Performance Comparison of Single and Dual Gates Organic Thin Film Transistors

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***Abstract*- Organic device modeling and application of organic transistors are rapidly emerging area of research now a day. This trend is developing due to various advantages of organic material offers such as fabrication over large area and flexible-electronics at lower-cost and temperature. Considering this fact, this paper presents overview of various OTFT structures. The result-analysis is implemented through industry standard Atlas 2-D-organic-module-simulator for both the devices. The comparison-between single-gate and dual-gate organic transistors is discusses based on various factors such as OTFT structures and thin-film-material-layers. The characteristics of the single-gate and dual-gate-structures is performed as well. Dual-gate-organic transistor is depicts-better-performance in comparison to its counterpart.**

Index Terms — Dual gate organic transistor, Bottom contact, Organic thin-film transistor, Pentacene, Single gate organic transistor, Top contact.

I. INTRODUCTION

The Over the past several years, organic field effect transistor (OFET) is under continuous development and extensively in use for low cost display applications and flexible circuitry owing to its compatibility with flexible substrates. Therefore, its popularity has been enhanced due to its unique properties such as ease of processing, lower temperature fabrication process, lower production cost, and large-area-applications which makes the fabrication of organic transistors easy on unconventional-substrates such as-plastic, paper and fabric etc. Shirakawa et al [1] demonstrated first conducting organic material which opened this new domain for research. Organic transistors fabricated by using solution-processing methods have been demonstrated for large-area, low-cost, and flexible-electronic-applications [2-10].

Organic transistors are extremely robust and flexible mechanically. One very important advantage of Organic transistor is that it can-be fabricated even at low-er temperature, which is best for the application of organic-light-emitting-diode (O-LED) display, as backplane driver and sensors which require large area for better operation and radio-frequency-identification-(RFID)-tags [3]. They emerge as best options for low-cost large-area-flexible integrated-circuits. Fabrication methodologies have improved tremendously which has made them appropriate for commercialization.

An OTFT structure design is layered in nature. It consists a thin film of organic semi-conductor (OSC) as the active layer, it also has three electrodes named source (S), drain (D) and gate (G) and insulator material, wherein source injects carriers and drain extracts the carriers, respectively, while gate act as controller of the channel conductivities. The organicthin film transistor is similar to MOSFET structure wise [4] yet both are different in terms of operation and method of channel formation.

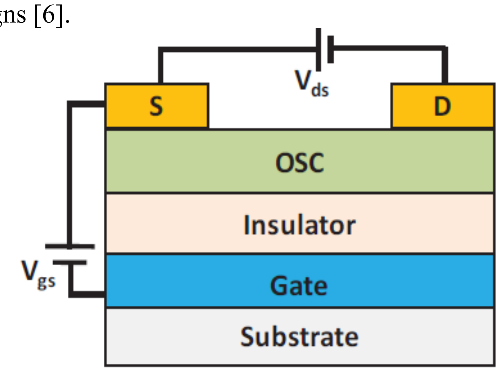
II. DIFFERENT ORGANIC TRANSISTOR STRUCTURES

There are mainly two types of organic transistors based on number of gates are available. First is single gate organic transistor and other is dual gate organic transistor.

A. Single Gate Organic Transistor

For the position of gate is concerned, the structure of a thin-film-transistor is of two types, depending upon the position of gate such as top-gate and-bottom-gate-structure. These structures are also of two types, classify-based on position of contacts (source- and drain), if the contacts are kept above active-layer it is called top-contact (T-C) and if contacts are planted inside the active layer, is called bottom contact (BC) structure. Based on these configurations four different combinations are possible [5]. The single gate OTFT structures are shown in Fig. 1 [10].

In top gate structure the gate metal is deposited at higher temperature thus suffers from contaminations and different types of defects. Therefore, bottom-gate-structures are generally-preferred in comparison to top-gate. Contact wise top-contact is easy to fabricate and demonstrate better stability and mobility. Due superior performance of bottom gate-top-contact device, it is used-in organic digital circuit designs [6].



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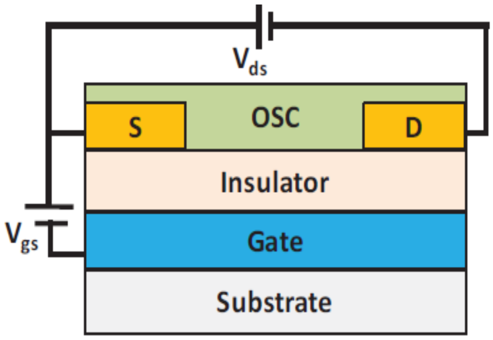

