

Electrical Contacts in Organic Transistors

- **Motivation, Materials and Methods**
- **Device Performance and Contact Resistance**
- **Nanoscale Organic Transistors**
- **Contacts Modified by Organic Monolayers and SWNT**

Jana Zaumseil*, Matthew Meitl, Graciela Blanchet***, Ray Cirelli******

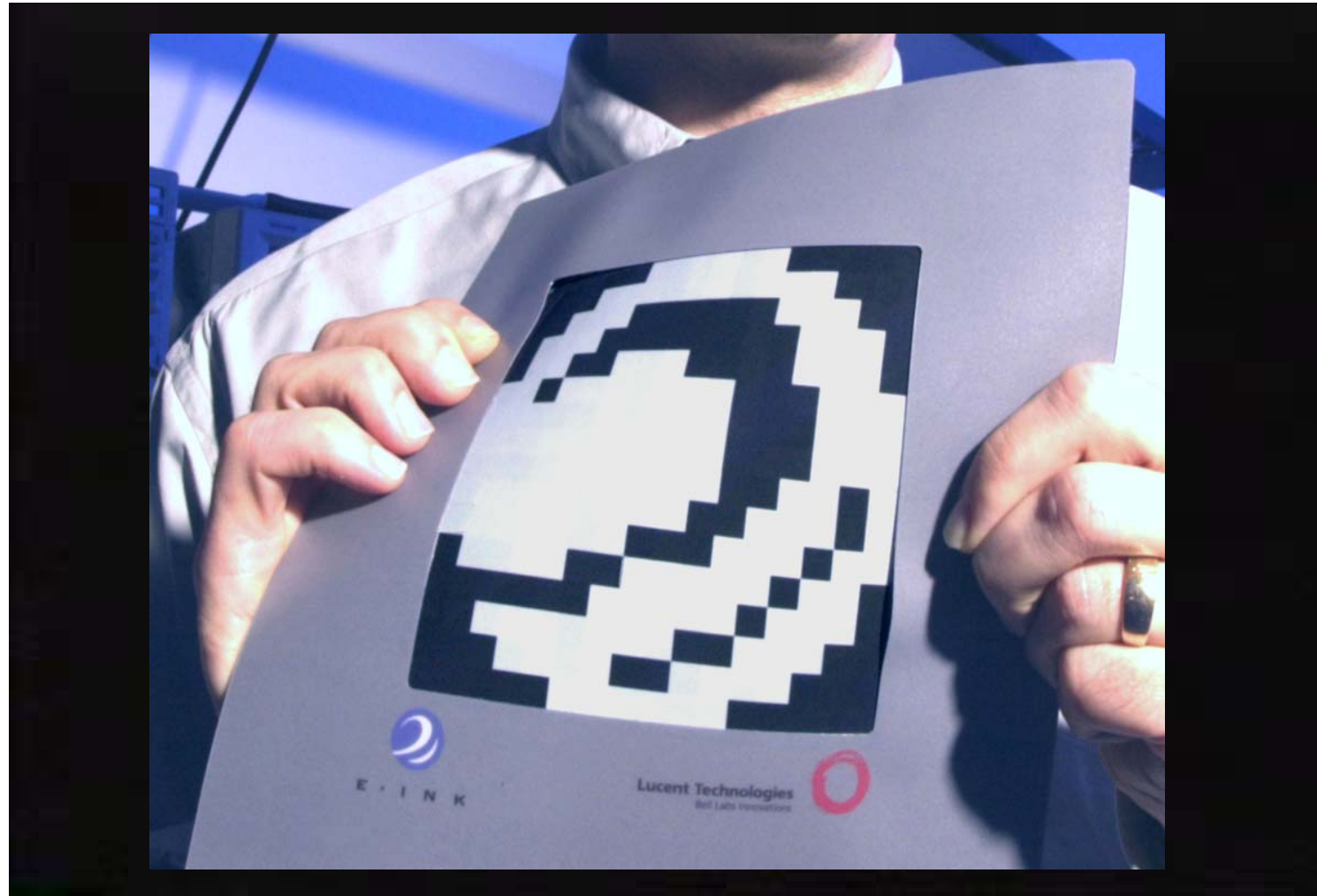
****Bell Laboratories, Lucent Technologies***

*****University of Illinois at Urbana-Champaign***

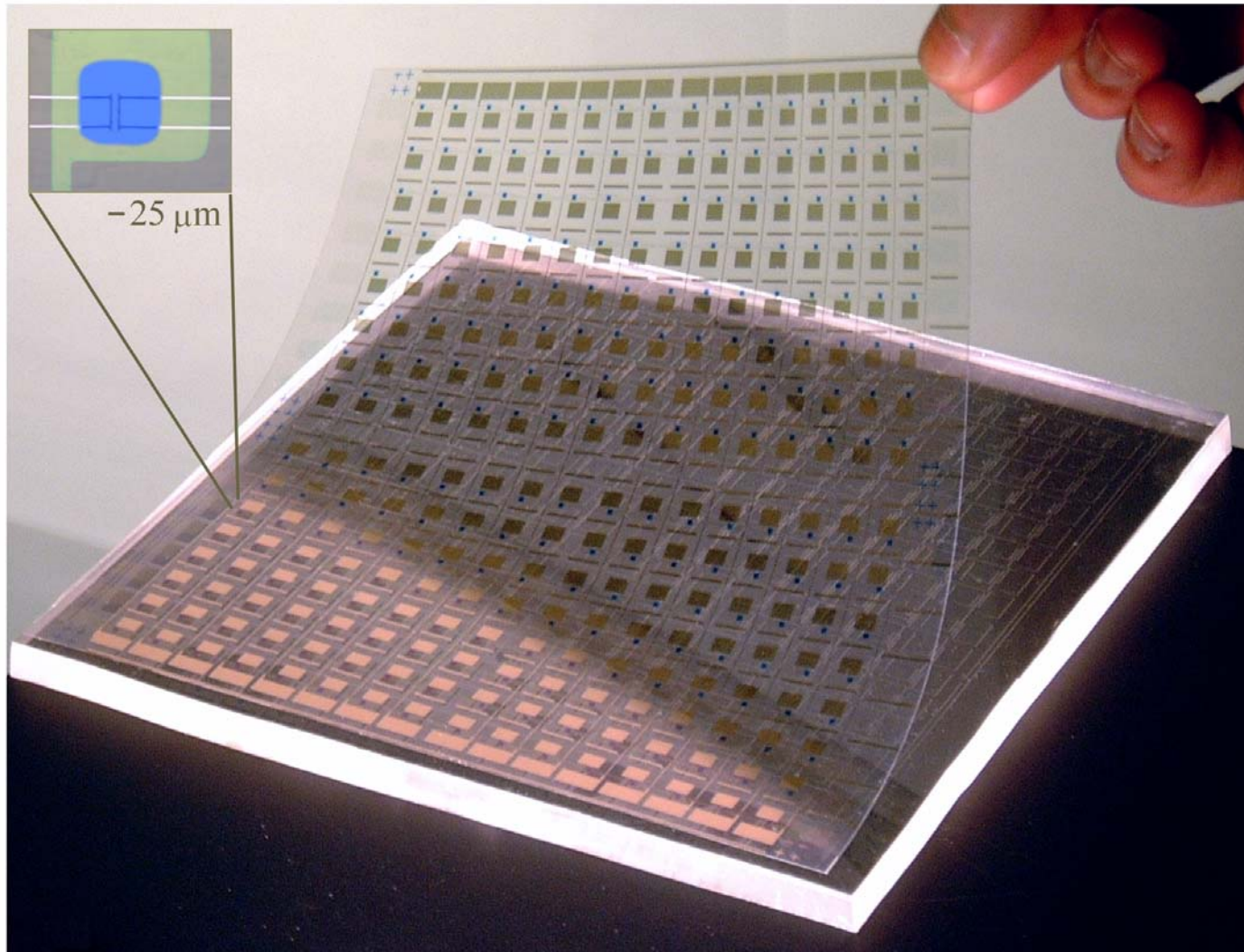
******DuPont Central Research***

*******New Jersey Nanotechnology Center***

Large, Mechanically Flexible Sheet of Electronic Paper

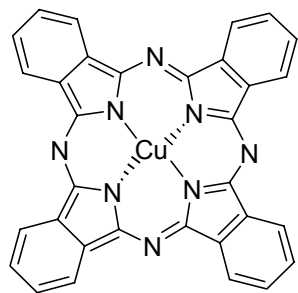


Rubber Stamps and Plastic Circuits for Electronic Paper

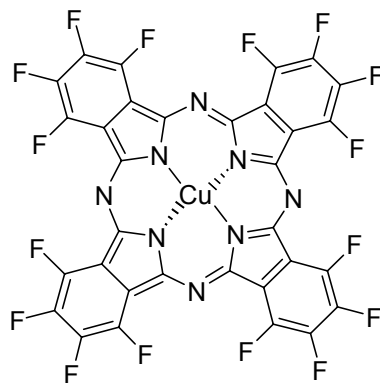


PNAS 98(9), 4835-4840 (2001).
Science 291, 1502-1503 (2001).

