IPST Executive Conference, Atlanta, GA March 9-10, 2011

Advancing Consumer Packaging Through Printable Electronics

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EFRC

CIS:SEM

Center for Organic Photonics and Electronics

- Established in 2003 at the Georgia Institute of Technology

- Interdisciplinary approach to research and training

- 25 faculty from six different schools

- Shared facilities in computing, synthesis, material characterization and device fabrication

- Industrial resource Center for technological innovation

- http://www.cope.gatech.edu

The Future of Consumer Packaging

- A convergence of emerging technologies: digital printing, flexible and printed electronics, and smart packaging.

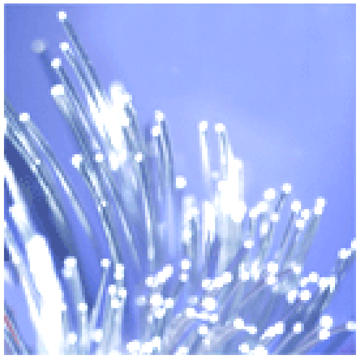
- Modernize the supply chain by retaining and monitoring product quality by active sensing and monitoring of physical properties.
  -Time, temperature, light, humidity, UV, oxygen, pathogens, bacteria…

- Interactive features can revolutionize the consumer/packaging interface which has remained unchanged for decades .

- Crime prevention and security:
  - Brand protection
  - Counterfeiting
  - Fight terrorism through explosive detectors

⇨ **Modernizing and securing the supply chain**

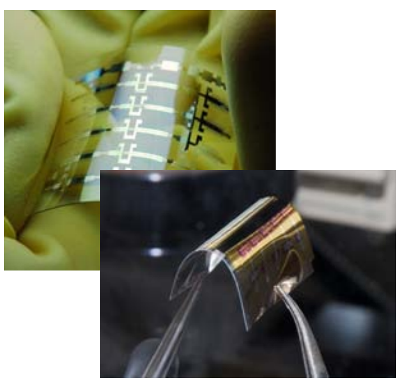
Smart Organic Materials



Communications Optoelectronics

Displays

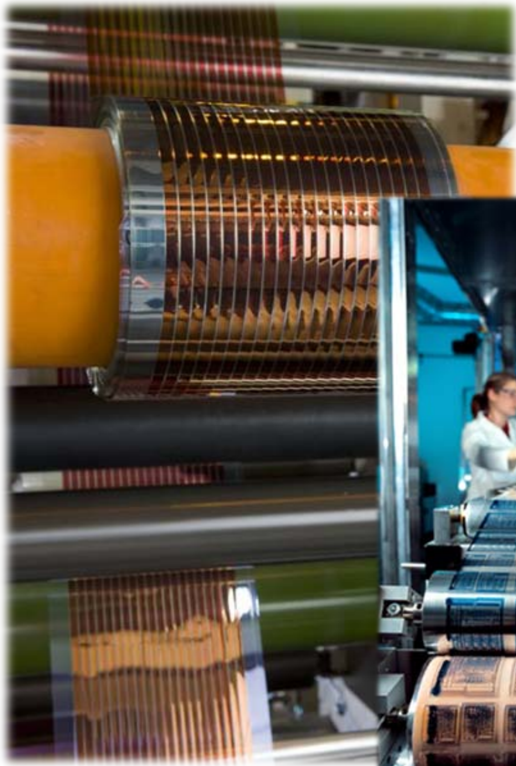
Energy conversion



Organic circuits/ Sensors

Solid-state lighting

A Paradigm Shift: Printed Electronics



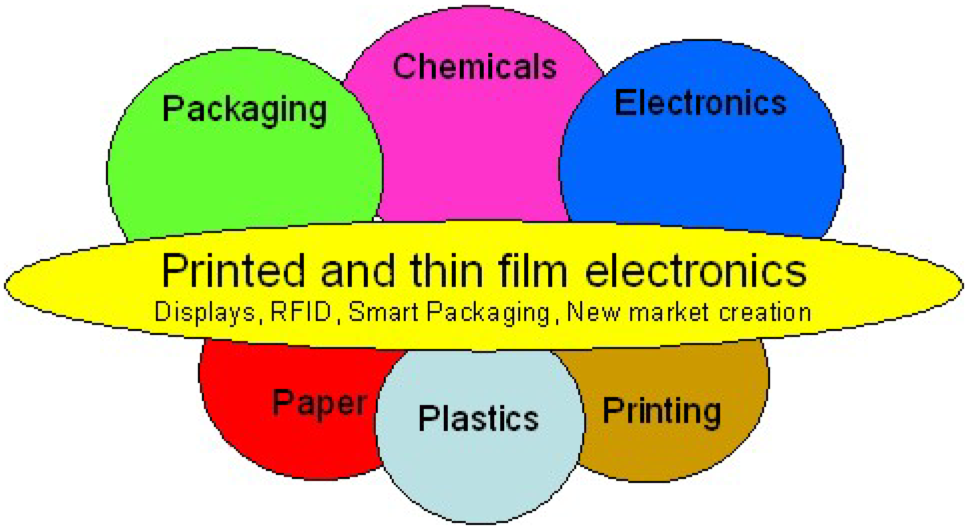
Konarka

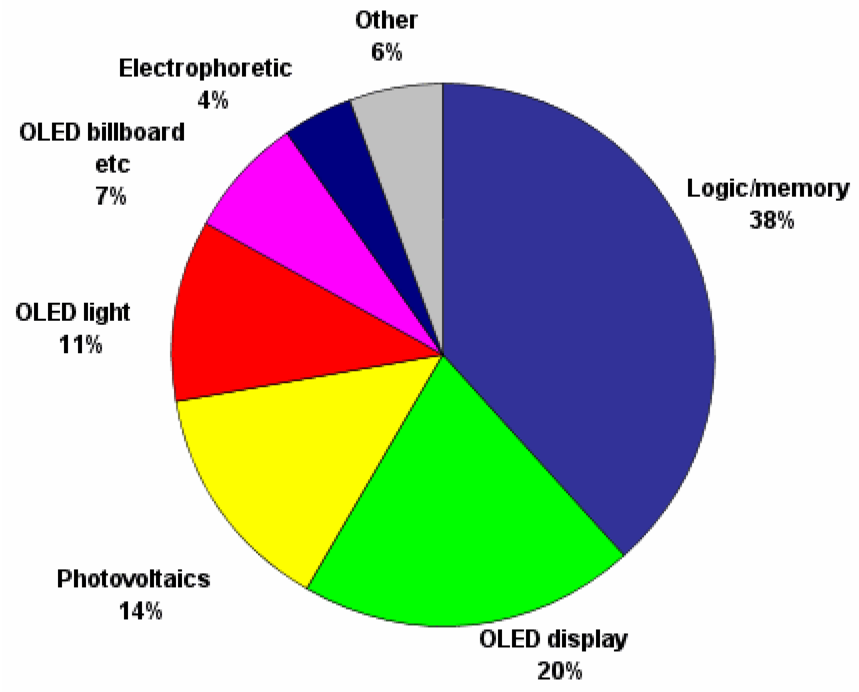
PolyIC

- ❑ Mobile/Wireless
- ❑ Light weight
- ❑ Wearable
- ❑ Puncture resistant
- ❑ Energy efficient

