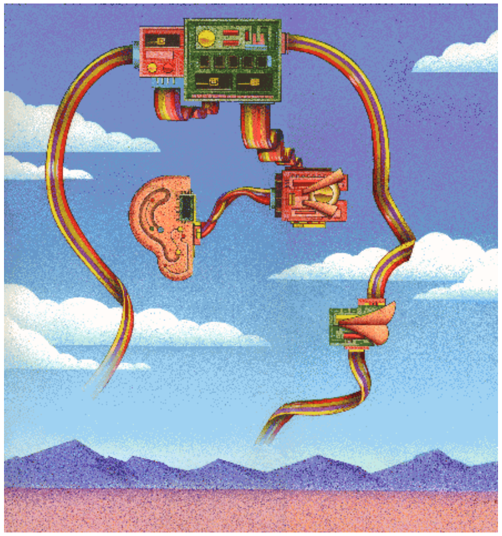


Compact Models for Organic Semiconductor Devices: Overview and Challenges

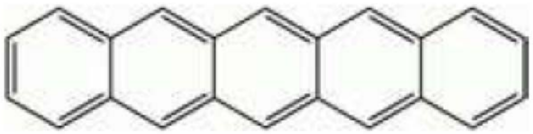
Andreas G. Andreou

andreou@jhu.edu

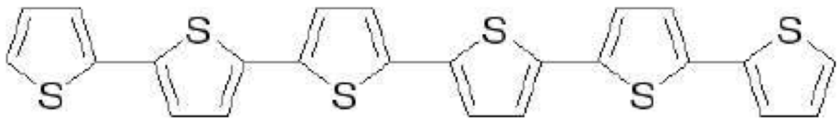
Electrical and Computer Engineering and
Whitaker Biomedical Engineering Institute
Johns Hopkins University
http://www.ece.jhu.edu/faculty/andreou/AGA/index.htm

ABC of organic semiconductor devices

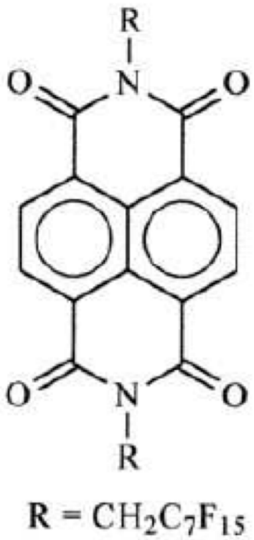
common organic semiconductor materials



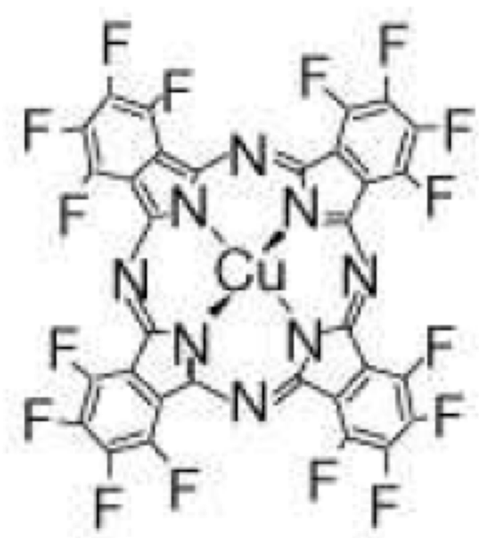
pentacene



alpha-sexiothiopene



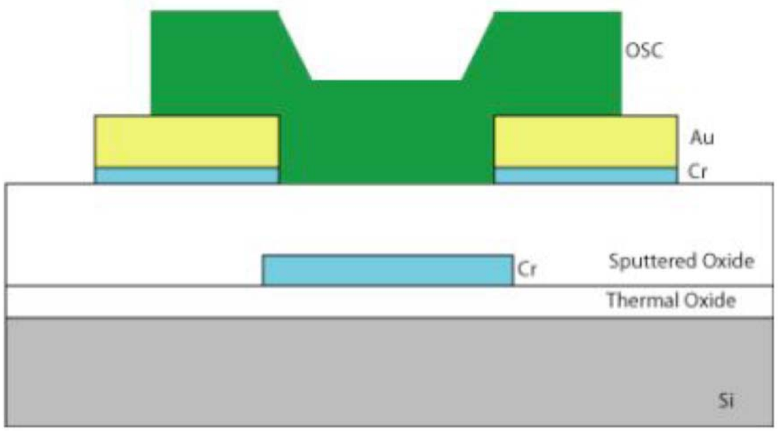
F_{15}NTCDI:
(bis(pentadecafluorooctyl)
napthalene-tricarboxylic diimide



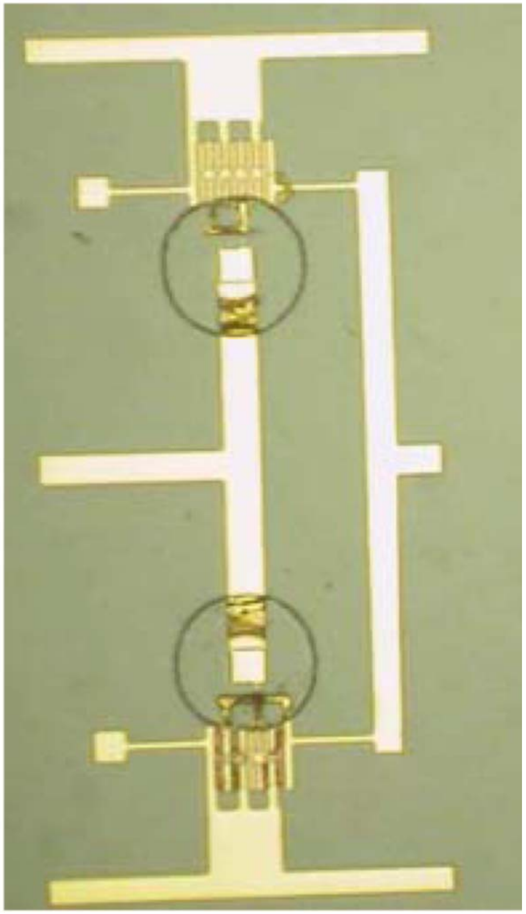
F_{16}CuPC:
Hexadecafluorocopper
pthalocyanine

device structures

Top-Contact-Bottom-Gate



Bottom-Contact-Bottom-Gate



E. Choi, R. Ozgun, B.M. Dhar, H. Katz and A.G. Andreou, “Fabrication Process Design For Metal-Cytop-Organic Semiconductor Circuits, EAMTA 08

compact modeling overview

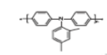
bibliography: device physics and models

ADVANCED MATERIALS

2005

Device Physics of Solution-Processed Organic Field-Effect Transistors**

By *Henning Sirringhaus**



1296 *Chem. Rev.* **2007**, *107*, 1296–1323

Electron and Ambipolar Transport in Organic Field-Effect Transistors

Jana Zaumseil and Henning Sirringhaus*

Cavendish Laboratory, JJ Thomson Avenue, Cambridge CB3 0HE, United Kingdom

Received July 31, 2006

JOURNAL OF APPLIED PHYSICS **97**, 023705 (2005)

