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RESEARCH ARTICLE OPEN ACCESS

Effect Of Dielectrics On Mobility Of Pentacene Ofet

Shyma Chandrasekharan, Smt Anu Assis, Smt Lekha Pankaj, Dr Shahul Hameed,
Mtech In Vlsi Design, Asst Professor, Don Bosco Arts And Science College, Mampetta, Mukkom, Kozhikkode,
Asst Professor, Dept Of Ece, Tkm Engineering College, Kollam,
Head Of Dept Of Ece, Awh Engineering College, Calicut
Head Of Dept Of Ece, Tkm Engineering Collge, Kollam,
Corresponding Auther: Shyma Chandrasekharan

ABSTRACT

Organic Field Effect Transistors Are Attracting Significant Attention Due To Their Application In Low Cost, Large Area And Biodegradable Electronic Devices. The Operating Characteristics Of Ofets Are Affected By The Boundary Conditions Imposed By The OFET Device Architecture, Such As Interfaces And Contacts. The Characteristics Are Not Much Dependent On The Properties Of The Semiconductor Material. Bottom Gate Top Contact (BGTC) Geometry Is Used For The Study With Pentacene As The Active Semiconducting Layer With A Thickness Of 40nm. The Analysis Comprises The Performance Evaluation Of The OFET In Terms Of Mobility With Different Polymer Dielectric Materials, As The Gate Insulating Material. It Is Found That PMMA Has The Better Performance When Comparing To PVP. It Is Also Found That Field Effect Mobility Increases With The Thickness Of Dielectric Layer. The Device Was Simulated Using Silvaco TCAD Tools. Structure Is Created In Devedit And The Electrical Characterization Is Done Using Atlas.

Keywords—Ofet,Tcad,Bgtc,Pmma,Pva,Pvp

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I. INTRODUCTION

The Principle Of Field Effect Transistor Was First Proposed By Julius Edger Lilienfield In 1930. But Practical Semiconducting Devices (JFET) Were Developed By The Team Of William Shockley At Bell Labs In 1947. Later, MOSFET Invented By Dawn Kahng Superceded The JFET And Had A Remarkable Effect On Digital Electronics.

The Rising Cost Of Materials And Manufacturing And The Need For Environment Friendly Electronics Leads To The Development Of Organic Based Electronics. Koezuka And Team Reported The First Organic FET Based On Polymer Of Thiophene Molecules. OFET Is A Field Effect Transistor Using An Organic Semiconductor In Its Channel. Ofets Can Be Prepared Either By Vacuum Evapouration Of Small Molecules Or By Solution Casting Of Polymers. These Devices Are Extensively Used In Low Cost, Large Area Electronic Products And Biodegradable Electronics.

The Weak Molecule-Molecule Bonds In Organic Materials Can Be Easily Broken Or Reformed. Thus, Molecules Can Be Dispersed In Solvents Or Evaporated At Moderate Temperature. This Allows Various New Process Concepts For Organic Semiconductors. Organic Semiconducting Inks Enables Deposition Of Functional Layers Only At Desired Positions On The Substrate By Ink-Jet Printing, Thus Minimizing Fabrication Cost Of Large-Area Electronic Circuits Compared To The Conventional Vacuum-Based Deposition And Lithographical Patternings. The Ultimate Goal Of Organic Electronics Is Therefore Based On The Fundamental Properties Of Organic Semiconductors. It Is Realization Of ‘flexible’ And ‘Low-Cost’ Electronic Systems.

Over The Past Years, So Many Researches Are Carried Out In The Field Of Organic Electronics. Even Though The Mobility Of Organic Semiconductors Are Lower Than Typical Semiconductors, They Have The Great Advantages Of Low Cost, Flexibility, Light Weight And Environmental Friendliness. However Their Hole Mobility Is Comparable To That Of Amorphous Silicon.

