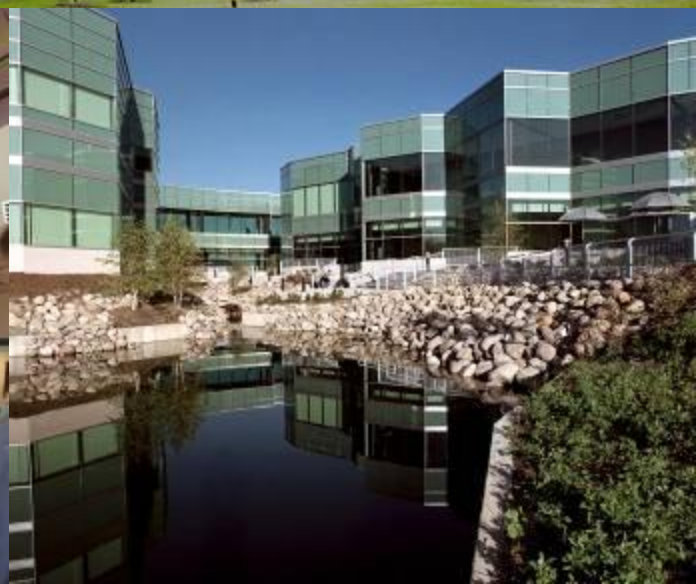
Center for the Advancement of Printed Electronics

Western Michigan University

Dr. Margaret Joyce



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
- Ph.D. 1994, Wood and Paper Science and Engineering, 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

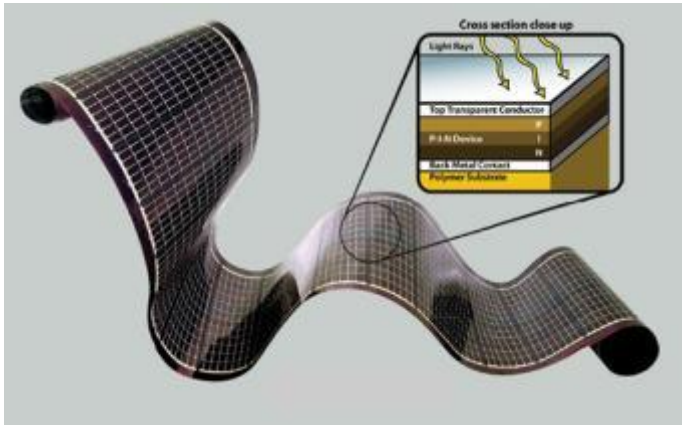
- http://www.paperbecause.com

The Paper Industry is not Dying

Its Transforming

Why Printed Electronics?

Inexpensive Implementation



Thinner & Easier Integration

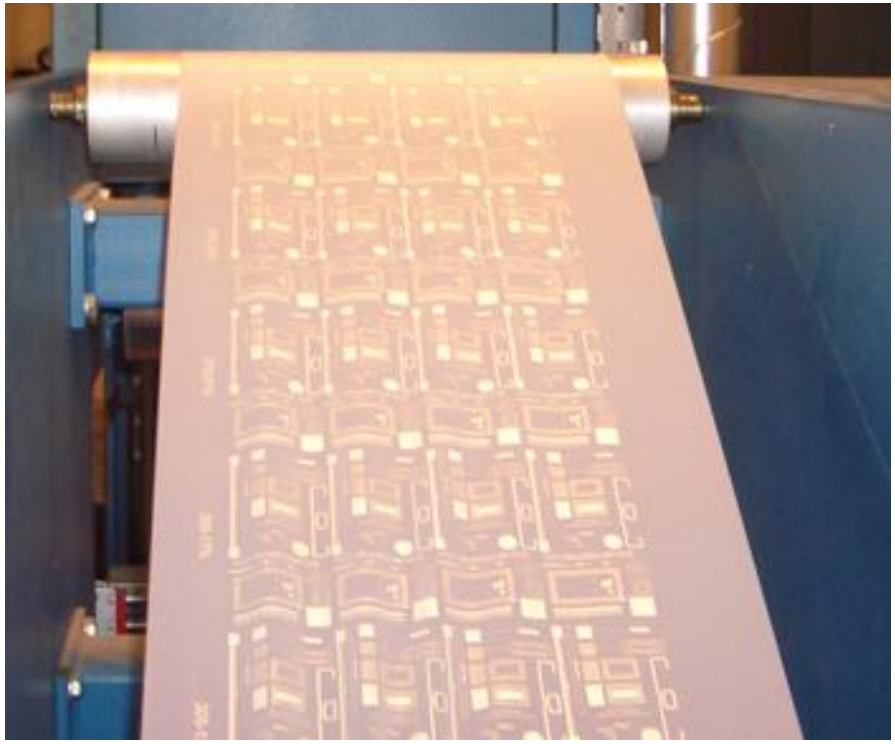
New Forms of Interaction

+

Unique Form Factors

Why Printed Electronics?

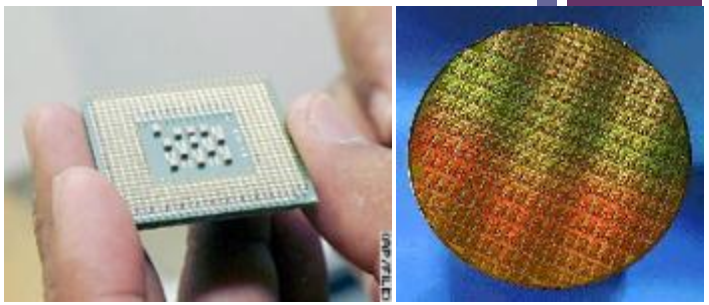
- Large area
- High throughput
- Low cost
- Flexible and rigid
- Inexpensive equipment
- Low temperature
- Integrateable
- Scaleable



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

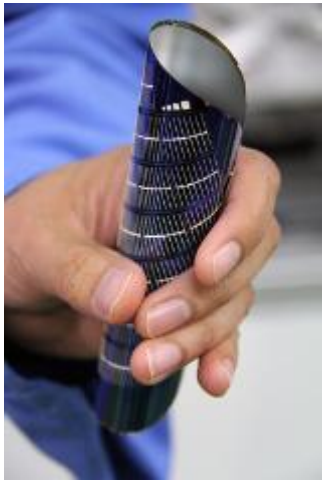


Source:
http://www.propertiesofmatter.si.edu/Silicon.html

Source:
http://www.cleanroombuilders.com/services.php

Source:
http://blogs.wsj.com/digits/2012/03/13/startup-pushes-skinny-flexible-silicon-for-solar/

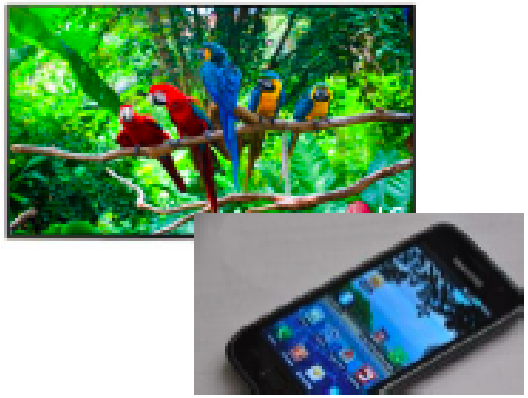
Source:
http://www.hanscomfamily.com/category/news/page/116/



Source:
http://www.medicaresolutions.com/blog/

Different Strategies

Replace whole existing devices

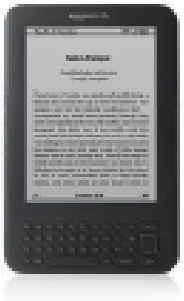


- OLED displays, lighting, RFID
- Large investment, high risk, high reward for a few