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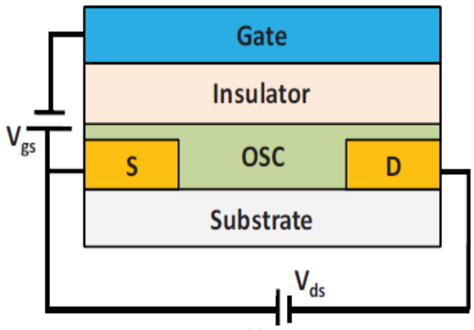

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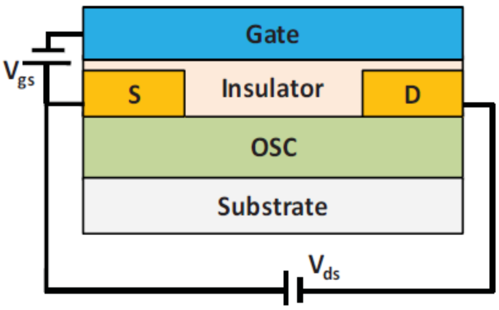

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Fig.1. Single Gate (a) bottom-gate-top-contact (b) bottom-gate-bottom-contact (c) top-gate-bottom-contact (d) top-gate-top-contact.

B. Dual-Gate-Organic-Transistor

Dual-gate-organic-transistors use two gates, one at the top and other at the bottom of active layer for better mobility and performance. Other materials such as OSC, gate electrodes, S/D metals are kept similar to that of single gate transistor as shown in Fig. 2. In 2005-Cui et-al. [7] discussed the first pentacene dual gate OSC. Bottom gate gathers the charges while the top gate biasing further increases carrier conductivity by attracting more charges in channel electro-statically. More charges shall provide better output characteristic. In dual-gate-mode the equation of the total-charge accumulated by-both-the-gates in active layer is-as-following:

$$Q_{Total} = C_B . V_B + C_T . V_T \qquad (1)$$

C_B/C_T is the capacitance at top gate and bottom gate.

Based on the biasing dual gate can work in three types of mode; first is top-gate, bottom-gate and dual-gate-modes. In case of top-gate-mode, a voltage at the top-gate is applied, while the gate-at-bottom is-grounded; however, case is opposite in the bottom-gate-mode as the bottom-gate is kept at supply voltage and top-gate has zero potential. Bottom-gate mode and top gate mode is similar-to-the-single gate structure.

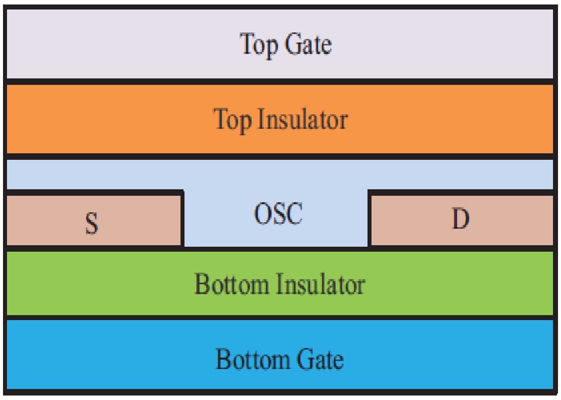


Fig. 2. Structure of dual gate organic transistors.

In single-gate-bias-mode, the second-gate-remains ineffective, whereas in DG-mode, both the gates are important in gathering the charge at the interface of OSC and insulator. By application of bias voltage at both the gates, more effective channel is formed in the active layer.

III. SIMULATION SETUP

Single and dual gate organic-transistor-structures are analyzed using standard-industry-standard-organic-module of Atlas Silvaco-simulator. ATLAS provides the physical 2-D and 3-D simulation of semiconductor devices. Atlas uses VWF interactive tools for analysis. VWF-interactive-tools-consists Deck build, Tony plot and Dev-edit [8]. Interactive-run-time-environment is provided by Deck-build whereas, Tony-plot provides scientific visualization capabilities. Poole-Frenkel mobility model for holes is adapted to calculate the device response and it is represented given by

$$\mu(E) = \mu_0 \exp\left[-\frac{\Delta}{kT} + \left(\frac{\beta}{kT} - \gamma\right)\right] \qquad (2)$$

Where μ_o is the zero mobility of field, E is electric field, μ is the field dependent mobility, Δ is the zero field activation energy and β is the hole Poole-Frenkel (PF) factor with value of 7.758 x 10^{-5}eV $(cm/V)^{0.5}$, T is temperature and k is the Boltzmann constant [9].

Poole-Frenkel conduction takes place because trapped charge carriers get excited thermally. The material properties of each layer and electrode of the simulated device are given in Table I with that all the structures are simulated [10,11]. Single gate structure is simulated with the parameters as shown in Table I. By Considering these structural parameters and material properties devices structure is analyzed. Both the structures are simulated with the identical parameters. The thickness of different layers and materials used in those layers are provides through Deck-build and performance is visualized through Tony-plot in terms of different plots and extracted parameters. Of both the devices.