Charge injection in doped organic semiconductors

A. R. Hosseini,[a)] Man Hoi Wong, Yulong Shen, and George G. Malliaras
Department of Materials Science and Engineering, Cornell University, Ithaca, New York 14853-1501

(Received 28 June 2004; accepted 27 October 2004; published online 23 December 2004)

bibliography: compact models and parameter extraction

An analytical model for organic-based thin-film transistors

Gilles Horowitz
Laboratoire des Matériaux Moléculaires, C.N.R.S., 2 rue Henry Dunant, F-94320 Thiais, France

Philippe Delannoy
Groupe de Physique des Solides, Université Paris 7, 2 place Jussieu, F-75251 Paris Cedex 05, France

(Received 6 March 1991; accepted for publication 29 March 1991)

Journal Applied Physics

2004

ADVANCED FUNCTIONAL MATERIALS

Extracting Parameters from the Current–Voltage Characteristics of Organic Field-Effect Transistors

By *Gilles Horowitz,* Philippe Lang, Mohamad Mottaghi,* and *Hervé Aubin*

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Solid-State Electronics 52 (2008) 400–405

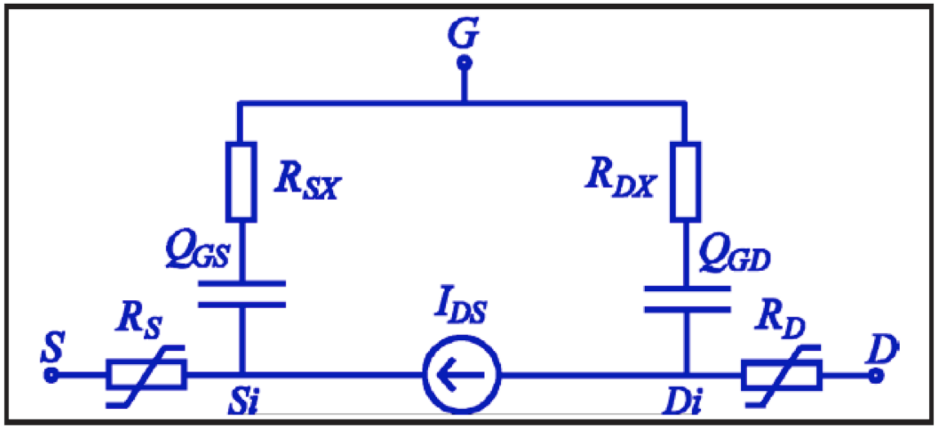
SOLID-STATE ELECTRONICS

www.elsevier.com/locate/sse

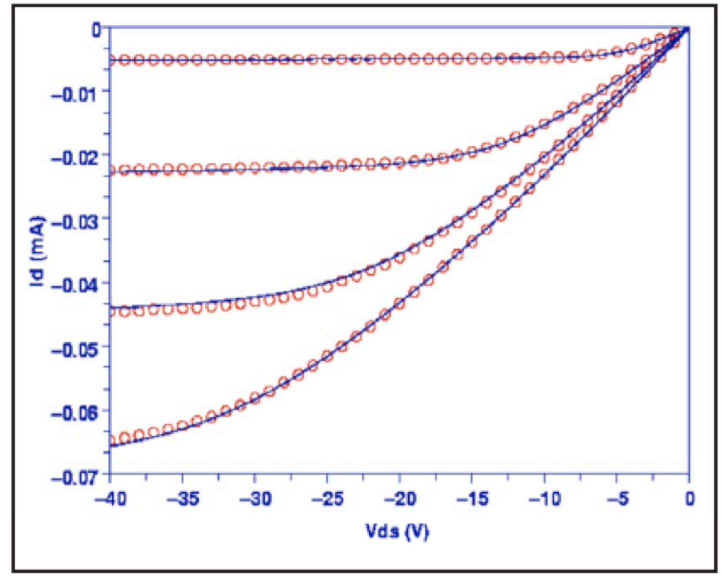
Universal compact model for long- and short-channel Thin-Film Transistors

Benjamin Iñiguez [a,*], Rodrigo Picos [b], Dmitry Veksler [c], A. Koudymov [c], Michael S. Shur [c], Trond Ytterdal [d], Warren Jackson [e]

compact models in SPICE



The equivalent circuit of the UOTFT model.



Comparison between simulated (lines) and measured (circles) output characteristics of the BGBC OTFT for Vg=-10V, -20V, -30V and -40V.

Simucad Implementation

- UOTFT is implemented in Simucad's independently compiled model library (ModelLib). It can be accessed within SmartSpice as TFT model LEVEL=37
- Equivalent circuit and the extrinsic model components are compatible with the existing a-Si and poly-Si RPI TFT models (LEVEL=35 and 36)

S. Mijalkovi, D. Green, A. Nejim, A. Rankov, E. Smith, T. Kugler, C. Newsome, J. Halls, "UOTFT: Universal Organic TFT Model for Circuit Design", Digest of the 6th International Conference on Organic Electronics, Liverpool, June, 2009.

Universal organic TFT model (I)

- Accurate implementation of a Unified Charge Control Model (UCCM) for OTFTs having exponentially distributed density of states in the organic semiconductor and operating in the channel accumulation mode in the presence of interface traps
- A new universal carrier mobility law valid in all operation regions
- A new unified description of the drain-source current in linear and saturation operation regimes including the effects of the channel length modulation and diffusion carrier transport
- Implicit non-linear gate bias dependent parasitic resistance model
- Drain-source leakage current model

Universal organic TFT model (II)