Flexible intelligence everywhere

Printed Electronics: Market Forecast



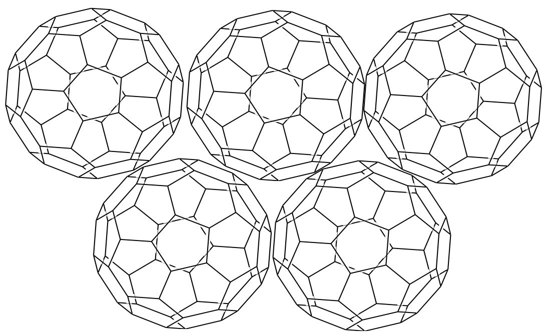


$55 B by 2020

Source: IDTechEx

Organics vs. Inorganics

Molecular properties

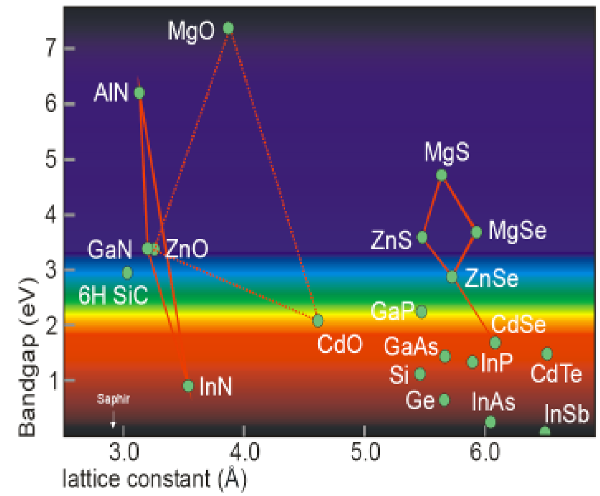


Highly **localized** electronic excitations

Morphology and structure difficult to define, disordered structures

Tolerant to defects

Lattice driven properties



Highly **delocalized** electronic excitations

Periodic lattice leads to well defined band structures

Requires nearly perfect crystalline structure

Technology Areas

Energy supply
- Flexible photovoltaics
- Flexible batteries

Displays
- AMOLED
- E-readers, electrochromic

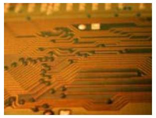
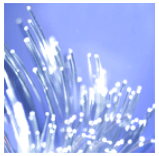
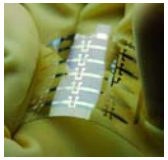
Sensing
- Environmental monitoring
- Physiological sensing

Imaging
- IR, visible UV imaging devices
- Surveillance

Communication
- Flexible antennas
- RFID/memory

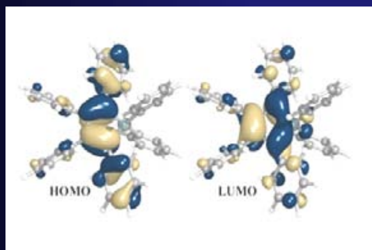
Logistics
- Real time location of assets
- Monitoring and inspection of assets

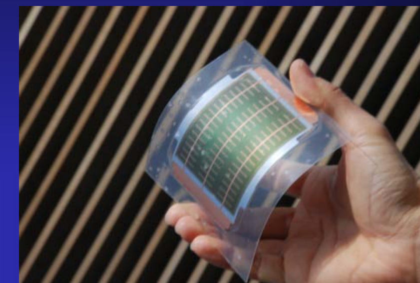


Heterogeneous integration on plastic , low cost

A System Approach

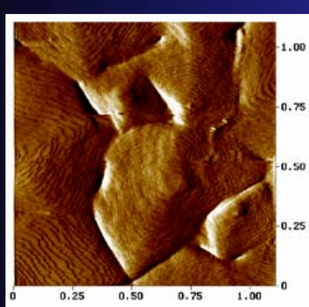




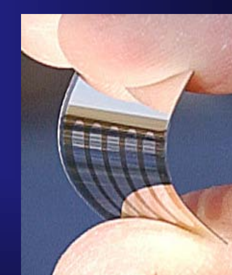
Material synthesis and modeling

Device physics and engineering

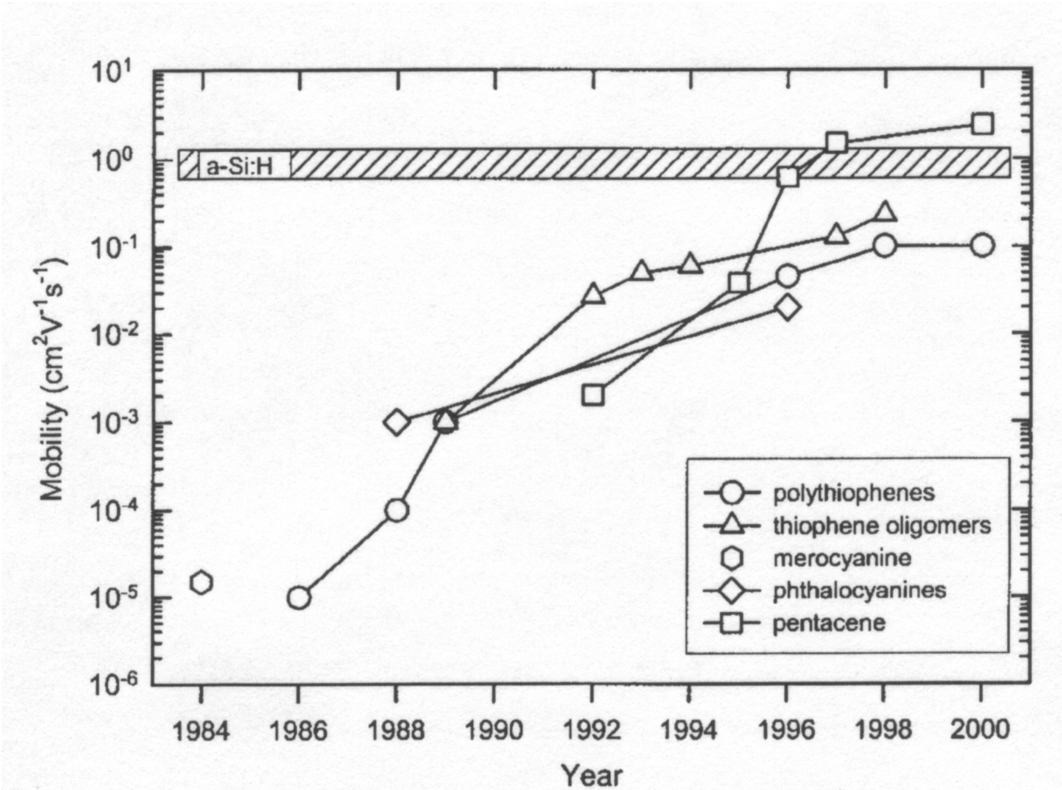
COPE
Center for Organic Photonics & Electronics



