

Functional Devices Using Organic Electronics

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Paper electronics

- Paper & Printing
 - › 2000 years old & among the greatest inventions
 - › Widely used, recyclable and low cost
- Print electronics on paper!
 - › 1960's: Inorganic TFTs
 - T.P. Brody and D.J. Page
 - › Renewed interest

Adv. Mater. 23 (2011) 1935.



Paper Electronics

Daniel Tóth and Ronald Österbacka*



REVIEW

Paper is ubiquitous in everyday life and a truly low-cost substrate. The use of paper substrates could be extended even further, if electronic applications would be applied next to or below the printed graphics. However, applying electronics on paper is challenging. The paper surface is not only very rough compared to plastics, but it is also porous. While this is detrimental for most electronic devices manufactured directly onto paper substrates, there are also approaches that are compatible with the rough and absorbent paper surface. In this review, recent advances and possibilities of these approaches are evaluated and the limitations of paper electronics are discussed.

Since the first devices of electronic and optoelectronic applications, based on solution-processable π -conjugated organic molecules and polymers, has renewed the interest in electronics manufactured on low-cost flexible plastic and paper substrates.¹

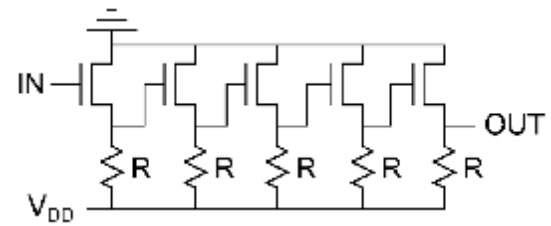
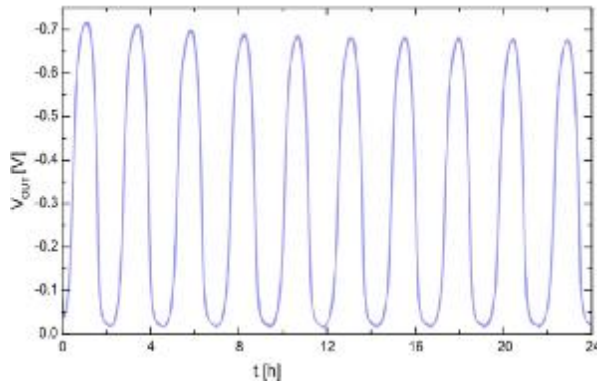
There have been many recent advances in the field of paper electronics. Many examples of paper electronics, however, involve the use of plastic covered paper substrates, lamination of a plastic film with electronics between two paper sheets (e.g., for electronic paper tablets) or gluing of electronic components or films (to) die-cast onto paper substrates. This is easy to understand, considering that paper substrates typically have a large roughness, poor chemical and mechanical barrier properties, absorb materials into the porous structure, and contain chemical compounds that often are considered to be toxicities. To fabricate electronic devices such as organic diodes or transistors that usually require well-defined smooth interfaces

1. Introduction

Paper is by far the cheapest and most widely used flexible substrate in daily life. The price of paper (400 g m⁻²) is substantially lower than that of plastic substrates such as polyethylene terephthalate (PET, ~2 mm thick) and polystyrene (PS, ~30 mm thick). The speed of the roll-to-roll (R2R) manufacturing process of paper substrates exceeds 100 km h⁻¹. In addition to this, paper is also environmentally friendly, since it

is a natural material and can be recycled. The use of paper substrates could be extended even further, if electronic applications would be applied next to or below the printed graphics. However, applying electronics on paper is challenging. The paper surface is not only very rough compared to plastics, but it is also porous. While this is detrimental for most electronic devices manufactured directly onto paper substrates, there are also approaches that are compatible with the rough and absorbent paper surface. In this review, recent advances and possibilities of these approaches are evaluated and the limitations of paper electronics are discussed.

Ring-oscillator on paper



5-stage ring oscillator made on recyclable paper-substrate.

With LPT and DPC

Oscillation @ $f=100\mu\text{Hz}$

F. Pettersson, J. Koskela, et al.,



BUT...

- › Some of the used materials used for creating the ion-modulation are toxic and environmentally not good!