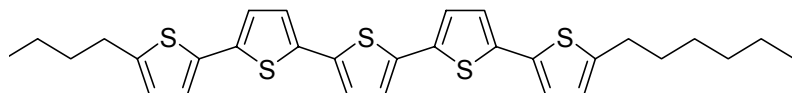
Organic Semiconductors



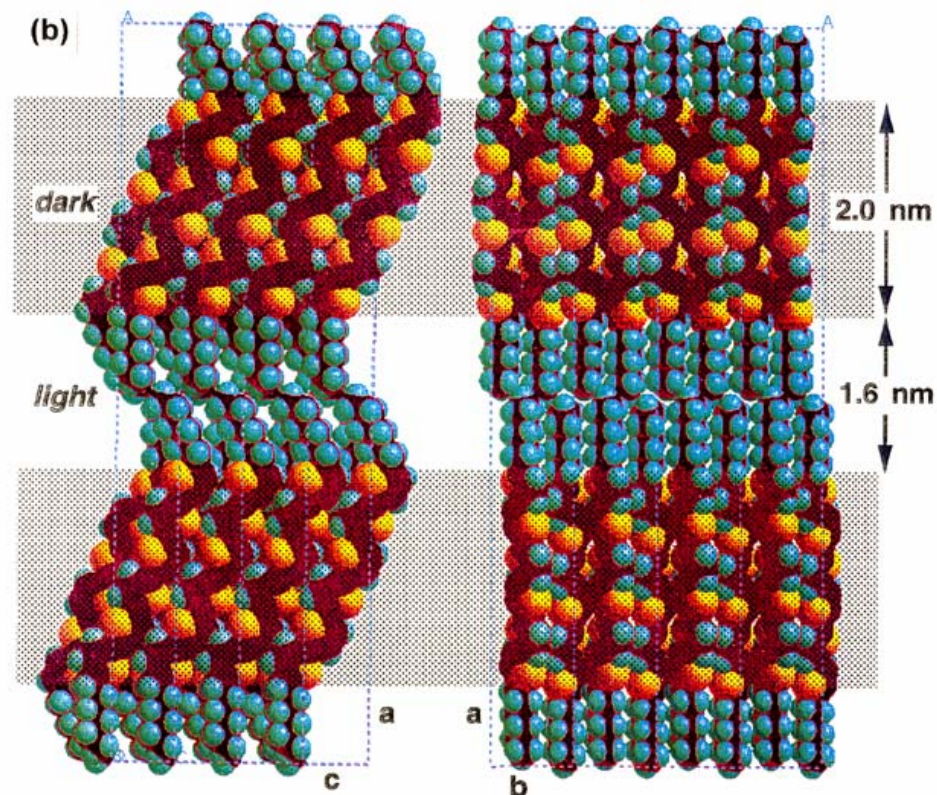
CuPc



FCuPc



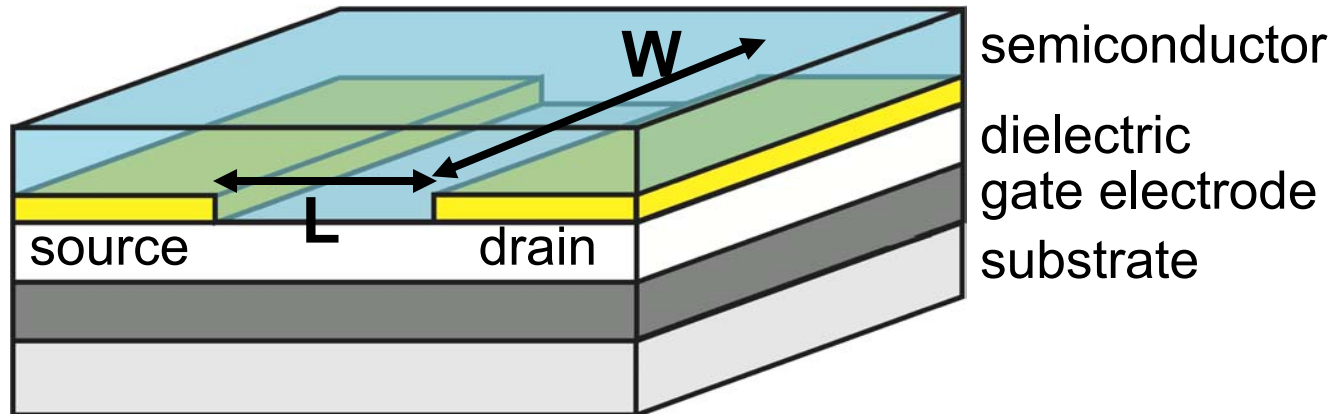
DH-α-5T



Chem. Mater. 10(11), 3275 (1998).

JACS 120(1), 207 (1998).

Transistor Basics



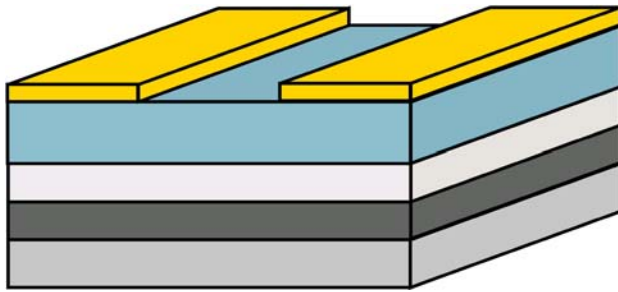
$$I_{D,sat} = \frac{W}{2L} \mu_{sat} C_i (V_G - V_{T,sat})^2$$

Improvements through:

- **better organic semiconductors (mobility, on/off ratio)**
- **smaller devices , thin or high-k (organic) dielectrics**

Organic Thin Film Transistors

Top Contact



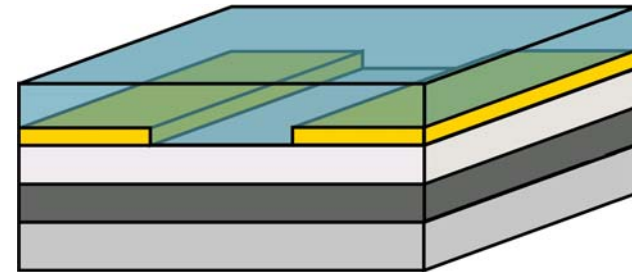
Better device performance
(higher mobilities)

BUT:

Electrodes cannot be patterned
by photolithography

Resolution limit of shadow
mask evaporation

Bottom Contact



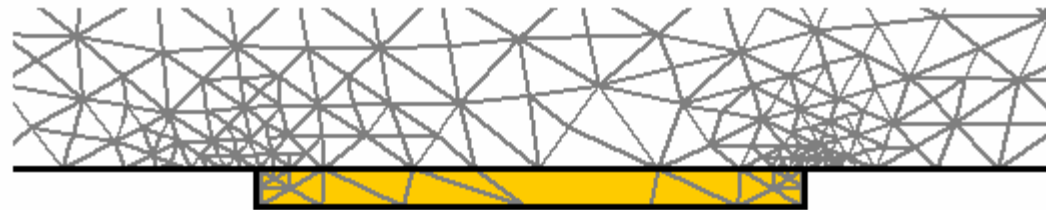
Patterning electrodes by
photolithography

BUT:

Disturbed crystal growth at
electrode interfaces
(low mobilities)

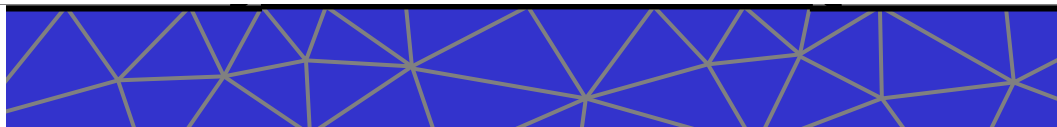
Often non-ohmic contacts

Soft Contact Lamination for Electroactive Organics

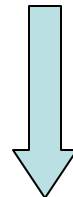


elastomer

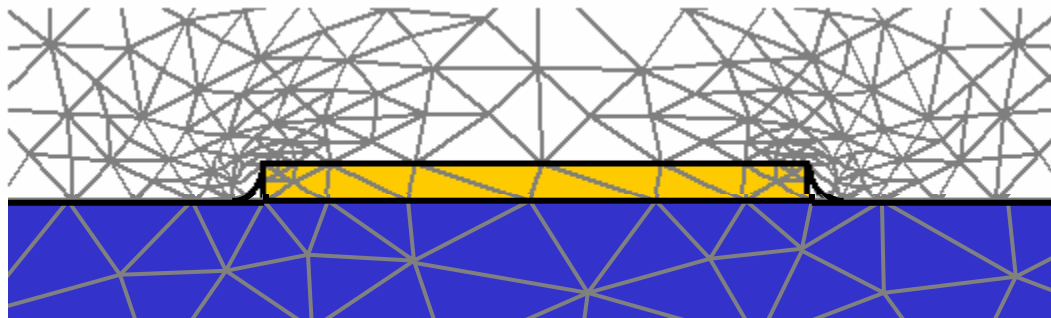
thin metal
electrode



organic
semiconductor



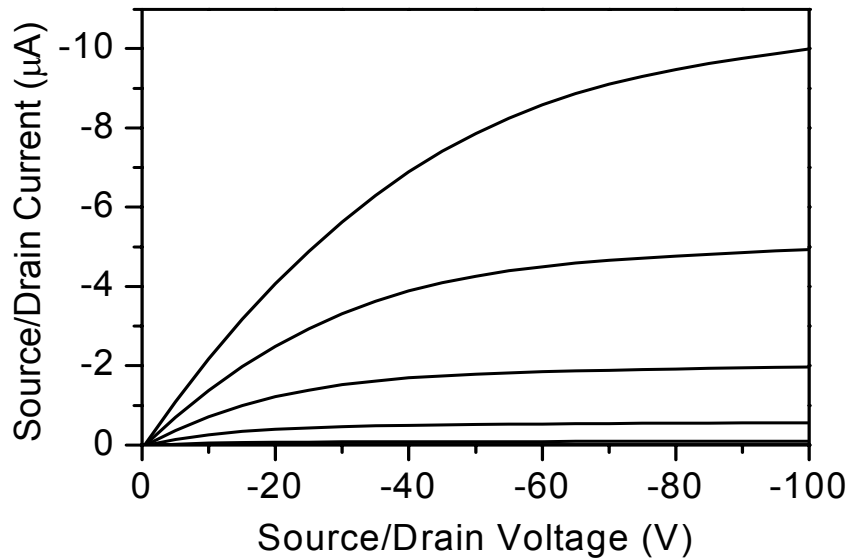
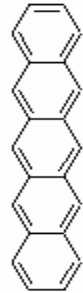
laminate
(RT, no pressure)



