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Effects Of Device Parameters On The Mobility Of An Organic Thin Film Transistor

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Dr. P. Sandeep Kumar

Authors

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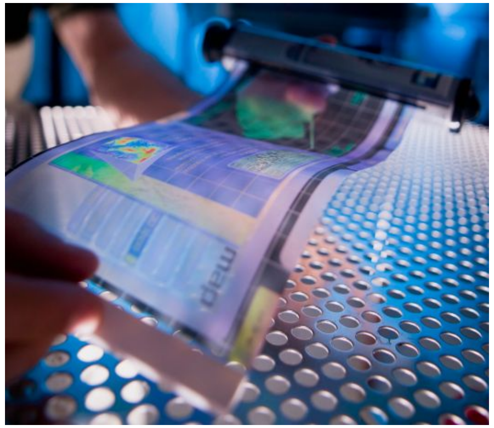
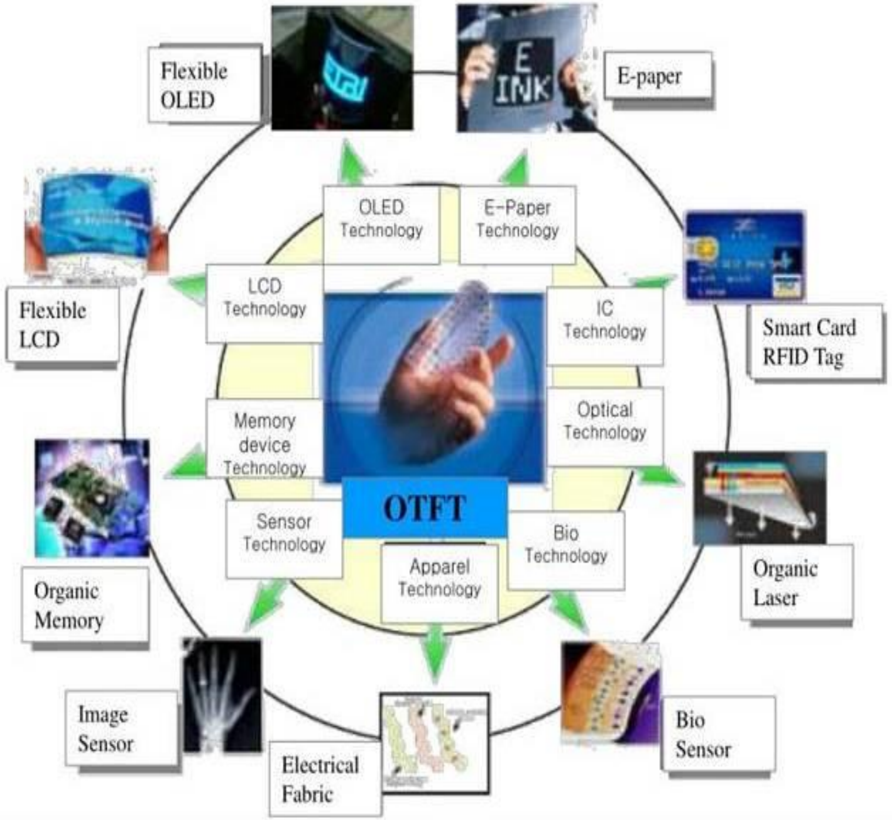
Organic Thin Film Transistor

Advantages

- Low cost
- Very Low Temperature Required For Processing
- Flexible in nature
- Printable
- Light Weight





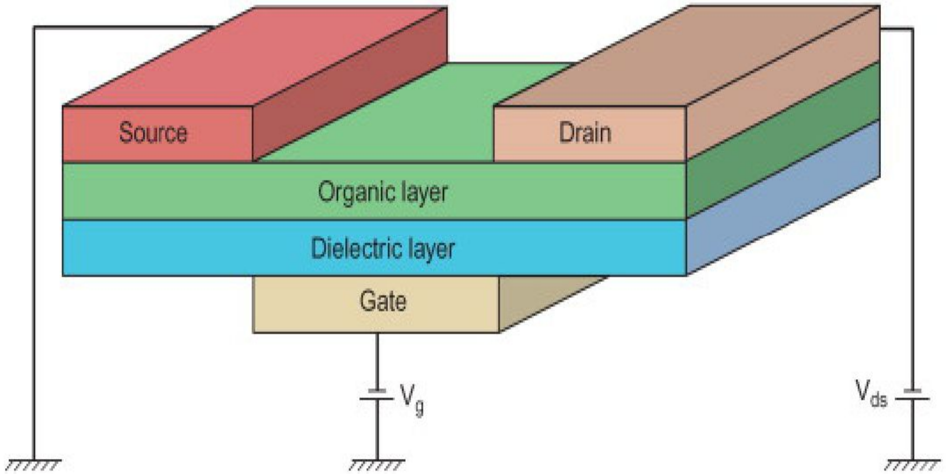
Applications

- 1. RFID Tags
- 2.Flexible Displays
- 3.Large Area Display
- 4.Solar Cells

Organic Thin Film Transistor

Various OTFT Parameters

- Contact Resistance
- Leakage Current
- Current On/Off Ratio
- Threshold Voltage
- Mobility



Structure Of An OTFT

Mobility

- The mobility of a semiconductor is the property that deals with how smoothly the charge carriers can travel in a given semiconductor.

- The mobility measures the ability of free carriers (electrons or holes) to move in the material as it is subjected to an external electric field.

- The magnitude of the mobility directly impacts on the device performance since it determines the operation speed across the device, the operating frequency, or the sensitivity.

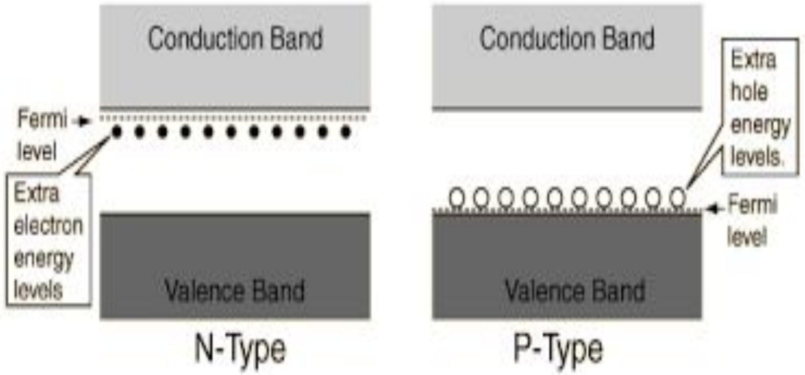
- Although it is considered as an intrinsic property, the more the carrier mobility, the better the transistor and more applications of the TFT can be used for.

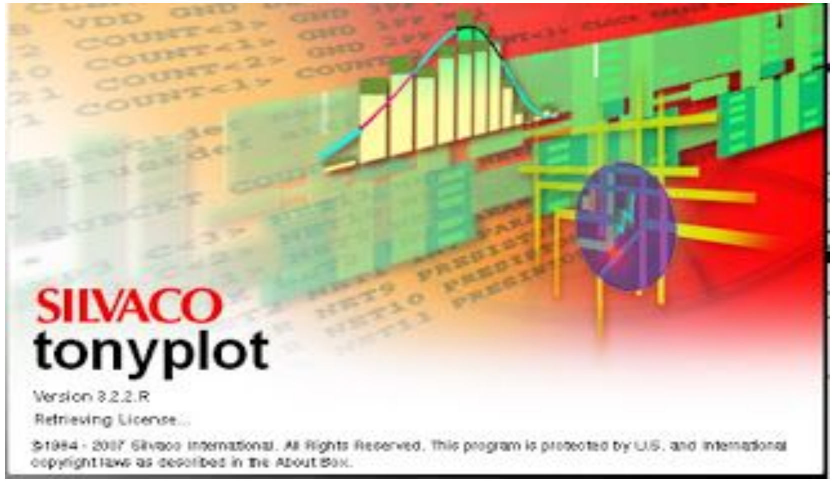
Work At A Glance

- The project focuses on varying the various device parameters such as : Source width , drain width , thickness of di-electric layer ,source voltage, drain voltage, gate voltage etc to understand the effects of it on the mobility of the organic thin film transistor.

- Performing various different simulations on TCAD Silvaco Software and extracting the graph on Tonyplot to calculate the slope of the graph and Mobility.

- Analyzing the various circumstances under which the mobility of P-type and N-type organic thin film transistor changes.





Motivation

- In the most recent couple of years, thin film transistors (TFTs) have experienced exceptional research in an academic level as well as industrially because of their wide range of uses.

- In order to take our planet more towards sustainable environment, OTFT has a key role since its made up with organic material.

- Simple circuits can be designed and fabricated at minimal cost using these organic TFTs.

- A large number constraints influencing these organic thin film transistors are still ineffectively controlled. One such said parameter is the **Mobility**.

Paper 1:**Organic thin-film transistors with over 10 cm^2/Vs mobility through low-temperature solution coating** (2018) , Journal Of Information Display

Authors:
Chuan Liu,Xuying Liu ,Takeo Minari , Masayuki Kanehara &Yong-Young Noh

This literature review takes into consideration that there are some abnormalities in the calculation oh high field mobility when the OTFT displays non ideal characteristics. In this study, the non-ideal transistor behavior was briefly investigated by considering the effect of charge injection, and a method of overcoming the effect was To overcome this, charge injection layers were developed in this work, and their effect on modifying the contacts was studied. The resulting OTFT exhibited almost ideal transistor behavior, with high (over 10 cm^2/Vs) field-effect mobility.