- Physical temperature scaling of mobility model parameters based on percolation theory
- Temperature scaling of parasitic resistances
- Unified Meyer capacitance model, or Leroux's charge model, for the description of the channel charge dynamics
- The extrinsic gate RC network for the modeling of frequency dispersion effects
- Extrinsic overlap capacitances
- Thermal RC network for the modeling of self-heating effects
- Noise model
- Geometrical scalability

traditional modeling and parameter extraction

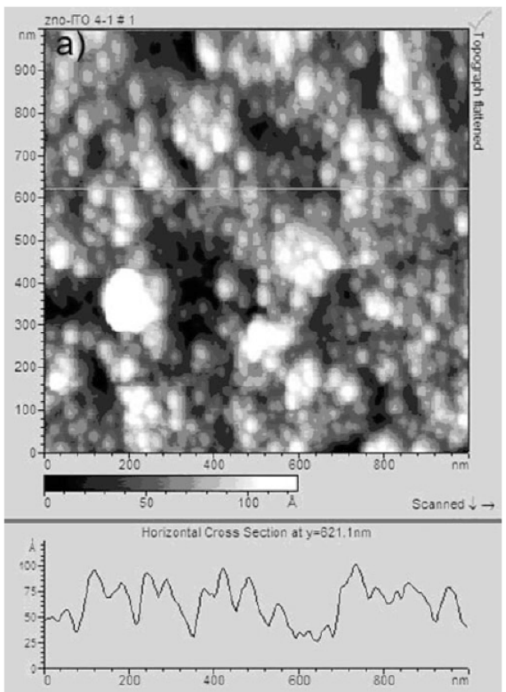
hybrid organic-inorganic diodes

ADVANCED MATERIALS

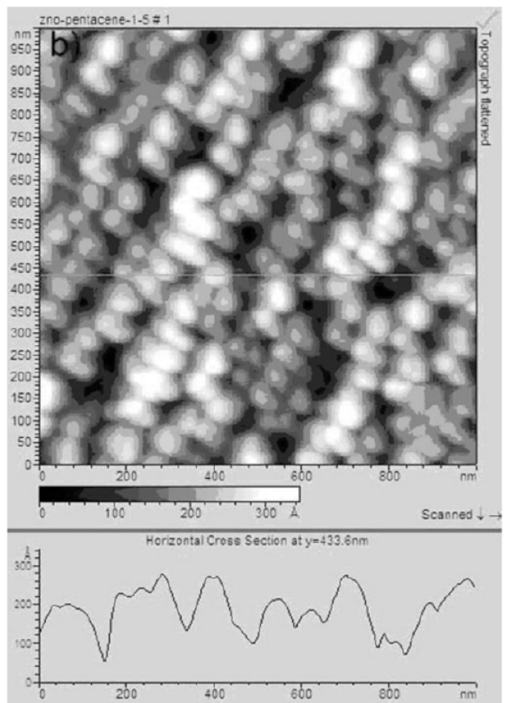
DOI: 10.1002/adma.200701550

Pentacene-Zinc Oxide Vertical Diode with Compatible Grains and 15-MHz Rectification**

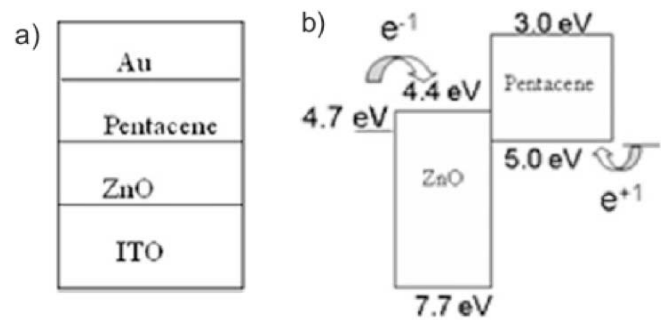
By *Bhola Nath Pal*, *Jia Sun*, *Byung Jun Jung*, *Edward Choi*, *Andreas G. Andreou*, and *Howard E. Katz**