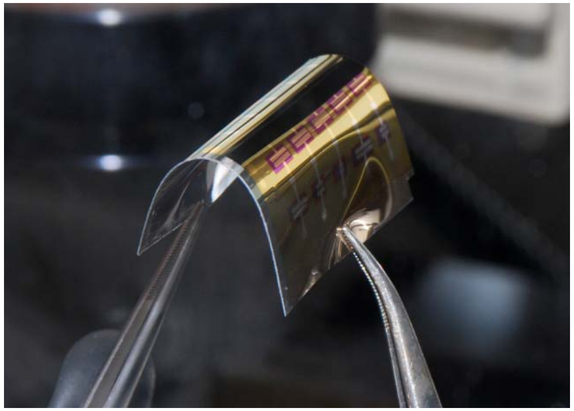
Processing and patterning



Progress in Organic Semiconductors

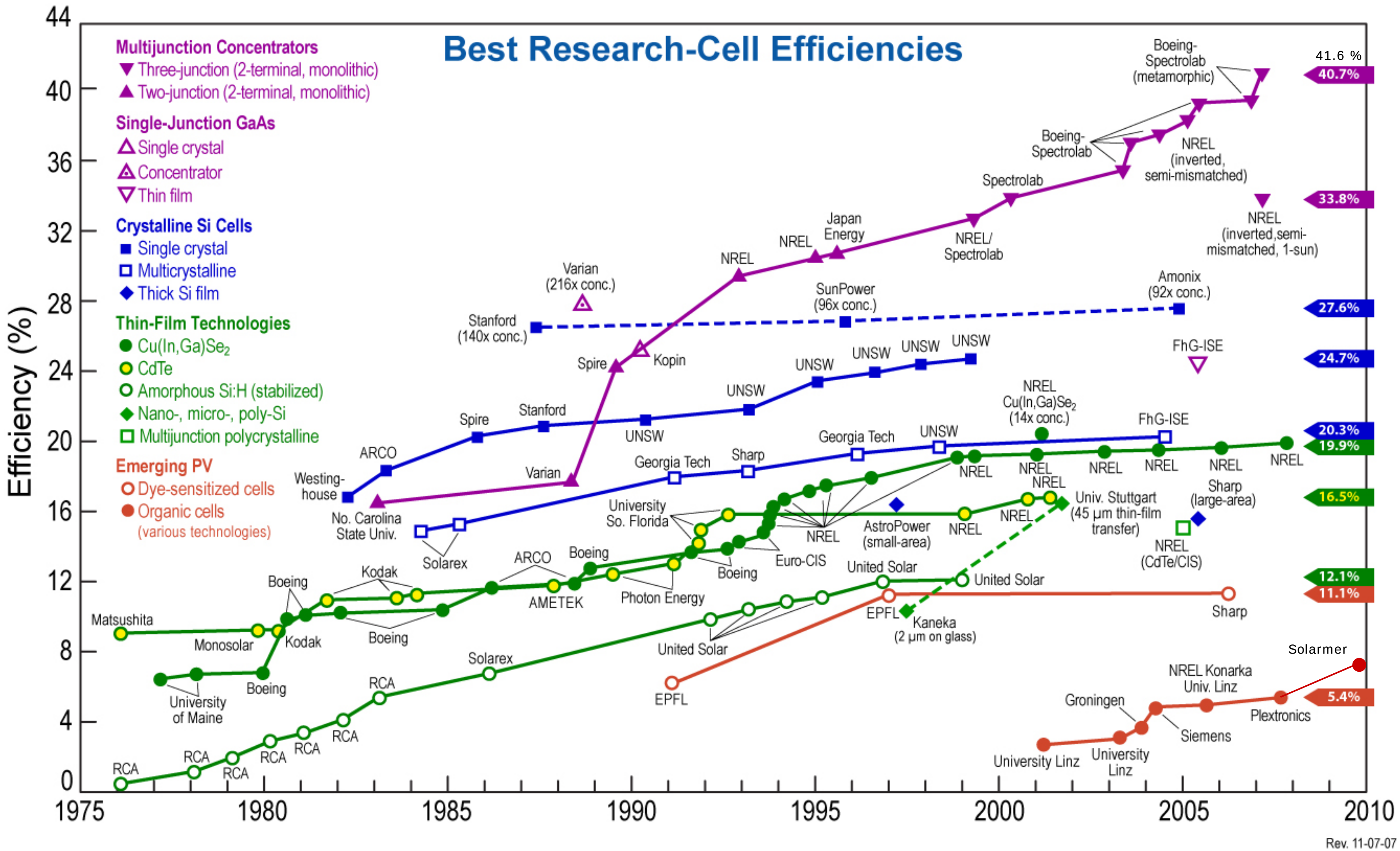


Dimitrakopoulos, Adv. Mater. 14, 99, (2002).