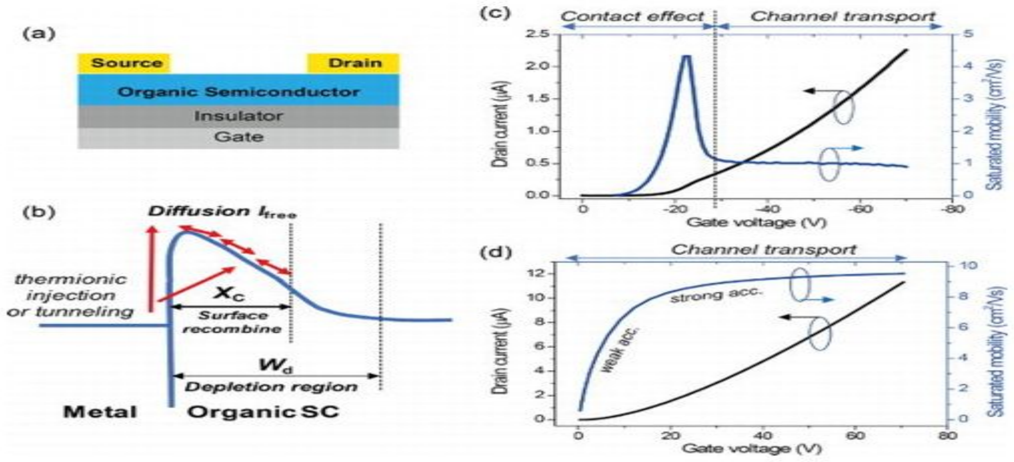


FIG.. (a) Structure of OTFT (b) Tunneling effect (c) Gate Voltage vs Drain Current.

Paper 2: **Organic Thin Film Transistors Characteristics Parameters, Structures and their Applications (2011) IEEE Recent Advances in Intelligent Computational Systems, RAICS**

Authors:
Brijesh Kumar, B. K. Kaushik , Y. S. Negi and Poornima Mittal

The paper mentioned above thoroughly discusses the parameters of the Organic Thin Film Transistors and mentions the way those parameters have been calculated thereby giving corresponding results.

The mobility is evaluated by the transfer characteristics of the OTFT and the following equation is employed to obtain values of the mobility under various circumstances.

$$\mu=(K^{2} \times 2 \times L)/(W \times C_{ox'})$$

The analysis of research data demonstrates that the field-effect Mobility decreases when the product of semiconducting film thickness and gate capacitance per unit area increases. The mobility of OTFTs is gate biased dependent.

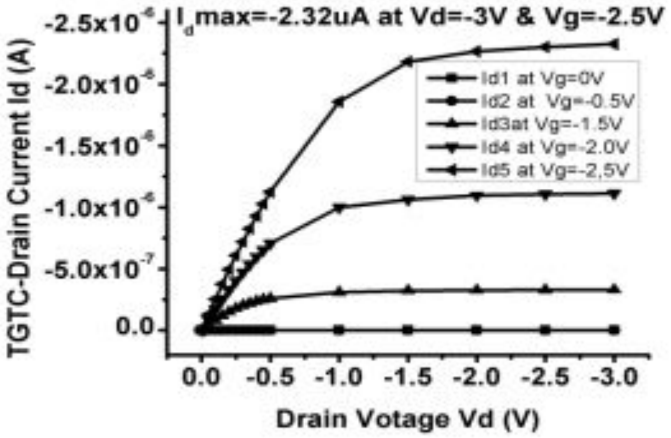


FIG.. (a) Vdrain voltage vs Draine current characteristics

Paper 3: **Estimation of carrier mobility at organic semiconductor/insulator interface using an asymmetric capacitive test structure (2016) AIP Advances**

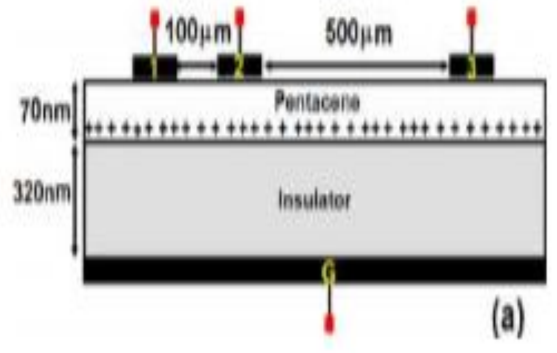
Authors:

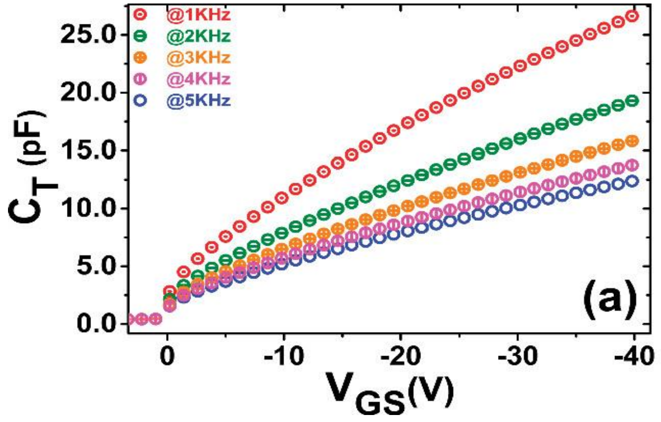
Rajesh Agarwal, Ashish K. Agarwal, and Baquer Mazhari

The standard way of obtaining the mobility which was in accordance with the prevalent conventions were to simply define the drain current using the expressions. It was found that the mobility remained constant .While mobility remained unchanged, it was not found to be dependent on the gate voltage anymore.

The mobility was calculated using the transconductance and saturation region method.

It proves that the calculated mobility is not constant, but is dependent on gate voltage.





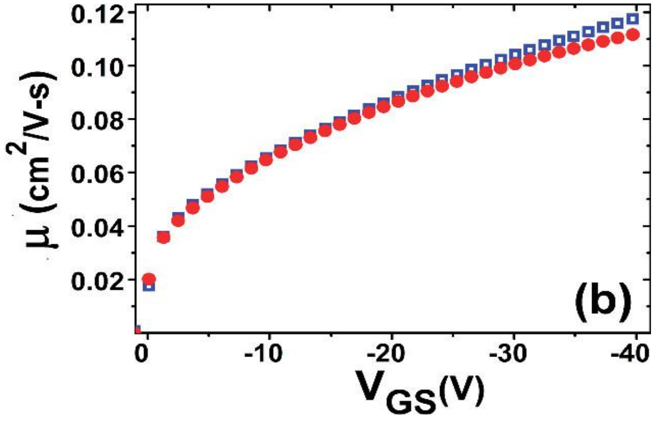


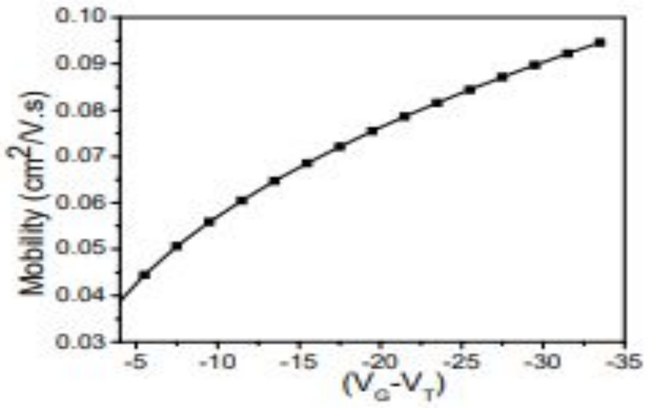
FIG.. (a) Variation of total capacitance (C_T) with gate voltage for different frequencies (b). Comparison of channel mobility extracted using proposed technique (open

Paper 4: Mobility estimation incorporating the effects of contact resistance and gate voltage dependent mobility in top contact organic thin film transistors (2006) , ASID

Authors:
Dipti Gupta, Monica Katiyar, Deepak Gupta

In this paper it was discussed the methods to estimate the mobility incorporating the effects of contact resistance and gate voltage dependence of mobility in top contact organic thin film transistors. The ideal MOSFET equations for the linear region were modified for contact resistance and mobility is estimated which is gate voltage dependent and higher than the value obtained from standard MOSFET equations in all gate voltage ranges.

The values of mobilities for a device with channel length of 30 µm as estimated in the linear and saturation region were 0.065 and 0.11 cm2 /V.sec, respectively.



Plot of Mobility vs. Gate Voltage

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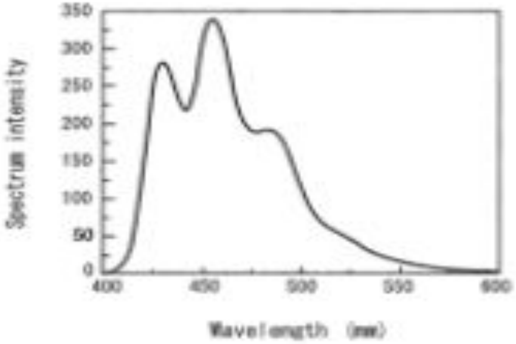
Paper 5: **Organic thin film transistor and organic thin film light-emitting transistor(2011) Journal of Materials Science and Engineering**

Authors:

Hideji OsugaIchiro Tanaka

Operation speed can be heightened, and the TFT can be stably kept in the atmosphere by forming an organic semiconductor layer on a crystallinity control layer that controls the crystallinity of the organic semiconductor molecular packing becomes tight, and atmospheric constituents are prevented from passing through the layers, and therefore stability in the atmosphere can be improved.



