KIET IJCE KIET International Journal of Communications & Electronics
Volume. No. 6, Issue No. 2, July-Dec 2018, ISSN: 2320 – 8996

Fabrication & Characterization of Organic Thin Film Transistor (OTFTs)

Abhinav Dwivedi[#1], Sumita Ray Chaudhuri[*2]
EIE Department, KIET Group of Institutions, Ghaziabad (UP)

Abstract

Organic Thin Film Field-Effect transistors (OTFTs) are particularly interesting as their fabrication process is much less complex compared with conventional Si technology, which involves high-temperature and high-vacuum deposition processes and sophisticated photolithographic patterning methods. In general, low-temperature deposition and solution processing can replace the more complicated processes involved in conventional Si technology. In addition, the mechanical flexibility of organic materials makes them naturally compatible with plastic substrates for lightweight and foldable products. Although OTFTs are not meant to replace conventional inorganic TFTs – because of the upper limit of their switching speed – they have great potential for a wide variety of applications, especially for new products that rely on their unique characteristics, such as electronic newspapers, inexpensive smart tags for inventory control, and large-area flexible displays. In this paper, authors describe the basic materials requirements and fabrication methods for building these devices.

Keywords:OTFT,Photolithography,
TFT,MOSFET etc.

INTRODUCTION

After the discovery of semiconductor based devices, substantial efforts were devoted to the use of organic semiconductors for commercial purpose. Because of low cost [1], lightweight, large-area [2] and flexible devices [3] these organic semiconductors are on the verge of changing semiconductor industry. Since the demonstrations of Organic Light Emitting Diode(OLED), Organic Light Emitting Transistors(OLET) and Organic Thin Film Transistors(OTFT) there has been a lot of research work on technology of organic semiconductors. There are mainly two types of organic semiconductors (i) organic molecular semiconductors(OMS) (ii) polymeric organic semiconductors. OMSs have low molecular weight while polymeric organic semiconductors are long chain organic molecules, e.g. poly(para-phenylene) (PPP), poly(Thiophene)(PT), Small OMSs include CuPc, Pentacene, Tetracene. Organic semiconductors are carbon based material. Due to alternate single and double bonds these molecules are called conjugated molecules. Carbon has four electrons in its outer shell and can hybridize in three possible ways: sp, sp2, and sp3. For sp2 only three electrons (one in s orbital and other two electrons in p orbitals) participate in hybridization and forms sigma bonds. The remaining pz orbital electrons forms weaker π bonds

which are delocalized in the molecule and are responsible for most of its electronic and optical properties.
The state possessing the highest energy of all occupied orbital is called Highest Occupied Molecular Orbital(HOMO) and the state with lowest energy of all the unoccupied molecular orbital is called Lowest Unoccupied Molecular
Orbital(LUMO). The energy difference between the HOMO and LUMO is called band gap of the organic semiconductor.
OTFTs are transistors that use organic thin film rather than silicon for their active channel material between source and drain. OTFTs are very similar to MOSFETs, i.e. they are voltage controlled three terminal devices. Essentially, in these devices current between source and drain are controlled by a gate [5]. In inorganic semiconductors, both p and n type MOSFETs are possible because of “doping” process which has not been possible effectively in organic semiconductors. Generally, hole mobility is higher than electron mobility in organic materials and large number of molecules show p-type conduction. All the hole transporting materials have conjugated carbon backbone that carries charge and confined primarily by hydrogen atoms. Hydrogen atoms are less electronegative than core carbon atoms and donate a partial electron charge to the core. This makes the backbone electron rich and shifts the energy levels so as to favor the loss of electrons over its gain.

Design and Operation of OTFTs

The top contact device configuration is of thin film transistor. in which a thin film of organic semiconductor is deposited on top of SiO2V_{DS} with an underlying gate electrode with the help of vapor deposition technique. Two metal (Cu) electrode source and drain are deposited on top of the organic film [7]. For the bottom contact device configuration, two metal (Cu) electrodes are deposited on the surface of SiO2 substrate prior to the deposition of organic semiconducting film [8]. During the coating of organic thin film some part of the electrodes are masked so that they do not get coated and contacts can be drawn over it for characterization.
Heavily doped Si/P++ wafer is used as gate electrode with 300nm thick layer of thermally oxidized SiO2 as the gate insulating layer. Organic thin film was deposited in high vacuum condition. Source and drain electrodes were fabricated by depositing contact pads of 30-40nm thick Cu on organic thin film shown in fig1. Patterning was done by shadow mask. The

(i) Saturation Region

$$I_{DS} = \frac{W}{2L}\mu C_i (V_G - V_T)^2 \qquad \{2\}$$

distance between source and drain is 5-10um and width of source and drain is 3mm. All depositions were done by using thermal evaporation technique under base pressure of 1-2×10^-6 Torr and at rate of 1-2 Å/sec.