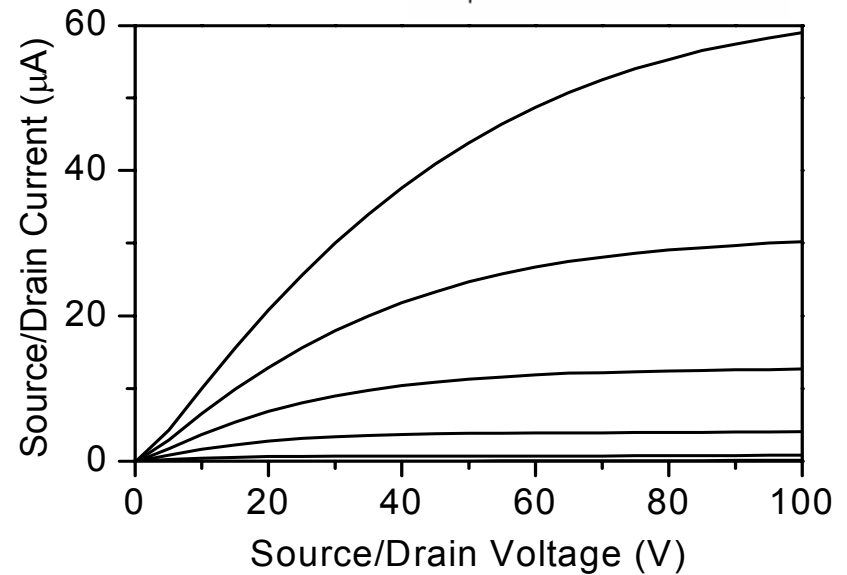
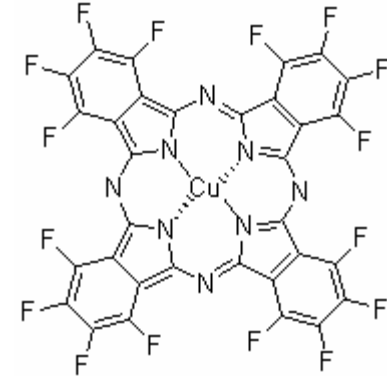
← 'wetting' and
atomic-scale
contact

Organic Transistors by Soft Contact Lamination

**p-channel
pentacene**

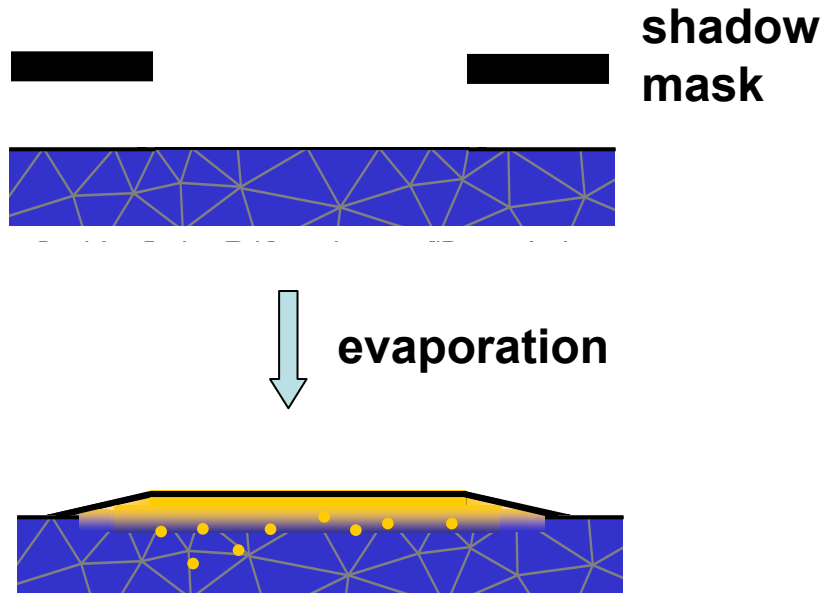


**n-channel
FCuPc**



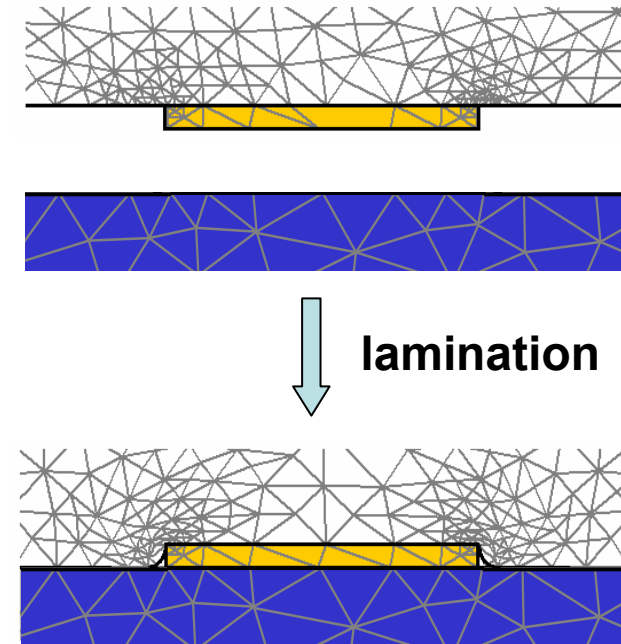
Fabricating Top Metal Contacts on Thin Electroactive Organics

Thermal Evaporation



- Hot metal deposition
- Chemical, thermal effects on organic
- Mobile metals, in-diffusion
- Time dependent behavior
- Sensitivity to deposition condits

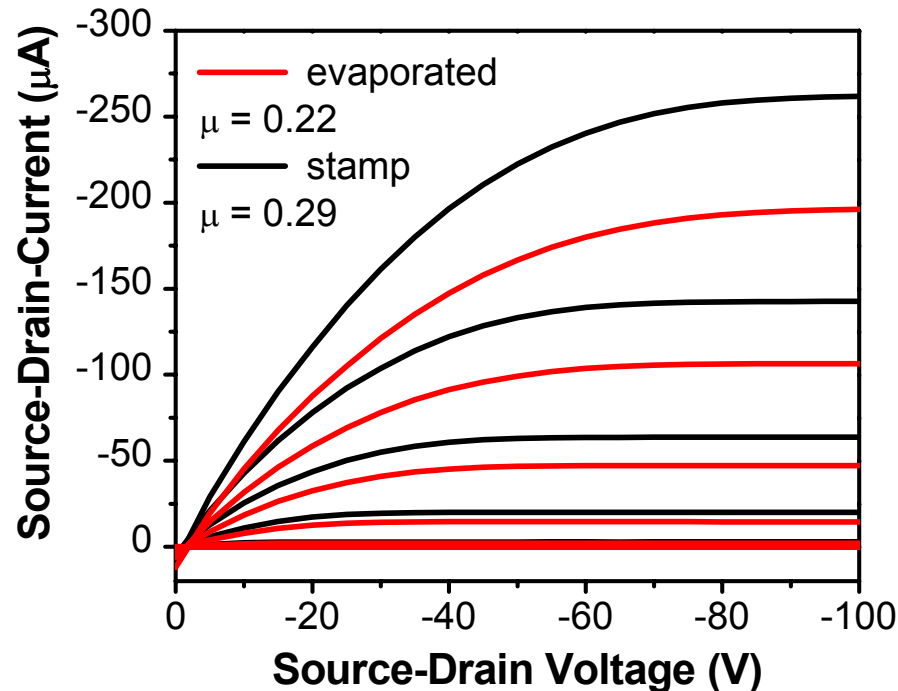
Soft Contact Lamination



- Room temperature, soft contact
- No adhesives
- Little or no applied pressure
- Reversible contacts
- Contact resistance ??