Complementary designs with n-channel and p-channel transistors with comparable performance

Progress in Organic Photovoltaics

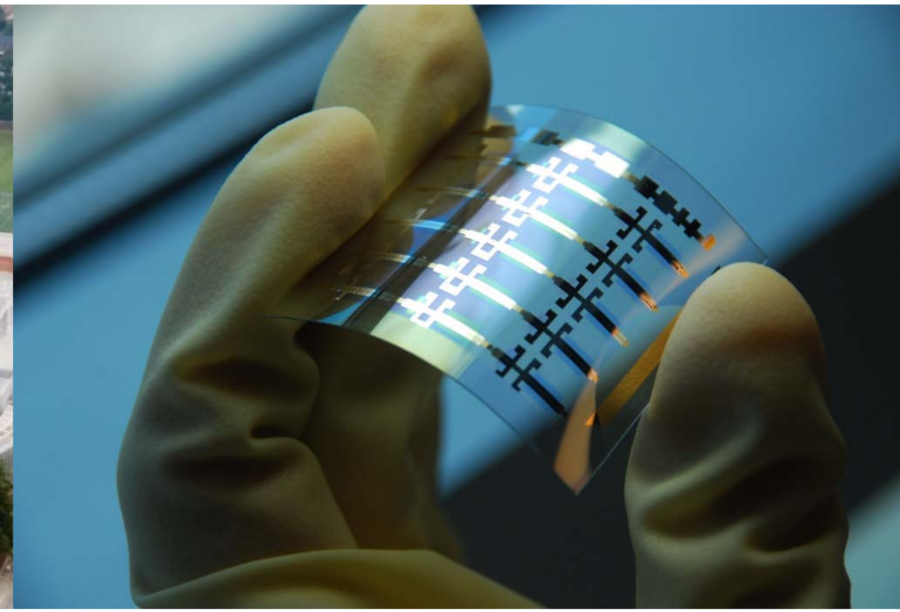


C.W. Tang, Appl. Phys. Lett, 48, 183 (1986)

1%

Konarka: 8.3% (polymer) Dec. 2010
HeliaTek: 8.3% (small molecules) Oct. 2010

Printed and Flexible Electronics at Georgia Tech

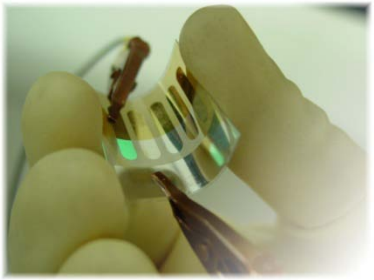


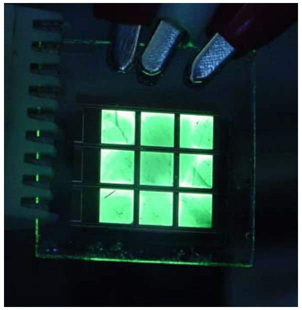
Georgia Institute of Technology

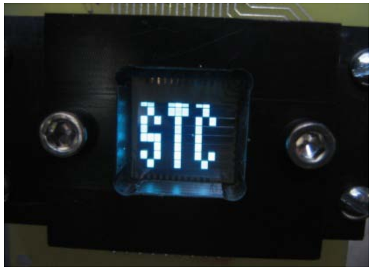
Flexible Display Technology

- RGB active high luminance at low voltage, processing at low temperature on flexible substrates

- Developed photo-patternable polymers that can be processed like a photoresist; provides easy patterning for color displays and <u>high thermal stability</u>.

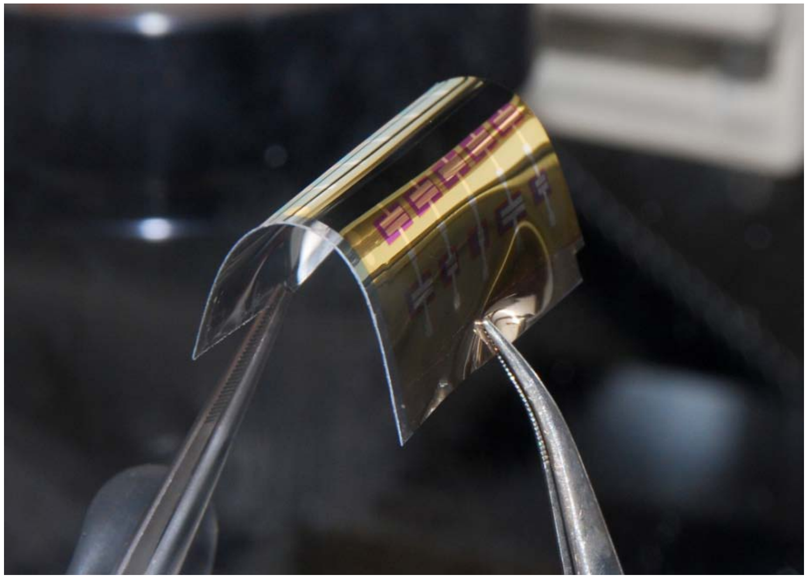






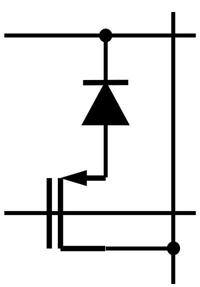
Chem. Mater. 15, 1491 (2003)

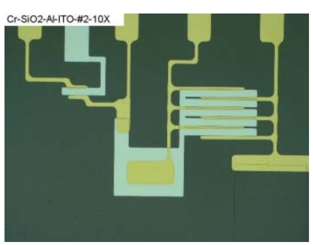
Printed electronics

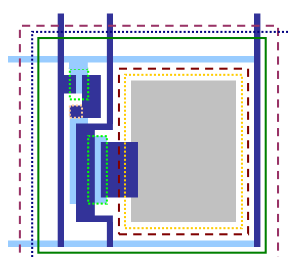


Low-temperature processing of organic semiconductors, metals and dielectrics on flexible substrates: low cost and performance superior to a:Si.

- Macroelectronics
- RF identification tags
- Electronic paper
- Active matrix drivers

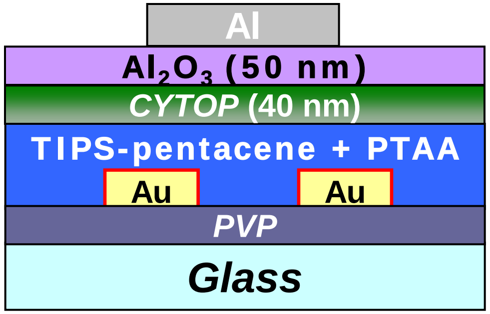


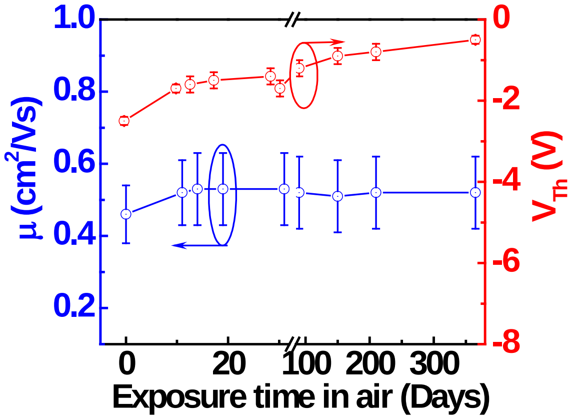




OFETs with bi-layer dielectrics

ACHIEVEMENTS: A new device architecture has been developed for organic field-effect transistors that allows for unprecedented operational and environmental stability. The device uses a new bi-layer geometry for the gate dielectric layer that allows for different degradation mechanisms to be compensated. Solution-processed OFETs with field effect mobility values of 0.5 cm^2/Vs and stability over a year were demonstrated.