II. METHODOLOGY

A. Organic Field Effect Transistors

Ofets Have Several Unique Properties Not Shared By Silicon Transistors, Most Notably Their Flexibility. Because Ofets Can Be Manufactured At Or Near Room Temperature, They Enable The Manufacture Of Integrated Circuits On Plastic Or Other Flexible Substrates That Would Otherwise Not Withstand The High Temperature Conditions Of

Silicon-Based Device Manufacture. Ofets Are Also Highly Sensitive To Specific Biological And Chemical Agents, Making Them Excellent Candidates For Biomedical Sensors And Other Devices That Interface With Biological Systems. With The Synthesis Of New Organic Materials, Chemists Have Improved Charge-Carrier Mobilities For Small-Molecule Ofets From < 1 Cm^2 /Vs In To 8-11 Cm^2 /Vs. Because Ofets Can Be Manufactured At Or Near Room Temperature, They Enable The Manufacture Of Integrated Circuits On Plastic Or Other Flexible Substrates That Would Otherwise Not Withstand The High Temperature Conditions Of Silicon-Based Device Manufacture. Ofets Are Also Highly Sensitive To Specific Biological And Chemical Agents, Making Them Excellent Candidates For Biomedical Sensors And Other Devices That Interface With Biological Systems. Initially, The Improved Mobilities Were Obtained Only Under Very Clean Conditions In Ultrahigh Vacuum Chambers. However, Recent Results Suggest That High Performance OFETS Can Be Fabricated Using Simple And Relatively Inexpensive Techniques, Such As Solution Processing. By 2020, With The Synthesis Of Even More Advanced Materials, Mobilities Could Increase To As Much As 100 Cm^2 /Vs. As With Small-Molecule Ofets, Polymer Ofets Have Also Increased In Performance, With Typical Mobilities Increasing From About 0.01 Cm2 /Vs In 2000 To Greater Than 1.0-3.0 Cm^2 /Vs In 2010. Despite This Progress, Several Challenges Remain Before Ofets Will Become A Widespread Commercial Reality. For Example, Only Recently Have Scientists Demonstrated The Fabrication Of Thermally Stable Flexible Ofets. High Thermal Stability Is Prerequisite To Integrating Ofets Into Biomedical Devices; Otherwise They Won't Survive High-Heat Sterilization.

B. Device Geometry

An OFET Is Composed Of Several Functional Layers. An Organic Semiconducting Layer Formed By Evaporated Small-Molecules, Solution-Cast Polymers, Or A Piece Of Organic Single Crystal Constitutes The Charge-Transport Medium Through Which The Electrical Current flows. A Gate Insulator Makes A Capacitor Between The Gate Electrode And Theconducting Channel Inside The Semiconductor. The Gate Electrode Controls The Capacitor By Accumulating Or Repelling The Charge-Carriers, Which In Turn Switches On Or Off The Transistor. A Source Electrode Provides The Charge Carriers Into The Semiconductor And A Drain Electrode Extracts Them Out Of The Semiconductor. The Above-Described 'Function' Of Each Layer Remains The Same, But There Are Different 'Configurations' Dependingon Their Relative Positions With Respect To The Substrate.

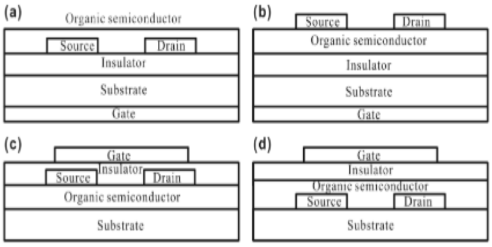

Figure 1. Four Possible OFET Geometries (A) Bottom Gate Bottom Contact(Coplanar) (B) Bottom Gate Top Contact(Staggered) (C) Topgate Top Contact(Coplanar) (D) Top Gate Bottom Contact(Staggered)