TABLE I: MATERIAL PROPERTIES USED IN DEVICE ANALYSIS.

Material	Parameter	Value
Pentacene	Band Gap, Eg (eV)	2.2
	Electron affinity, χ (eV)	2.4
	Conduction Band Carrier Concentration, N_C (cm^{-3})	10^{21}
	Valence Band Carrier Concentration, N_V (cm^{-3})	10^{21}
	Acceptor Doping Carrier Concentration, N_A (cm^{-3})	10^{17}
	Permittivity	4.0
Gold(Au)	Work function	5.1
Aluminum	Work function	4.28
Aluminum Oxide	Permittivity	4.5

IV. PERFORMANCE ANALYSIS OF SG AND DG ORGANIC TRANSISTOR

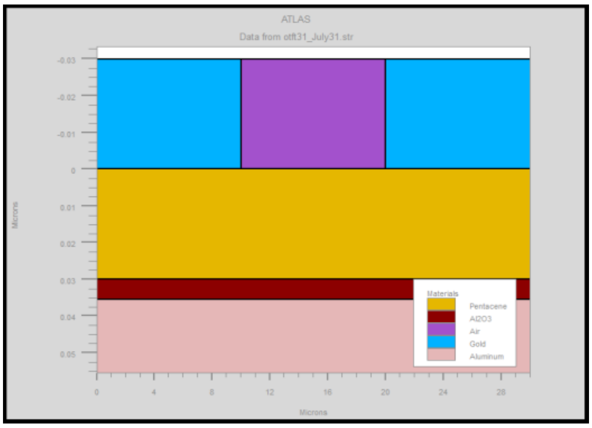
In digital circuits, the control of threshold-voltage is very important for better circuit operations. Since, the threshold voltage is the key to describe the switching power of a device, this parameter is very critical for any device. Similarly, there are several other parameters which should be kept in mind for comparison among various structures. A device simulation is performed for both the devices and the results are compared. The performance comparison is performed for single and dual gate device by considering the structural dimensions and material parameters as shown in Table II and Table III. The simulated schematic structure of both the devices are shown in Fig. 3 (a) and (b).

TABLE II: STRUCTURAL DIMENSION AND MATERIAL PARAMETERS OF SINGLE GATE ORGANIC TRANSISTOR.

Parameters	Dimensions	Materials
Organic Semiconductor Thickness	30nm	Pentacene
Gate Thickness	25nm	Silver
Gate Dielectric Thickness	5nm	Air
Source/Drain Thickness	30nm	Gold

TABLE III: STRUCTURAL DIMENSION AND MATERIAL PARAMETERS OF DUAL GATE ORGANIC TRANSISTOR.

Parameter	Dimensions	Materials
Organic Semiconductor Thickness	42.5nm	Pentacene
Top Gate Thickness	30nm	Silver
Top Gate Dielectric Thickness	23nm	Al2O3
Source/Drain Thickness	21nm	Gold
Bottom Gate Dielectric Thickness	23nm	SiO2
Bottom Gate Thickness	30nm	Silver



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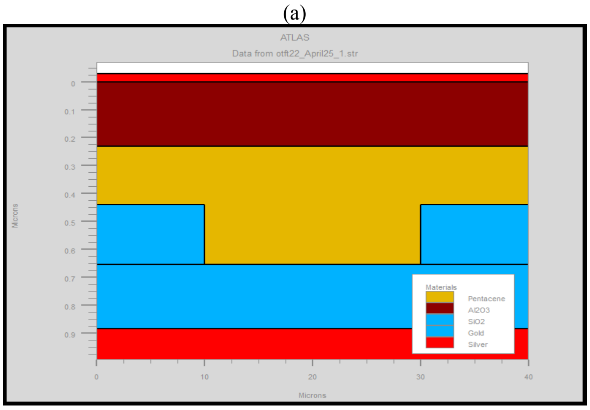

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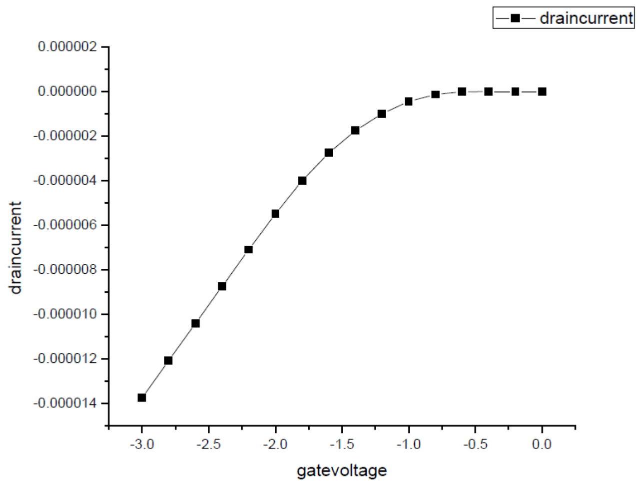
Fig. 3. Simulated structures of (a) single gate (b) dual gate organic transistor.