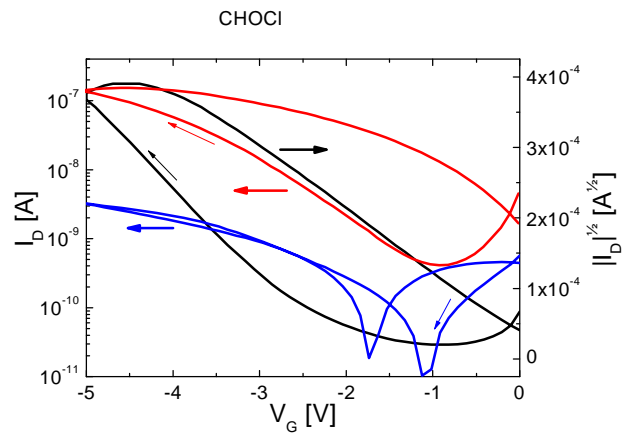
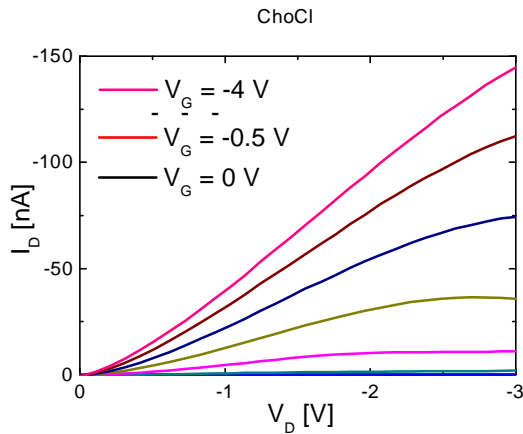
- › Can we make more suitable materials for ion-modulated transistors?
 - › Also suitable for food-packages?

T. Remonen et al.,



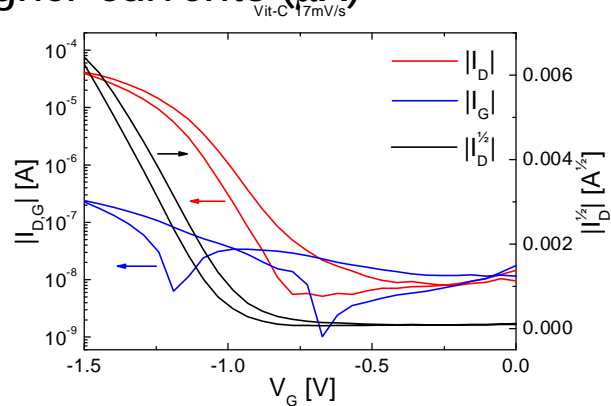
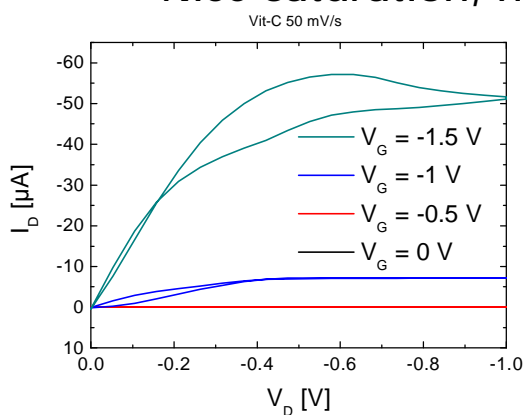
Vitamine based ionic liquids –not good...

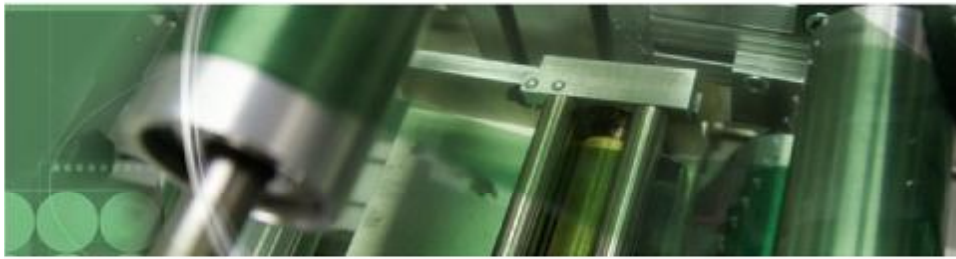
- › No good transistor curves using choline chloride!
 - Allmost no saturation, low currents (nA) and large gate leakages...



