Western Michigan University
Dr. Margaret Joyce
Center for the Advancement of Printed Electronics
A Little Bit About Me

- B.Sc. 1982, Chemical Engineering, North Carolina State University
- B.Sc. 1984, Pulp and Paper Engineering, North Carolina State University
- M.S., 1987, Textile and Polymer Chemistry, North Carolina State University
- Director of Electronic Device Consortium, January 2009
- Director of Center for the Advancement of Printed Electronics, August 2008
- Tenure-track Professor, Fall 2007
- Tenure-track Associate Professor, Fall 2003
- Director of Center for Coating Research and Development, August 2000
- Tenure-track Assistant Professor, Fall 1999
A Little Fun to Start

- [Link](http://www.paperbecause.com)
The Paper Industry is not Dying
Its Transforming
Why Printed Electronics?

- Inexpensive Implementation
- Thinner & Easier Integration
- New Forms of Interaction
- Unique Form Factors
Why Printed Electronics?

- Large area
- High throughput
- Low cost
- Flexible and rigid
- Inexpensive equipment
- Low temperature
- Integrateable
- Scaleable

Source: http://www.printelectronicnews.com/2684/printed-electronics-bigger-than-the-silicon-chip/
Current Technology and Disadvantages

- **Typical substrate - Silicon Wafer**
  - Clean Room, batch process
  - Toxic Chemicals (Health Problems)
  - Rising cost of Silicon
  - Non-flexible Products

Source:
- http://www.propertiesofmatter.si.edu/Silicon.html
- http://www.cleanroombuilders.com/services.php
- http://www.medicaresolutions.com/blog/
Different Strategies

**Replace whole existing devices**
- OLED displays, lighting, RFID
- Large investment, high risk, high reward for a few

**Improve something**
- Cost reduction (use less material or cheaper materials)
- Better performance e.g. flexibility

**Create a new product – replace nothing**
- Usually involves moving downstream to conceive and create complete solutions

Repositioning of companies or bidding time

Few companies
PE Paper Product Innovation
RFID Tags

- April 12, 2012

- NewPage Corporation was awarded a U.S. (8,096,479) and Canadian (CA 2678556) patent for PointTrac™ TT, a new paper-based substrate for printed Radio Frequency Identification (RFID) labels

- It enabled thermal transfer printed variable analog information to be combined with advanced RFID chip technology
Lignin-Based Battery

- Scientists have shown lignin can be used to store an electrical charge.
- A prototype lignin-based rechargeable battery has been made.
- The results suggest that lignin could one day be used as a less expensive, safer alternative to the precious metals currently utilized in battery cathodes.

http://www.gizmag.com/lignin-rechargeable-battery/21931/#comments
Interactive Print Media

http://www.youtube.com/watch?v=P8u3OfKG3tI
Point of Sale
Attention Grabbing Packaging
Intelligent and Interactive Packaging

- Interactive Packaging
- Package Enhancements
- Heating
- Display Interaction
- Sensing and Inventory
- Power to the package
- Power to the product in the package
Interactive Packaging Demo
+ Fully Printed Sensing Devices

- Electrochemical Biochemical Sensor
- Wireless LC Sensor
- Flexible Strain Gauge Sensor
- Flexible Pressure Sensor
Printed Electroluminescent (EL) Lamps

Automotive dashboard display backlighting
Remote control and cell phone backlighting

Wall plug in night lighting

Point of purchase displays
Other Applications

- Circuit Materials
- Medical Applications
- High Speed Printed Electronics
- Rigid and Flexible Board Applications
- Display, Lighting
Current Research

- Fully printed multi-component printed circuit
How is it done?
Conventional Printing
Basic Components of Electronics

Passive Components
- Conductors (wires)
- Resistors
- Capacitors
- Inductors (coils)

Active Components
- Transistors
- Pixels (LCD, LED...)