Improve something

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

Create a new product – replace nothing



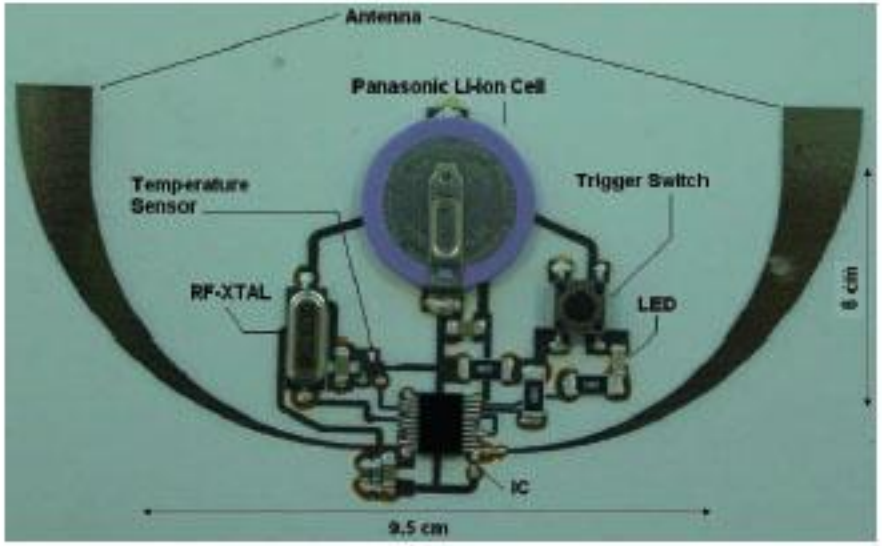
- Usually involves moving downstream to conceive and create complete solutions

Repositioning of companies or biding time

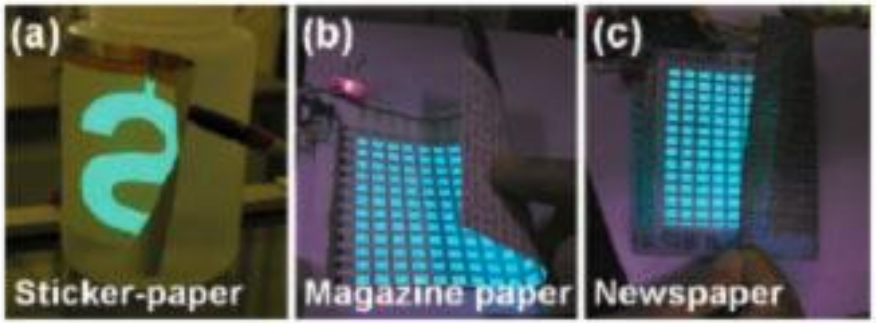
Few companies

PE Paper Product Innovation

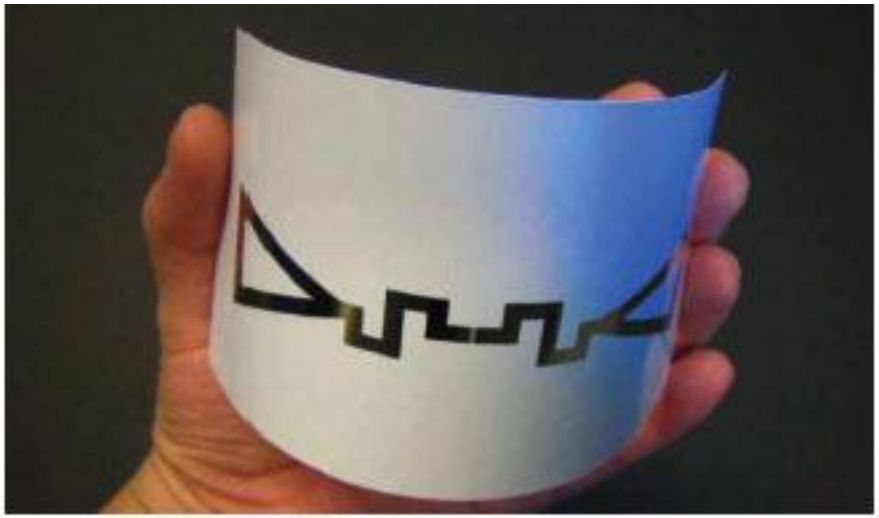
PE on Paper



A temperature sensor integrated into an assembled RFID tag on paper with inkjet-printed dipole antenna and wires.



Photographs of the light emission from inorganic powder electroluminescent devices that have been fabricated on different paper substrates. The size of the squares in (b) and (c) are 15 × 15 mm^2.



A printed, passive RFID gas sensor node on paper. The dipole antenna consists of inkjetted Ag NPs and the load in the small gap in the middle consists of inkjetted CNTs.

Roger Bollström, Anni Määttänen, Daniel Tobjörk, Petri Ihalainen, Nikolai Kaihovirta, Ronald Österbacka, Jouko Peltonen, Martti Toivakka, "A multilayer coated fiber-based substrate suitable for printed functionality", Organic Electronics, 10 (2009) pp. 1020–1023.

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

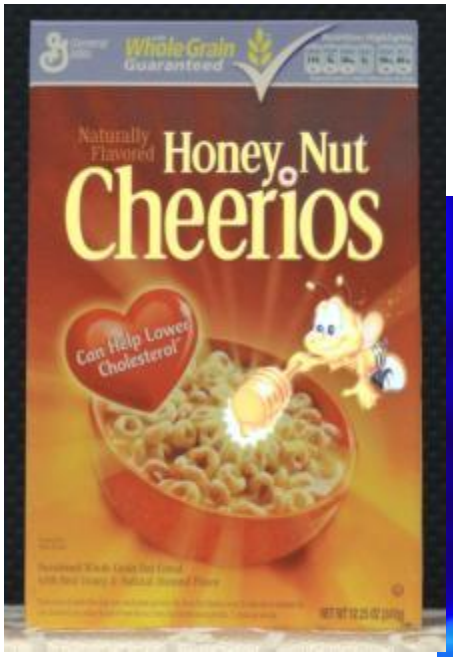
- http://www.youtube.com/watch?v=P8u3OfKG3tI

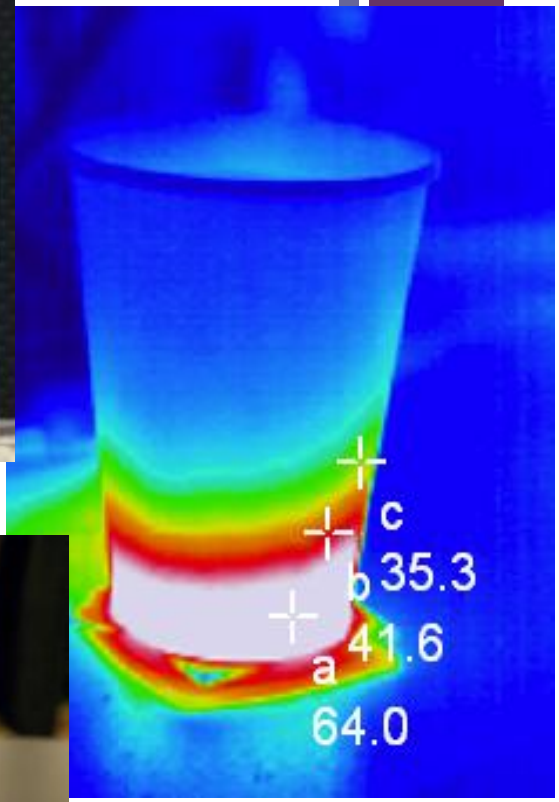
Point of Sale
Attention Grabbing Packaging

Intelligent and Interactive Packaging

- Interactive Packaging
- Package Enhancements
- Heating
- Display Interaction
- Sensing and Inventory
- Power to the package
- Power to the product