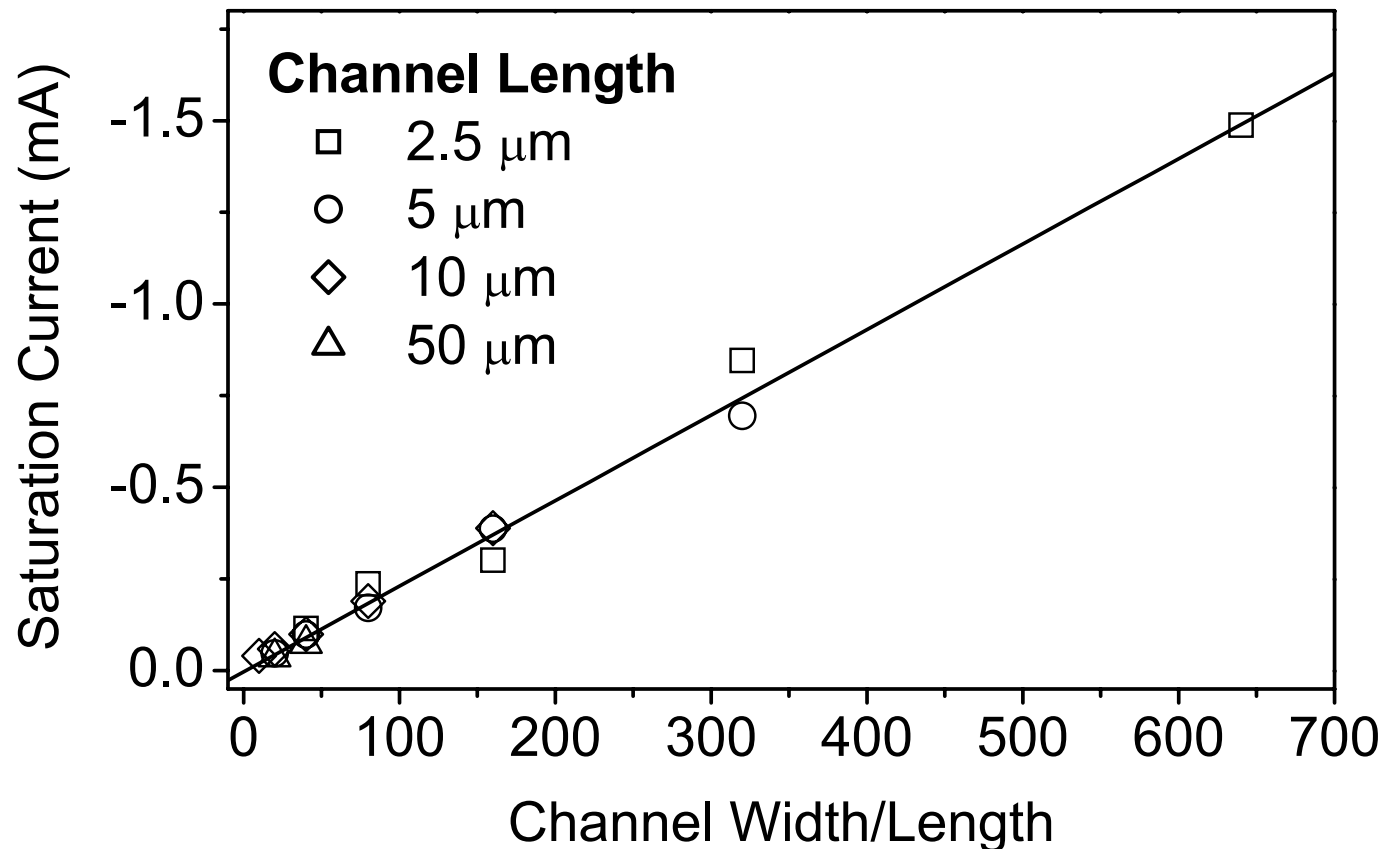
Soft Contact Laminated vs. Evaporated Electrodes

pentacene (25 nm) on SiO₂ (300 nm) on doped Si
 Au electrodes: L = 250 μm ; W = 5 mm



Laminated devices yield saturation currents ~20-50% higher than shadow mask evaporated devices !!

Linear Scaling of Saturation Current with W/L

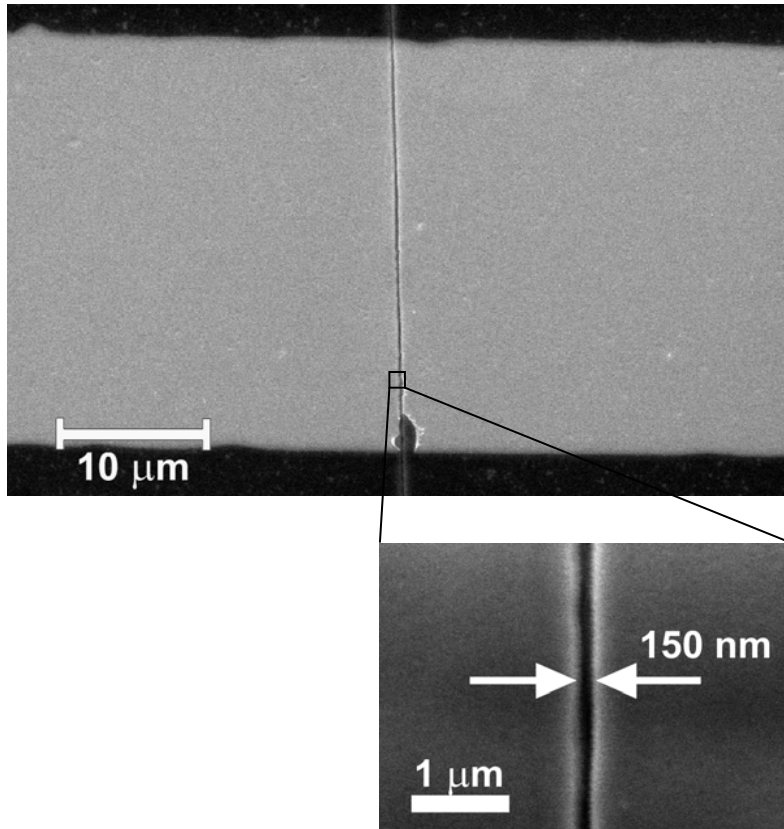


17 devices made *one after another* by soft lamination on a single, small region of pentacene !!

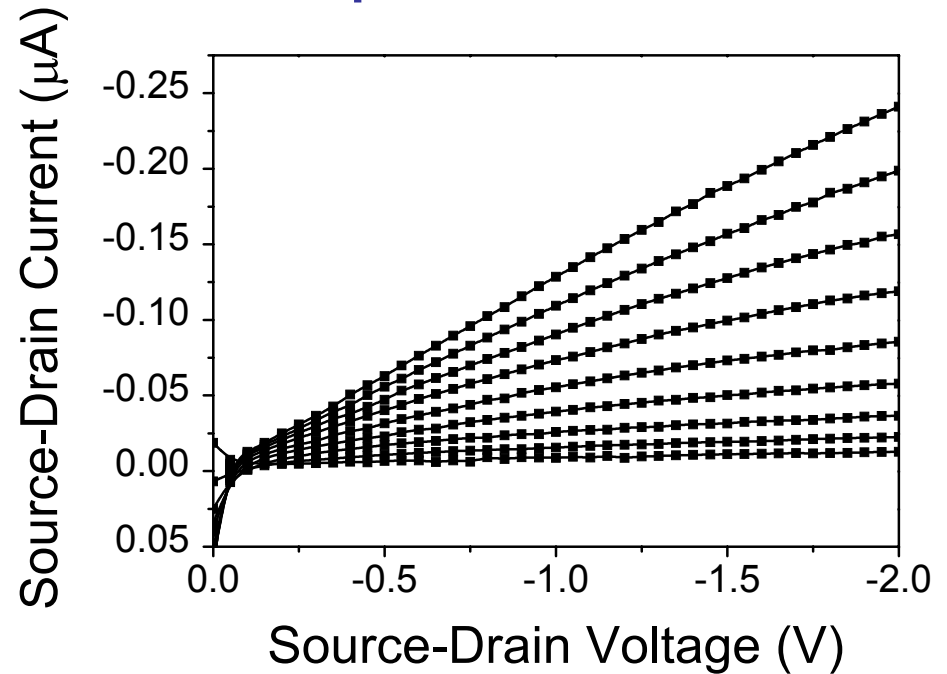
Nanoscale Organic Transistors

Channel length: ~150 nm

Channel width: 20 μm



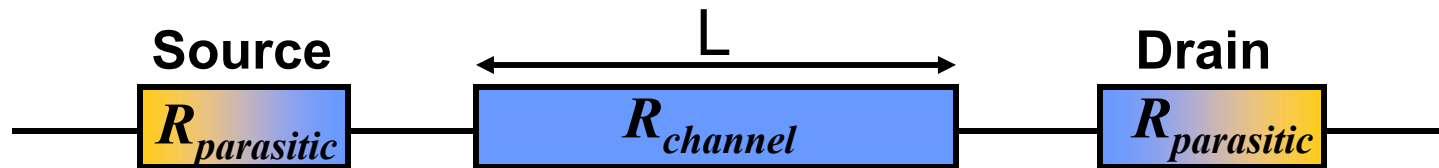
Output characteristics



**~4x lower mobility than
micron-scale devices**

Analysis of Contacts in Field Effect Transistors

If the contacts are *ohmic*, then:



$$R_{on} = R_{channel} + 2 \cdot R_{parasitic}$$

where:

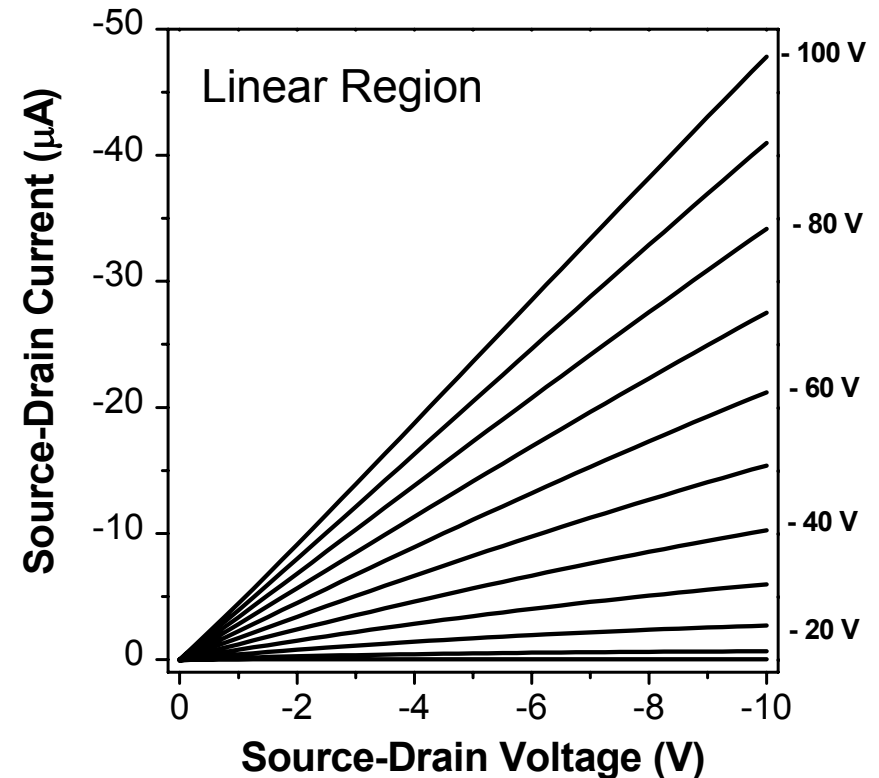
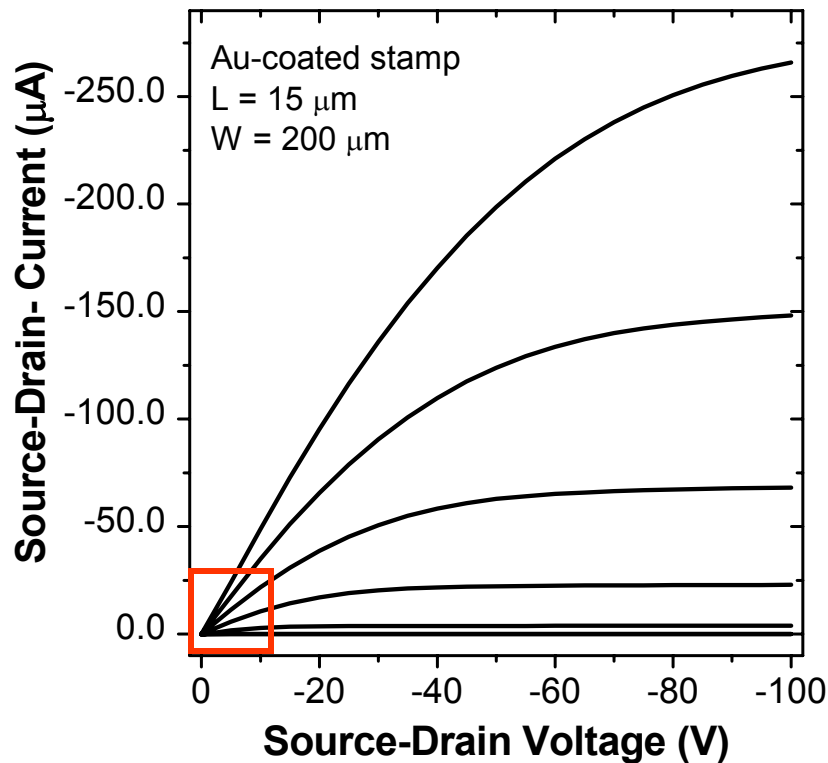
$$R_{channel} = \frac{L}{W} \frac{1}{\mu C} \frac{1}{(V_G - V_T)}$$