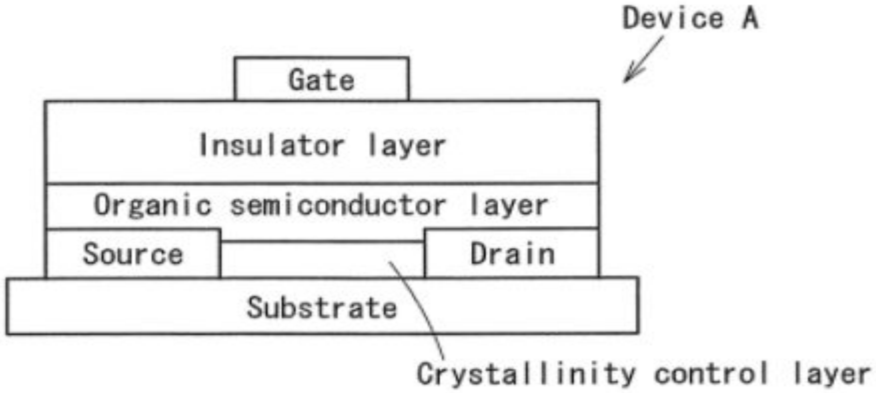
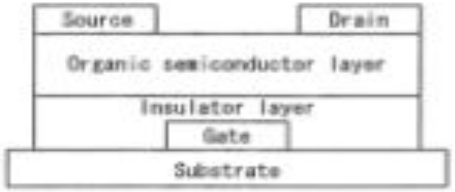


Fig. 11



Expression Derivation

In the linear region, the conventional drain current expression for an OTFT is expressed as:

$$I_{ds} = \frac{W}{L} \times \mu_p \times C_{ox}' \times \left(V_{gs} - V_{th}\right) \times V_{ds} \qquad \text{-- (1)}$$

where I_{ds} is the drain current, C_{ox}' is capacitance per unit oxide layer, μ_p is mobility, L is the channel length, W is the width, V_{gs} is the gate voltage, V_{th} is threshold voltage and V_{ds} is drain voltage. Equation (1) can be written as :

$$I_d = K \times \left(V_{gs} - V_{th}\right) \qquad \text{-- (2)}$$

where K represents the slope. From a plot between V_{gs} and I_{ds} using equation (2), mobility can be calculated as :

$$\mu_p = \frac{K \times L}{W \times C_{ox}' \times V_{ds}} \qquad \text{-- (3)}$$

Similarly, for the saturation region, the mobility can be calculated from the following expression as :

$$\mu_p = \frac{K^2 \times 2L}{W \times C_{ox}'} \qquad \text{-- (4)}$$

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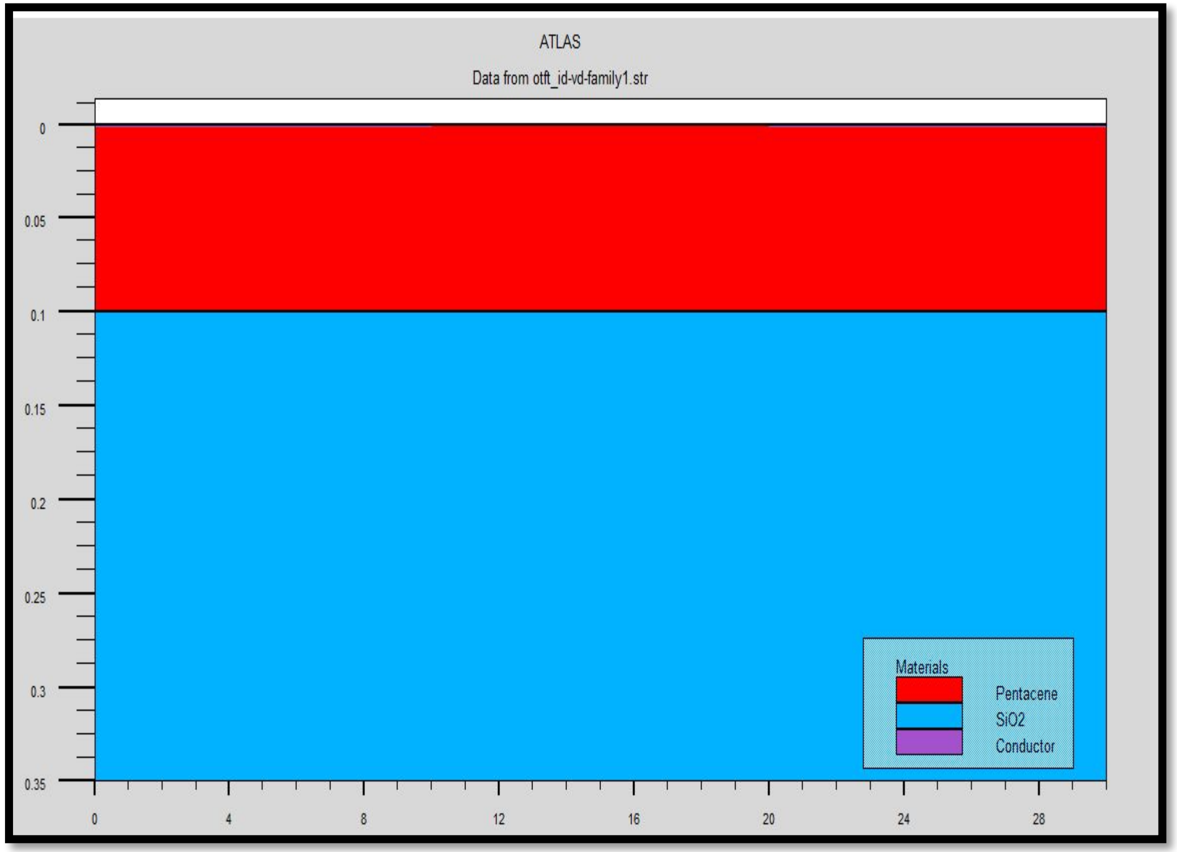
Active Layer Material - 1

Pentacene [P-Type Material]

Structure of OTFT With Pentacene



Varying Parameters :

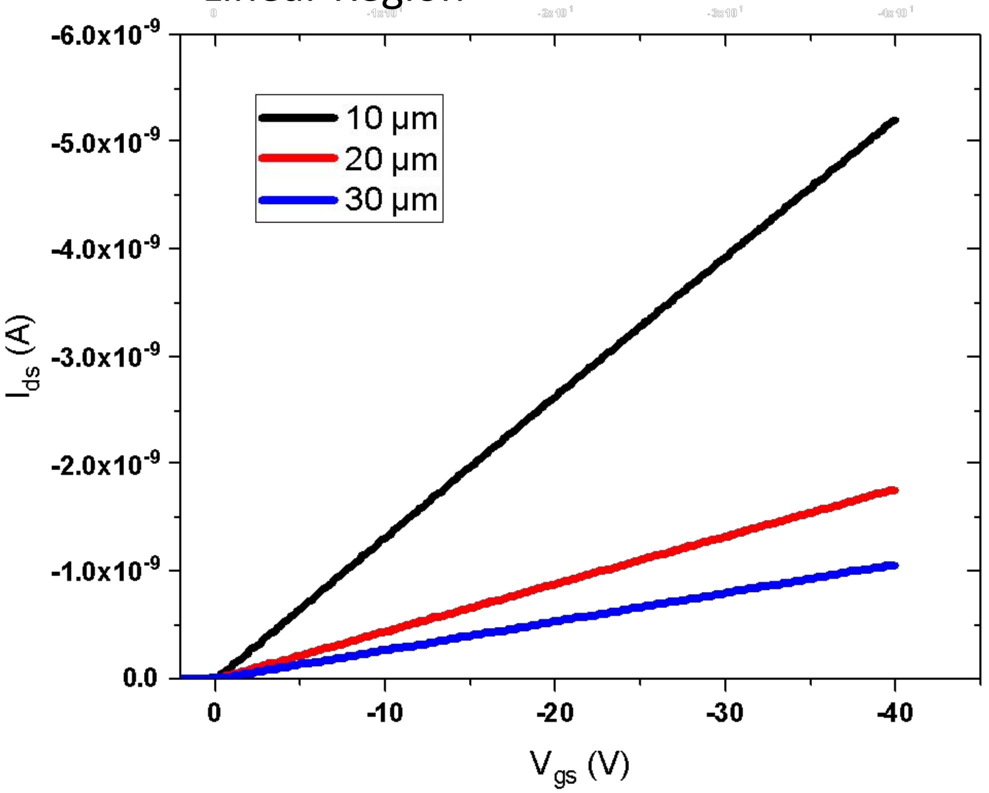
- Channel Length
- Band Gap
- Electron Affinity
- Di-Electric Thickness
- Defect States