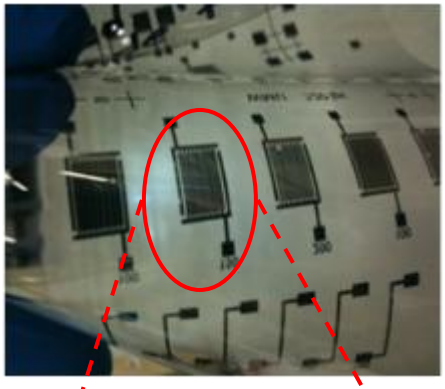
  in the package

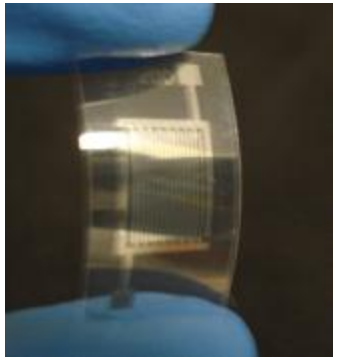




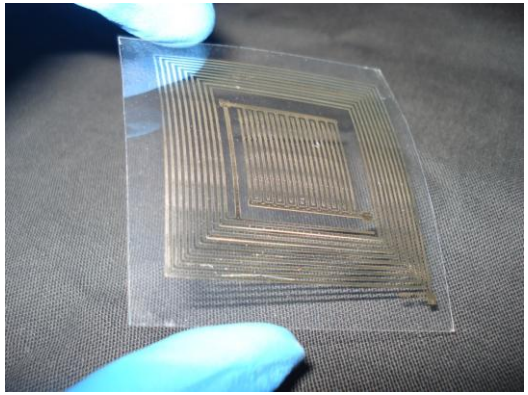
Interactive Packaging Demo

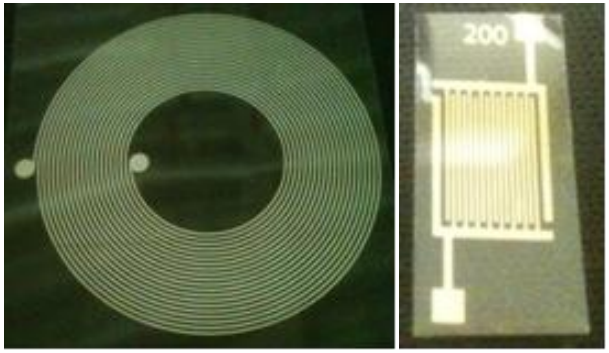
+ Fully Printed Sensing Devices



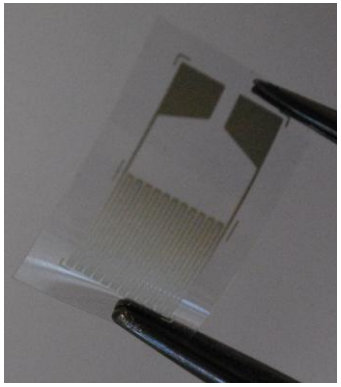


Electrochemical Biochemical Sensor

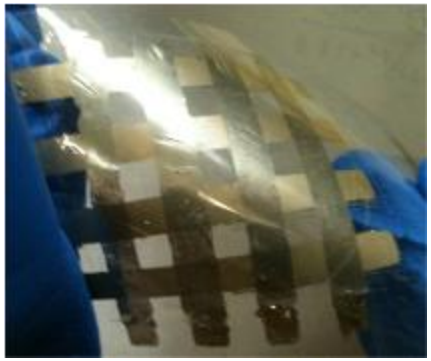




Wireless LC Sensor

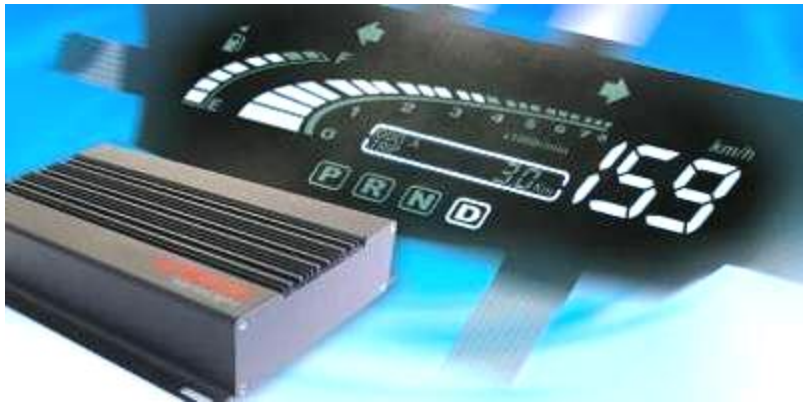


Flexible Strain Gauge Sensor



Flexible Pressure Sensor

Printed Electroluminescent (EL) Lamps



Automotive dashboard display backlighting

Wall plug in night lighting

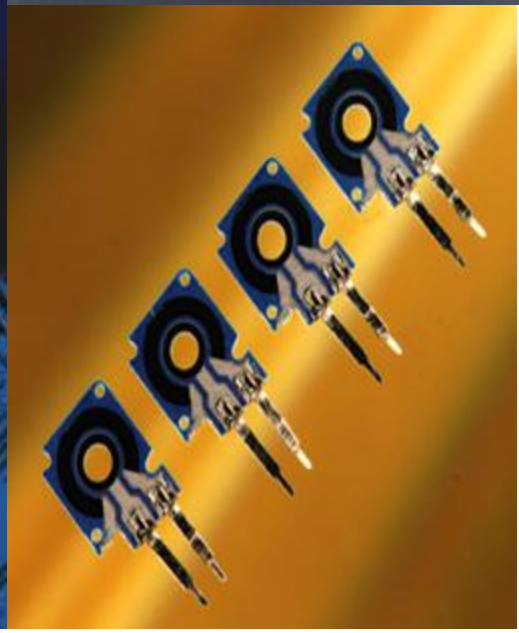
Remote control and cell phone backlighting

Point of purchase displays

Other Applications

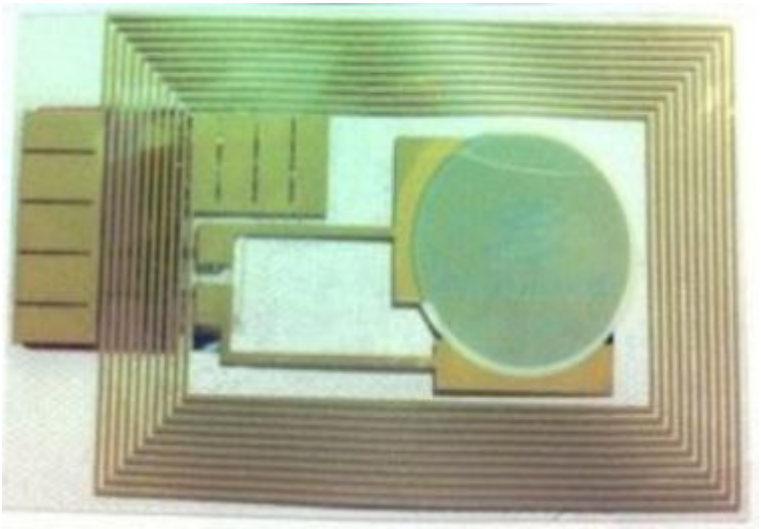
- Circuit Materials
- Medical Applications
- High Speed Printed Electronics
- Rigid and Flexible Board Applications
- Display, Lighting