and: $R_{parasitic}$ is independent of L

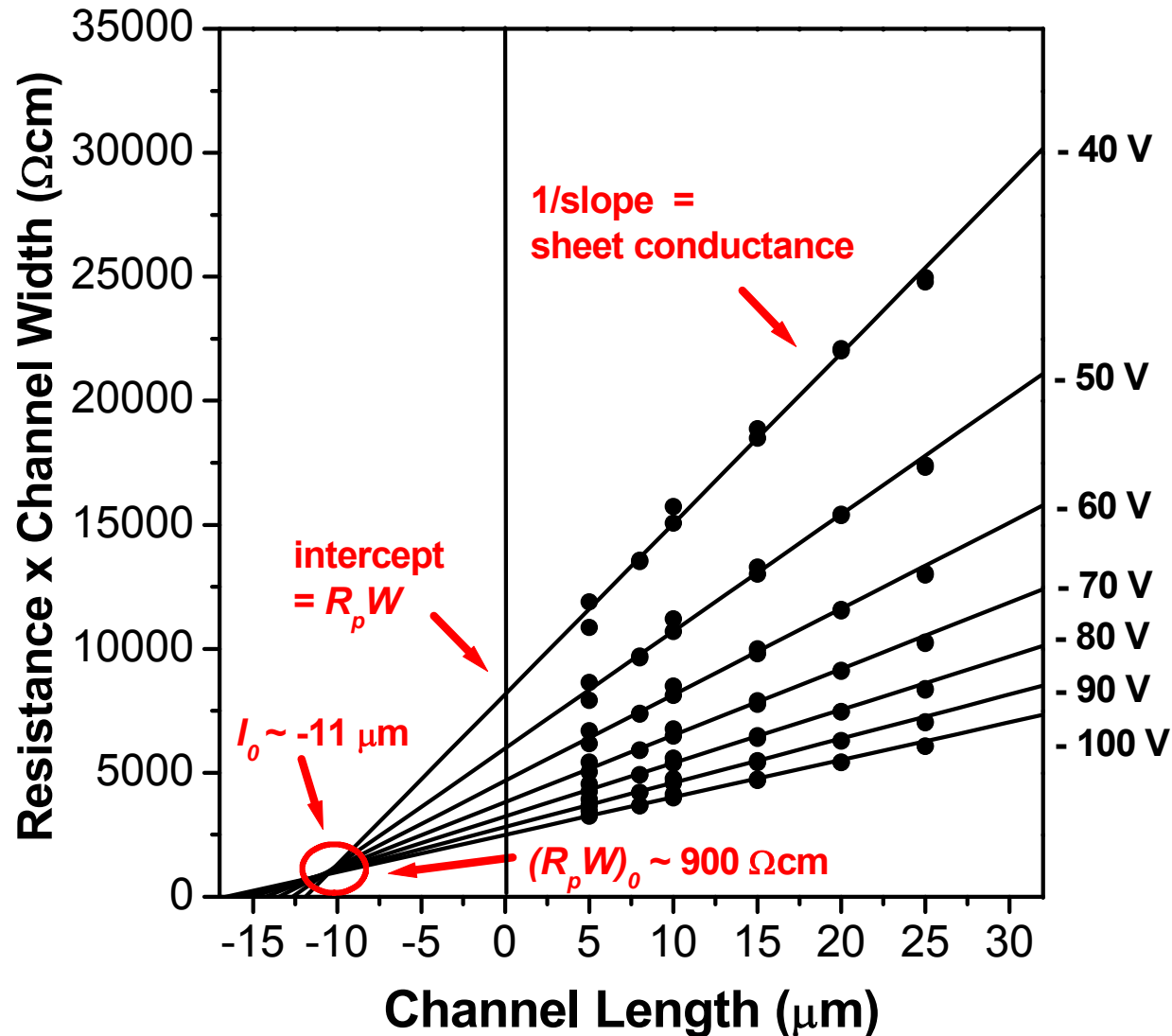


Measure devices with different L to determine $R_{parasitic}$

Saturation and Linear Response of Laminated Transistors

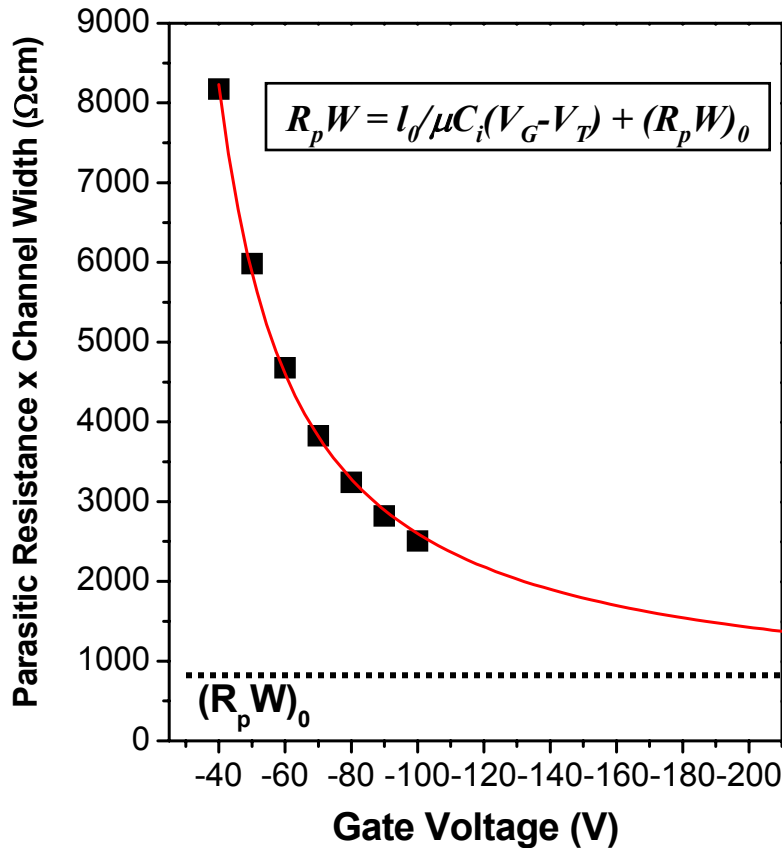


Channel Length Dependent 'On' Resistance

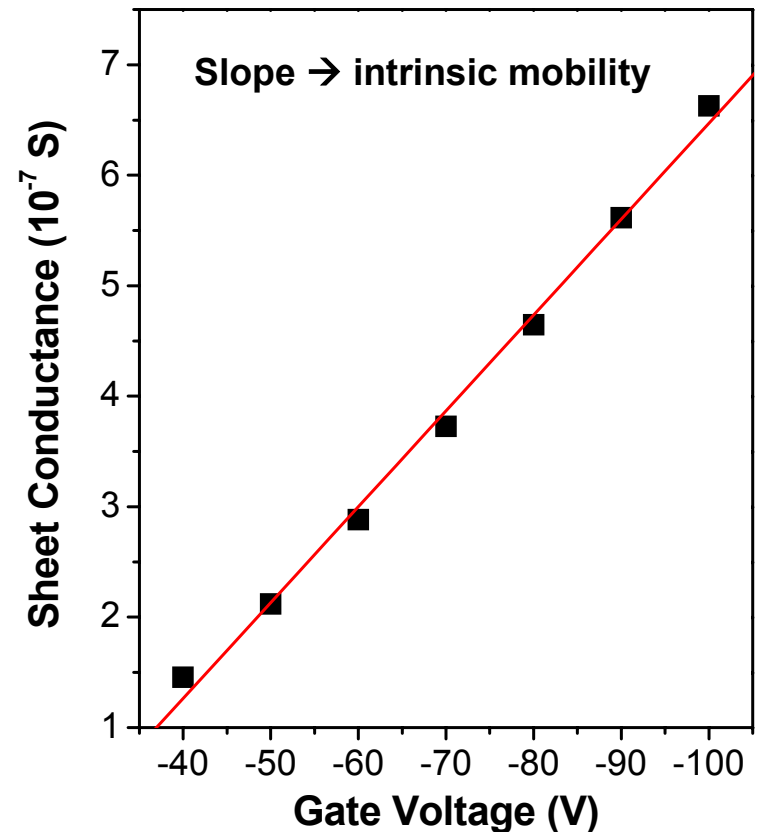


Parasitic Resistance and Intrinsic Properties

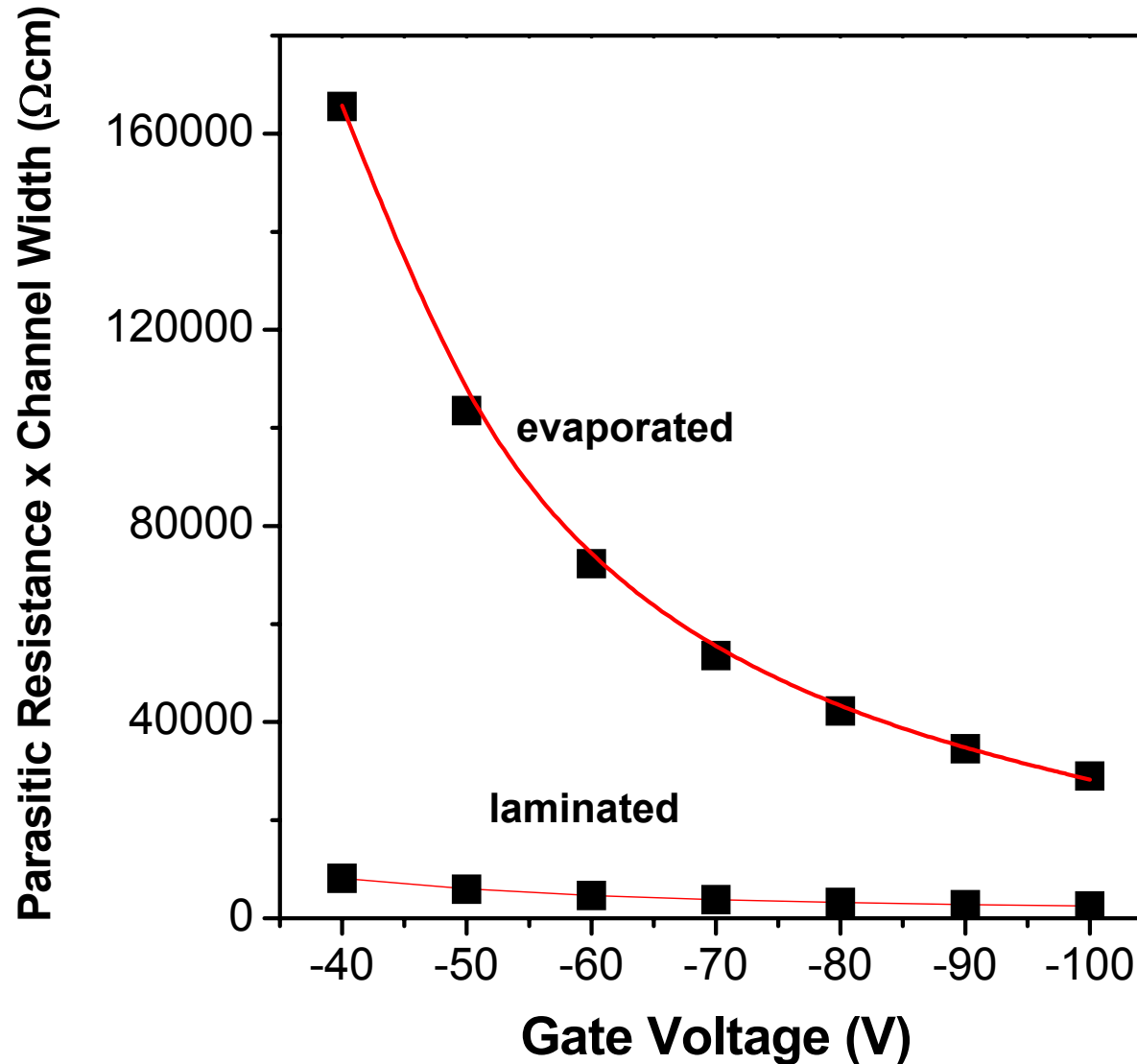
Gate voltage dependent parasitic resistance