Initial Simulation Values

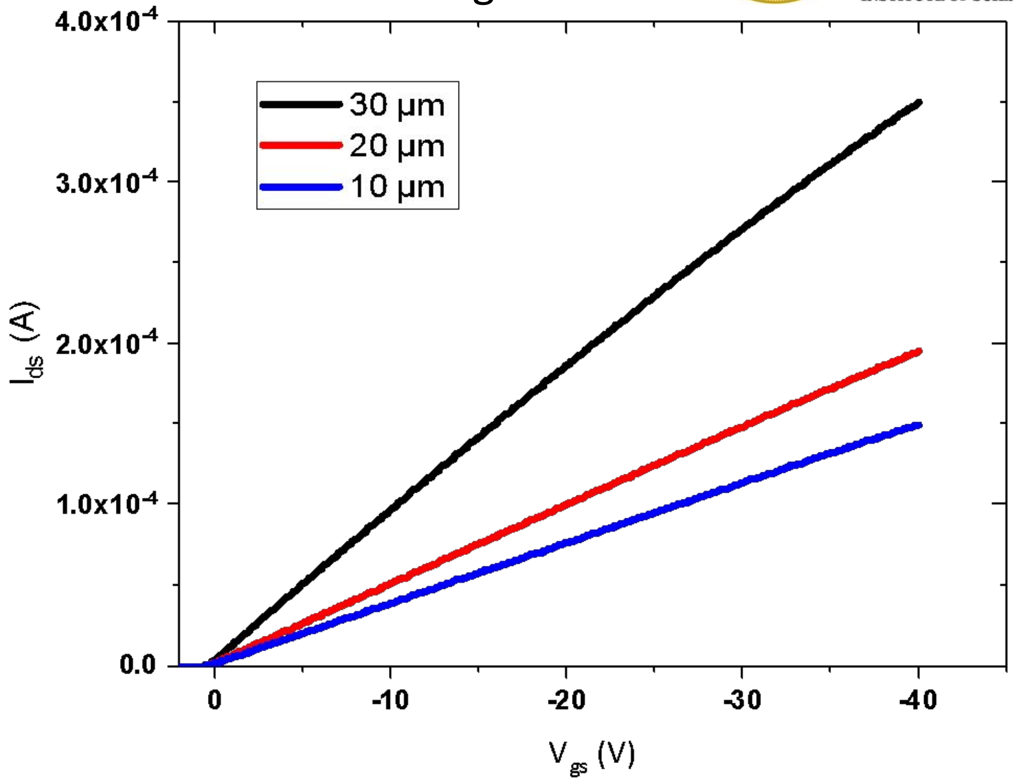
L (µm)	T_{sc} (nm)	T_{ox} (nm)	E_g (eV)	χ (eV)	ϕ (eV)	V_{ds} (V)	C_{ox}' (F/cm^2)
10	100	250	2.2	2.9	4.9	-1	1.34×10^{-8}

Varying Channel Length

Linear Region



Saturation Region



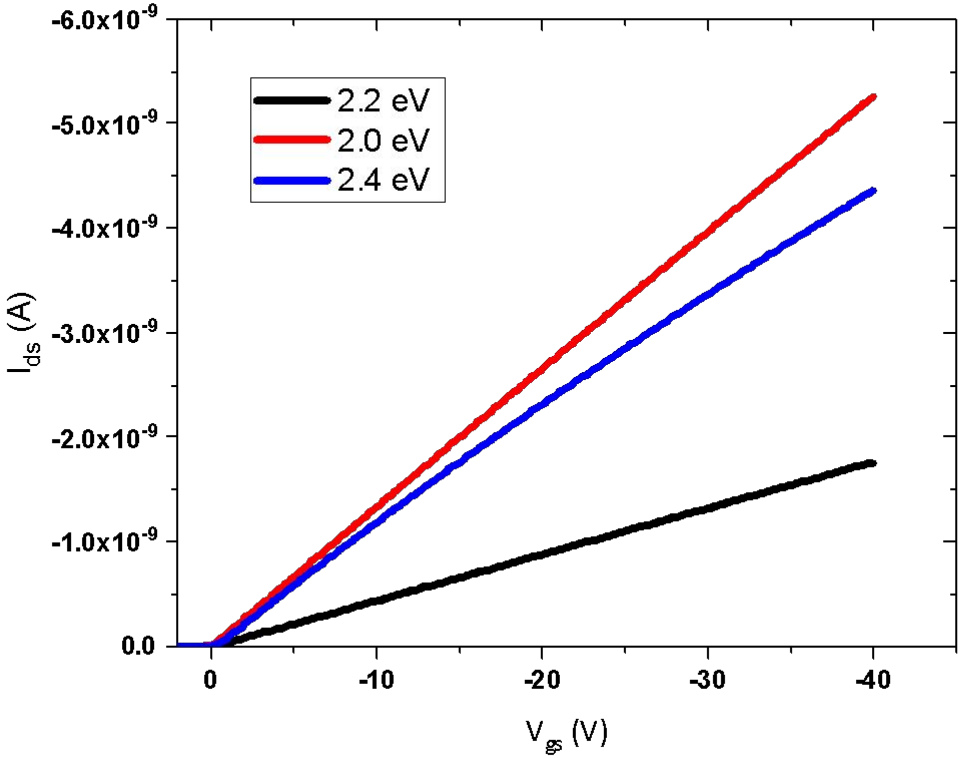
Channel Length (µm)						
	Linear Region			Saturation Region		
L (µm)	10	20	30	10	20	30
µ (cm^2/Vs)	0.094	0.0937	0.0932	0.1093	0.1021	0.1001

Inference

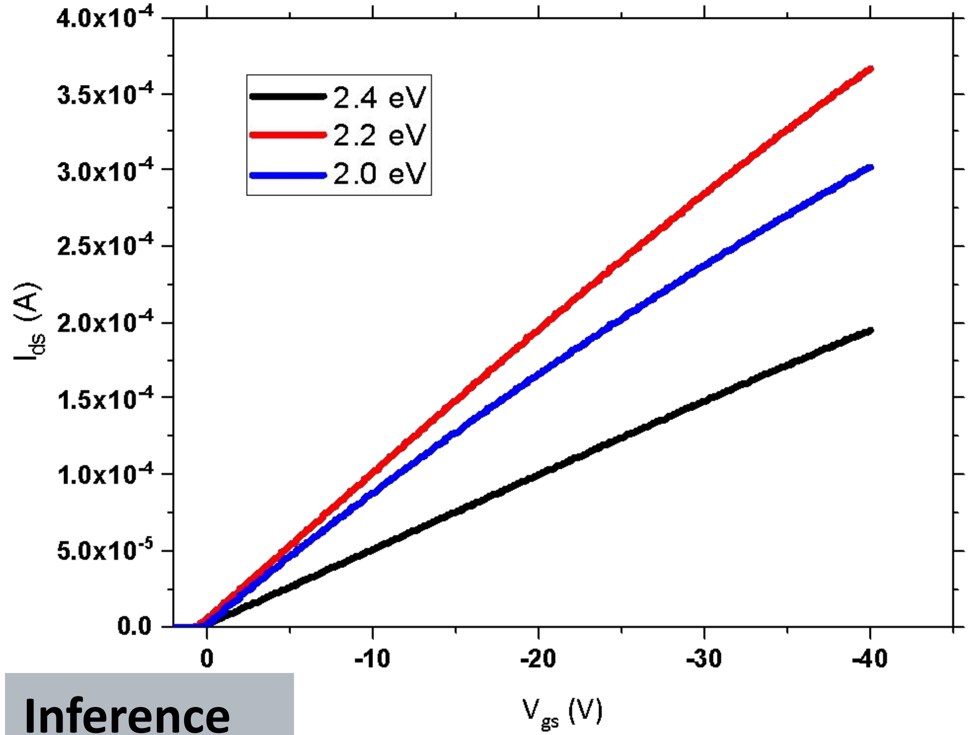
- **Resistance Increases with Increase in Channel Length.**
- **Increased Resistance restricts the flow of electron, Hence Mobility Decreases.**