Figure 1 Shows The Four Possible OFET Structures [10]. Two Criteria Are Applied For Categorization; The Position Of The Gate Electrode With Respect To The Whole Structure And The Position Of The Source/Drain Electrodes With Respect To The Semiconductor. In Addition, These Four Main Structures Can Be Grouped Into Staggered Or Coplanar Geometry. By Definition, In Staggered Geometry, The Source/Drain Electrodes Are Separated From The Conducting Channel By The Semiconductor. In Contrast, The Source/Drain Electrodes Are On The Same Plane With The Conducting Channel In Coplanar Transistors. In This Paper, Bottom Gate Top Contact (BGTC) Staggered Geometry Is Used For The Numerical Simulation (ATLAS) Due To The Fact That TC Ofets Show Superior Electrical Performance Compared To The BC Ofets Under The Same Fabrication Condition, Especially In Terms Of The field-Effect Mobility (μ) And The Contact Resistance (R_c). Another Advantage Of TC Ofets Is Related To The Metal Penetration Into The Organic film. Because Of The Fragility Of Organic Molecular films, The Metal Cluster Deposited On Top Of An Organic Layer Can Form More Continuous Interface, Whereas, In BC Ofets, This Interface Should Be Mechanically Sharp.

C. Field Effect Mobility

The Carrier Field-Effect Mobility In The Linear Regime Can Be Extracted From The Transconductance G_m Which Is The Change Of I_{DS} With V_{GS} For A Small Drain Voltage V_{DS}.

$$g_m = \frac{\partial I_{DS}}{\partial V_{GS}}\Big|_{small\ constant\ V_{DS}} = -\frac{W\mu C_{ox}}{L}V_{DS} \qquad (1)$$

Therefore, The Linear Mobility Solved From Equation 1 Is Given As:

$$\mu = -g_m \frac{L}{W}\frac{1}{C_{ox}}\frac{1}{V_{DS}}\Big|_{V_{DS\,small\,constant}}$$

(2)

The Field-Effect Mobility In The Saturation Regime Is Also Extracted From The Transfer Characteristics (I_{DS} Vs. V_{GS}) For The Device Biased As $|V_{DS}| \geq |V_{GS} - V_T|$. The Field-Effect Mobility Can Be Extracted From The Slope Of The Curve Which Plots The Square Root Of The Saturation Current As A Function Of Gate Voltage V_{GS}. The Mobility Can Be Calculated And Is Given As:

$$\mu = 2\frac{L}{W}\frac{1}{C_{ox}}\left(\frac{\partial\sqrt{I_{DS}}}{\partial V_{GS}}\right)^2$$

(3)

III. SIMULATION RESULTS AND DISCUSSIONS

The Three Basic Steps Involved In Simulating A Device Using Silvaco Are – Create The Structure In Devedit Or Using Athena, Simulate Using Atlas, Obtain The Plots In Tonyplot. Figure 2 Shows The Steps Involved In Simulation Of The Device Using Silvaco's TCAD. Bottom Gate Top Contact Configuration Is Chosen For This Study.

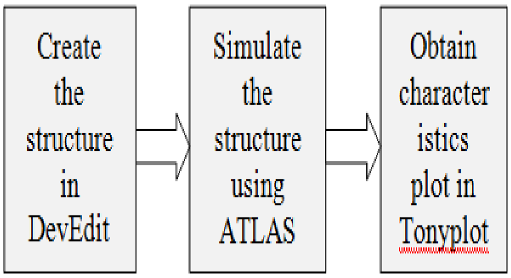

Figure 2. Simulation Steps

A Comparison Of Simulation Results Obtained By Using The Three Dielectric Materials, Ie, PMMA, PVP And PVA Is Given In Table 1.

Table1 Summary Of Results With Three Different Dielectrics

Gate dielectric material	Thickness (nm)	Threshold voltage (in volts)	Dielectric constant	Mobility (cm^2/Vs)
PMMA	400nm	-22.24	3.6	0.09
PVP	400nm	-18.07	5.0	0.06
PVA	400nm	-10.1	7.8	0.0028

While Analyzing The Last Column Of Table 1, We Can See That The Mobility Decreases With Dielectric Constant Of The Gate Insulating Material. Figure 3 Illustrates The Variations In The Mobility Values With Dielectric Constant. In This Mobility V/S Dielectric Constant Plot, We Can See That Mobility Falls When The Dielectric Constant Is High.