Complexing choline chloride with urea

- › The complex forms "immobile anions"
- › Better transistor curves!
 - Nice saturation, higher currents (μA)

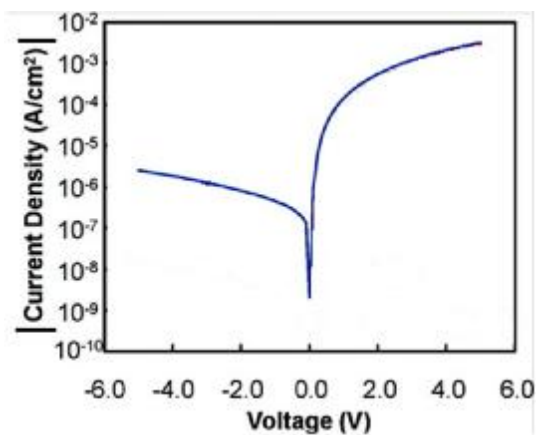
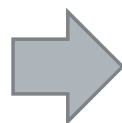
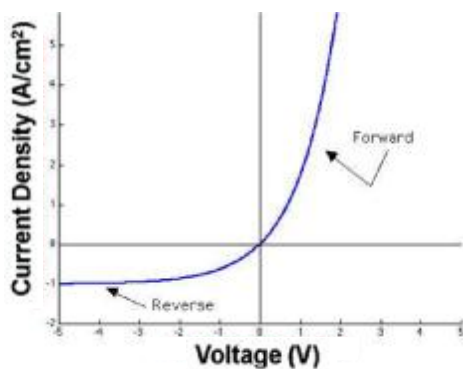
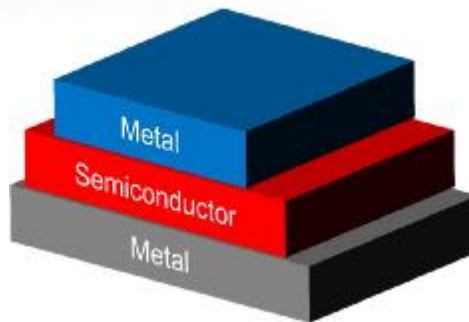


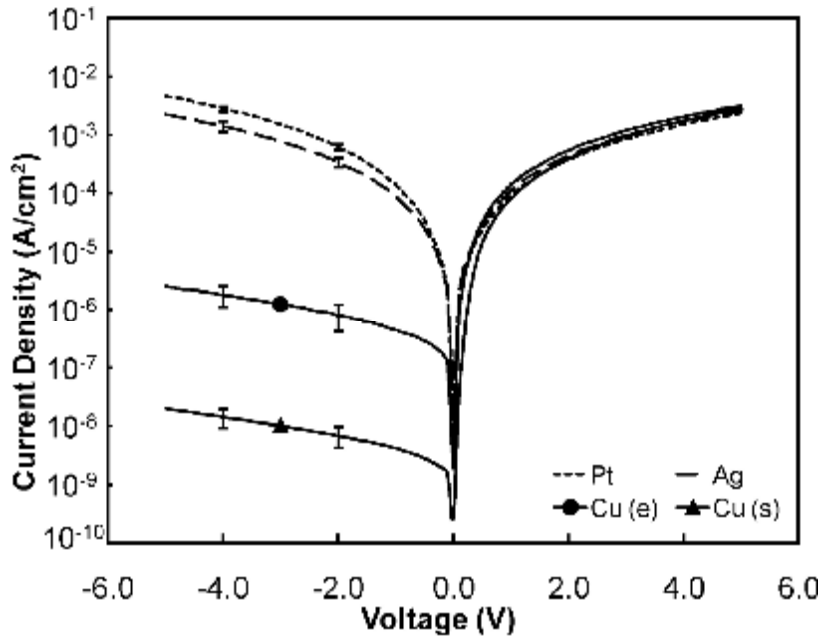
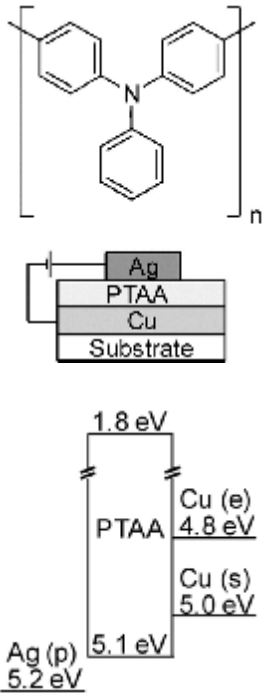