Varying Band Gap

Linear Region



Saturation Region



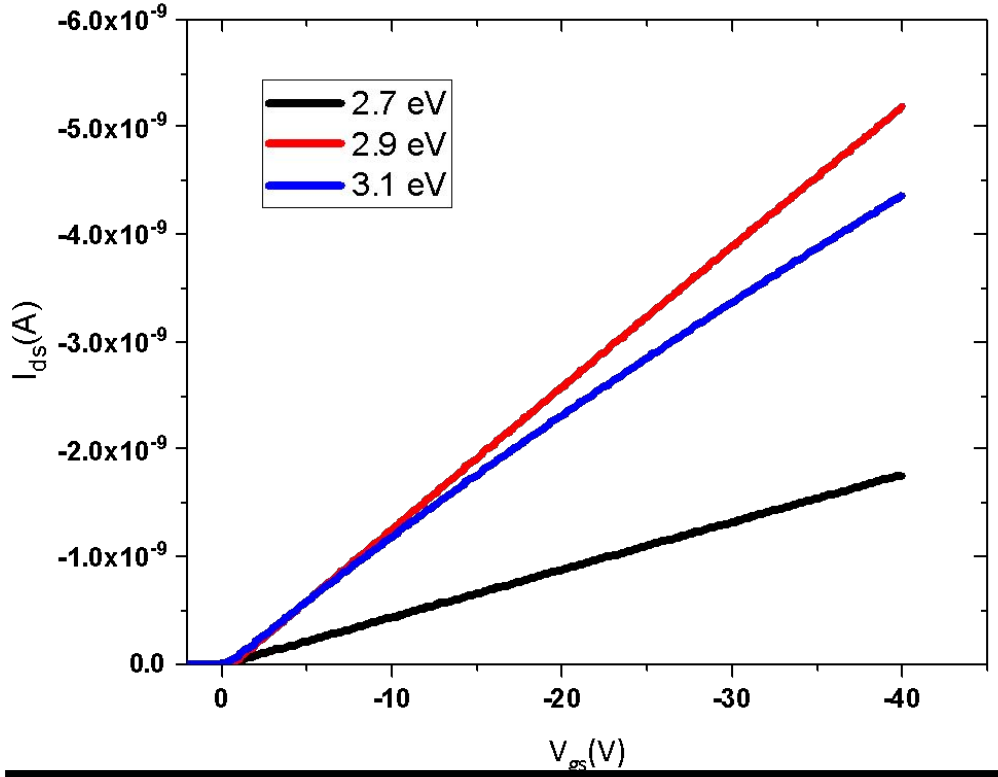
Bandgap (eV)						
	Linear Region			Saturation Region		
E_g (eV)	2.0	2.2	2.4	2.0	2.2	2.4
μ (cm^2/Vs)	0.0946	0.0942	0.078	0.1193	0.1093	0.0808

Inference

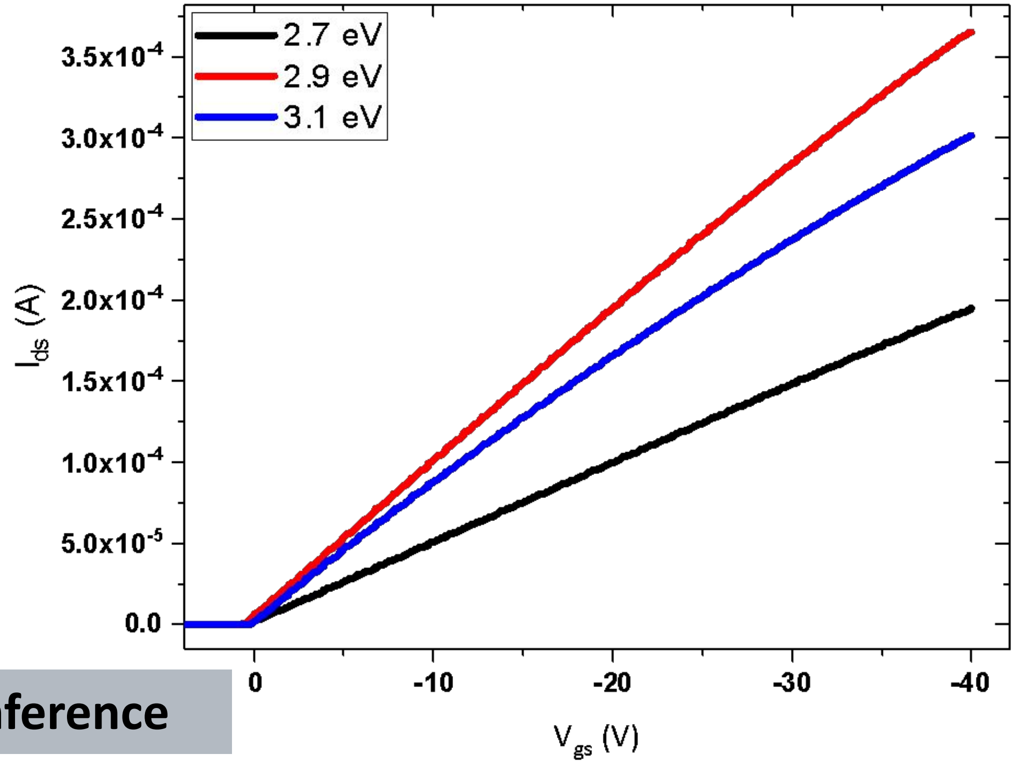
- With Increase in band gap, the separation between fermi level of injecting material and HOMO of semiconductor increases.
- Thus it becomes difficult for holes to get injected into the channel of semiconductor.
- Thus Mobility Decreases.

Varying Electron Affinity

Linear Region



Saturation Region



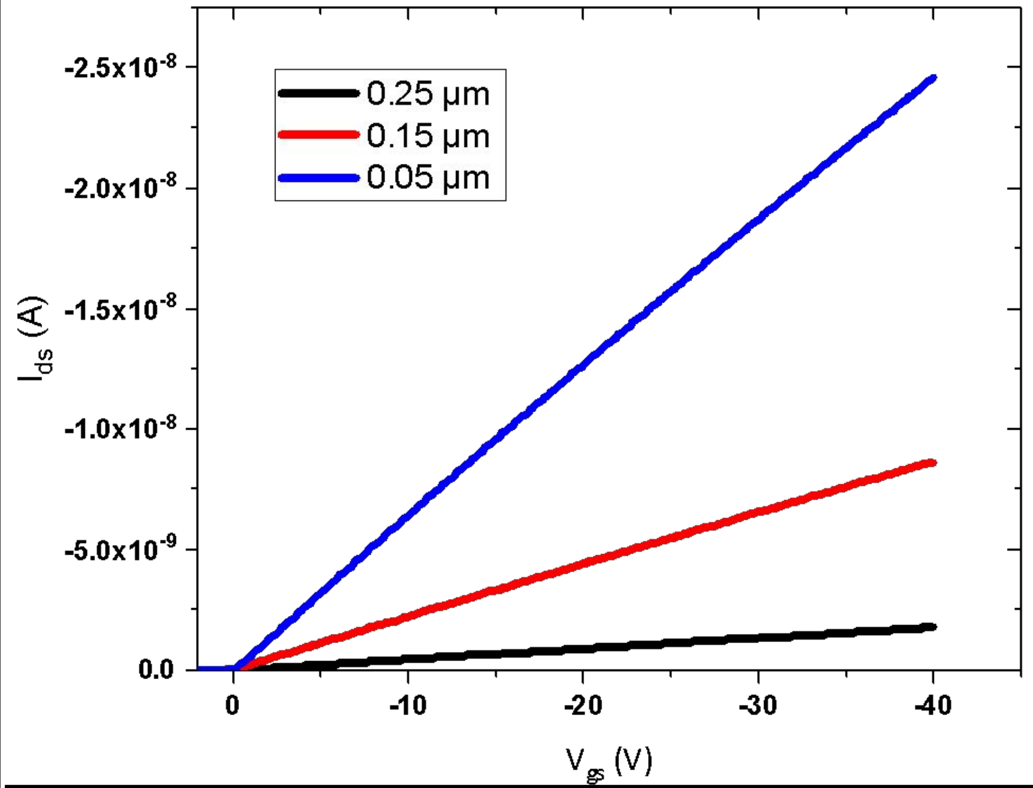
Electron Affinity (eV)						
	Linear Region			Saturation Region		
X (eV)	2.7	2.9	3.1	2.7	2.9	3.1
μ (cm^2/Vs)	0.095	0.094	0.0789	0.1196	0.1093	0.0815

Inference

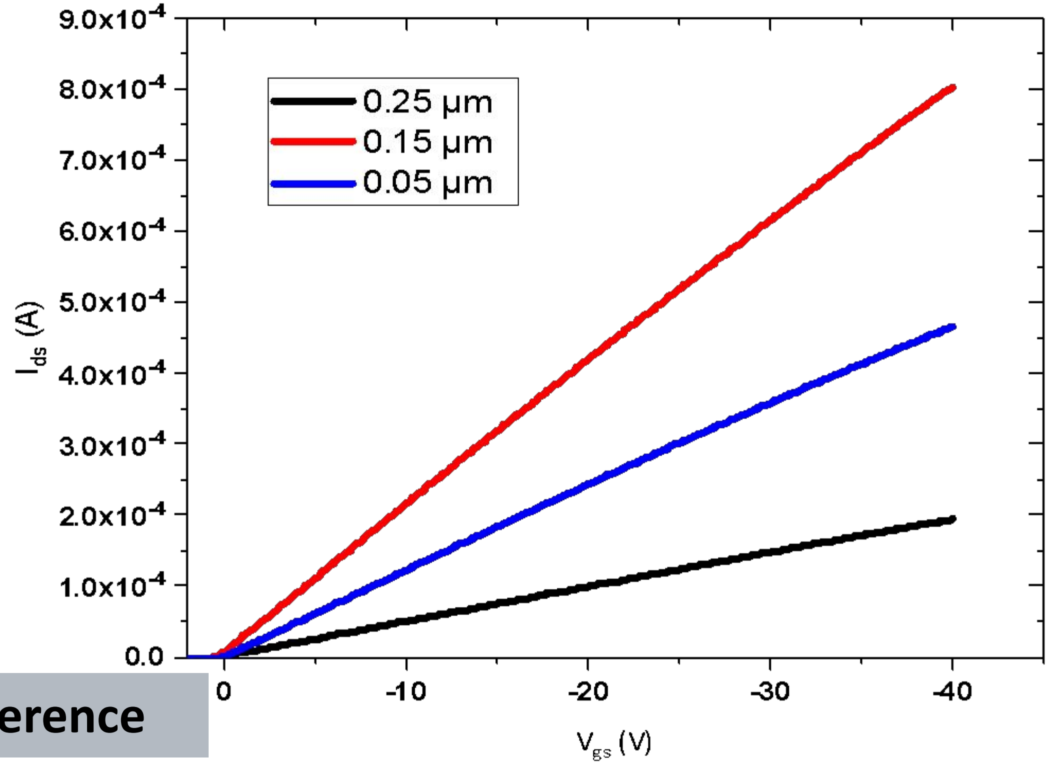
- In a P-type TFT (Pentacene as an active layer),the fermi level of metal is close to HOMO of semiconductor.
- Thus transfer of charge carriers require more energy.
- So the current decreases.
- Thus Mobility decreases.