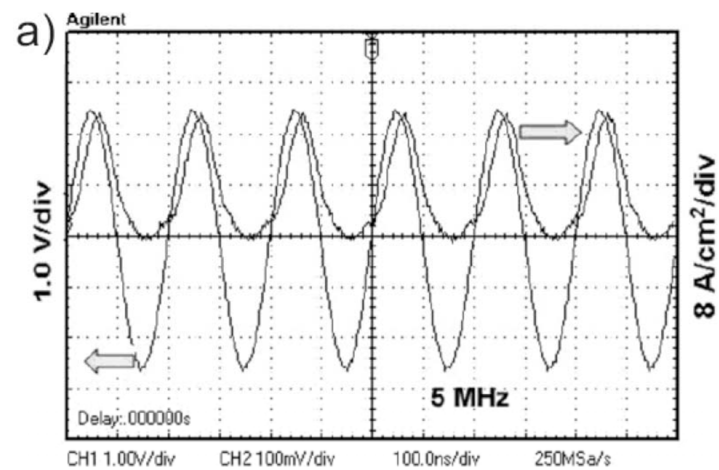


ZnO



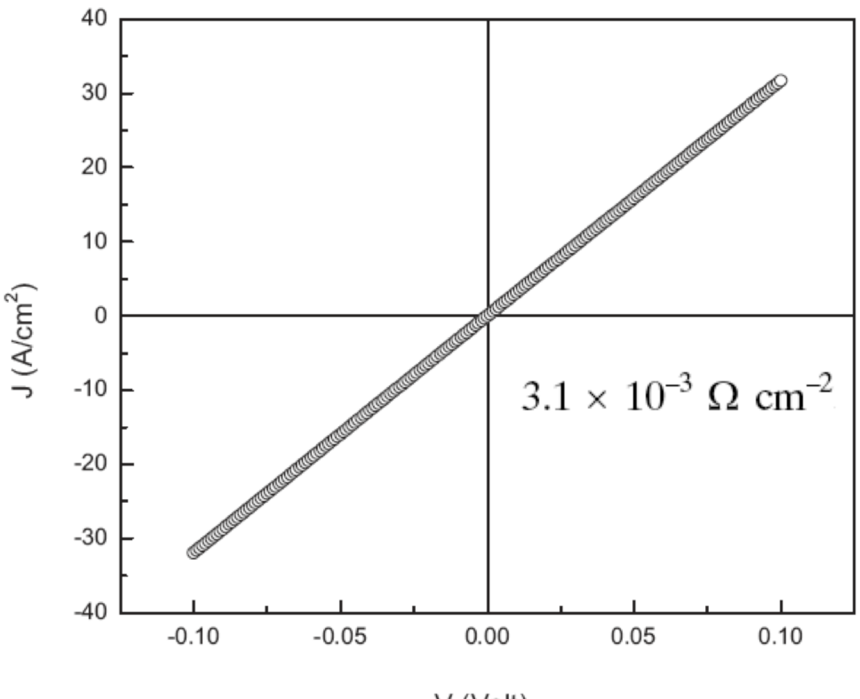
Pentacene

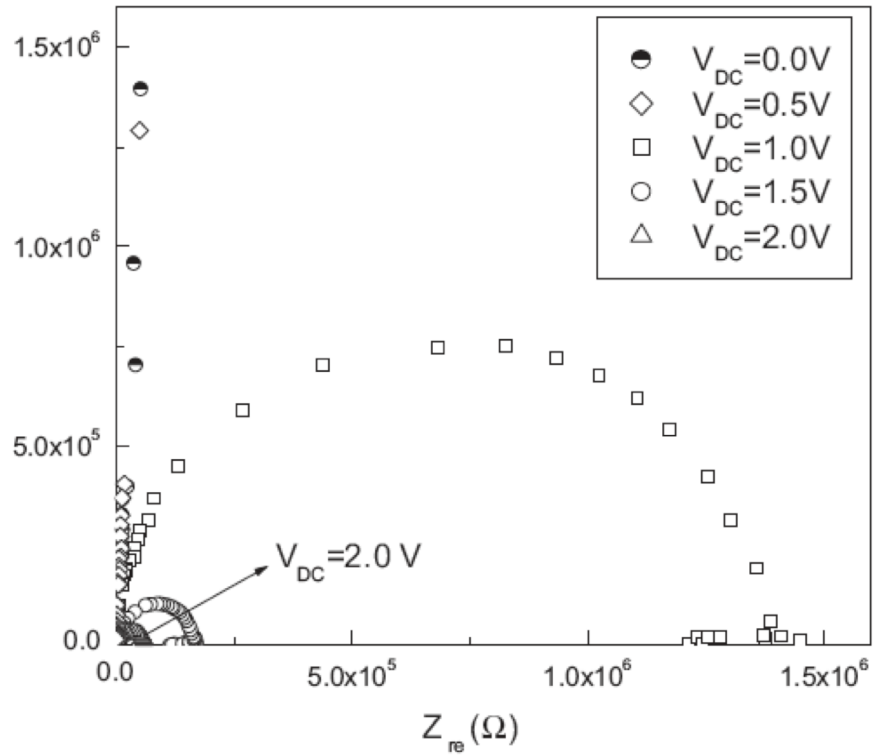


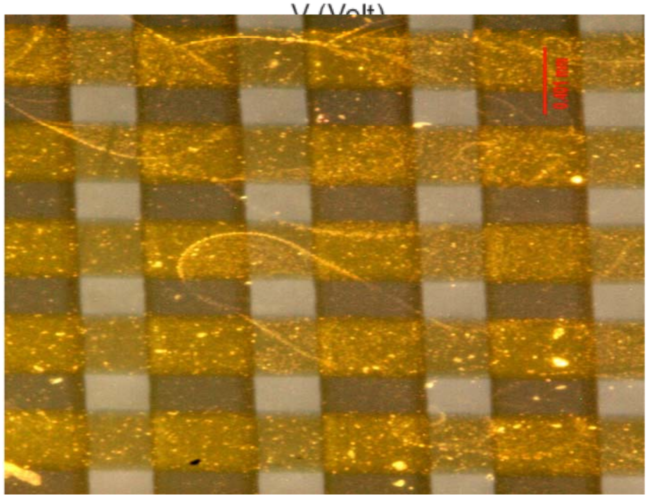


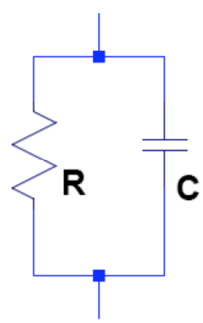
device diagnostics

contact resistance: probe-Au-ITO-probe





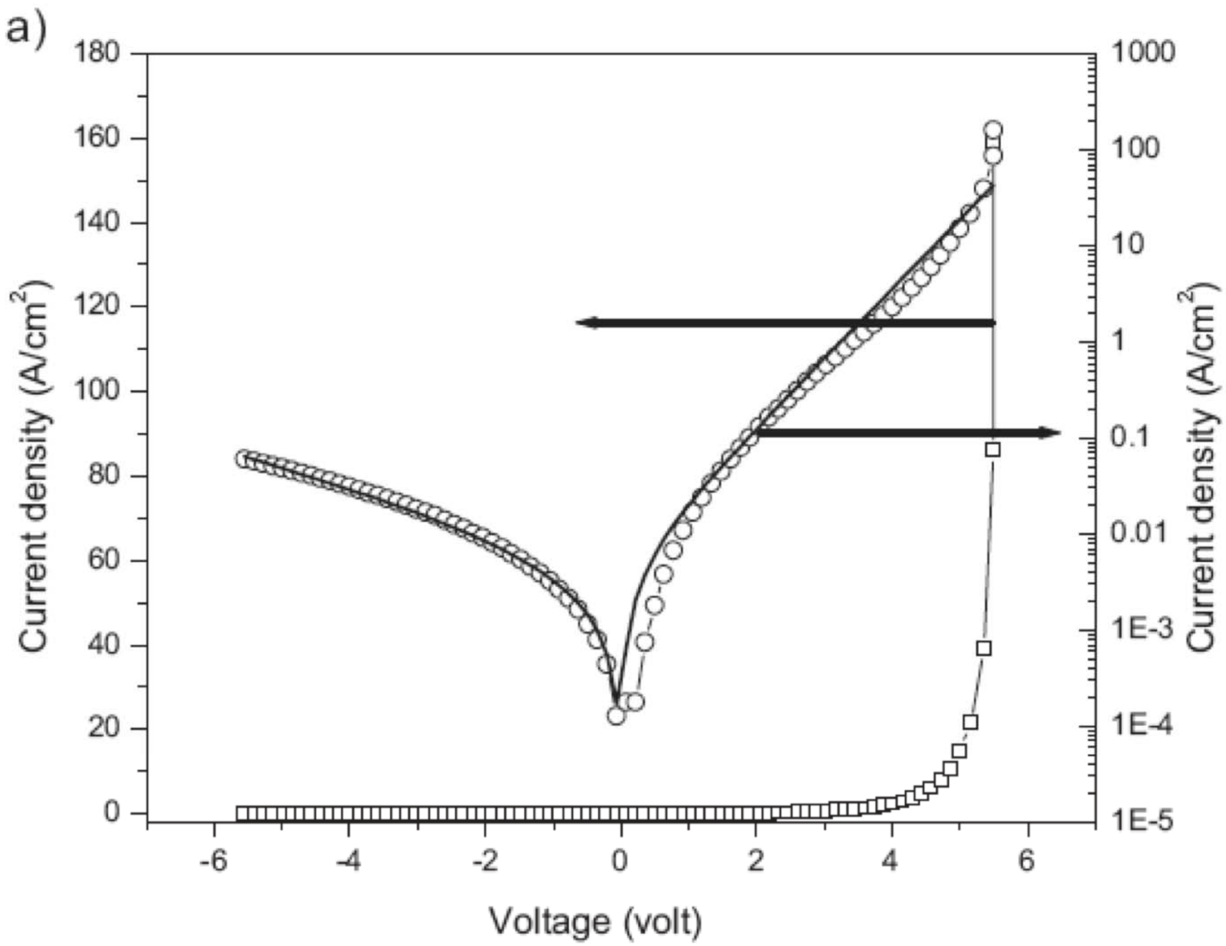




$$\mathrm{Re}(Z) = \frac{R}{1+\omega^2 R^2 C^2}$$

$$\mathrm{Im}(Z) = \frac{\omega R^2 C}{1+\omega^2 R^2 C^2}$$