Controlling Device Properties by Interfacial Dipoles



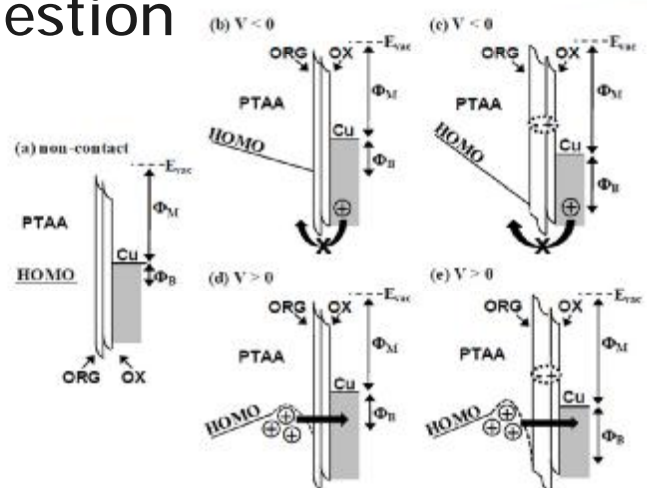
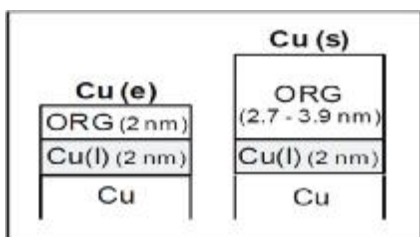
Diodes





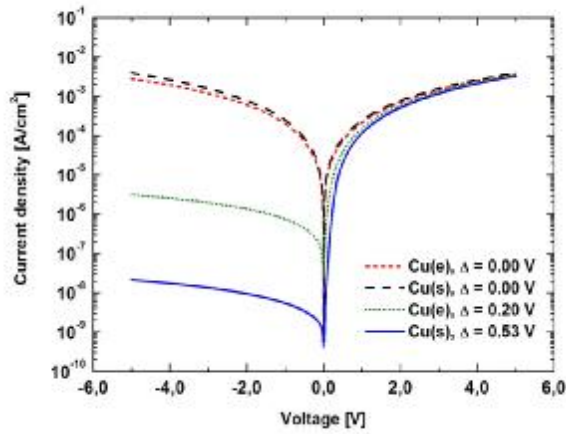
K.E. Lilja; H.S. Majumdar; F.S. Pettersson; R. Österbacka; T. Joutsenoja; *ACS Appl. Mater. Interfaces* 2011, 3, 7-10.

- XPS and impedance data reveal a thin dual interfacial layer
- For sputtered Cu a slightly thicker interfacial layer was observed

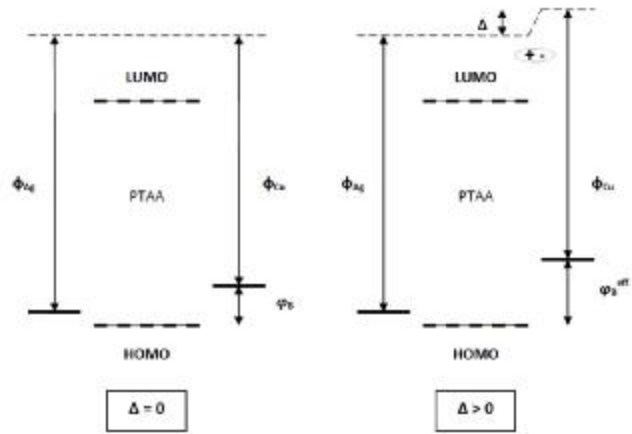


- Formation of intrinsic dipole between the dielectric layers
- Controlling the injection