Varying Di-electric Thickness

Linear Region



Saturation Region



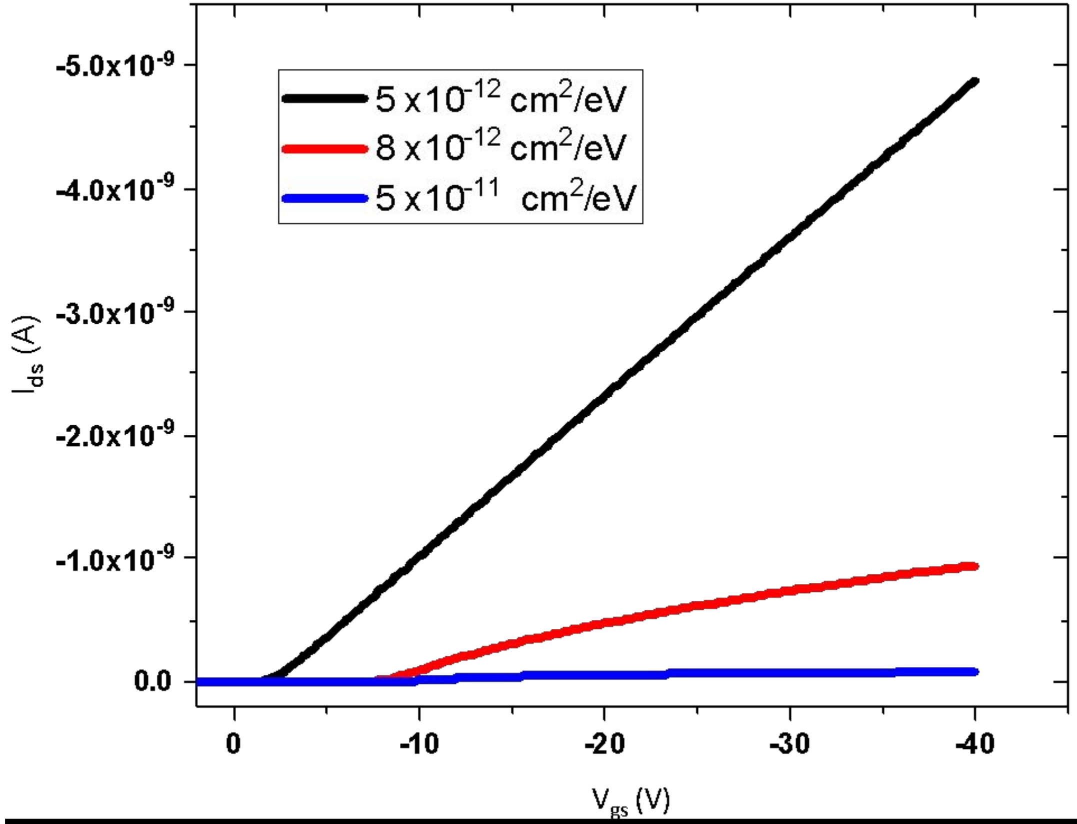
Di-electric Thickness (nm)						
	Linear Region			Saturation Region		
T_{ox} (nm)	50	150	250	50	150	250
μ (cm^2/Vs)	0.095	0.0945	0.0941	0.1169	0.1146	0.1093

Inference

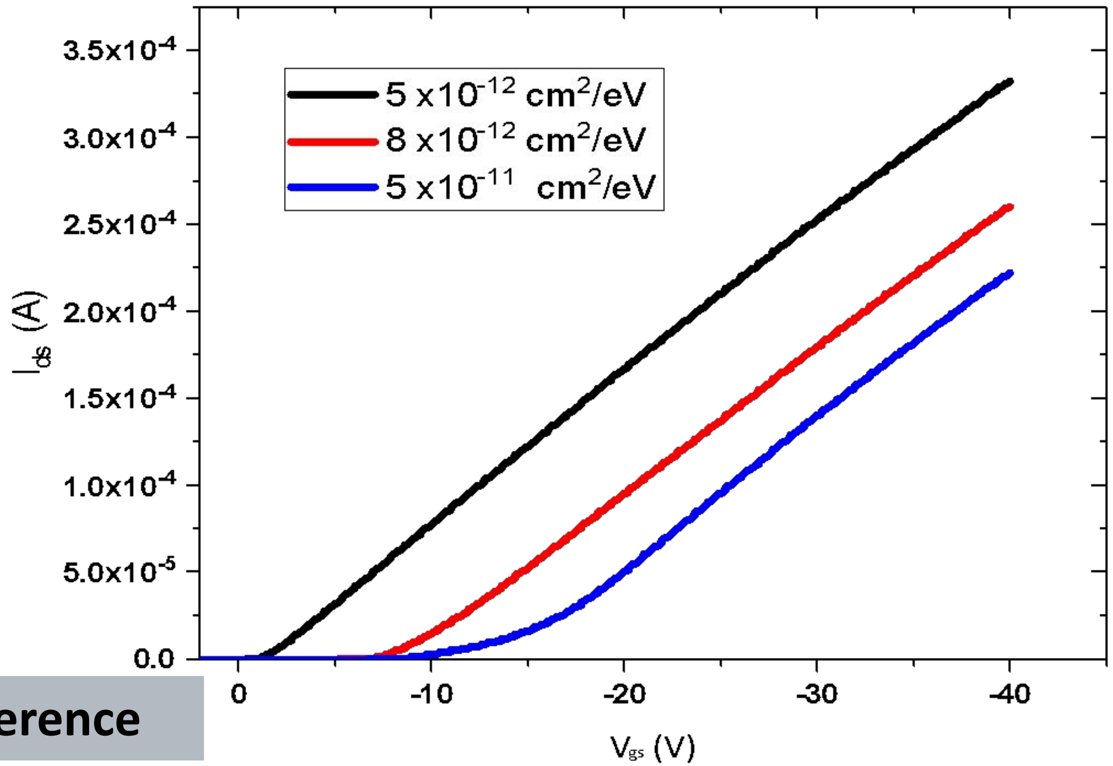
- **The increase in oxide thickness shields the gate bias from creating a strong hole accumulation layer at the semiconductor/insulator interface.**
- **This manifests as less channel charge density.**
- **This results in low mobility of charge carriers.**

Varying Defect States

Linear Region



Saturation Region



Trap States (cm^2/eV)						
	Linear Region			Saturation Region		
HD ($x10^{11}$) (cm^2/eV)	5	50	80	0.5	50	80
μ (cm^2/Vs)	0.0926	0.0204	0.00143	0.1088	0.0985	0.00159

Inference

- **The devices fabricated outside the cleanroom show lots of traps states.**
- **They are due to moisture and other environmental factors and thus revels less channel current, mobility, turn-on voltage and channel pinch off.**
- **Thus with an increase in trap states, the mobility decreases substantially.**

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Paper 6: *N*-type organic thin-film transistor with high field-effect mobility based on a N,N′N,N′-dialkyl-3,4,9,10-perylene tetracarboxylic diimide derivative(2002) , Applied Physics Letters

Authors:

Patrick R. L. Malenfant, Christos D. Dimitrakopoulos, Jeffrey D. Gelorme, Laura L. Kosbar, *and* Teresita O. Graham

Inference

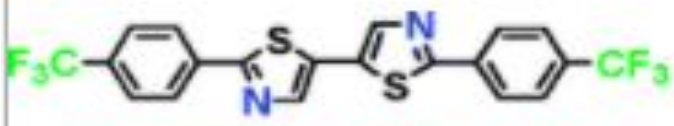
N,N′N,N′-dioctyl-3,4,9,10-perylene tetracarboxylic diimide (PTCDI-C8H) thin films have been implemented into organic thin-film field-effect transistors. Mobilities up to 0.6 cm^2 V^{-1} s^{-1} and current on/off ratios >105>105 were obtained. Linear regime mobilities were typically half of those measured in the saturation regime. X-ray studies in reflection mode suggest a spacing of ~20 Å for thin evaporated films of PTCDI-C8H, which is consistent with the value of ~21±2 Å~21±2 Å obtained from our simulations when an interdigitated packing structure is assumed.