KIET IJCE KIET International Journal of Communications & Electronics
Volume. No. 6, Issue No. 2, July-Dec 2018, ISSN: 2320 – 8996

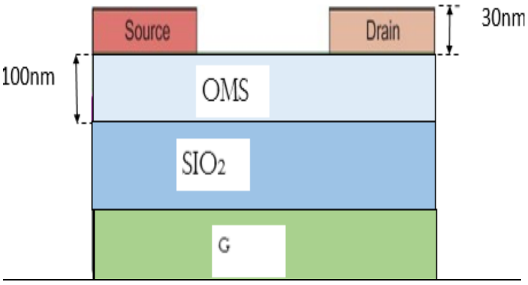


Fig1: Schematic illustration of OTFTs dimension in side view.

OTFT is a three-terminal device. Device is in the "off state" when gate voltage is not applied and minimum current flows between Source and drain electrodes. When the gate voltage is applied, electrons or holes can be induced at semiconductor/dielectric interface and the source drain current increases (device "On state"). when an OTFT is made active by applying, negative V_G and V_{DS}, holes are the majority charge carriers [9] in the channel and the organic material is said to be p-channel. On the other hand, upon application of positive V_G and V_{DS} current flows from source to drain, then electrons form the majority charge carriers in the channel and organic material is said to be N-channel. The relationship describing the drain current of OTFT is defined by

(ii) Linear Region

$$I_{DS} = \frac{W}{L}\mu C_i\left(V_G - V_T - \frac{V_{DS}}{2}\right)V_{DS} \qquad \{1\}$$

Where,

μ = Field effect carrier mobility of the OMS.
V_G =Gate voltage
W = channel width
V_{DS}= Source Drain voltage
L = Channel length
V_T= Threshold voltage
C_i = Capacitance per unit area of SiO_2 layer

At low drain voltage V_{DS} linear current region is observed, followed by a saturation region when drain voltage exceeds the gate voltage. OTFTs operate in accumulation mode [10], where an increase in magnitude of V_G enhances the chemical conductivity contrast to conventional Si transistor, where V_G induces inversion mode.

Performance Parameters of OTFT

The performance of OTFT is evaluated by its parameter extraction. The main parameter which evaluate OTFT performance are [11]

1. Mobility(μ): The charge carrier speed in the channel and is extracted from the linear region in the $I_D - V_{DS}$ curve.
2. Threshold voltage(V_T): Minimum V_G required to turn on OTFT and id calculated by the trans conductance change method[12]
3. Contact resistance(R_c): All series resistance which does not scale with channel length $R_{total} = R_C + L \times r_{channel}$, where L is channel length and $r_{channel}$ is its resistivity.
4. ON-OFF ratio: Ratio of maximum and minimum current in $I_D - V_{DS}$.
5. Subthreshold swing(S): The subthreshold swing is the inverse slope of the $\log I_{DS}$ vs. V_G. It is reported in base10 logarithm units of mV/decade (i.e. mV of gate bias for decade of drain current modulation). Smaller values in these corresponds to larger slope. Which is generally more desirable.
   a. $S = \left(\frac{\log_{10} I_{DS}}{V_G}\right)^{-1}$.
6. Output Conductance: The device characteristic in saturation does not exhibit a perfect current source characteristic as V_{DS} is increased, The current generally continues to increase at some rate. $g = \frac{\Delta I_{DS}}{\Delta V_{DS}}$.

Experimental Techniques

The characterization of the devices requires a stable thin film with reproducible properties. Thin film of Organic material(CuPc) deposited over cleaned glass/quartz substrate using vacuum deposition. All the deposition was done at a pressure of 2-3 × 10^-6 torr in an oil free thermal evaporation chamber. The rate

of deposition was measured using quartz crystal based thickness monitor and varied for optimization of thin film growth. Substrate was kept at room temperature and thickness of grown film is 100nm. I-V characterization was done by Keithley picoammeter and voltage sources, Surface morphological studies by Atomic force microscope (XE-Series, Park System), Optical characterization was done using UV-Visible spectroscopy.