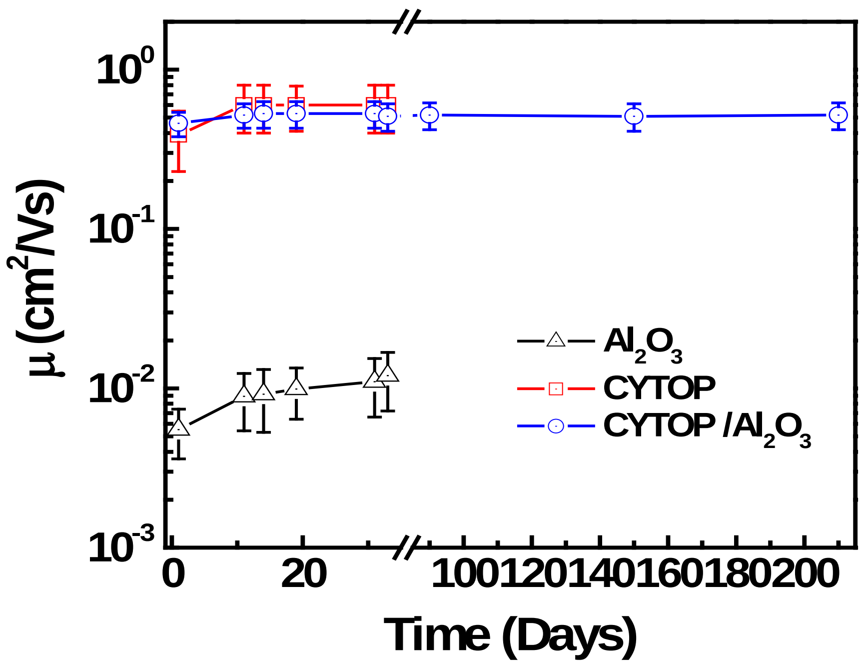


Impact: This breakthrough in demonstrating air stable OFETs with high performance, and high operational and environmental stability brings organic printed electronics one step closer to commercialization.

D.K. Hwang et al., Advanced Materials, published or (2011).

Environmental and operational stability

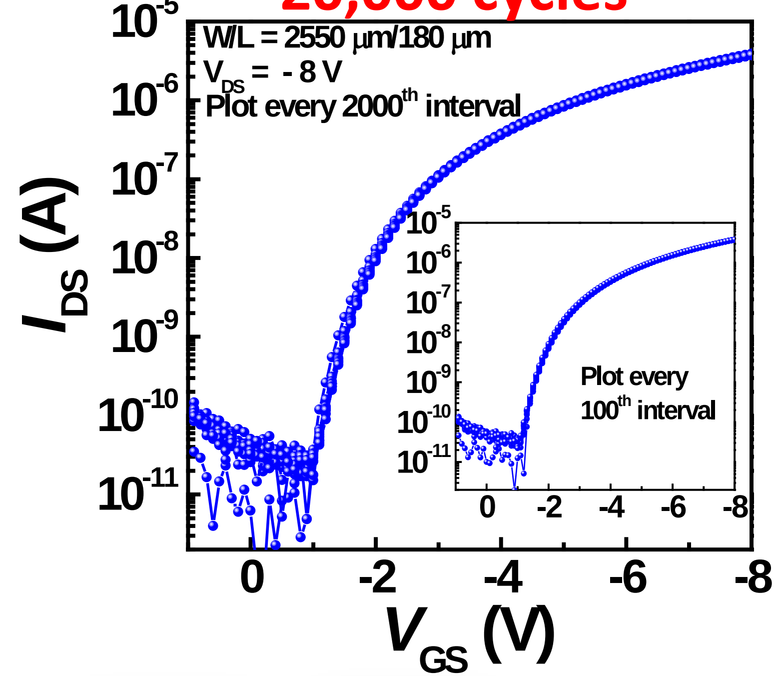
Environmental stability



At 31 days: O_2 plasma treatment for 5 min

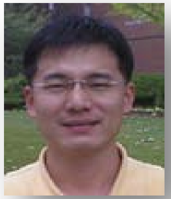
Operational stability

20,000 cycles



Canek Fuentes Hernandez

Do Kyung Hwang



Jungbae Kim

Technology Parameters

Performance
- Charge mobility
- Circuit operating frequency

Resolution
- TFT channel length
- Registration

Encapsulation
- Barrier properties
- Bending radius

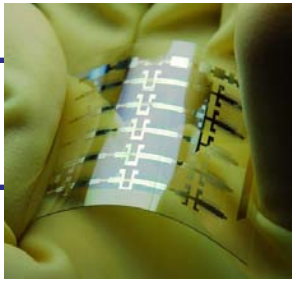
Process parameters
- Printing parameters
- Integration

Manufacturing
- Yield
- Cost

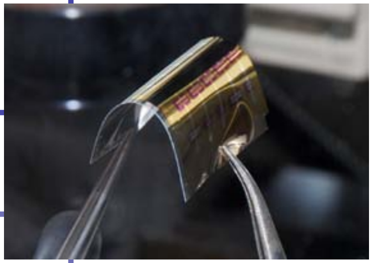
10 – 100 x improvements possible

Technology Drivers

Organic transistors with comparable n-channel and p-channel mobility: today 1 cm^2/Vs, possible 10 cm^2/Vs



Amorphous metal oxide n-channel transistors: today 10 cm^2/Vs, possible 300 cm^2/Vs (transparent)



Dielectrics with high capacitance and energy density: today 10 J/cm^3, possible 500 J/cm^3.

