Numerical Simulation and Characterization of Pentacene based Organic Thin Film Transistors with Top and Bottom Gate Configurations

Pooja Kumari¹ and A. D. D. Dwivedi²

¹ Poornima University Jaipur

Received: 13 December 2018 Accepted: 5 January 2019 Published: 15 January 2019

Abstract

In this paper, we model the characteristics of top and bottom gate configurations of organic thin film transistors (OTFTs) including top gate top contact (TGTC), top gate bottom contact (TGBC), bottom gate top contact (BGTC), bottom gate bottom contact (BGBC). The path of charge carriers changes in different geometries which possess difference in the electrical behaviour of the devices. The performances of bottom and top gate pentacene based OTFT devices have been analyzed and their performance parameters like mobility, threshold voltage, sub threshold slope, trans conductance, on off ratio have been extracted and compared.

Keywords: organic thin film transistors (OTFTS), numerical simulation, pentacene, top gate top contact (TGTC), top gate bottom contact (TGBC), bottom gate top contact (BGTC) and bottom gate bottom contact (BGBC).

Index terms—organic thin film transistors (OTFTS), numerical simulation, pentacene, top gate top contact (tgtc).
1 II.
2 Experimental Setup
3 III. MODELLING AND NUMERICAL SIMULATION
4 a) Poisson’s equation
5 Poisson’s Equation relates variations in the electrostatic potential to local charge densities. It is mathematically described by the following relation [9][10][11][12][13][14][15][16][17][18][19][20][21][22][23].

\[ \frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2} = \rho_f/\varepsilon \]

Where \( V \) is the electrostatic potential, \( \rho_f \) is the local space charge density, \( \varepsilon \) is the local permittivity of the semiconductor (F/cm), \( m \) is the density of the crystal lattice (cm\(^{-2}\)), \( n \) is the electron density (cm\(^{-3}\)), \( N_0 \) is the ionized donor density (cm\(^{-3}\)) and \( N_a \) is the ionized acceptor density (cm\(^{-3}\)). The reference potential is always taken as the intrinsic Fermi potential for simulations in ATLAS. The local space charge density is the sum of all contributions from all mobile and fixed charges, including electrons, holes and ionized impurities.

5 b) Continuity Equations
6 For electrons and holes, the continuity equations are defined as follows:

\[ \frac{\partial n}{\partial t} + \nabla \cdot (n \mu E) = \mathcal{J}_n \]

\[ \frac{\partial p}{\partial t} + \nabla \cdot (p \mu E) = \mathcal{J}_p \]

Where \( n \) and \( p \) are the electron and hole densities, \( \mu \) is the mobility, \( E \) is the electric field, and \( \mathcal{J} \) is the generation rate.

5 c) Transport Equations
6 These equations are to specify the physical models for electrons and holes current densities and generation (recombination) rates. The Current density equations are obtained by using the "drift-diffusion" charge transport model. The reason for this choice lies in the inherent simplicity and the limitation of the number of independent variables to just three, \( n \), \( p \) and \( \mu \). The accuracy of this model is excellent for all technologically feasible feature sizes. The drift -diffusion model is described as follows:

\[ \mathcal{J}_n = n \mu E \]

\[ \mathcal{J}_p = p \mu E \]

7 The Density of Defect States
9 The density of the defect states (DOS) \( g(E) \), which dominates the properties of amorphous or polycrystalline TFTs, is modeled as a combination of four components [3], where \( E \) denotes the state energy.

The equations describing these terms are given as follows [5][6][7][8][9][10][11][12][13][14][15][16][17][18][19][20][21][22][23].

\[ g(E) = \begin{cases} A_1 E^{1/2} e^{-E/E_0} & E < E_0 \\ A_2 e^{-E/E_1} & E > E_0 \end{cases} \]

where \( A_1 \) and \( A_2 \) are the pre-exponential factors, \( E_0 \) is the trap energy level, \( E_1 \) is the recombination energy level, \( E_T \) is the trap energy level, and \( E_1 \) is the recombination energy level.
(N GA and N GD ), its characteristic decay energy (W GA and W GD ), and its peak energy/peak distribution (E GA and E GD ).

