2D Numerical Simulation and Modeling of High Performance Pentacene Organic Thin Film Transistor based on Poly (3-Dodecylthiophene-2, 5-Diyl) Dielectric Layer

Er. Pooja Kumari
Department of Electrical and Electronics Engineering
Poornima University
Jaipur, India
Email: poojaswami1410@gmail.com

Dr. A D D Dwivedi
Department of Electrical and Electronics Engineering
Poornima University
Jaipur, India
Email: adddwivedi@gmail.com

Abstract— Performance parameters are sarcastic to advance development of pentacene based organic thin film transistors (OTFTs). This paper presents design and numerical simulation of pentacene based organic thin film transistor with polymeric dielectric, Poly(3-Dodecylthiophene-2,5-Diyl) using two dimensional Computer aided Design (TCAD) tool. Transfer and Output Characteristics of device have been simulated and examined. Further, the model is presented with good electrical performance parameters such as, mobility, threshold voltage, on/off ratio and sub threshold slope. The simulation results designate the relevancy of the model under organic thin film transistors at process level.

***Keywords**—OTFT; Dielectric;TCAD; Numerical Simulation*

*****

I. INTRODUCTION

Organic thin film transistor is involving in the market because of its features like low temperature, low power, low fabrication cost which helped in the conception of electronic devices like Organic light emitting diode[1], Organic RFID tags[2], Organic sensors[3] and analog and digital circuits[4], active image matrix[5], static random access memory(SRAM)[6], e-paper[7], flexible integrated circuits[8] . A continuous development is being carried out with semiconductor and insulator materials to outcome a model with good electrical properties. This has led to focus on the transport phenomenon, models, electrical parameters, materials as well as the details of chemical and physical properties of the material. Requirement of numerical simulation is rising to optimize the device structures and to understand the operation of device. When we compare the silicon technology to this organic device technology, organic area is not so mature, as there is a demand of advancement in the electrical properties. Silvaco has been effort to develop the OTFT model which comprises organic device physics. In this paper, an attempt has been made to enquire OTFT technology using these models with 2D numerical Simulation.

This paper demonstrates finite element based 2D Numerical Simulation results of pentacene based bottom gate top contact Organic thin film transistor with Poly(3-Dodecylthiophene-2,5-Diyl) organic dielectric using technology computer aided design (TCAD) tool ATLAS^{TM} and extracted the performance parameters like mobility, threshold voltage, sub threshold slope and on off ratio.

II. EXPERIMENT

I. Numercal Simulation

Numerical Simulation of Pentacene based organic thin film transistor using Bottom gate Top contact (BGTC) technology has been executed using TCAD ATLAS by Silvaco international device simulation software. Fig.1. Shows the device structure which is used for the simulation. In the device under circumstances active channel of 30nm thick pentacene with 5.7nm thick Poly(3-Dodecylthiophene-2,5-Diyl) organic dielectric layer. In the structure, gold acts as source and drain contact and aluminum serves as gate electrode.

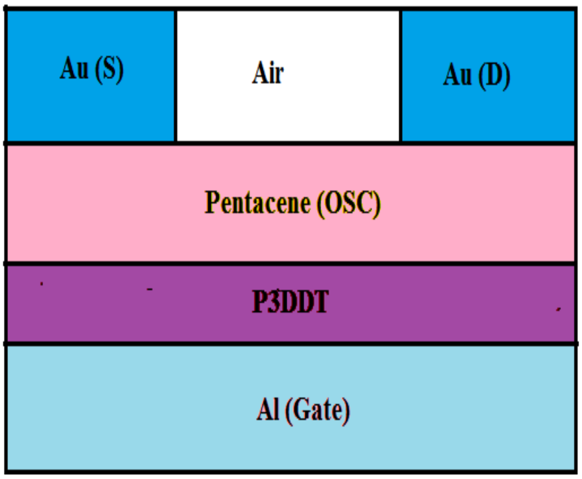

Figure1. Pentacene based OTFT Model used in Simulation

To simulate I-V characteristics of the device, It is important to know the charge carrier transportation in the semiconductor. In OTFT technology, determining factor for charge transport characteristics are energy distributions of density of states (DOS) within the bandgap. Software is able to anticipate the electrical characteristics of device by solving drift diffusion models for charge transport using finite element method. For holes and electrons to be set coupled, some differential equations like Poisson's equation and Continuity equations are solved numerically in the software which tends to obtain the electrical characteristics of the device [9-13]. These equations are given below:

ISSN: 2454-4248
05 – 07

$$\nabla.(\epsilon\nabla\varphi) = -\rho \quad (1)$$

$$\frac{\partial n}{\partial t} = \frac{1}{q}\nabla.Jn + Gn - Rn \quad (2)$$

$$\frac{\partial p}{\partial t} = -\frac{1}{q}\nabla.Jp + Gp - Rp \quad (3)$$

Here, φ is electrostatic potential, ρ is local space charge density, ε is local permittivity of the semiconductor, p is hole density, n is the electron density, N_d^+, ionized donor density and N_a^+, ionized acceptor density. n and p refers the electron and hole concentrations, J_n and J_p refers electron and hole current densities, G_n and G_p refers generation rate, R_n and R_p refers recombination rate for the electron and hole and q is electronic charge. Transport equations for electrons and holes in which J is current density for drift and diffusion components are given below:

$$J_n = q\, n\, \mu_n E_n + qD_n\, \Delta n \quad (4)$$

$$J_p = q\, n\, \mu_p E_p - qD_p\, \Delta p \quad (5)$$

As in the organic materials, the charge transport becomes field dependent at high electric field. Field dependent mobility which can be expressed by Poole Frenkel Model is admitted in the numerical simulation and given by equation (6)[10-13].

$$\mu(F(x),t) = \mu_0 \exp[-\frac{\Delta}{kT_0} + \frac{\delta}{kT_0}\sqrt{F(x)}] \quad (6)$$

Where, μ_0 denotes zero-field mobility, *F* denotes electric field intensity, Δ refers activation energy which is 1.792×10^{-2}eV for the simulation and δ is the characteristic parameter for field-dependence named Poole-Frenkel factor for simulation, it is taken as 7.758×10^{-5} eV$(cm/v)^{1/2}$.
For the device simulation in the simulator, Effective DOS for conduction and valence band was taken as1.0×10^{21} cm^{-3}. Valance and conduction band edge intercept densities was chosen as $1.0\times10^{18}cm^{-3}/eV$ and $2.5\times10^{18}cm^{-3}/eV$ respectively. Valance and conduction band characteristic decay energy was 0.5eV and 0.129eV respectively. Valence and conduction peak energy distribution were 0.78eV and 0.62eV respectively. The simulated transfer and output characteristics for Pentacene OTFT with P3DDT dielectric material are shown in Fig (2) and Fig.(3).

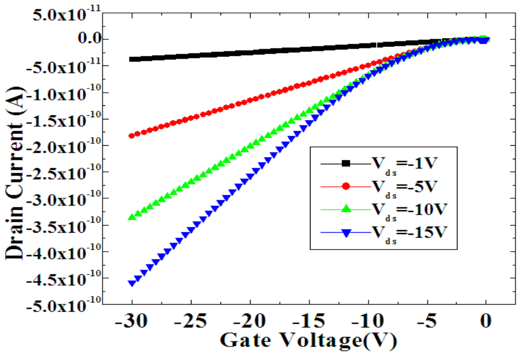

Figure2. Transfer Characteristics of Pentacene based OTFT with Poly(3-Dodecylthiophene-2,5-Diyl) Dielectric Material

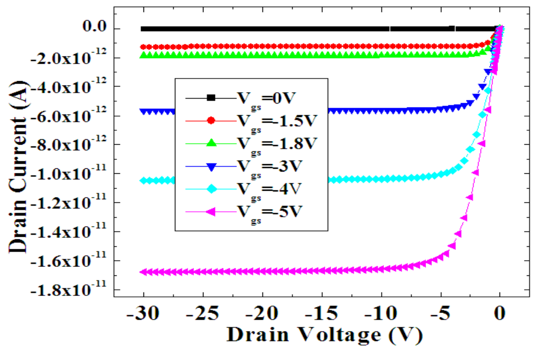

Figure3. Output Characteristics of Pentacene based OTFT with Poly(3-Dodecylthiophene-2,5-Diyl) Dielectric Material

II. *Parameter Extraction:*

For the extraction of Electrical parameters following equations are used during numerical simulation [11].

- *Mobility:* Velocity of average charge carrier per unit electric field is known as Mobility. Mobility shows efficient movement of charge carriers in conducting path which defines processing speed and on current.

$$\mu = \frac{g_m L}{W \times C_{ox} \times V_{ds}} \quad (7)$$

$$g_m = \frac{\partial I_{ds}}{\partial V_{gs}} \quad (8)$$

Where, μ is Mobility, g_m is transconductance, C_{ox} tends to capacitance of oxide. Mobility is also affected by another factor that is grain size which is how perfectly semiconductor layer is deposited.

- *Threshold Voltage:* Threshold Voltage is least gate voltage which is demanded to collect charge carriers at semiconductor insulator interface configurating a conducting path between drain to source. It influences on/off nature of device which should be controlled for getting proper operated device.
- *Current On/Off Ratio:* The ratio of the current in accumulation mode to the depletion mode is termed as the current on/off ratio.

$$I_{ON}/I_{OFF} = C_i\mu(V_{gs} - V_t)^2/t_{osc}V_{ds}\sigma \quad (9)$$

$$I_{OFF} = W/L\ (t_{osc}V_{ds}\sigma) \quad (10)$$

Where, σ refers conductivity of the channel, L and W tends channel length and channel width, C_i represents the gate dielectric capacitance per unit area. When we decrease the thickness of dielectric and semiconductor layer that increases I_{on} and decreases I_{off} and overall increase its ratio.