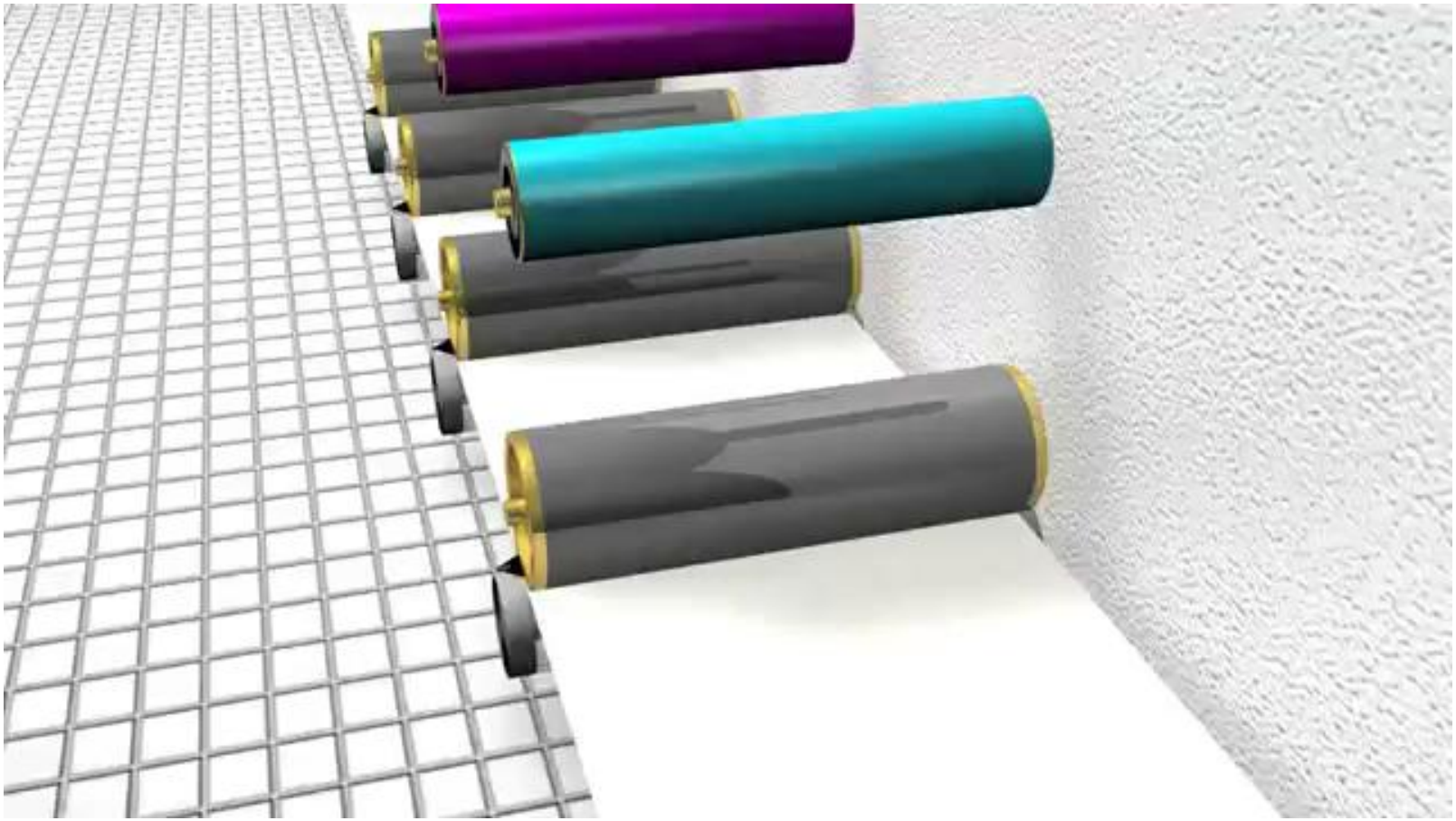

Current Research

- Fully printed multi-component printed circuit

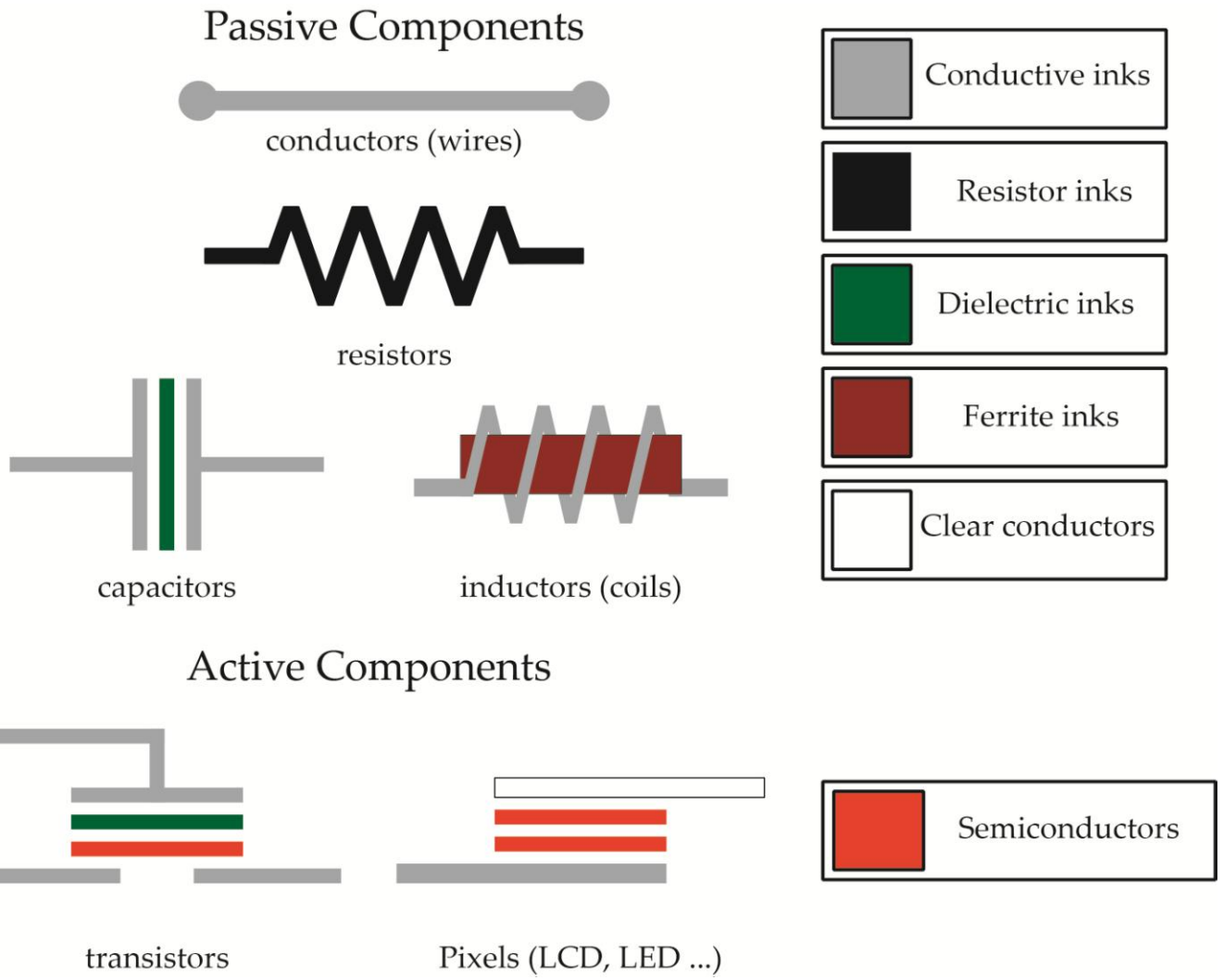


How is it done?