Input parameters used in the simulation of the OTFT devices with different geometries are summarized in Table ??I. V. RESULTS AND DISCUSSIONS All Organic thin film transistor devices were built up with technique of top gate and bottom gate configuration with top and bottom contacts. Electrical characterization and numerical simulation of the devices are measured using TCAD ATLAS by Silvaco International software and with the of characterization of devices, electrical performance parameters such as Mobility, Trans conductance, threshold voltage, Sub threshold sweep and on/off ratio were calculated.

Mobility is the rate of flow of charge carriers in the electric field. It is the parameter which deals with processing speed of device. This mobility (µ) has been calculated using the following equations, µ = (L × g m ) / (W × C ox × V ds ) (10) g m = dI ds / dV gs (11) C ox = ? ox / d ox (12) Here, g m is the trans conductance which is calculated by transfer characteristics curve (I ds /V ds ) and calculation is done by equation (11). L and W are length and width of device respectively. C ox is the capacitance of oxide with is the ratio of permittivity of oxide and thickness of oxide, given by equation ( ??2).V ds is drain voltage which is taken as 1V for all the devices.

Minimum From above calculation, it was observed that bottom gate configuration perform better than top gate configuration in terms of mobility, sub threshold slope and with good on off ratio but top gate configuration have higher on off ratio as compared to bottom gate configuration which is in magnitude of 10 8 .

8 VI. CONCLUSION

This paper presented the numerical simulation and characterization of bottom and top gate pentacene based OTFTs. The performances of these devices have been analyzed and their performance parameters like mobility, threshold voltage, sub threshold slope, trans conductance, on off ratio have been extracted and compared. It was observed that bottom gate configuration perform better than top gate configuration in terms of mobility, sub threshold slope and with good on off ratio but top gate configuration have higher on off ratio as compared to bottom gate configuration which is in magnitude of 10 8 .

9 Global Journal of Researches in Engineering ( ) Volume XIX Issue III Version I

Figure 1:
Figure 2: Fig. 1:

Figure 3: Fig. 2:
Figure 4:

Figure 5: Fig. 2 : Figure 3
1

<table>
<thead>
<tr>
<th>Device Parameter</th>
<th>Value (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel Width (W)</td>
<td>220</td>
</tr>
<tr>
<td>Channel length</td>
<td>10</td>
</tr>
<tr>
<td>Gate thickness, T_G</td>
<td>0.02</td>
</tr>
<tr>
<td>Dielectric thickness, t_ox</td>
<td>5.7 × 10^-3</td>
</tr>
<tr>
<td>Organic semiconductor thickness, t_osc</td>
<td>0.03</td>
</tr>
<tr>
<td>S/D contact thickness, t_c</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Figure 6: Table 1:

2

<table>
<thead>
<tr>
<th>Year</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>NTD</td>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters Effective density of state in conduction band (N_c)</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective density of state in valence</td>
<td>1.0 × 10^21 cm^-3</td>
</tr>
<tr>
<td>Dielectric constant for Al2O3 at 300K NTD band</td>
<td>8.5, 2.8, 1.0 × 10^18 cm^-3, 1.0 × 10^21 cm^-3</td>
</tr>
<tr>
<td>1.0 × 10^21 cm^-3</td>
<td></td>
</tr>
<tr>
<td>WTA</td>
<td>2.5 × 10^18 cm^-3 /eV</td>
</tr>
<tr>
<td>WTD</td>
<td>0.5 eV</td>
</tr>
<tr>
<td>WGD</td>
<td>0.129 eV</td>
</tr>
<tr>
<td>WGA</td>
<td>0.15 eV</td>
</tr>
</tbody>
</table>

Figure 7: Table 2:

3

<table>
<thead>
<tr>
<th>Structures</th>
<th>BGBG</th>
<th>BGTC</th>
<th>TGBG</th>
<th>TGTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>V t (V)</td>
<td>1.1</td>
<td>1.2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>On off ratio</td>
<td>1.9 × 10^-4</td>
<td>9.5 × 10^-3</td>
<td>1.9 × 10</td>
<td>7.9 × 10^-8</td>
</tr>
</tbody>
</table>

Figure 8: Table 3:
.1 ACKNOWLEDGEMENT

The authors are thankful to SERB, DST Government of India for the financial support under Early Career Research Award (ECRA) for Project No.ECR/2017/000179.


.1 ACKNOWLEDGEMENT