RESULTS AND DISCUSSION

Setting up the range of voltage between source and Drain, which are set at -60V to +20V and the gate voltage range is (0V to 60V) at the step of 10. The I-V characteristics of top contact OTFT obtained with help of Keithley Picoammeter which is shown in fig.2

Atomic Force Microscopy of Copper Phthalocyanine (CuPc) thin films grown at the substrate temperature of 30 °C with different thicknesses with the first one at 5um and the second one at 2um shows the morphology of organic thin films grown at silicon substrate.

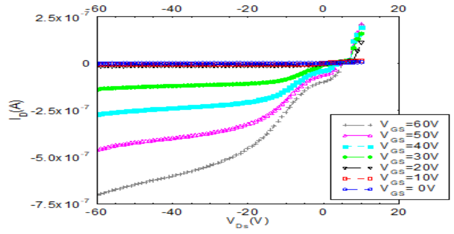
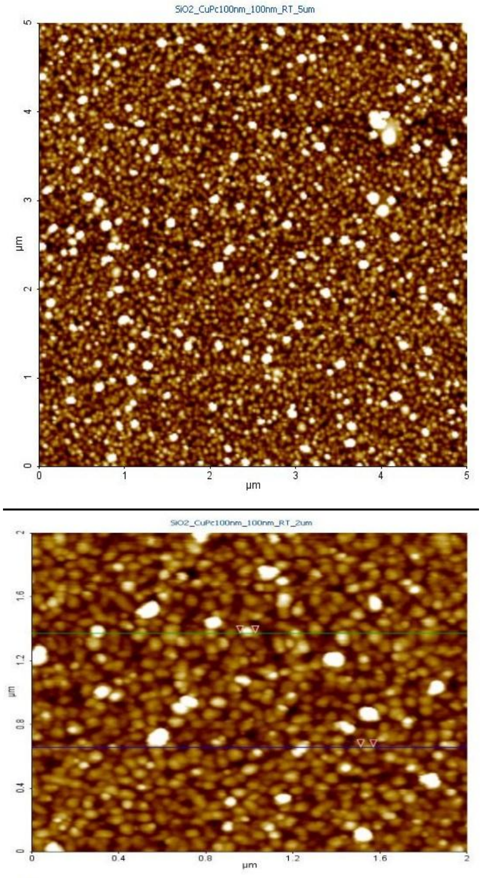


Fig 2: I-V characteristics of Copper Thalocyanine(CuPc) based Oraganic Thin Film Transister.



(A)

(B)

Fig 3:AFM topographic imagesof CuPc thin films grown at substrate temperature of 30 °C with thickness (A) 5um and (B) 2um

CONCLUSIONS

In conclusion, the charge carrier transport in copper Thalocyanines (CuPc) have been analysed by its current-voltage characteristics. In this work Field Effect Mobility of Copper Thalocyanine (CuPc) based OTFTs are found to be $1.20\times10^{-3}.10^{-6}$ The mobility shown by organic transistor is higher than that of the inorganic transistors. The surface study has been carried out by the help of Atomic Force Microscopy(AFM), the AFM topographic images of CuPc thin films grown at substrate temperature of *30 °C* with thicknesses 5um and 2um shows the clear surface topography of transistor.

ACKNOWLEDGEMENTS

Authors thankfully acknowledge Prof. Subhasis Ghosh, for providing them an opportunity to do the experimental work at School of Physical Science, JNU, New Delhi and giving us all support and guidance which led to the timely completion of this work. Authors also own deep gratitude to Dr. Akansha Sharma for guidance in experimental work.

REFERENCES

[1] S.R. Forrest, Nature,428, 911(2004).
[2] K. Sanderson, Nature, 445, 473(2007).
[3]L.Zhou, A. Wanga, S.C. Wu, J. Sun, S. Park and T.N. Jackson, Appl. Phys. Lett., 88, 083502(2006).
[4] I. Mcculoch, Nature Mater., 4,583(2005).
[5]D. A. Neamen, Semiconductor physics and devices, McGraw-Hill Publication.
[6] L.L. Chua, J. Zamseil, J.-FChang, E. C. W. Ou, P.K.H. Ho,
[7] H. Sirringhaus and R.H. Friend, Nature, 434, 194(2005).