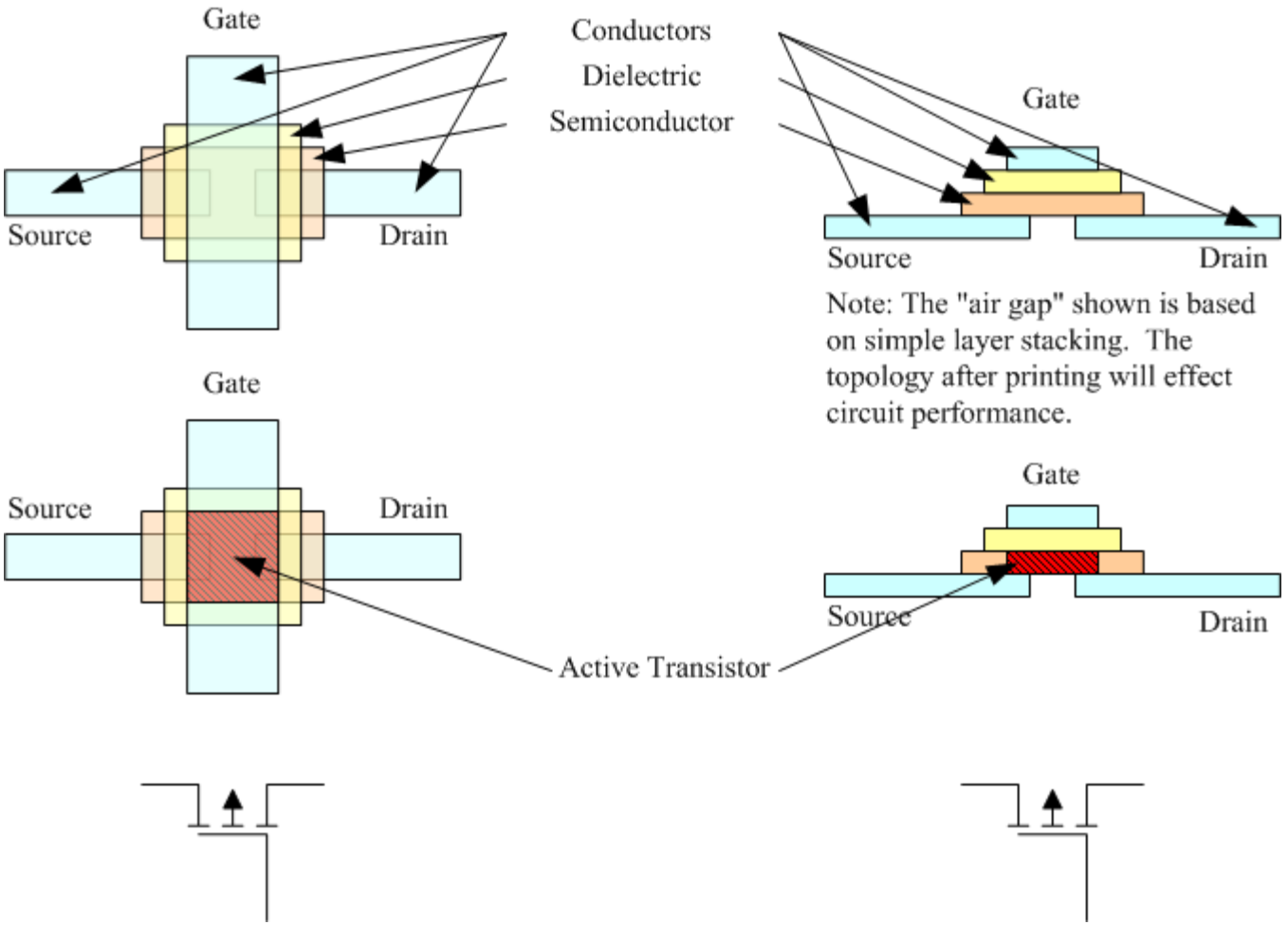
Conventional Printing



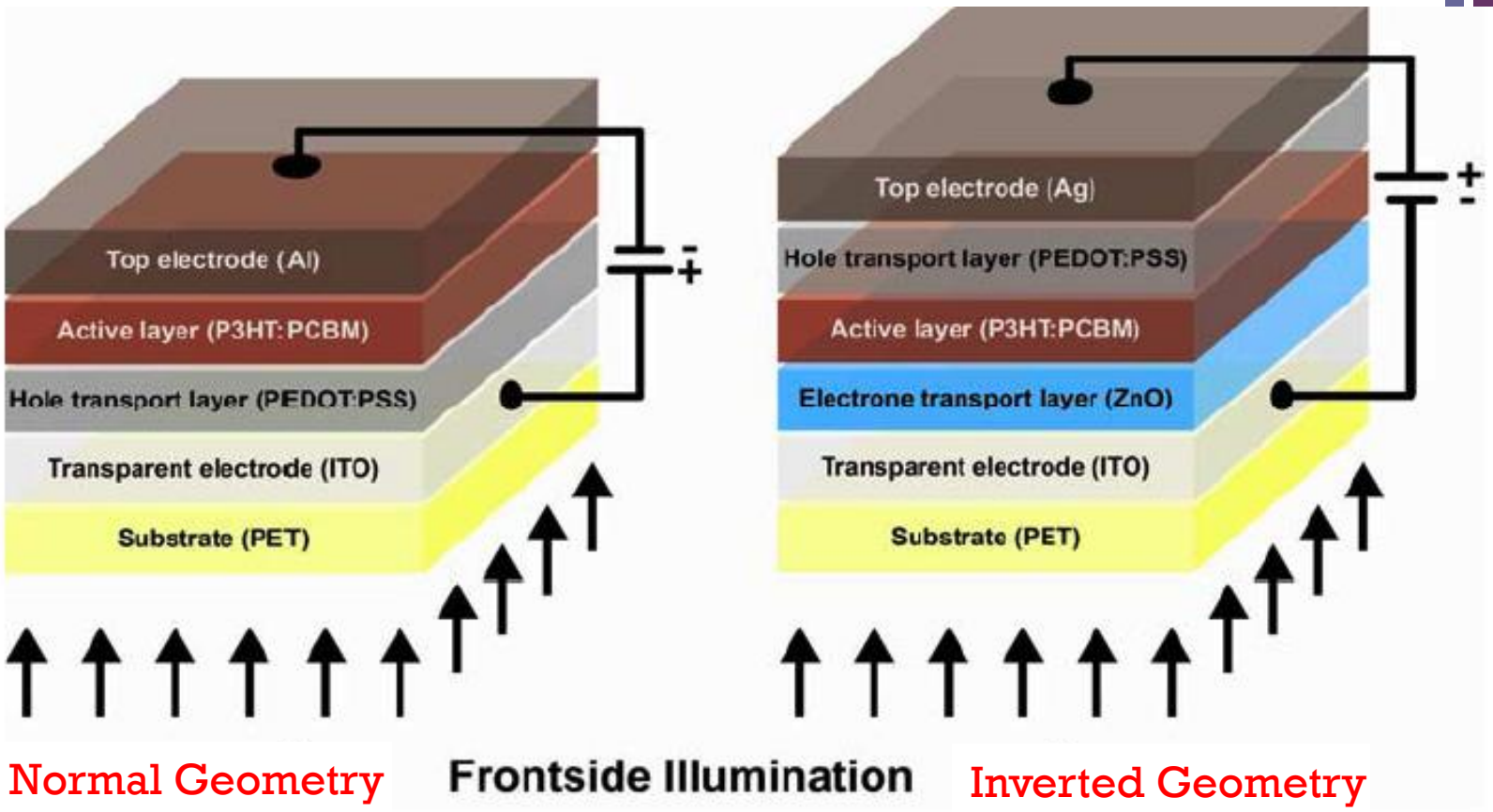
Basic Components of Electronics



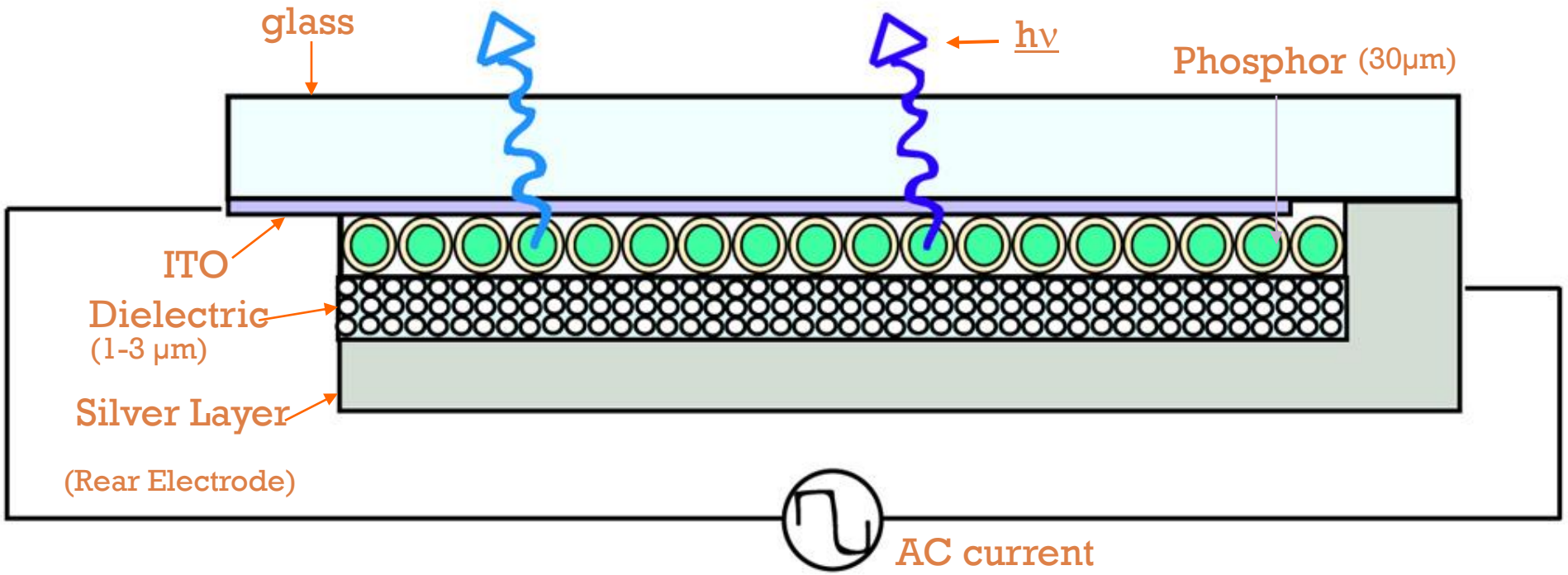
Top-Gate Printed Transistors