Paper 7: n-Type Organic Field-Effect Transistors with Very High Electron Mobility Based on Thiazole Oligomers with Trifluoromethylphenyl Groups (2005) , American Chemical Society

Authors:
Shinji Ando, Ryo Murakami, Jun-ichi Nishida, Hirokazu Tada, Youji Inoue, Shizuo Tokito, and Yoshiro Yamashita

Inference

Thiazole oligomers and thiazole/thiophene co-oligomers with trifluoromethylphenyl groups were developed as n-type semiconductors for OFETs. They showed excellent n-type performances with high electron mobilities. The electron mobility was enhanced and found to be 1.83 cm^2/Vs.



(Mobility : 1.83 cm^2/Vs)

Active Layer Material - 2

Indium Gallium Zinc Oxide [N-Type Material]

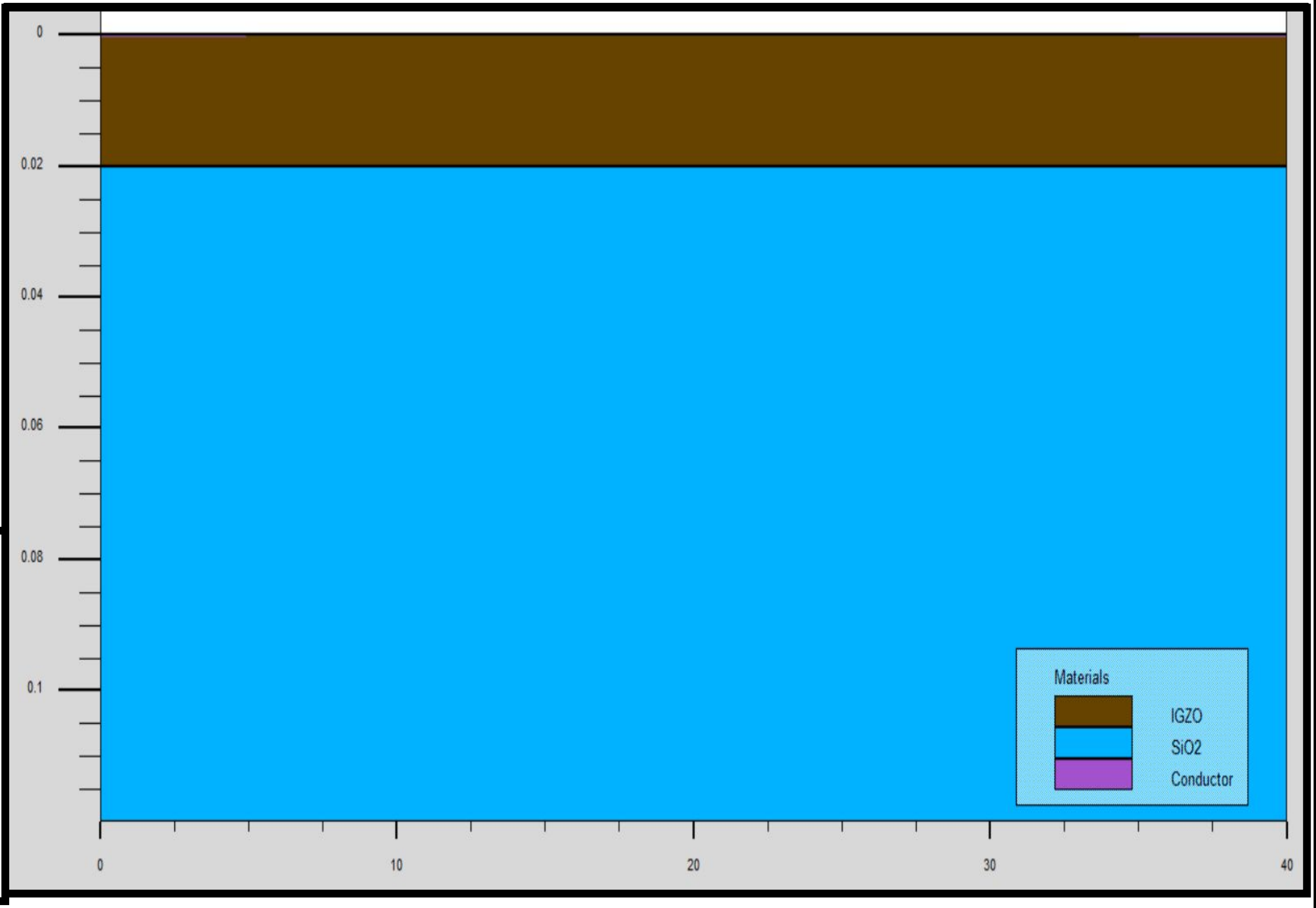
- IGZO in its amorphous form ($In_2Ga_2ZnO_7$) is a transparent amorphous oxide semiconductor.
- IGZO is used in the backplane of flat-panel liquid crystal display or LCD.

Varying Parameters :

- Channel Length
- Electron Affinity

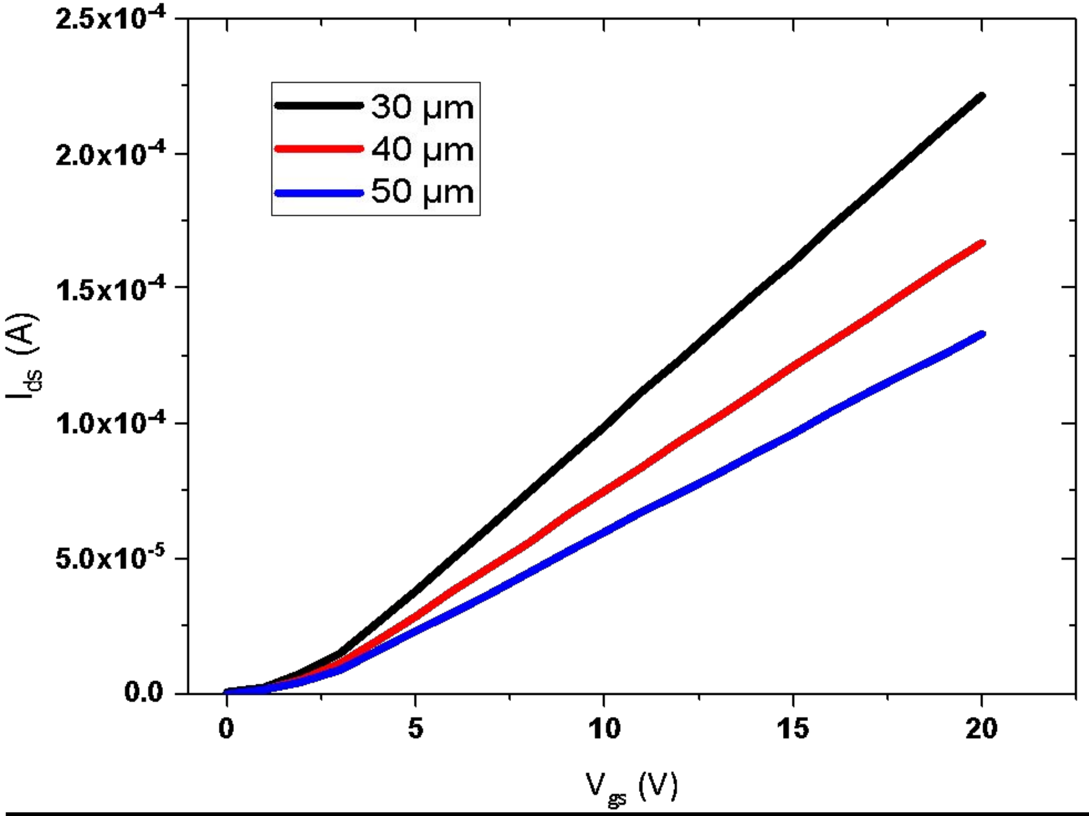
Initial Simulation Values							
L (µm)	Tsc (nm)	Tox (nm)	Eg (eV)	χ (eV)	ϕ (eV)	Vds (V)	Cox′ (F/cm^2)
30	20	100	3.05	4.16	4.33	1	3.45□10 8