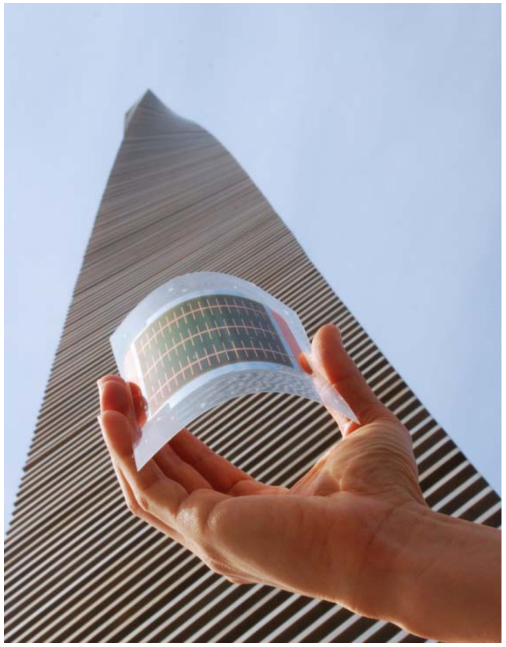
Printing resolution: today 100 μm, possible < 1 μm.

Potential for disruptive breakthroughs

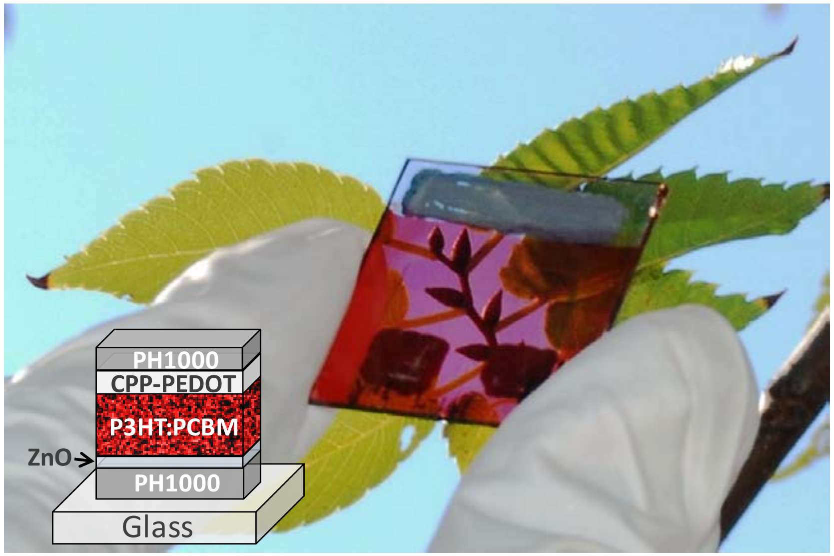
Organic PV Research at COPE

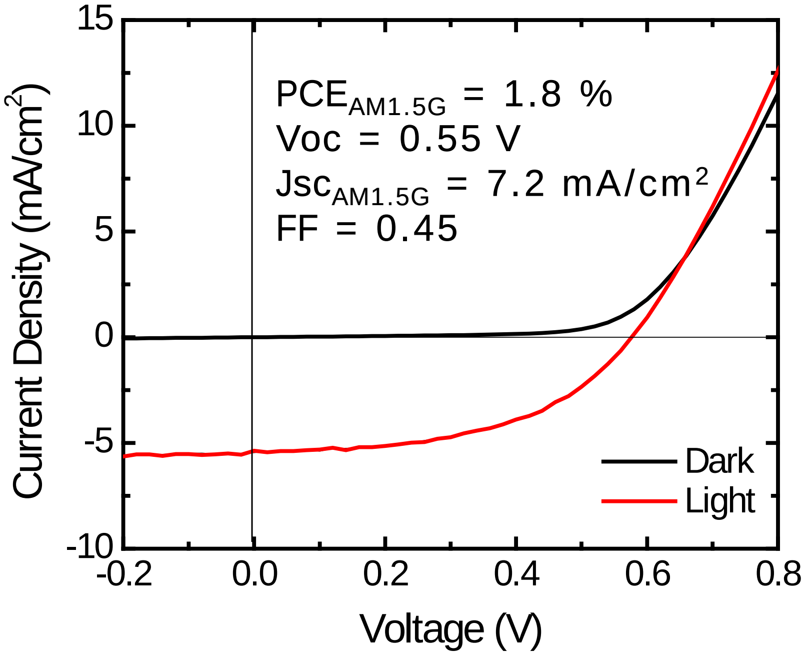
Materials → Processing → PV cell → Packaging → PV module

- Synthesis of new molecules and polymers with tailored optical and electrical properties
- Quantum chemical modeling of material properties and interfaces
- Optical and electrical characterization of thin films and discrete PV devices
- Physical models based on engineering level descriptors
- Monolithic integration of cells into modules
- New flexible transparent electrodes (beyond ITO)
- Flexible packaging technology with barrier coatings



Semitransparent Solar Cells: Metal-free and ITO-free OPVs



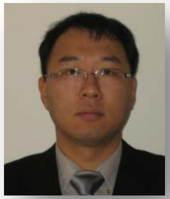


Zhou Y. et.al. Applied Physics Letters 97(15), 153304 Oct. (2010)

Jaewon Shim

Seungkeun Choi

Yinhua Zhou



Hyeunseok Cheun

Summary

- ❑ Printed electronics is emerging and competes with well established electronic material platform like a:Si.

- ❑ Potential of 10 to 100 x improvements in technology parameters can generate real disruptive technologies.

- ❑ Printable, light weight, rugged, flexible, and integrated electronic platforms can revolutionize the consumer/packaging interface.

- ❑ Printed Electronics, a strategic technology for the packaging industry.

- ❑ Integrated team and infrastructure in place at Georgia Tech to engage into scaled up R&D effort in Printed Electronics.

