Advancing Consumer Packaging Through Printable Electronics

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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](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

- 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

Processing and patterning

Center for Organic Photonics & Electronics
Progress in Organic Semiconductors


Complementary designs with n-channel and p-channel transistors with comparable performance
Progress in Organic Photovoltaics

Best Research-Cell Efficiencies


1% Konarka: 8.3% (polymer) Dec. 2010

HeliaTek: 8.3% (small molecules) Oct. 2010
Printed and Flexible Electronics at Georgia Tech
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 high thermal stability.

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 cm²/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.

Environmental and operational stability

Environmental stability

At 31 days: O$_2$ plasma treatment for 5 min

Operational stability

20,000 cycles

At 31 days: O$_2$ plasma treatment for 5 min

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
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

- 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


PCE\textsubscript{AM1.5G} = 1.8 \%
Voc = 0.55 V
Jsc\textsubscript{AM1.5G} = 7.2 mA/cm\textsuperscript{2}
FF = 0.45
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

P-channel pentacene TFT

\[ V_{GS} = 0, -30 \text{ V}, 2.5 \text{ V} \]

\[ V_{GS} = V_{DS} \]

\( I_{DS} \) (\( \mu \text{A} \))

\( V_{DS} \) (V)

Mobility: 0.15 cm\(^2\)/Vs

N-channel InGaZnO TFT

\[ V_{GS} = 0, 30 \text{ V}, 2.5 \text{ V} \]

\[ V_{GS} = V_{DS} \]

\( I_{DS} \) (\( \mu \text{A} \))

\( V_{DS} \) (V)

Mobility: 3.8 cm\(^2\)/Vs
Supporting information

Al₂O₃ (100 nm)

TIPS-pentacene + PTAA

Au

PVP

Glass

CYTOP (780 nm)

TIPS-pentacene + PTAA

Au

PVP

Glass

CYTOP (40 nm)

Al₂O₃ (50 nm)

TIPS-pentacene + PTAA

Au

PVP

Glass

$V_{DS} = -8 \text{ V}$

$I_{DS}$ vs. $V_{GS}$

$V_{DS} = -50 \text{ V}$

$I_{DS}^{1/2}$ vs. $V_{GS}$

$V_{DS} = -8 \text{ V}$

$I_{DS}$ vs. $V_{GS}$
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 cm²/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.