquinodimethane (TCNQ) improved its work function which ultimately enhanced the performance of device [11]. In an experiment done on top contact device structure by taking these three different materials for source and drainelectrode various device performances were improved as being shown in the table 3 below –

TABLE 3. PERFORMANCE OF OFET FOR DIFFERENT ELECTRODE MATERIAL.

Electrode Material	**Mobility (cm^2/Vs)**	**On/off ratio**	**Threshold voltage (V)**	**Ref.**
Silver (Ag)	0.01	10^5	-36	[11]
Copper (Cu)	0.18	10^6	-17	
Gold (Au)	0.15	10^6	-17	

In another experiment two different material – multilayer graphene (MLG) and Gold (Au) were taken for source and drain electrode. In this case also it was observed that the performance was varied and good results were obtained with the device having graphene electrodes. MLG is having the good conductivity, great stability which enhances the performance and in addition to this good interconnection of pentacene with graphene. Improved performance parameters of these devices are shown in table 4-

TABLE 4. PERFORMANCE OF OFET FOR TWO DIFFERENT ELECTRODE MATERIAL.

Electrode Material	**Mobility (cm^2/Vs)**	**On/off ratio**	**Drain Current (μA)**	**Ref.**
Graphene	0.41	10^7	-175	[13]
Gold (Au)	0.16	10^6	-2.1	

Form the above results obtained it can be observed that by using such material which have good stability, good conductivity, high work function and compatibility with OSC can enhance various device performance and optimization can be done as per the need.

C. Dielectric material dependence –

Performance of device depends on the dielectric material used in device. When we use material having high-k it enhances gate capacitance of device and helps in inducing high charge carrier density which enhances on current of device [14].
Experiment was performed by taking ATO and silicon dioxide (SiO_2) as the dielectric material for two different devices and the variations were observed in – on/off ratio, threshold voltage and mobility as shown in the table 5 below –

TABLE 5. DEVICE PARAMETERS FOR DIFFERENT DIEELCTRIC MATERIAL.

Parameters	**Values**		**Ref.**
Dielectric material	SiO_2	ATO	[14]
On/off ratio	10^4	$3x10^3$	
Threshold voltage (V)	-6.0	-0.99	
Mobility (cm^2/Vs)	0.17	0.80	

It's clearly observed that by using ATO material as dielectric mobility and threshold voltages were enhanced but on/off ratio was degraded [14].

III. CONCLUSION

On the basis of the experimental data analysed it can be stated that by changing the thickness of the organic semiconductor material, different type of material used for the source and drain electrodes and type of dielectric material used some of the parameters are improved while some does not show any improvement. So, according to the need of the device such as whether it should have low threshold voltage or high on/off ratio or higher mobility corresponding parameter should be altered and optimum results can be obtained.

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