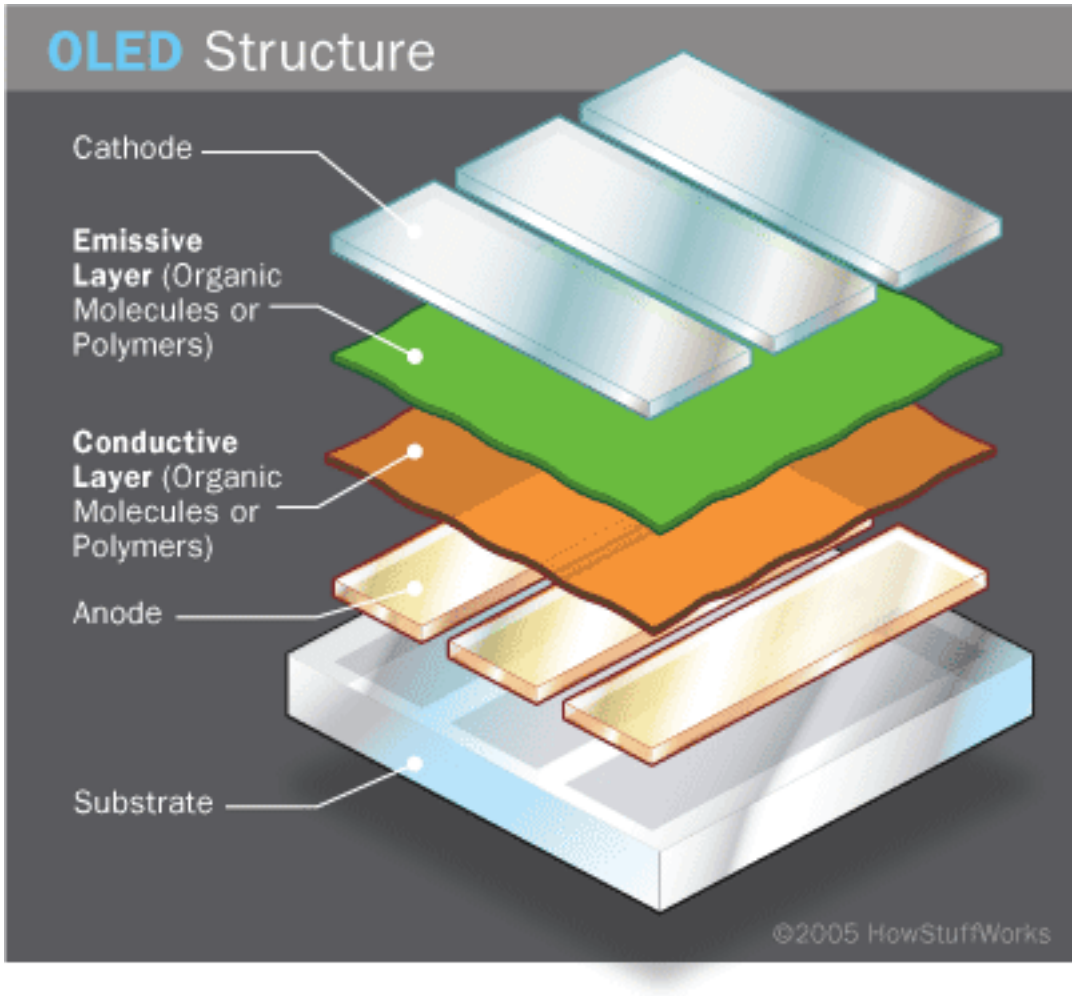
Organic Photovoltaics (OPV) – Bulk-Heterojunction PV Structure



EL Lamp - Device Design



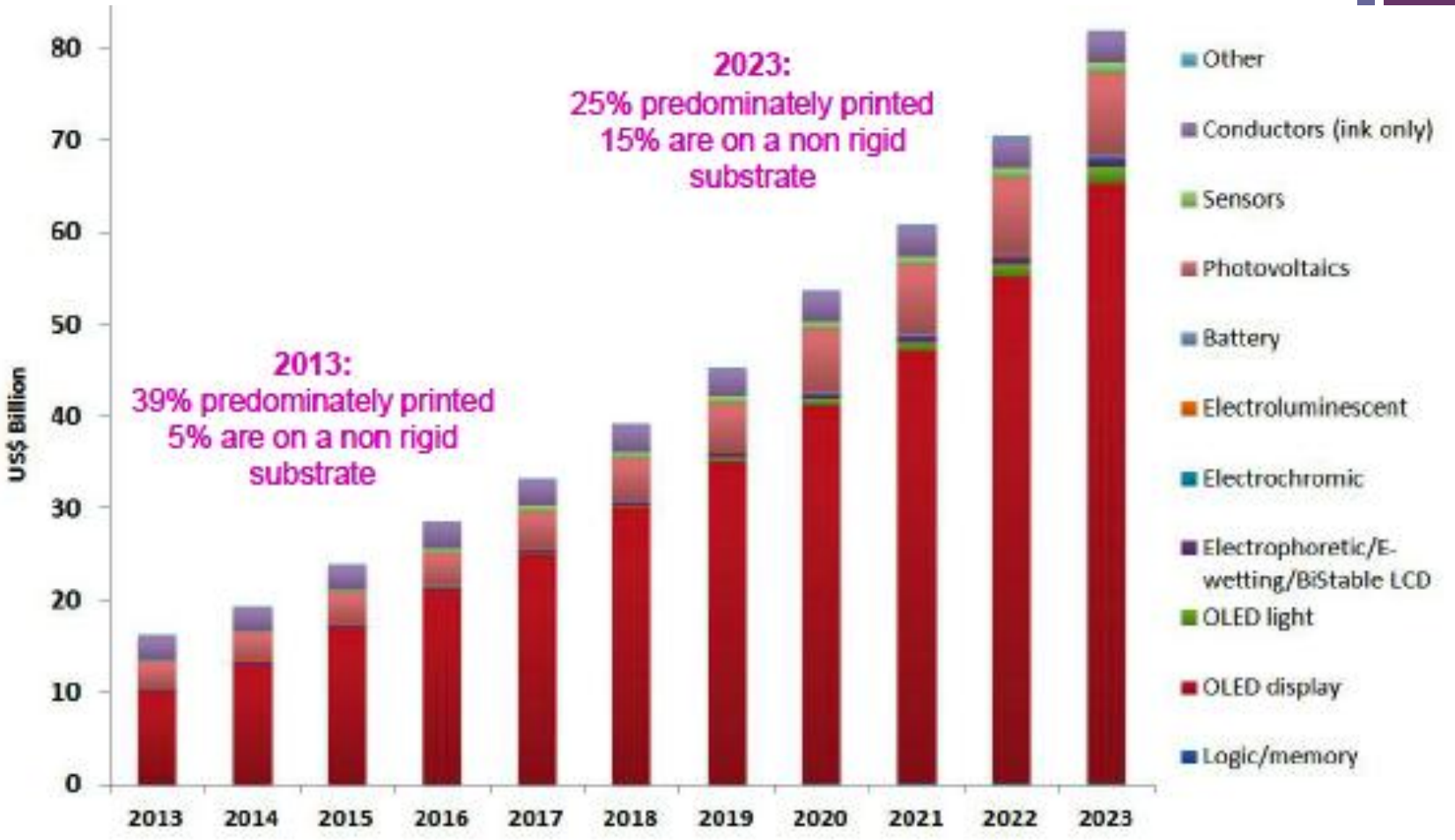
OLED (Organic Light Emitting Diode)