current-voltage model

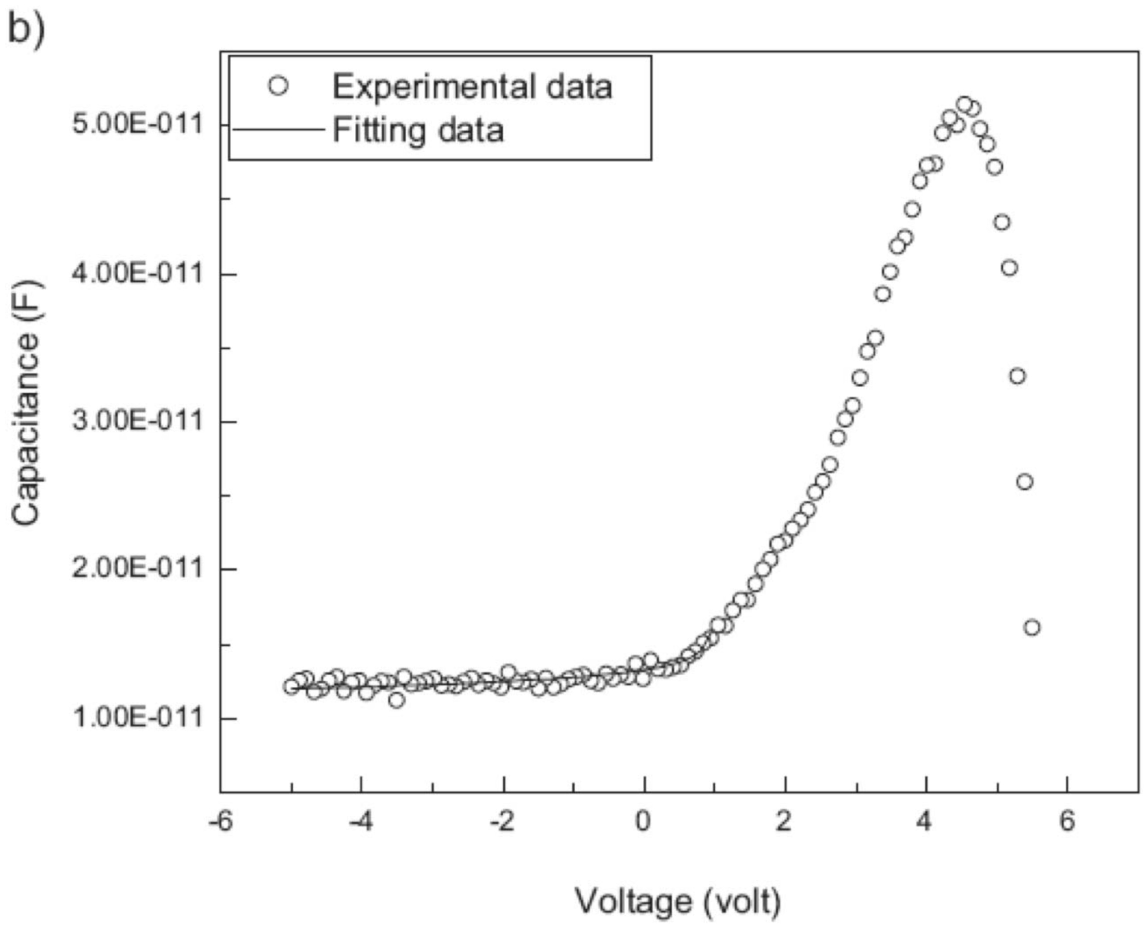


I_S [A]	η
4.68×10^{-3}	21.25

I_{tun} [A]	η_{tun}
5.74×10^{-3}	86.4

$$I = I_s\,[\exp(qV/\eta kT)-1] - I_{tun}\,[\exp(-qV/\eta_{tun}kT)-1]$$

capacitance model



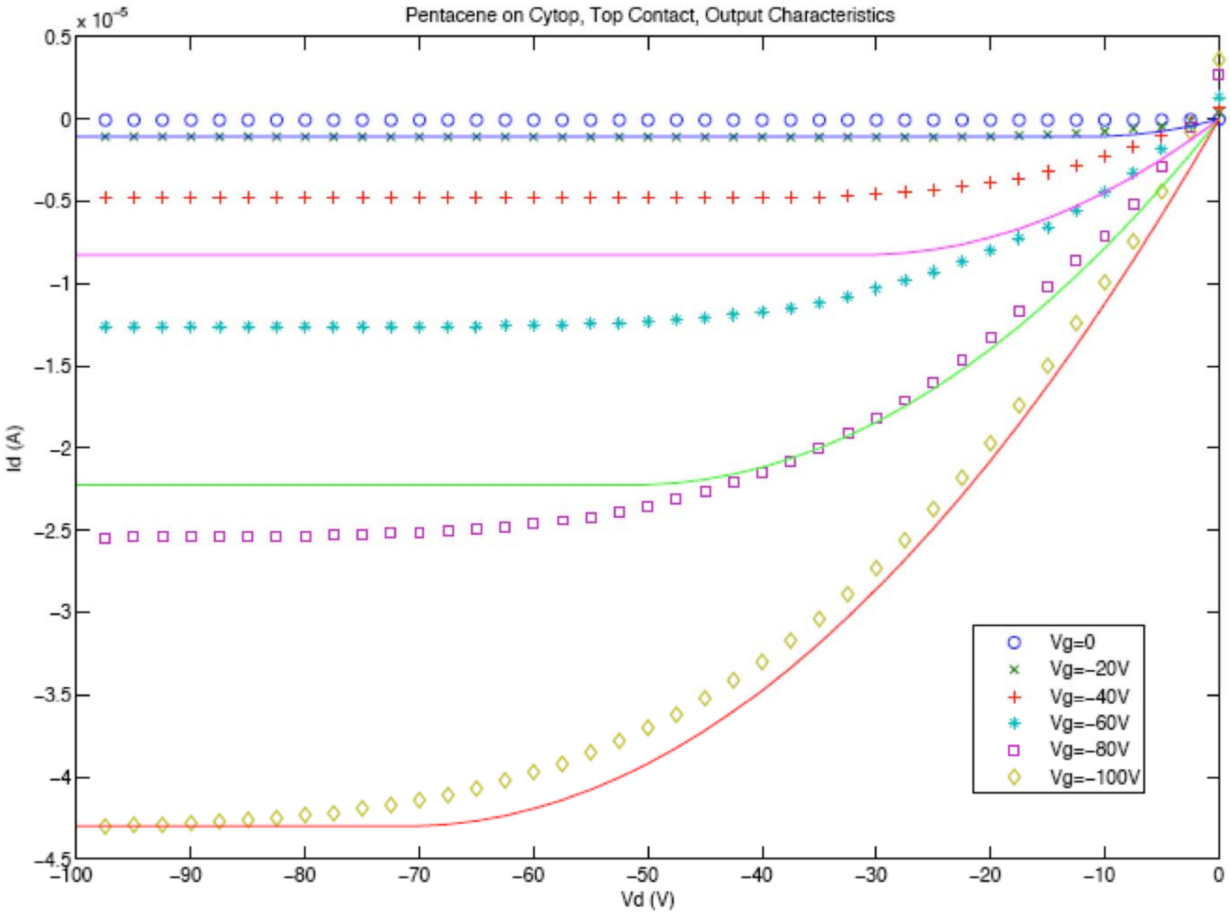
$$C_o = 1.32 \times 10^{-11} F$$

$$m = 0.056$$

$$V_o = 1V$$

$$C = \frac{C_0}{\left(1 - \frac{V}{V_0}\right)^m}$$

Pentacene – Cytop oxide