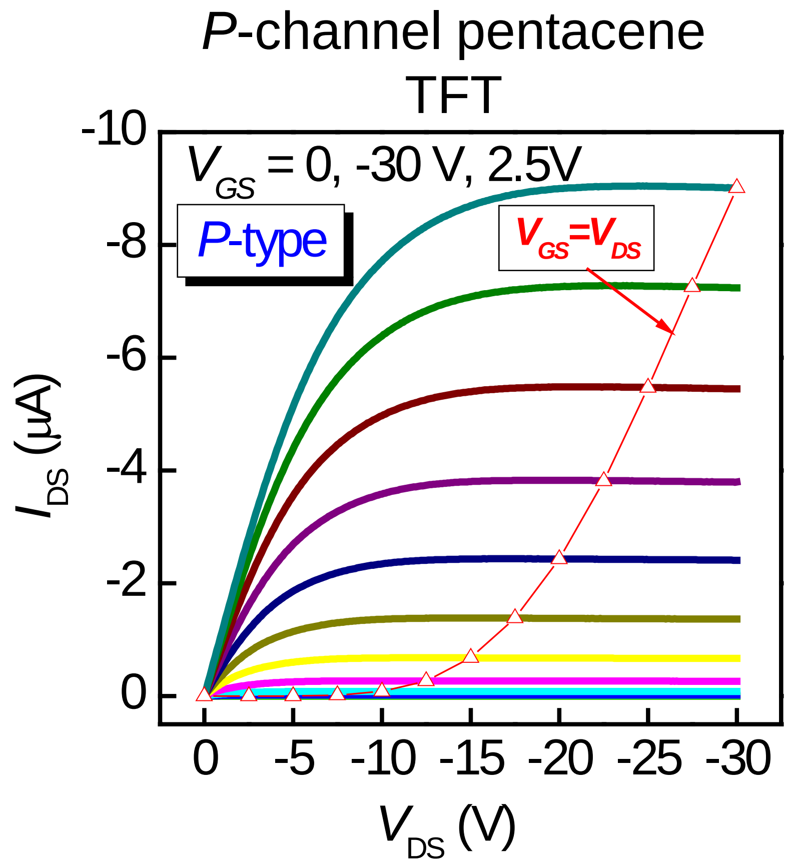
COPE Faculty

Thank you for your attention

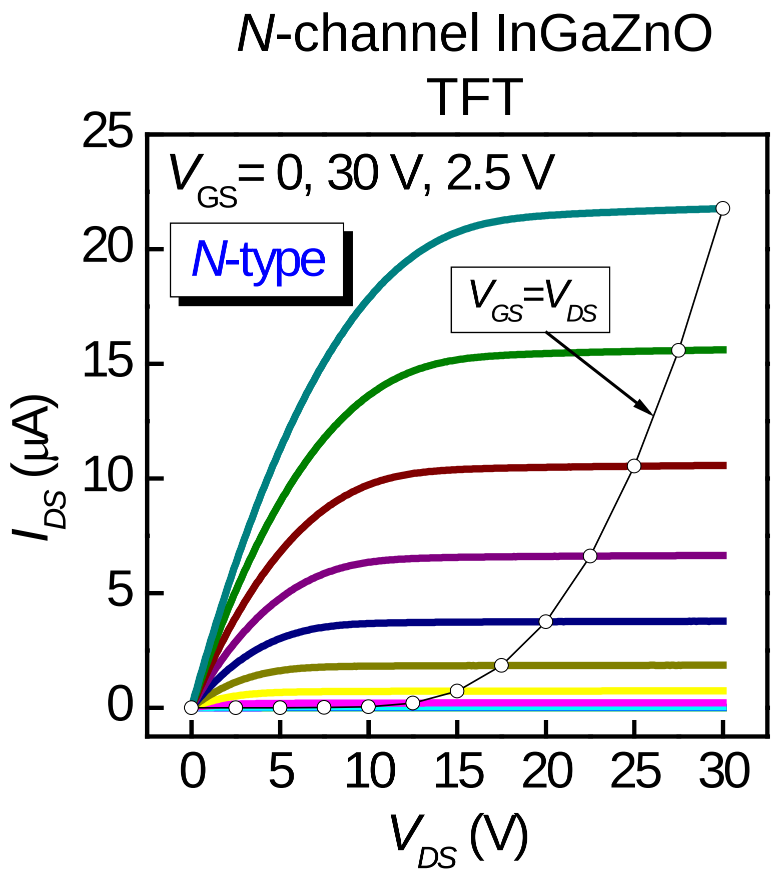
Glossary

AMOLED: Active matrix organic light-emitting diodes
N-channel transistor: a transistor that conducts electrons
P-channel transistor: a transistor that conducts holes
a:Si: amorphous silicon
OFET: organic field-effect transistor
TFT: thin-film transistor
ITO: indium tin oxide
OPV: Organic photovoltaics