Interfacial-dipole-controlled currents



Simulated JV-curves with and without interfacial dipoles



Modelling using drift-diffusion and injection barriers

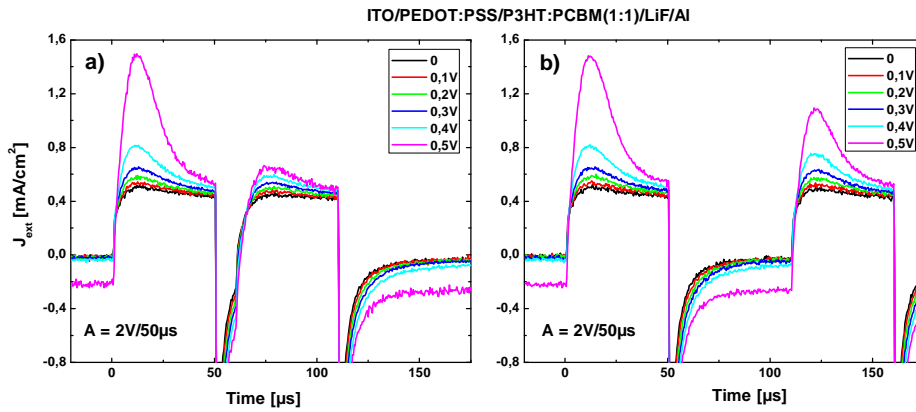
O. Sandberg, et al



How general is the dipole concept?

Bulk-heterojunction solar cells

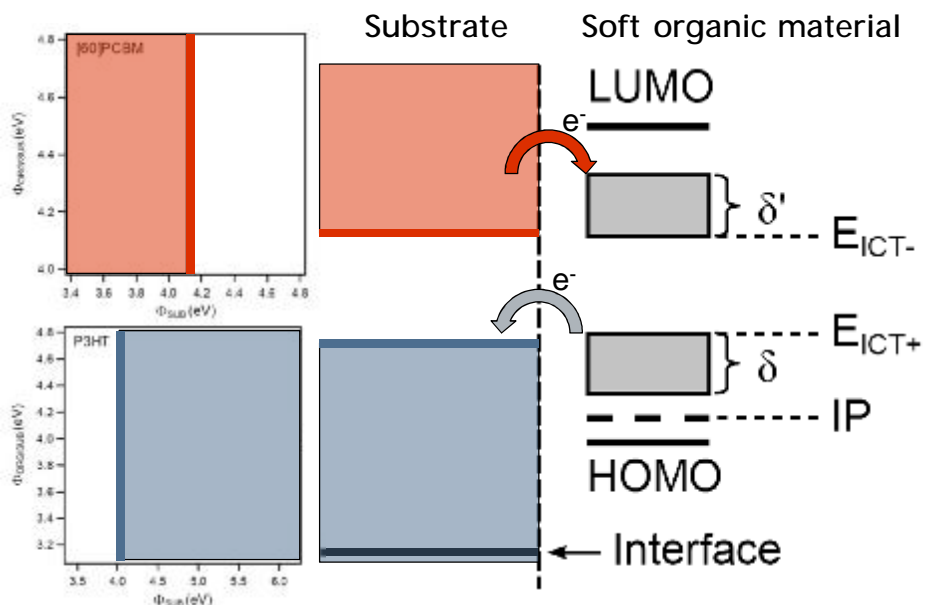
Equilibrium carriers in solar-cell diodes



- Equilibrium charges exist at 0V
- Extracted equilibrium charges are regenerated by a current backflow