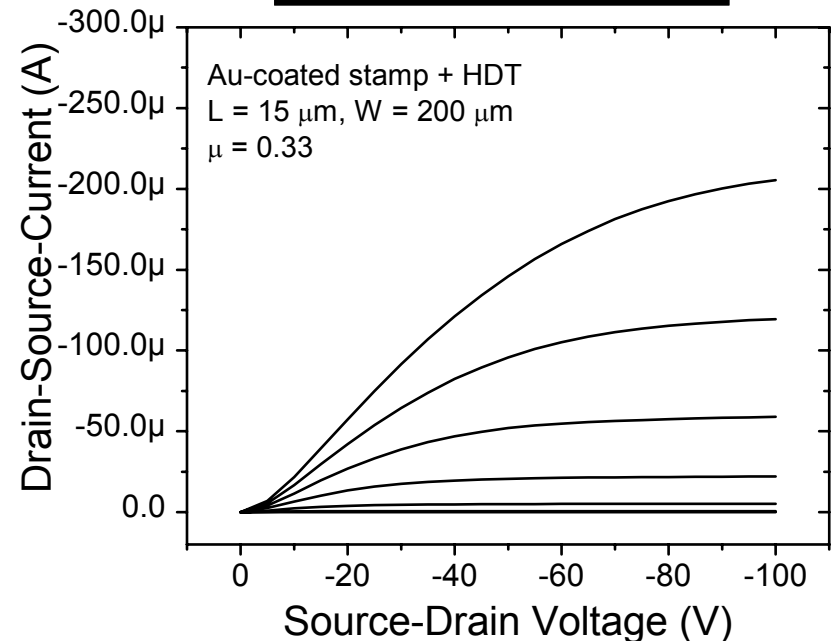
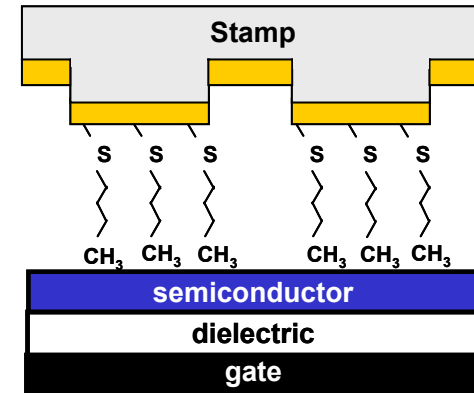
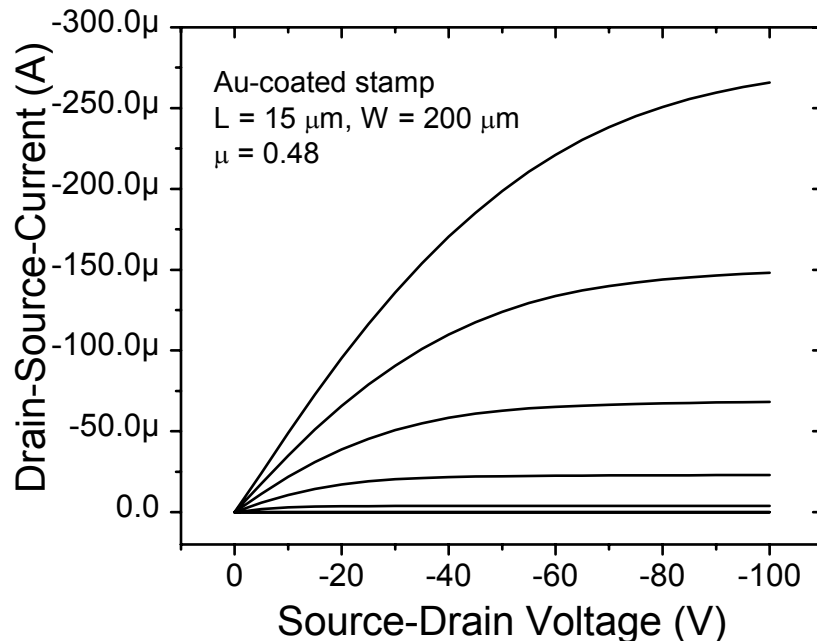
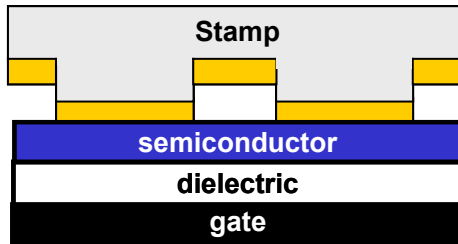
Gate voltage dependent Sheet Conductance



Parasitic Resistances in Laminated and Evaporated Contacts

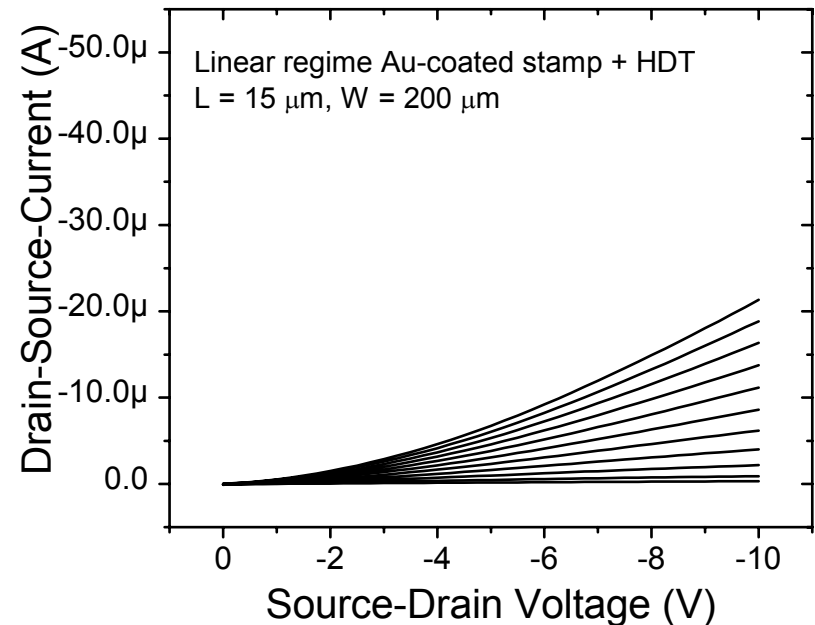
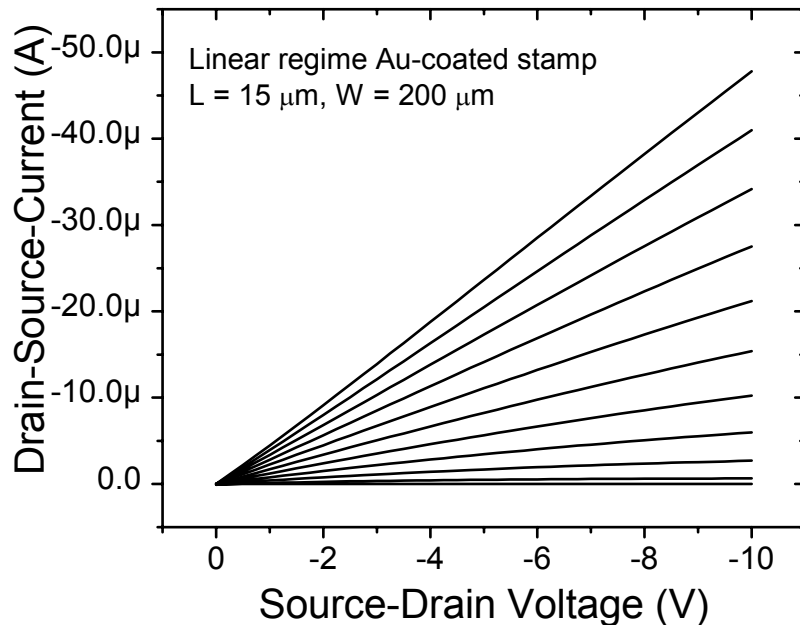
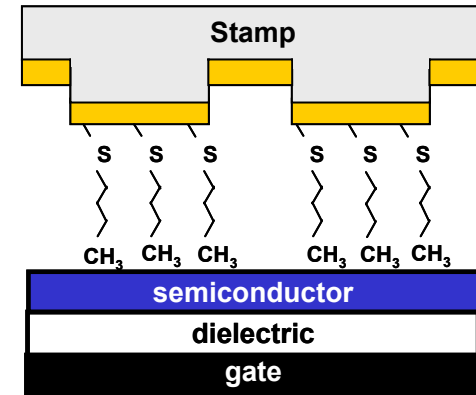
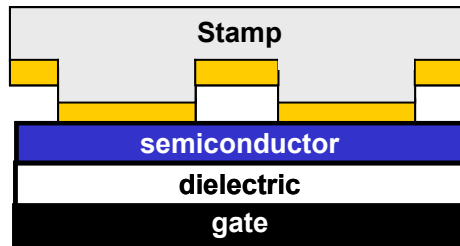