Structure of OTFT With IGZO

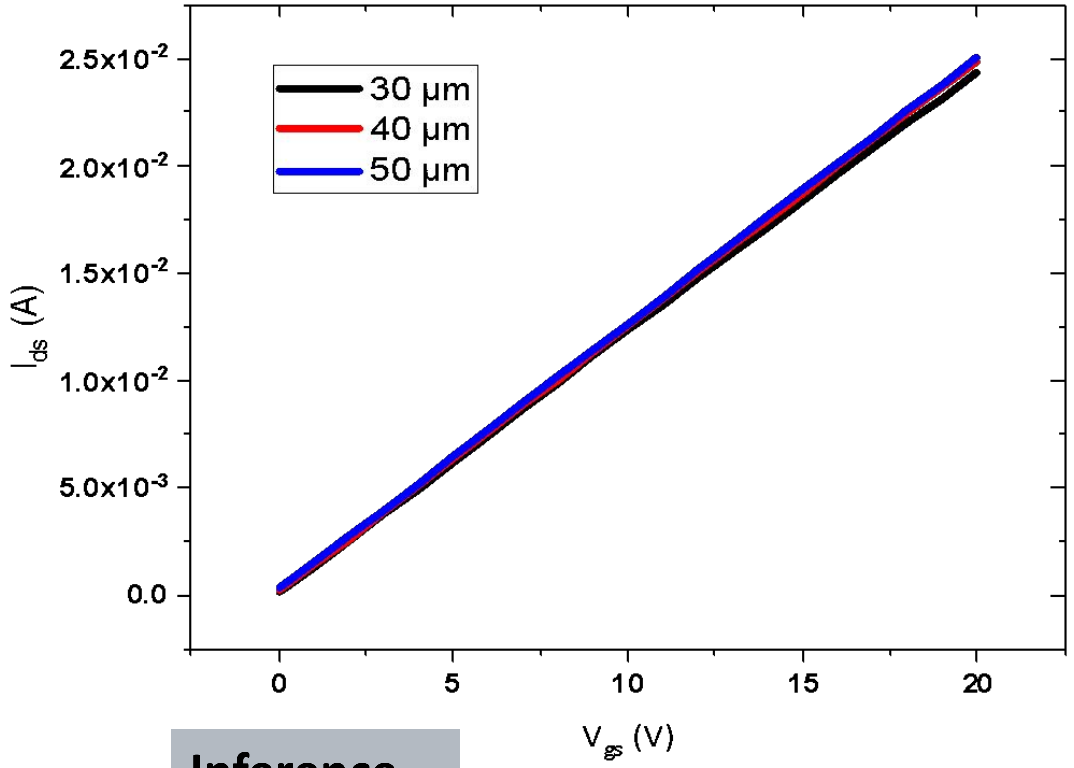


Varying Channel Length

Linear Region



Saturation Region



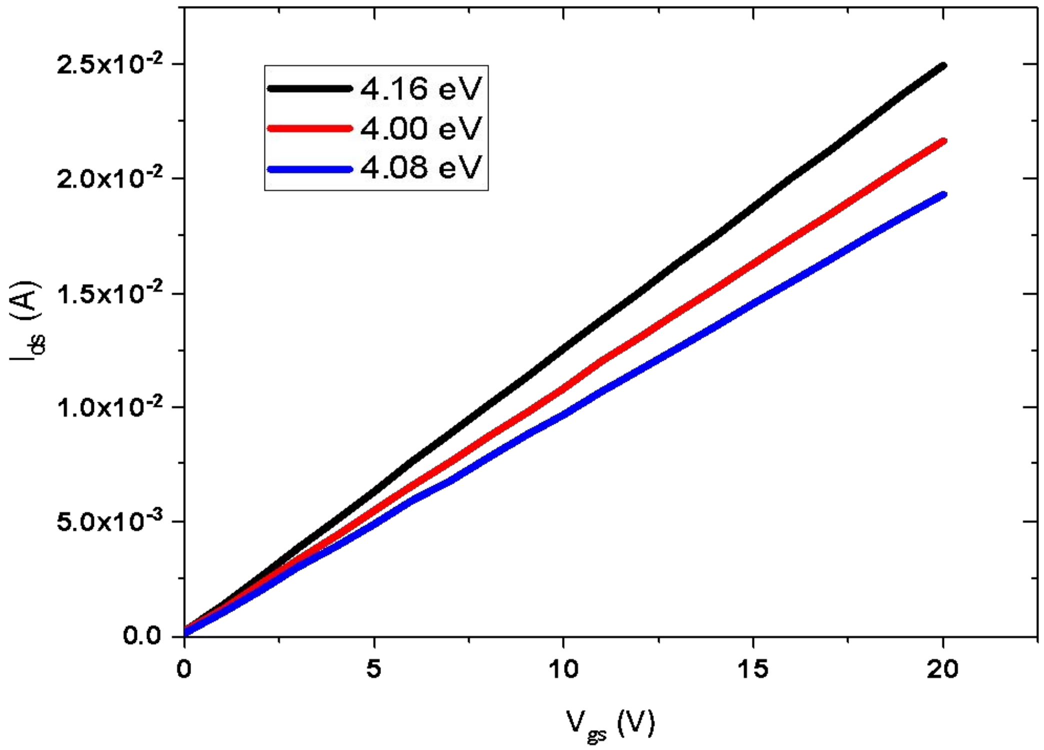
Channel Length (µm)						
	Linear Region			Saturation Region		
L (µm)	10	40	50	10	40	50
µ (cm^2/Vs)	14.613	14.534	14.492	14.85	14.84	14.83

Inference

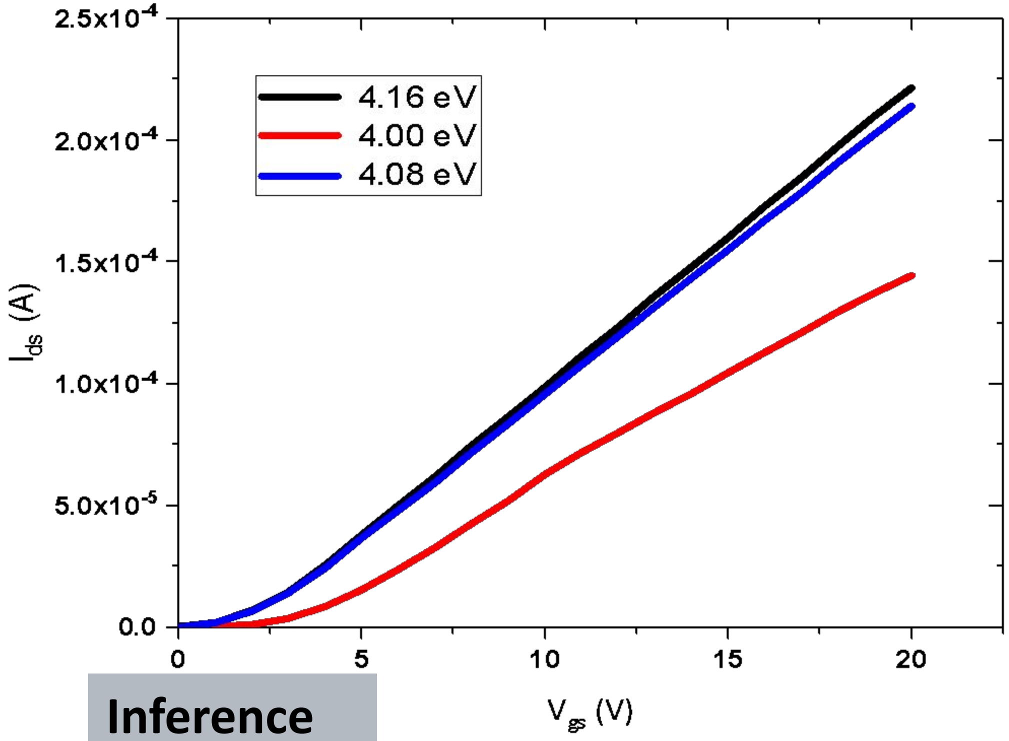
- Channel length is proportional to channel resistance which restricts the mobility of the electrons.
- Thus, with an increase in the channel length of the device, the mobility decreases.

Varying Electron Affinity

Linear Region



Saturation Region



Electron Affinity (eV)						
	Linear Region			Saturation Region		
Χ (eV)	4.0	4.08	4.16	4.0	4.08	4.16
μ (cm^2/Vs)	10.1	14.13	14.613	13.92	14.51	14.85

Inference

- Due to the fact that the metal work function tends to align with the LUMO of the IGZO.
- Thereby facilitating electron transport efficiently.
- This leads to an increase in channel current. So Mobility Increases with increase in Electron Affinity.

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Summary

P-type OTFT

Channel Length (μm)						
	Linear Region			Saturation Region		
L (μm)	10	20	30	10	20	30
μ (cm^2/Vs)	0.094	0.0937	0.0932	0.1093	0.1021	0.1001

Di-electric Thickness (nm)						
	Linear Region			Saturation Region		
T_{ox} (nm)	50	150	250	50	150	250
μ (cm^2/Vs)	0.095	0.0945	0.0941	0.1169	0.1146	0.1093

Bandgap (eV)						
	Linear Region			Saturation Region		
E_g (eV)	2.0	2.2	2.4	2.0	2.2	2.4
μ (cm^2/Vs)	0.0946	0.0942	0.078	0.1193	0.1093	0.0808

Electron Affinity (eV)						
	Linear Region			Saturation Region		
X (eV)	2.7	2.9	3.1	2.7	2.9	3.1
μ (cm^2/Vs)	0.095	0.094	0.0789	0.1196	0.1093	0.0815

Trap States (cm^2/eV)						
	Linear Region			Saturation Region		
HD ($x10^{11}$) (cm^2/eV)	5	50	80	0.5	50	80
μ (cm^2/Vs)	0.0926	0.0204	0.00143	0.1088	0.0985	0.00159

N-type OTFT

Channel Length (μm)						
	Linear Region			Saturation Region		
L (μm)	10	40	50	10	40	50
μ (cm^2/Vs)	14.613	14.534	14.492	14.85	14.84	14.83

Electron Affinity (eV)						
	Linear Region			Saturation Region		
χ (eV)	4.0	4.08	4.16	4.0	4.08	4.16
μ (cm^2/Vs)	10.1	14.13	14.613	13.92	14.51	14.85

INFERENCE

- By comparing the mobility calculated by varying the parameters of both Pentacene and Indium Gallium Zinc Oxide, it is concluded that the mobility for IGZO devices, n-type material (~15) is 150 times more than that of Pentacene, p-type material (~0.1).

RESULT

- The goal of this project was to study the effect of the device parameters on the mobility of an Organic Thin Film Transistor, which was achieved.

Thank You

Your Suggestions Will Be Appreciated