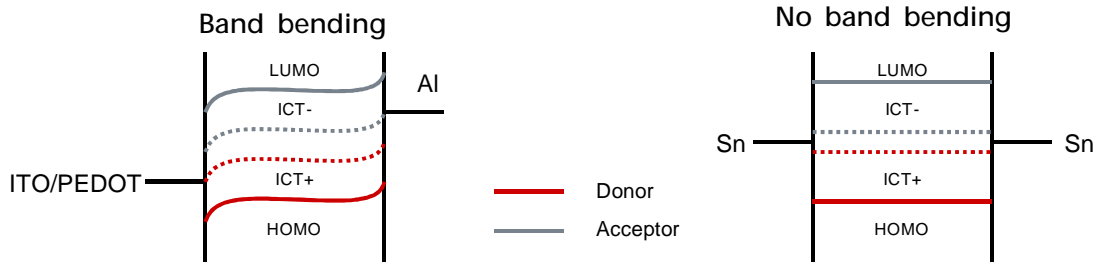
WHY?

Integer Charge Transfer Model

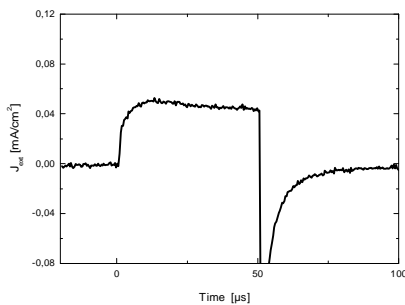


S. Braun, W. R. Salaneck and M. Fahlman, *Adv. Mater.* 21, 1450-1472 (2009)
 P. Sehati, et al., *IEEE JSTQE* 6, 1718-1724 (2010)

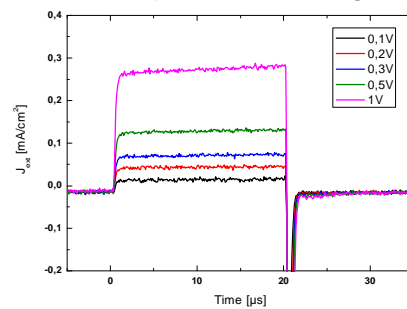
Fermi-level pinning causing dark carriers



Equilibrium charges in the dark



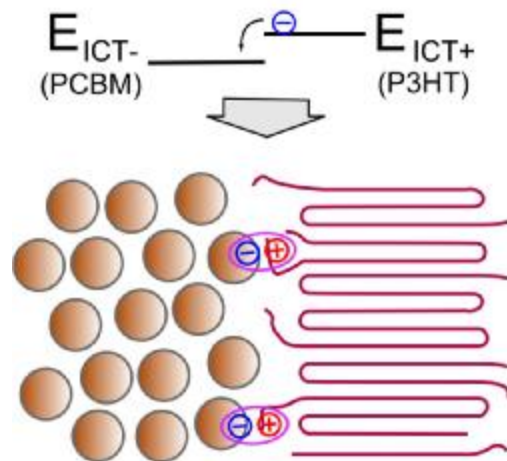
No equilibrium charges



M. Nyman et al., Chem. Phys in press

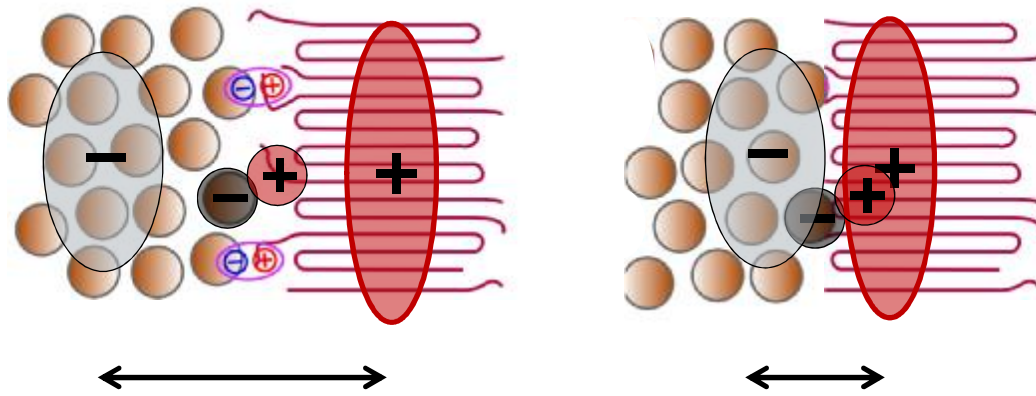
ICT also in P3HT:PCBM blends

- Energy level alignment at interfaces by charge transfer
 - › Charge transfer from the P3HT E_{ICT+} to PCBM E_{ICT-}
 - › Dipole formation!
- Effect on recombination?
 - › Reduction in the geminate recombination