http://electronics.howstuffworks.com/oled1.htm

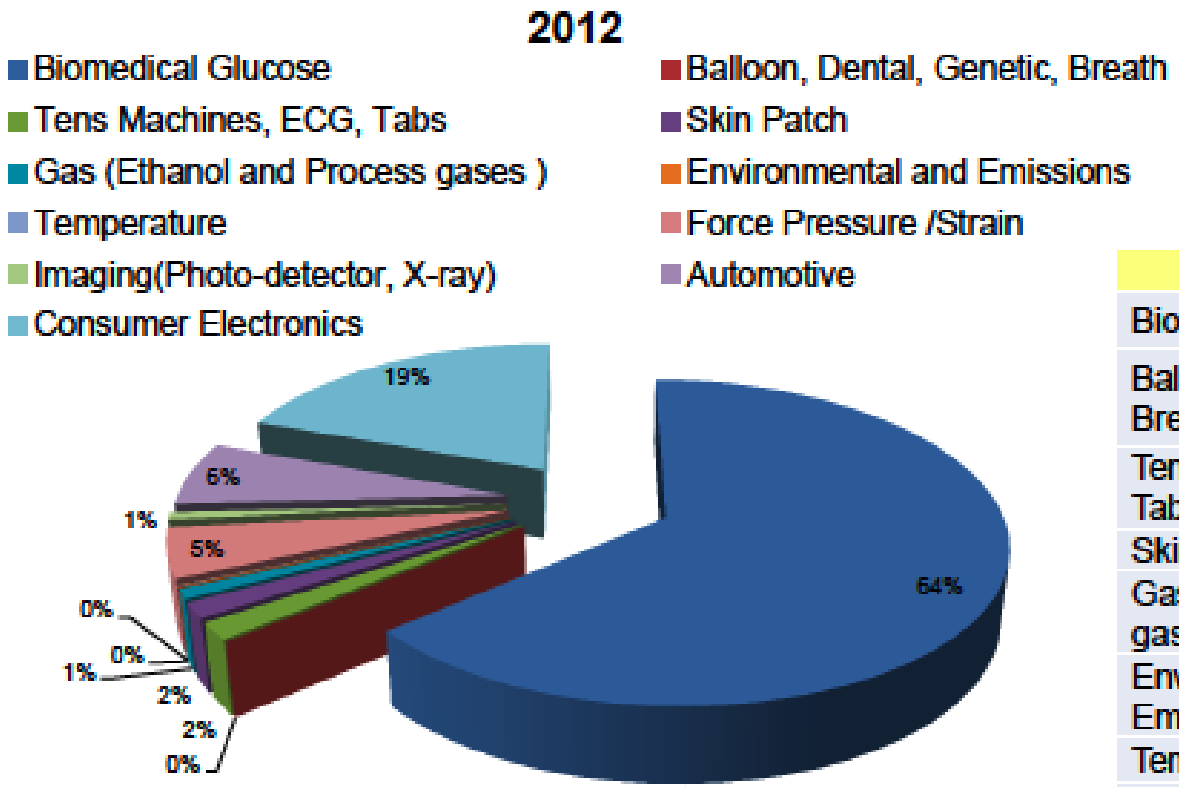
PE Market Forecasts

2013-2023 Forecast



Source: IDTechEx Report "Printed, Organic & Flexible Electronics 2013-2023" www.IDTechEx.com

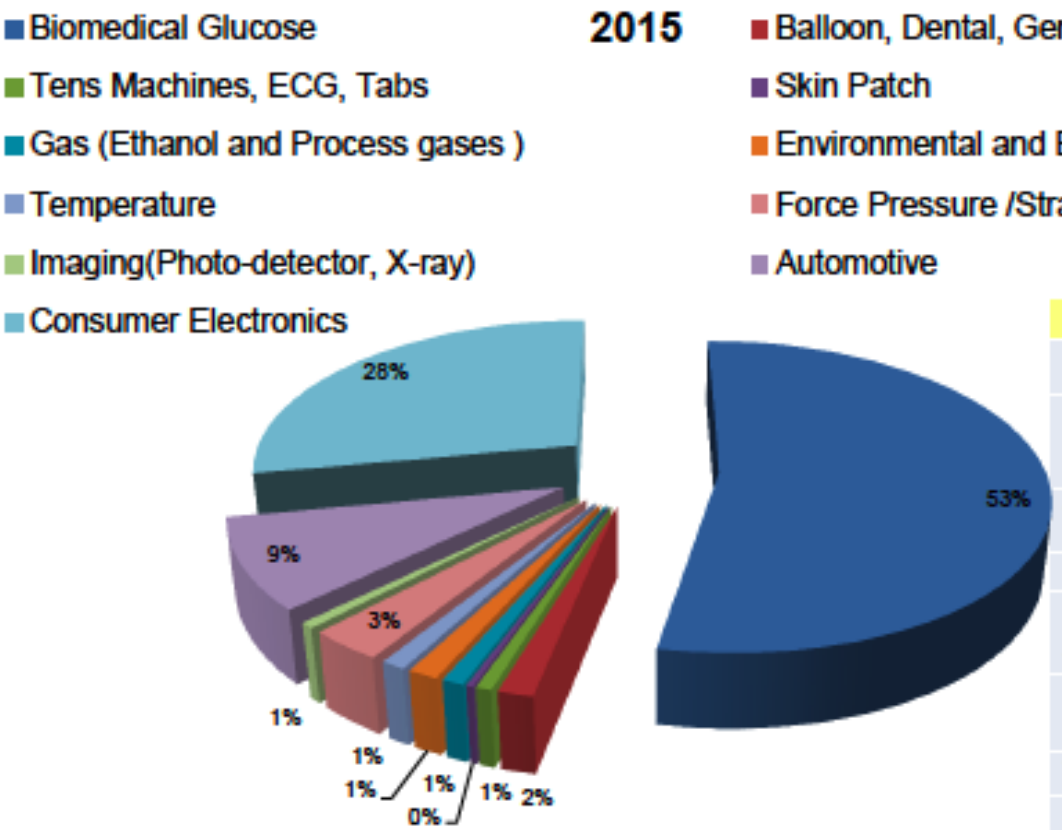
Sensors Forecasts 2012-2015



	2012
Biomedical Glucose	64.48
Balloon, Dental, Genetic, Breath	0.01
Tens Machines, ECG, Tabs	1.76
Skin Patch	1.57
Gas (Ethanol and Process gases)	1
Environmental and Emissions	0.11
Temperature	0.05
Force Pressure /Strain	5.07
Imaging(Photo-detector, X-ray)	0.74
Automotive	6.53
Consumer Electronics	19.58

Source: IDTechEx www.IDTechEx.com

Sensors Forecasts 2012-2015

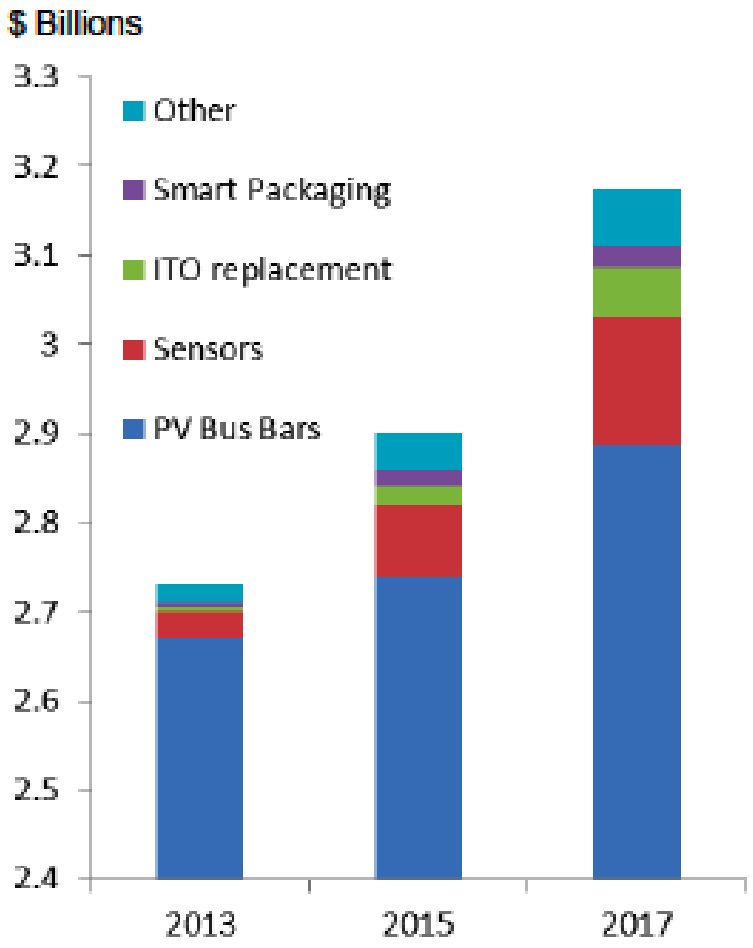


	2015
Biomedical Glucose	191.9
Balloon, Dental, Genetic, Breath	5.34
Tens Machines, ECG, Tabs	2.41
Skin Patch	1.04
Gas (Ethanol and Process gases)	3.33
Environmental and Emissions	4.59
Temperature	3.72
Force Pressure /Strain	11.44
Imaging(Photo-detector, X-ray)	2.24
Automotive	33.69
Consumer Electronics	101.0