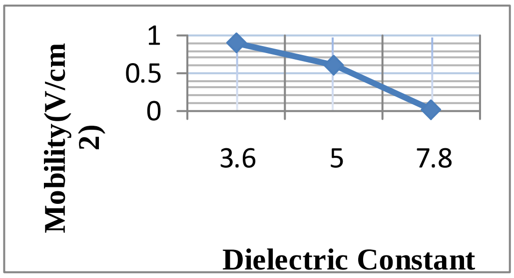

Figure 3. Variations In Mobility With Dielectric Constant

In Organic Field Effect Transistors, Charges Move Near The Surface Of An Organic Semi Conductor, At The Interface With A Dielectric. In The Past, The Nature Of The Microscopic Motion Of Charge Carriers Has Been Related To The Quality Of The Organic Semi Conductor. Recently, It Has Been Found That Also The Nearby Dielectric Has A Strong Influence On The Device Performance. The Dependence Of Mobility On The Dielectric Properties Of The Gate Insulator Is Suggests The Phenomenon Of Interaction Of The Charge Carriers With Their Polar Movement.

The Summary Of Results With Two Different Dielectric Materials Of Different Thickness Is Shown In Table 2. From The Table, It Is Found That Higher Mobility Will Be Obtained For Thicker Dielectrics.

Table 2 Summary Of Results With Different Dielectrics Of Varying Thickness

Material	Dielectric constant	Thickness (nm)	Threshold voltage(Volts)	Mobility,(µ) cm^2/Vs
PMMA	3.6	400	-22.24	0.06
		150	-11.8	0.04561
		50	-10	0.03276
PVP	5.0	400	-18.07	0.09
		150	-10	0.0895
		50	-8.58	0.0636

Using The Data Given In Table 2, We Can Plot Mobility V/S Electric Field Characteristics Of The Organic FET Which Is Shown In Figure 4.

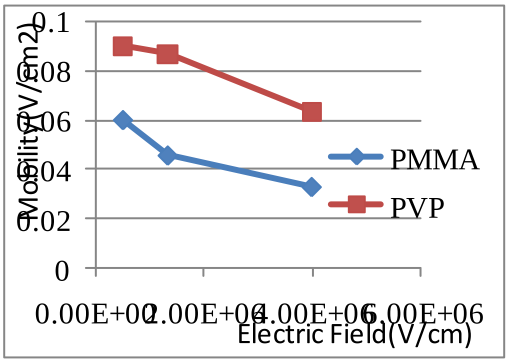

Figure 4. Variations Of Mobility With Electric Field

IV. CONCLUSION

In This Paper, Results On The Simulation Based Analysis Of Organic FET With Different Dielectric Materials Of Varying Thickness Have Been Presented. Two Polymer Dielectric Materials, PMMA And PVP Of Different Thickness Are Used. Here, The Major findings And Related Conclusions Are Summarized. The Study Revealed That The Performance Of Ofets Varies With Different Dielectric Materials. Apart From That, The Thickness Of The Dielectric Material Used Also Has A Great Influence In The Device Performance. The Device Shows Better Performance In Terms Of Mobility When Gate Dielectric Material Was PMMA, Also Superior Insulating Properties Were Measured For PMMA Devices.

Therefore, The Dielectrics Characteristics Are Found To Have A Prominent Influence On The Performance Of Pentacene Fets. Improving The Insulator-Semiconductor Interface Seems To Be More Important Than Using A High Dielectric Constant Material As Gate Because The Latter Exhibits Hysteresis In Transfer Characteristics. In Order To Increase The Capacitance Of Low Dielectric Constant Films, Very Thin Films Have To Be Employed. But This Will Lead To The Problem Of Gate Leakage. Studies Are Going On To Improve The Insulator-Semiconductor Interface .

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