Types of inks:
- Conductive inks
- Resistor inks
- Dielectric inks
- Ferrite inks
- Clear conductors
- Semiconductors
Top-Gate Printed Transistors

Note: The "air gap" shown is based on simple layer stacking. The topology after printing will affect circuit performance.
Organic Photovoltaics (OPV) – Bulk-Heterojunction PV Structure

Normal Geometry  Frontside Illumination  Inverted Geometry
EL Lamp - Device Design

- glass
- ITO
- Dielectric (1-3 µm)
- Silver Layer (Rear Electrode)
- Phosphor (30 µm)
- AC current
OLED (Organic Light Emitting Diode)

http://electronics.howstuffworks.com/oled1.htm
PE Market Forecasts
2013-2023 Forecast

Sensors Forecasts 2012-2015

Source: IDTechEx  www.IDTechEx.com
Sensors Forecasts 2012-2015

Source: IDTechEx  www.IDTechEx.com
Conductive Inks: Markets & Trends

- PV bus bars
- Sensors – glucose test strips, ECG etc
- Other – including touch surfaces (e.g. automotive capacitive touch)
- ITO replacement – lower end consumer electronics & flexible devices
- Smart packaging

OPPORTUNITIES for PAPER
and PAPER MAKERS
Advantages of PAPER

Paper products provide a wide array of beneficial and controllable properties that are attractive for printed electronics.

- Renewable
- Recyclable
- Compostable
- Varying degrees of transparency
- Various weights and colors
- Low Cost

Conductivity or resistivity can be manipulated with use of conductive materials
TOLERANCE TO TEMPERATURE

The glass transition of paper is 200-250°C. Paper burns at 450°C

- Temperature can cause shrinkage as drying occurs.
- The amount of shrinkage is determined by the moisture and fiber content of the paper
TOLERANCE TO SOLVENTS

Paper is very hygroscopic but can be coated or impregnated with lattices or other polymer based materials to vastly improve its water and solvent resistance.
MOISTURE AND GAS VAPOR TRANSMISSION

The degree to which moisture or gases penetrate the substrate can be managed via coatings and other surface treatments. The range goes from extremely permeable to completely impermeable.

Paper has been used as an insulating material for over 100 years.
Multi-layer coated paper for PE

- Recyclable multilayer coated paper (fabricated for organic transistor)
- Blade, rod, reverse gravure
- Precoat, smoothing layer, barrier coat of latex, pigmented top coat
- Calendered
- RMS 55 nm, AFM (100 x 100 microns)

Surface topography of layers

New coated paper

<table>
<thead>
<tr>
<th>Samples</th>
<th>Average of Roughness (µm)</th>
<th>Scanned Images</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET</td>
<td>0.147</td>
<td></td>
</tr>
<tr>
<td>New Paper</td>
<td>0.367</td>
<td></td>
</tr>
</tbody>
</table>
# Thermal Properties

(important for sintering)

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal conductivity (W/mK)</th>
<th>Heat Capacity (J/g/K)</th>
<th>Density (g/cm³)</th>
<th>Melting Temp. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>170</td>
<td>0.386</td>
<td>8.71</td>
<td>1084</td>
</tr>
<tr>
<td>PET</td>
<td>0.14</td>
<td>1.3</td>
<td>1.39</td>
<td>255</td>
</tr>
<tr>
<td>Glass</td>
<td>0.01</td>
<td>0.768</td>
<td>2.38</td>
<td>1500-2300</td>
</tr>
<tr>
<td>Paper</td>
<td>0.05</td>
<td>1.4</td>
<td>0.25-1.50</td>
<td>does not melt</td>
</tr>
</tbody>
</table>
Summary

It’s ultimately about cost reduction

- Paper is Renewable and Recyclable
- Paper is mass produced by the roll
- Paper is flexible, tunable and can be heated to higher temp. than PET film

New paper-based products are needed for this industry.
Thank You!

CONTACT:
Dr. Margaret Joyce
CAPE - Center for the Advancement of Printed Electronics
Western Michigan University
office: 269-276-3514
fax: 269-276-3501
Email: margaret.joyce@wmich.edu
www.wmich.edu/engineer/cape