$$V_{th} = -26.5V$$

$$\beta = 2.86 * 10^{-8} A/V^2$$

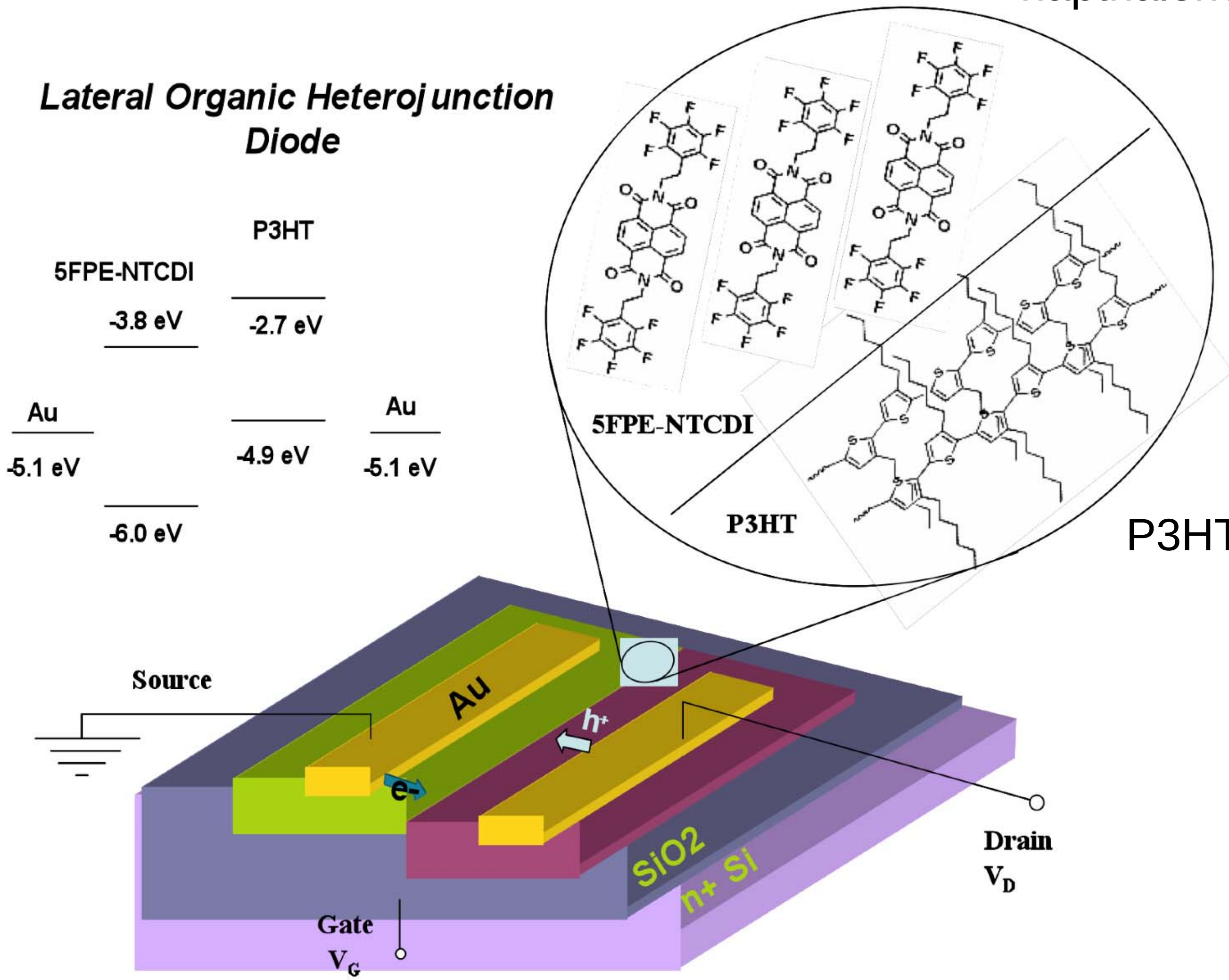
$$I_{ds,sat} = \frac{1}{2}\beta(V_g - V_{th})^2$$

E. Choi, Ph.D. Dissertation, Johns Hopkins University, 2008

challenges and opportunities

lateral heterojunction diodes

5FPE-NTCDI: pentafluorolphenyl-ethyl napthalene tetracarboxylic diimide

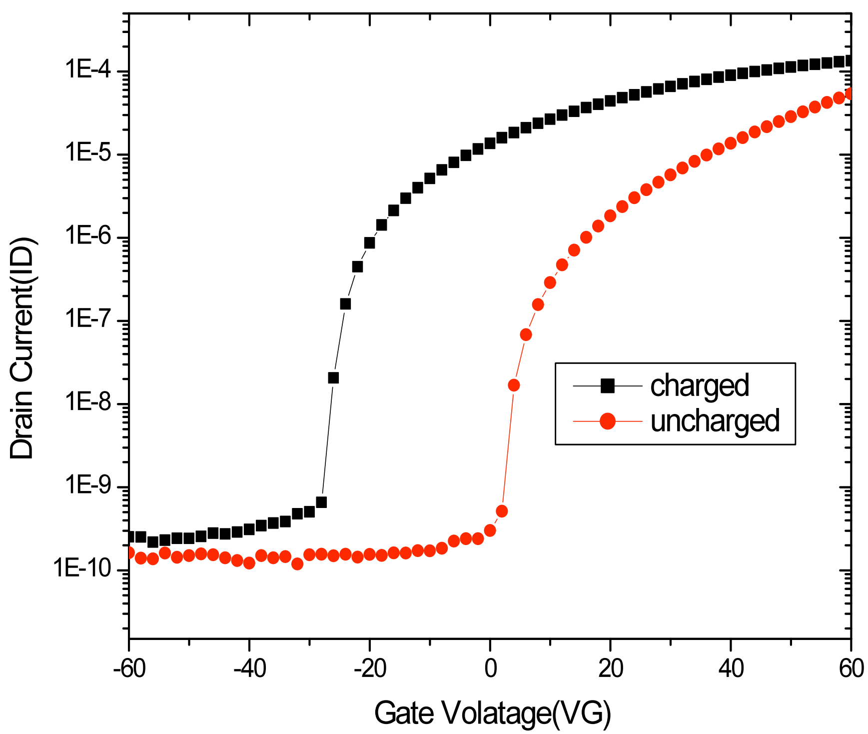


P3HT: poly(3-hexylthiophene)