- *Sub Threshold Slope:* The ratio of change in the gate bias to the change in the drain current in logarithmic scale that can be expressed as,

$$SS = \partial V_{gs}/\partial \log_{10}(I_{ds}) \quad (11)$$

 ISSN: 2454-4248
05 – 07

It quantifies impurity concentration, interface state, and trap density which play role to involve switching behavior of a transistor.

Pentacene based Organic thin film transistor with P3DDT (Poly(3-Dodecylthiophene-2,5-Diyl)) dielectric layer was numerically simulated and the extracted value of Mobility was 6×10^{-3} $cm^2/v.s$, threshold voltage 1.4V, Sub threshold slope was 0.51 and on/off ratio was 1.2×10^3.

These results can be justified considering that the devices shows good eletcrical performance with this polymeric dielectric material Poly(3-Dodecylthiophene-2,5-Diyl) which shows a good on/off ratio with enhanced mobility results the overall device low cost and low power.

III. CONCLUSION

Poly(3-Dodecylthiophene-2,5-Diyl) polymeric gate dielectric was used in Pentacene based OTFT with Bottom gate top contact technology. 2D numerical simulation and modeling of device is done using technology computer aided design (TCAD) tool ATLAS™ from Silvaco International. We have simulated I-V characteristics of the device and extracted the performance parameters. The device shows good Electrical performance with values of parameters like Mobility of $6\times10^{-3} cm^2/v.s$, threshold voltage 1.4V, Sub threshold slope was 0.51 and on/off ratio was 1.2×10^3. Therefore, in the field of organic electronics, various developments are needed to achieve better performance and the device can better perform with improvement in materials which can be used for further work.

ACKNOWLEDGEMENT

The authors are thankful to SERB, DST Government of India for the financial support under the grant sanctioned for Project No.ECR/2017/000179.

REFERENCES

[1] Vacca, P., Petrosino, M., Guerra, A., Chierchia, R., Minarini, C., Sala, D. D., Rubino, "A.: The relation between the electrical, chemical, and morphological properties of indiumtin oxide layers and double-layer light-emitting diode performance", *Phys. Chem. C*, Vol. 111, 2007, pp. 17404-17408.

[2] S. Shen, R. Tinivella, M. Pirola, G. Ghione and V. Camarchia, "SPICE Library for Low-Cost RFID Applications Based on Pentacene Organic FET," *2010 6th International Conference on Wireless Communications Networking and Mobile Computing (WiCOM)*, Chengdu, 2010, pp. 1-4.

[3] M. Takamiya, T. Sekitani, Y. Kato, H. Kawaguchi, T. Someya and T. Sakurai, "Low Power and Flexible Braille Sheet Display with Organic FET's and Plastic Actuators," *2006 IEEE International Conference on IC Design and Technology*, Padova, 2006, pp. 1-4

[4] M. G. Kane J. Campi, M. S. Hammond, F. P. Cuomo, B. Greening, C. D. Sheraw, J. A. Nichols, D. J. Gundlach, J. R. Huang, C. C. Kuo, L. Jia, H. Klauk, and T. N. Jackson, "Analog and digital circuits using organic thin-film transistors on polyester substrates," in *IEEE Electron Device Letters*, vol. 21, no. 11, Nov. 2000, pp. 534-536.

[5] I. Nausieda, K. Ryu, I. Kymissis, A. Ibitayo Akinwande, V. Bulovic and C. G. Sodini, "An Organic Active-Matrix Imager," in *IEEE Transactions on Electron Devices*, vol. 55, no. 2, Feb. 2008, pp. 527-532.

[6] M. Takamiya, T. Sekitani, Y.Kato, H. Kawaguchi, "An organic FET SRAM with back gate to increase static noise margin and its application to braille sheet display", *IEEE J. Solid-State Circuits.* 2007, *42*(1), 93–100.

[7] D.Tobjork, R.Osterbacka, "Paper electronics", *Adv. Mater.* 2011, *23*(17), 1935–1961.

[8] M.Guerin, A.Daami, S.Jacob, E.Bergeret, E.Benevent, P.Pannier, R.Coppard, "High gain fully printed organic complementary circuits on flexible plastic foils", *IEEE Trans. Electron Devices.* 2011, *58*(10), 3587–3593.

[9] ATLAS User's Manual from SILVACO International.

[10] S.Mijalkovic *et al*., Modelling of organic field-effect transistors for technology and circuit design, *26th International Conference on Microelectronics (MIEL)*, Nis, Serbia , May 11-2008; 14: 469-476.

[11] Graciella Nall , "Organic Electronics" First edition ISBN 978-93-81157-27-5, 2011

[12] A.D.D. Dwivedi, Rajeev Dhar Dwivedi, Raghvendra Dhar Dwivedi, Sumit Vyas and P. Chakrabarti, "Numerical simulation of P3HT based Organic Thin Film Transistors (OTFTs)" International Journal of Microelectronics and Digital integrated circuits, Vol.1, issue-2, pp.13-20, 2015.

[13] A. D .D. Dwivedi, "Numerical Simulation and Spice Modeling of Organic Thin Film Transistors (OTFTs)" International Journal of Advanced Applied Physics Research, Vol.1, pp.14-21, 2014.