Charge Transport Through Organic Self-Assembled Monolayers

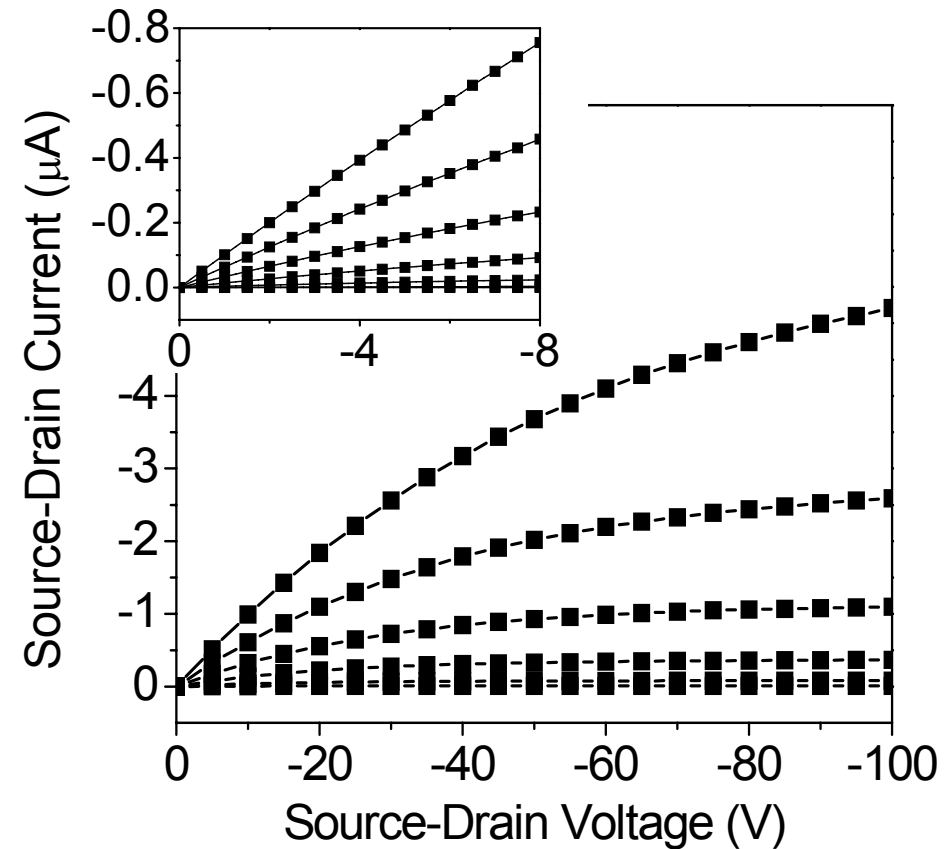
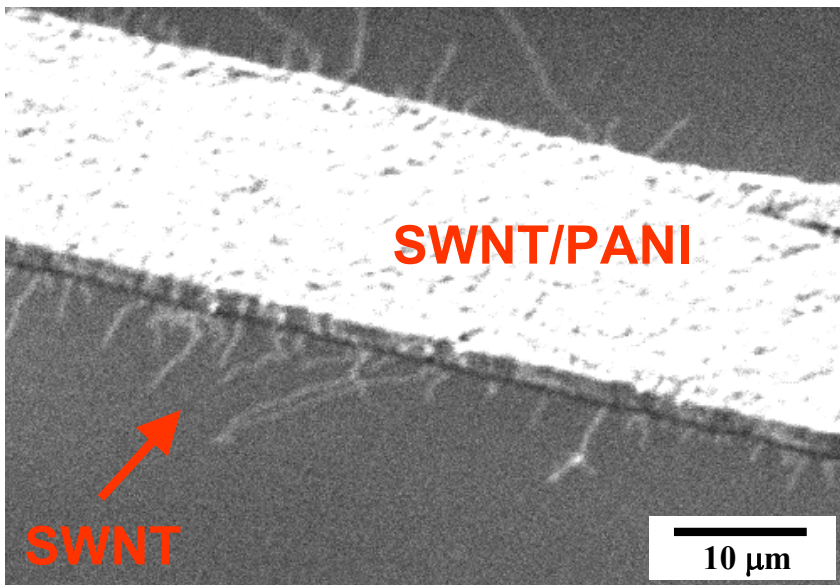
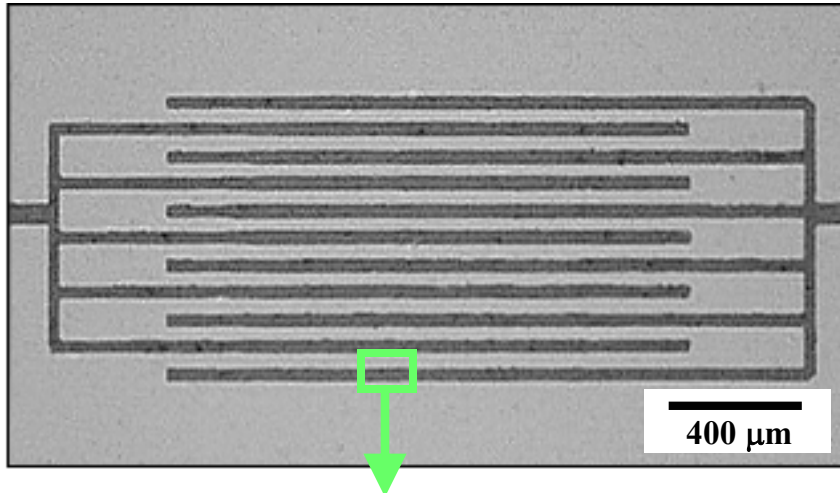


Reduced currents and strongly non-ohmic behavior due to SAM !!

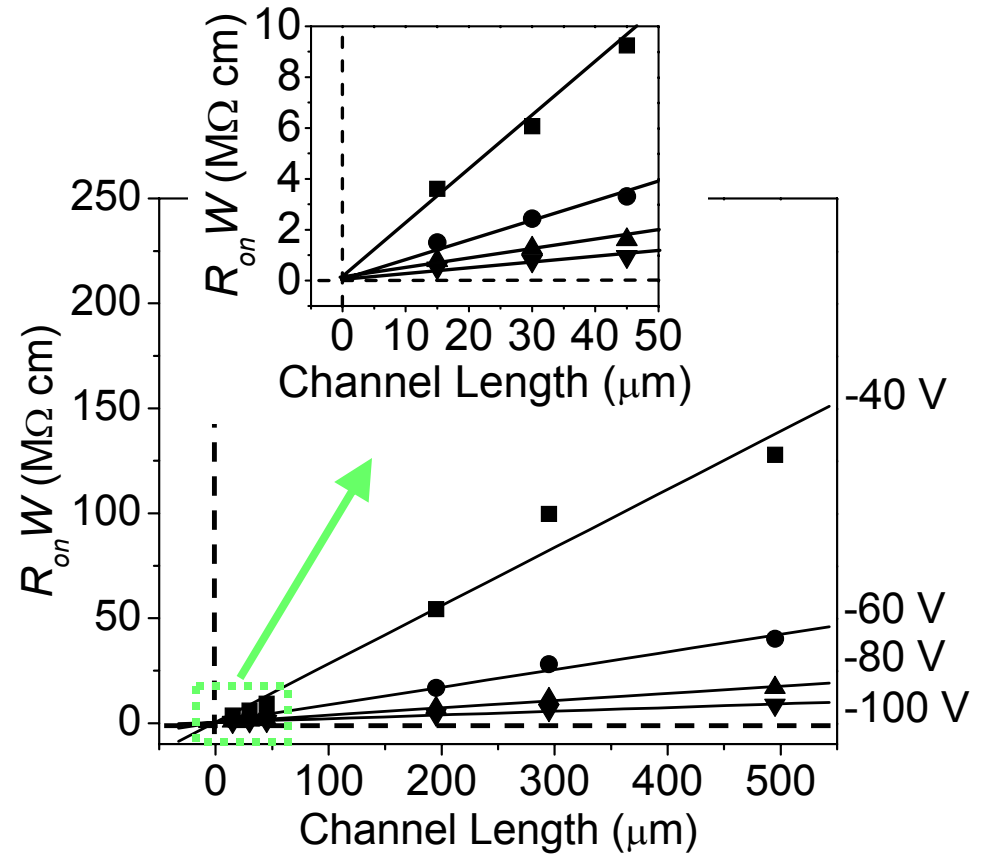
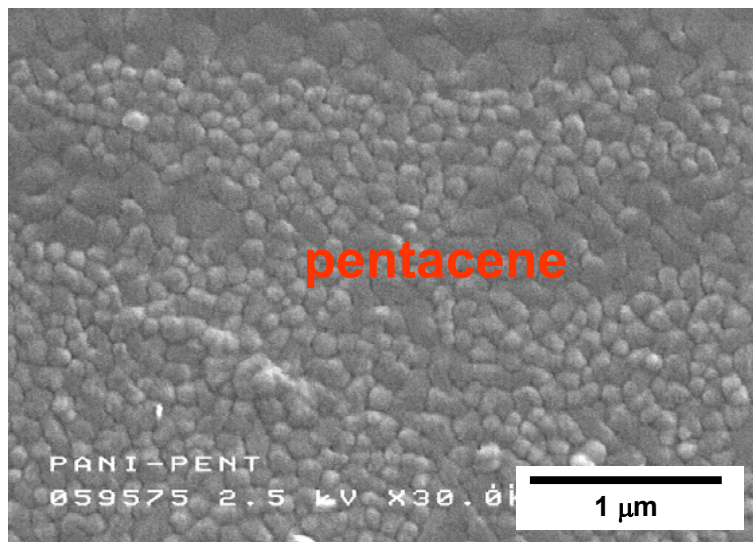
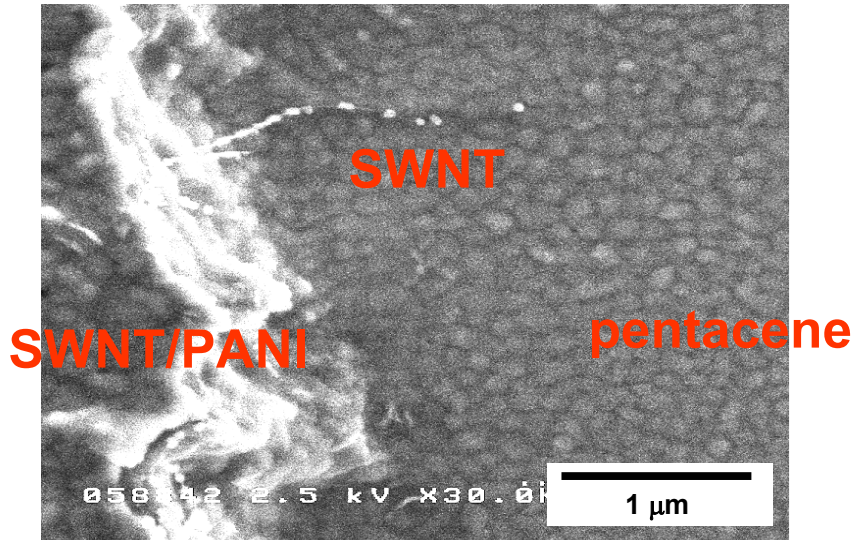
Charge Transport Through Organic Self-Assembled Monolayers



Printed Contacts of Single Walled Carbon Nanotubes/PANI



Printed Contacts of SWNT/PANI: Negligible Contact Resistance !



Electrical Contacts in Organic Transistors

- ***Soft Contact Lamination Provides High Quality, Reversible Contacts to Organic Semiconductors, Monolayers, etc.***

- ***PANI/SWNT Electrodes Exhibit Negligible Contact Resistance***

Contacts in Organic Transistors Represent Complex Interfaces That Are Critically Important to the Future of Plastic and Molecular Electronics