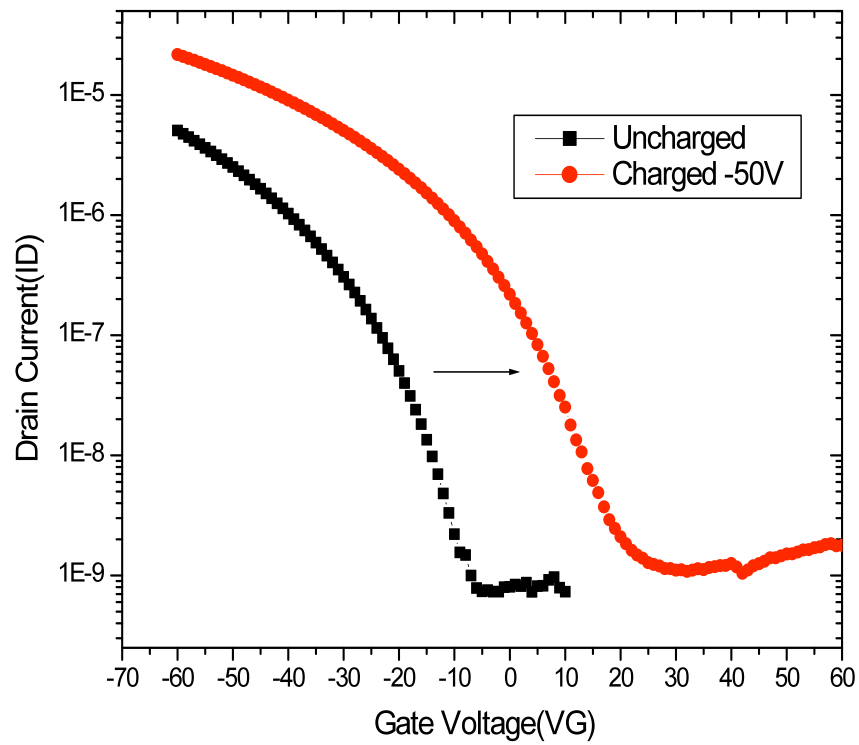
B.M. Dhar, G.S. Kini, G.Xia, B.J.Jung, N. Markovic, H. Katz, Field effect-tuned lateral oxide diodes, to appear PNAS 2010

OFET p-type and n-type threshold tuning

5FPE-NTCDI: pentafluorolphenyl-ethyl napthalene tetracarboxylic diimide



Pentacene

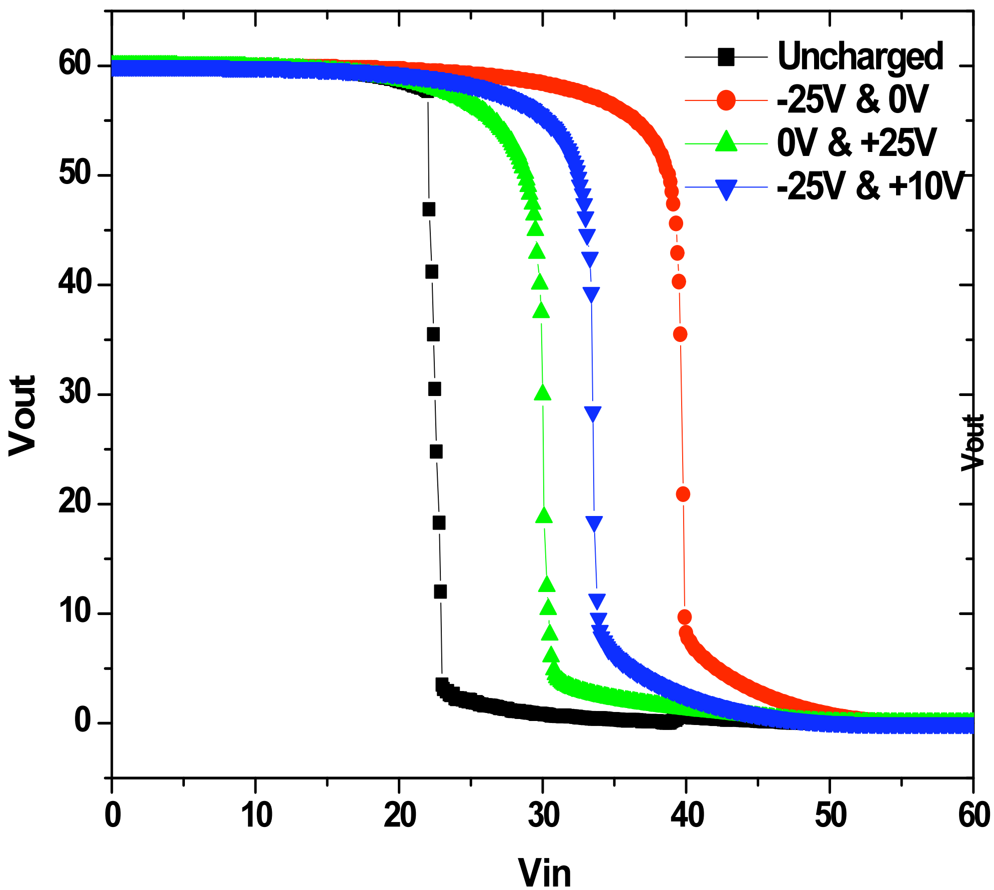


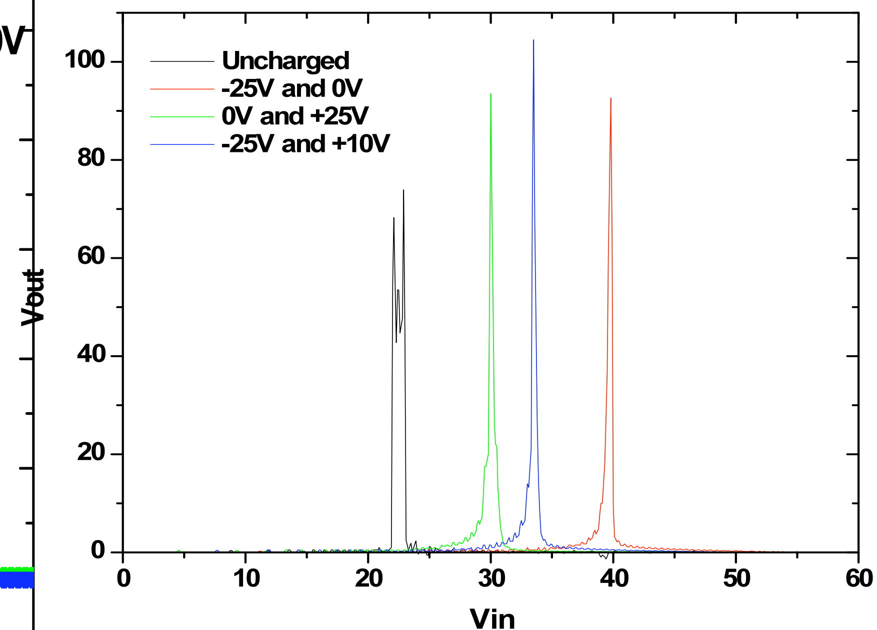
Gate: Atactic Polysterene (APS)