Supporting information

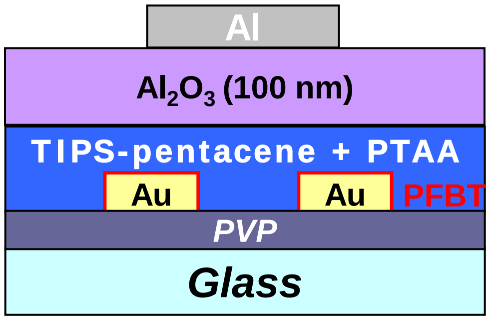


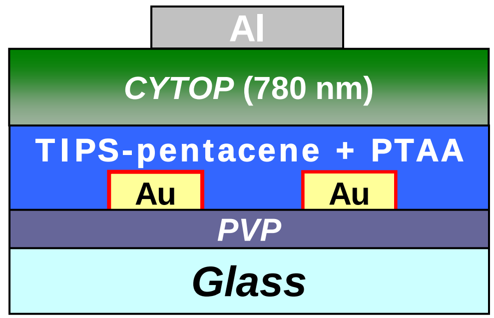
Mobility: 0.15 cm^2/Vs

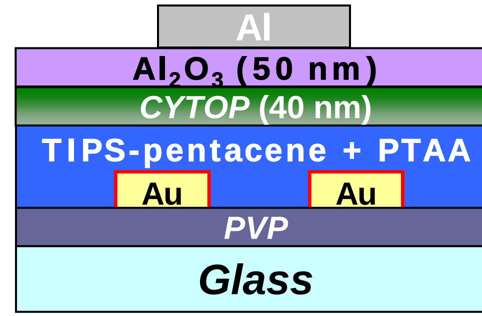


Mobility: 3.8 cm^2/Vs

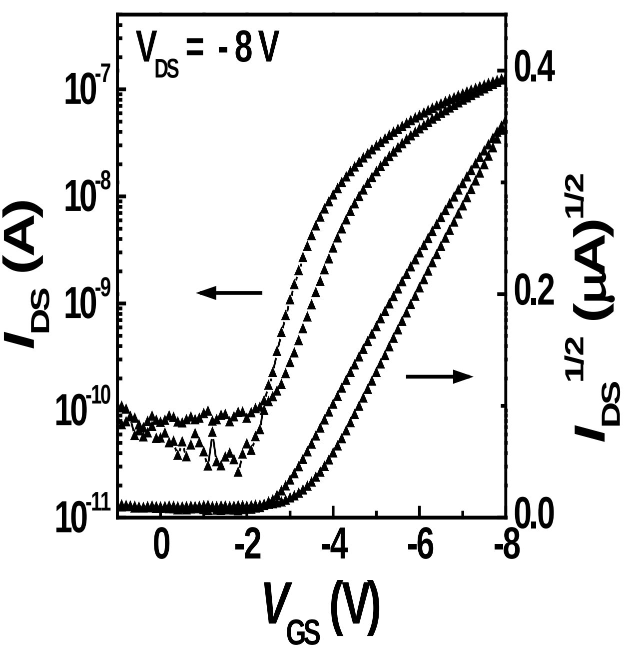
Supporting information



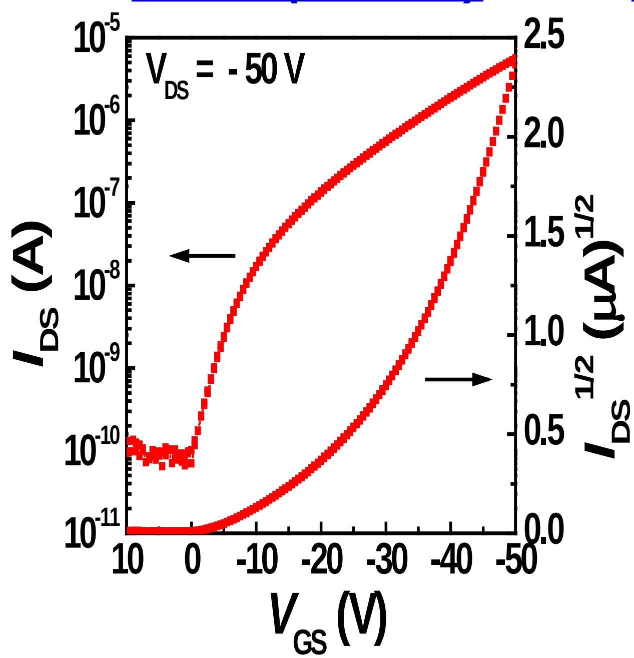




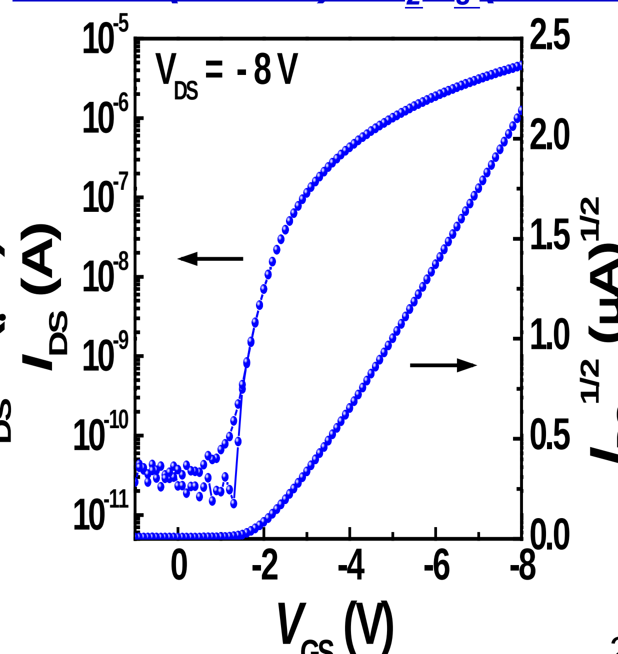
Al_2O_3 (100 nm)



CYTOP (780 nm)

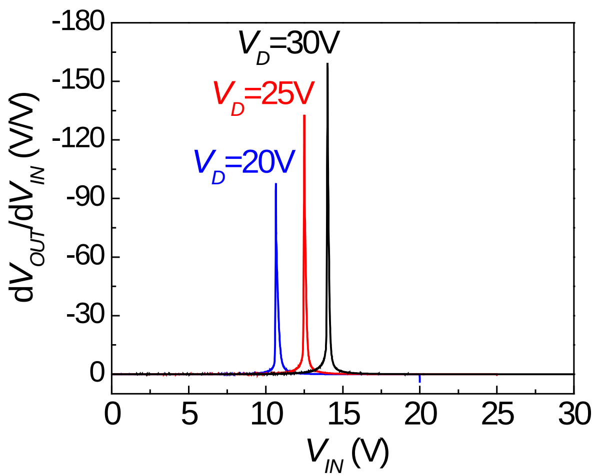


CYTOP (40 nm) / Al_2O_3 (50 nm)



Supporting Information

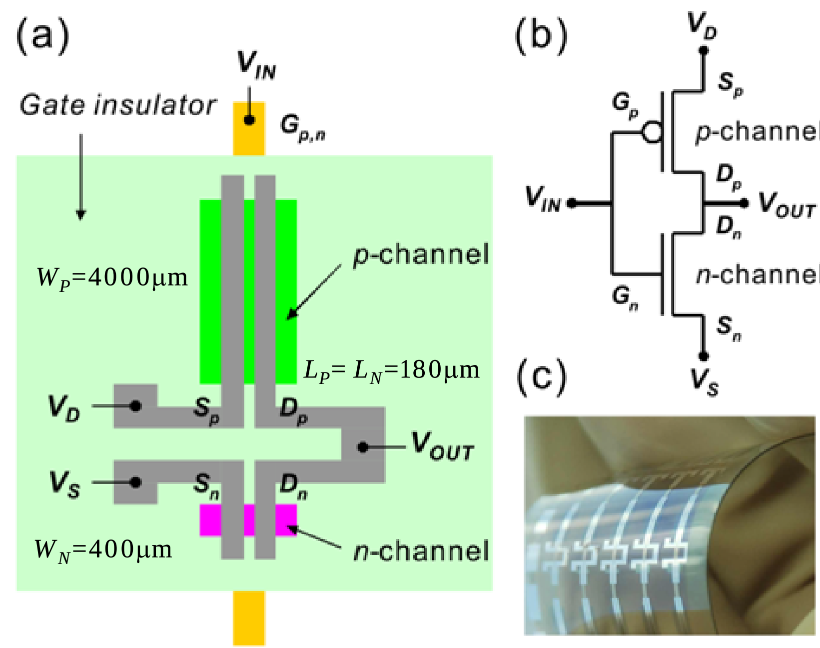
ACHIEVEMENTS: Hybrid inverters were fabricated on flexible substrates. The n-channel transistor was formed from an amorphous InGaZnO metal oxide semiconductor and yielded mobility values of 3.8 cm^2/Vs. Since p-channel transistors are more difficult to fabricate with metal oxides, pentacene was selected for the p-channel transistor. Inverters with balanced noise margins and gain values of 150 were demonstrated.



Impact: Researchers demonstrated state-of-the-art printable hybrid inverters on flexible substrates. All processing temperature steps were lower than 180 °C.

J.B. Kim et al. Organic Electronics 11, 1074 (2010)

Bottom gate, top contact geometry



n-channel : InGaZnO *p*-channel : Pentacene