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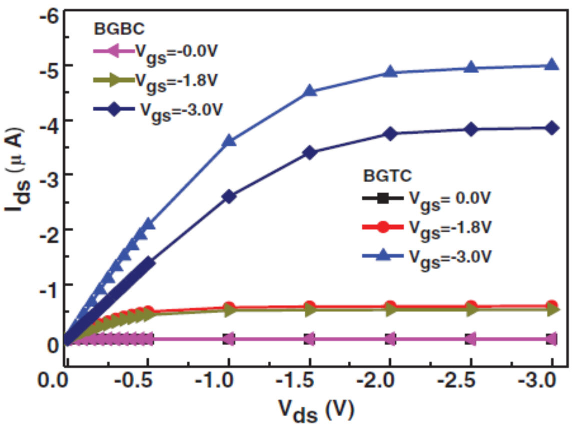

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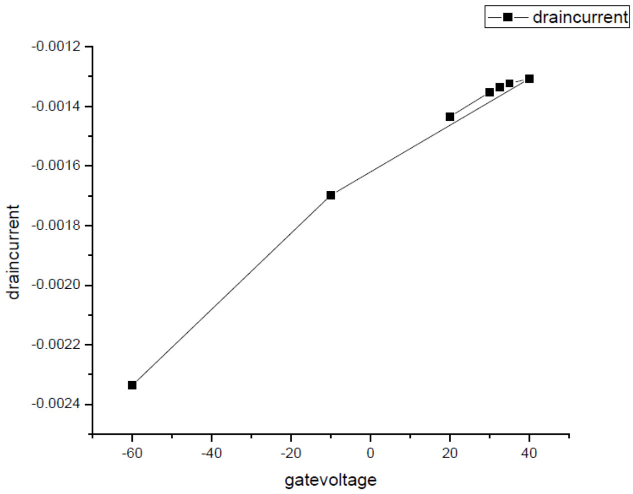

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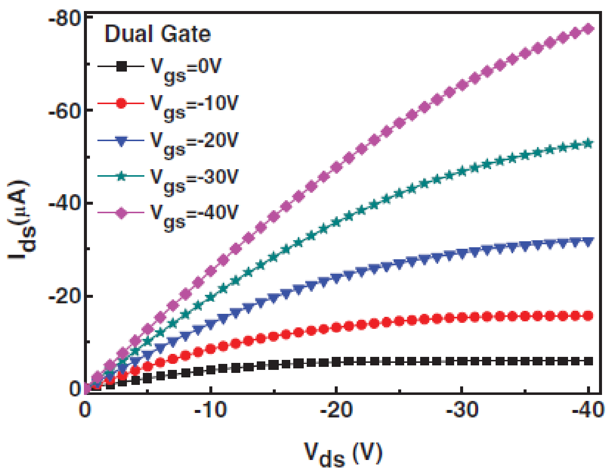

(d)

Fig. 4. (a) Single gate drain current-gate voltage characteristics (b) single gate output characteristics (c) dual gate drain current-gate voltage characteristics (d) dual gate output characteristics.

Based on the results analysis, the dual gate device has shown better performance in comparison to the single gate structure. The characteristic plots of both the devices are shown in the Figs. 4 (a) to (d). Dual gate may operate in large voltage range and the output drain current is several times higher than the single gate structure of any type. This certainly is due to one extra gate which provides higher charge accumulation in the channel area. The extracted performance parameters of SG and DG are shown in Table IV

TABLE IV: COMPARISON OF DIFFERENT PARAMETERS OF SINGLE GATE (SG) AND DUAL GATE (DG) ORGANIC TRANSISTORS.

Parameters	**Single Gate Organic Transistors (BGTC)**	**Dual Gate Organic Transistor**
Drain Current(A) (at3 V)	$14\text{x}10^{-5}$	$16\ \text{x}10^{-4}$
Threshold Voltage(V)	-1.0	-0.65
Sub Threshold Slope	1.3	2.8×10^{-5}
I_{on}/I_{off} Ratio	2×10^{2}	1.2×10^{4}

IV. CONCLUSION

The organic transistors have benefit of the flexibility over their silicon counterparts. Several structures of organic transistors have been presented. This paper compared their individual performances based on several factors. Here we can see that dual gate organic transistors possess higher performance than their single gate organic thin film counterparts. The drain current in dual gate is almost 10 times greater than the single gate structure. The organic transistors are quite comparable and even better to the silicon based devices considering high current on-off ratio and ease of fabrication. Therefore, dual gate devices should be preferred for the applications in flexible electronics such OLED displays, DNA sensors, smart cards, disposable circuitry and RFID Tags.

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