$$\mu = 0.1\, cm^2 / V \cdot \sec$$

R. Ozgun, B.M. Dhar, B.J. Jung, H. Katz and A.G. Andreou, "Threshold tuning of complementary organic FET inverters" in preparation

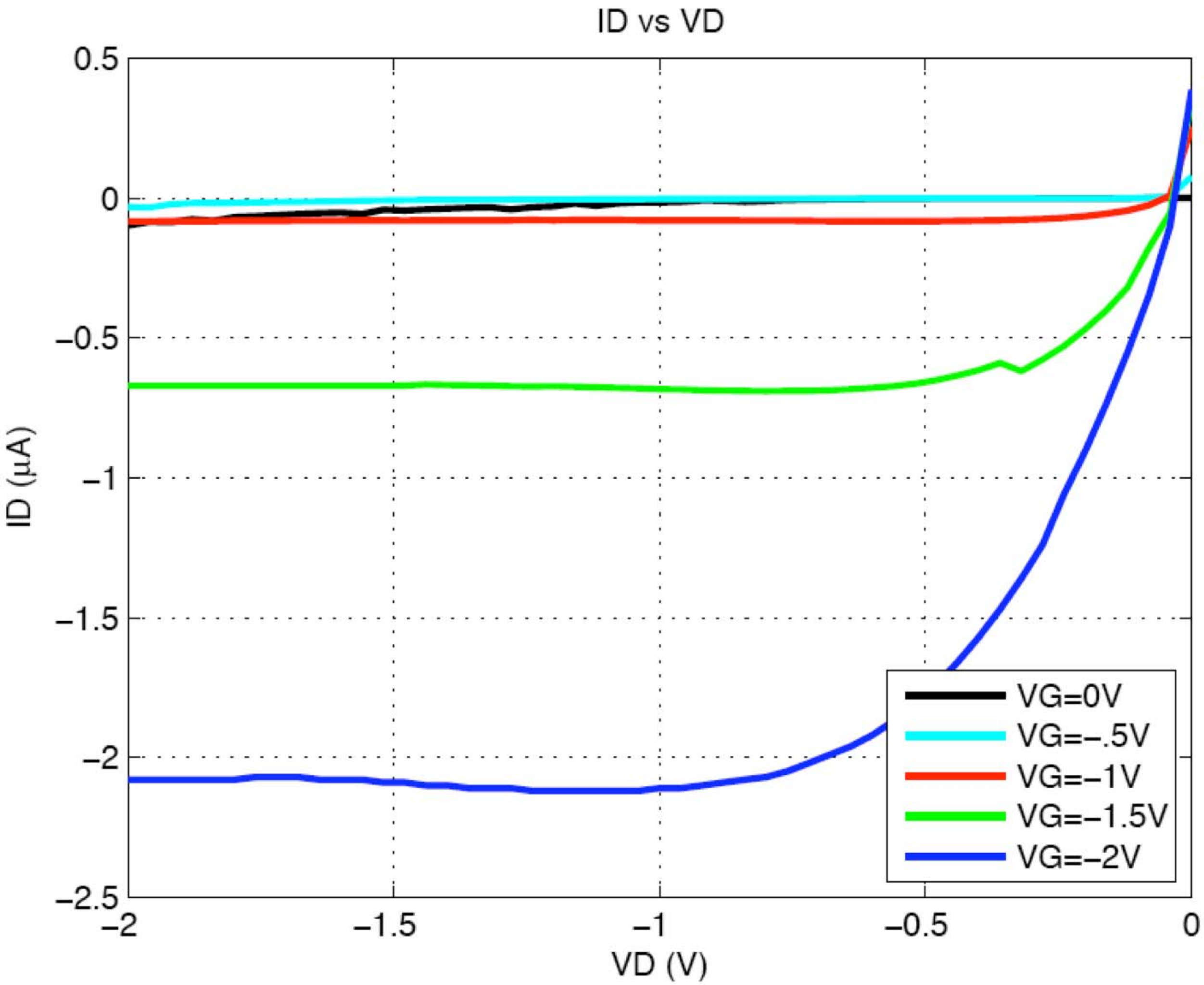
OFET inverter circuit characteristics



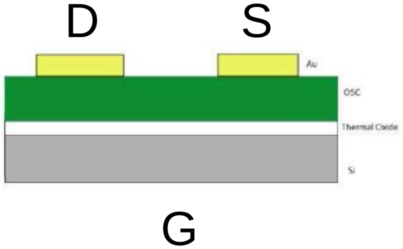


R. Ozgun, B.M. Dhar, B.J. Jung, H. Katz and A.G. Andreou, "Threshold tuning of complementary organic FET inverters" in preparation

Top-contact Pentacene with SBA dielectric



SBA: Sodium Beta-Alumina



conclusions

Compact modeling and model parameter extraction can carried in some extend using approaches that have been used in Silicon, Germanium and other compound semiconductor devices.

Models developed for a-Si TFT are good starting points for modeling OFETs. Many methods for parameter extraction on Silicon devices are applicable to OFETs.

Compact modeling for OSC devices other than simple FETs or diodes is still in its infancy.

Need models that capture threshold shift for charged dielectric OFETs; for example gated diodes or OFET with non-volatile storage capability.

Compact physics based models of mobility are crucial for predicting temperature dependence and strain effects that affect the characteristics of devices and circuits fabricated in conformal surfaces

acknowledgements

Prof. Howard Katz and Group @ JHU
Bhola Nath Pal (ZnO-Pentacene diode)
Bal Mukund Dhar (OFETs and lateral gated diode)

Andreou Group @ JHU
Ed Choi (ZnO-Pentacene diode/OFETs)
Recep Ozgun (OFETs)

work supported by:

Air Force Office of Scientific Research (Award number FA9550-06-01-0076 to HK)
Department of Energy (Award number DE-FG02-07ER46465 to HK and AGA)