Aarnio et al., Adv. Energy Materials, 2012

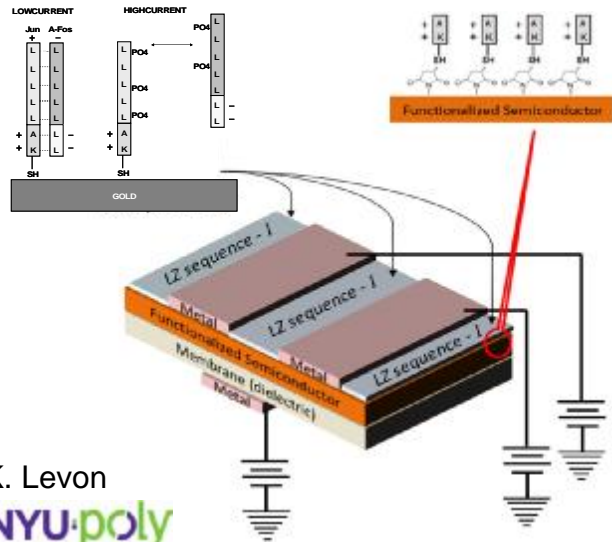
Delocalization in 2D lamellae



The Future?

Bioelectronic sensing using OFETs

- The membrane based OFET offers several advantages:
- Low-voltage operation
- Semiconductor OR electrodes exposed to analyte
- Novel detection scheme suggested utilizing functionalized
 - semiconductor OR
 - Electrodes



In collaboration:



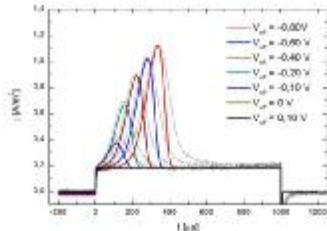
H. Härmä
Tampere University of Applied Sciences

S. Hietala
University of Helsinki

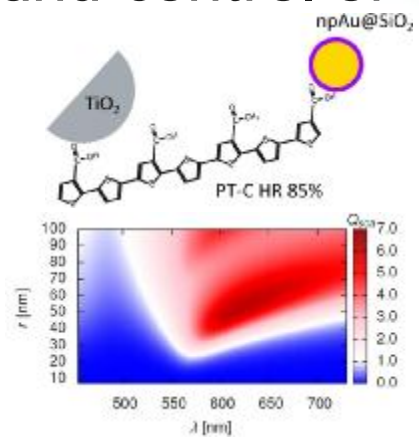
K. Levon
NYU poly

Interfacial understanding and control of device behavior

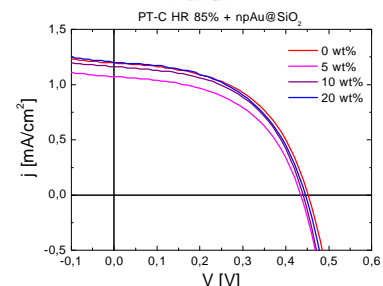
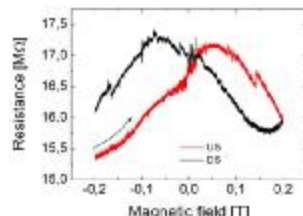
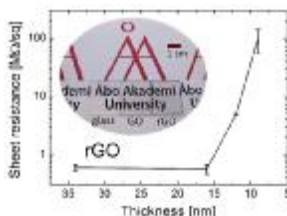
Simulated interfacially controlled transport (Sanden, Sandberg, Nyman et al.,)



Collaborators:
J. Hardgree and H. Katz,
John Hopkins Univ



Graphene oxide for electronic applications
Majumdar, Pesonen et al.,



(Sanden, Smått, Ylinen et al.,)