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



Source: IDTechEx Report "Conductive Ink Markets 2012-2018" www.IDTechEx.com

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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

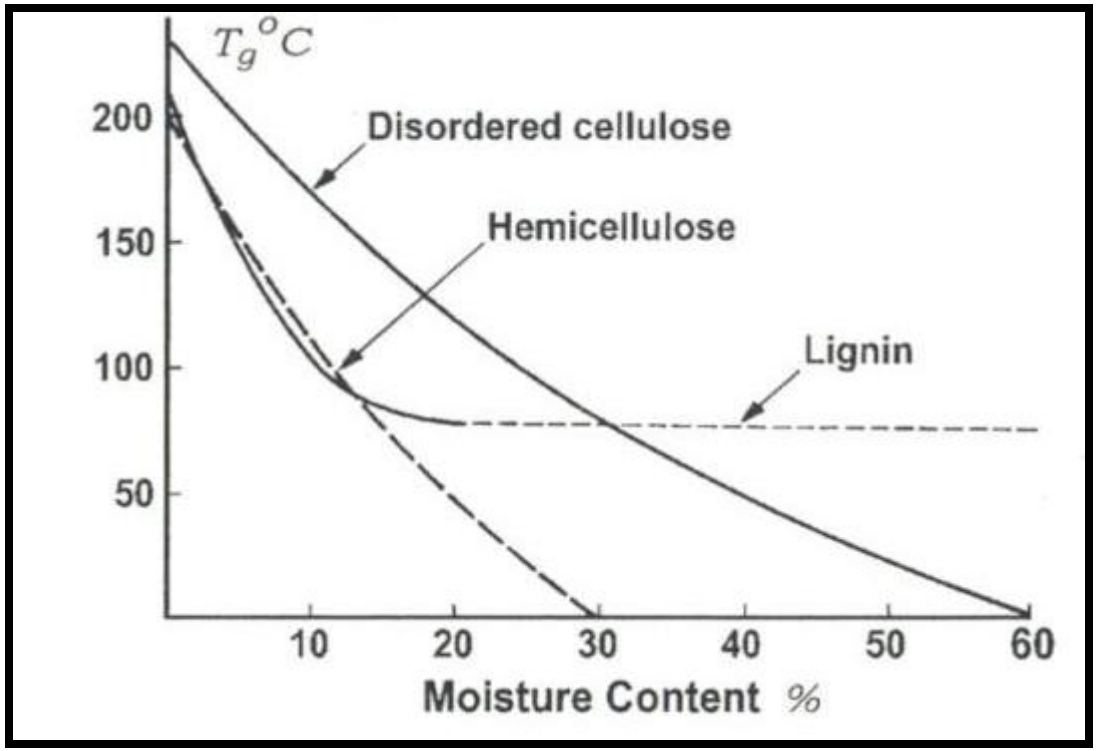
Paper: .10 cent dm-2
PET: 2.0 cent dm-2
PI: 30 cent dm-2

Conductivity or resistivity can be manipulated with use of conductive materials

TOLERANCE TO TEMPERATURE

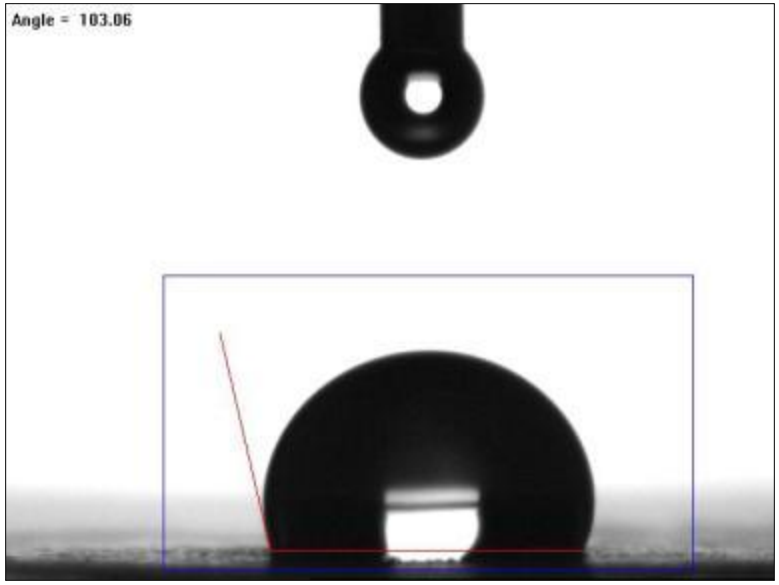
The glass transition of paper is 200-250˚C. Paper burns at 450˚C

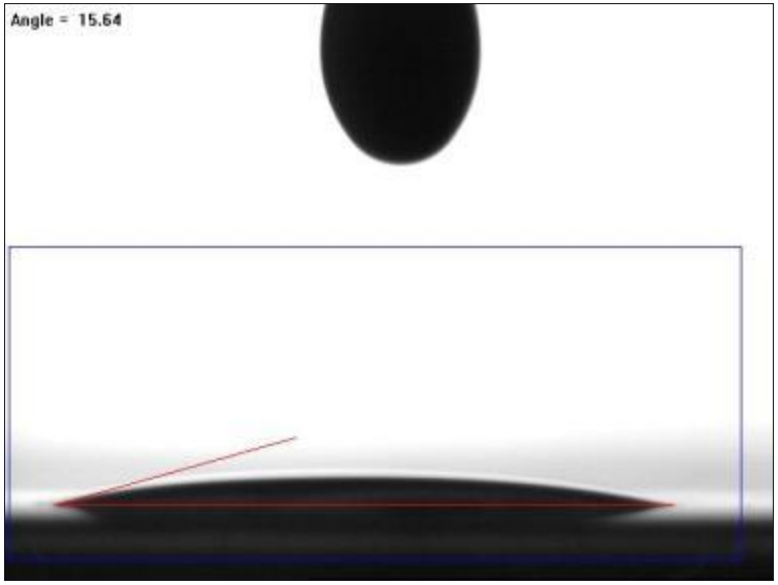
- Temperature can cause shrinkage as drying occurs.
- The amount of shrinkage is determined by the moisture and fiber content of the paper



TOLERANCE TO SOLVENTS

Paper is very hydroscopic but can be coated or impregnated with lattices or other polymer based materials to vastly improve its water and solvent resistance.





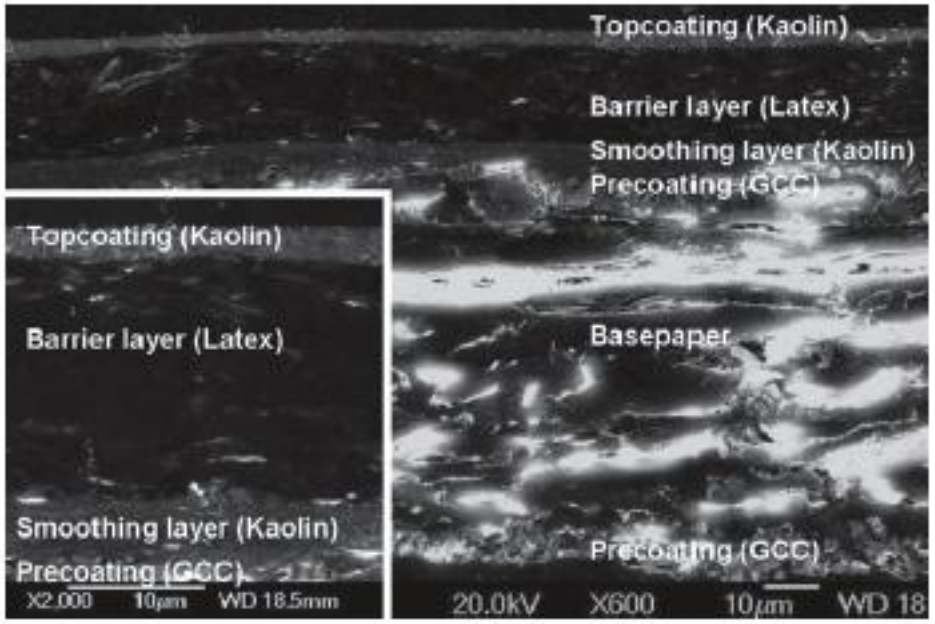
MOISTURE AND GAS VAPOR TRANSMISSION

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.

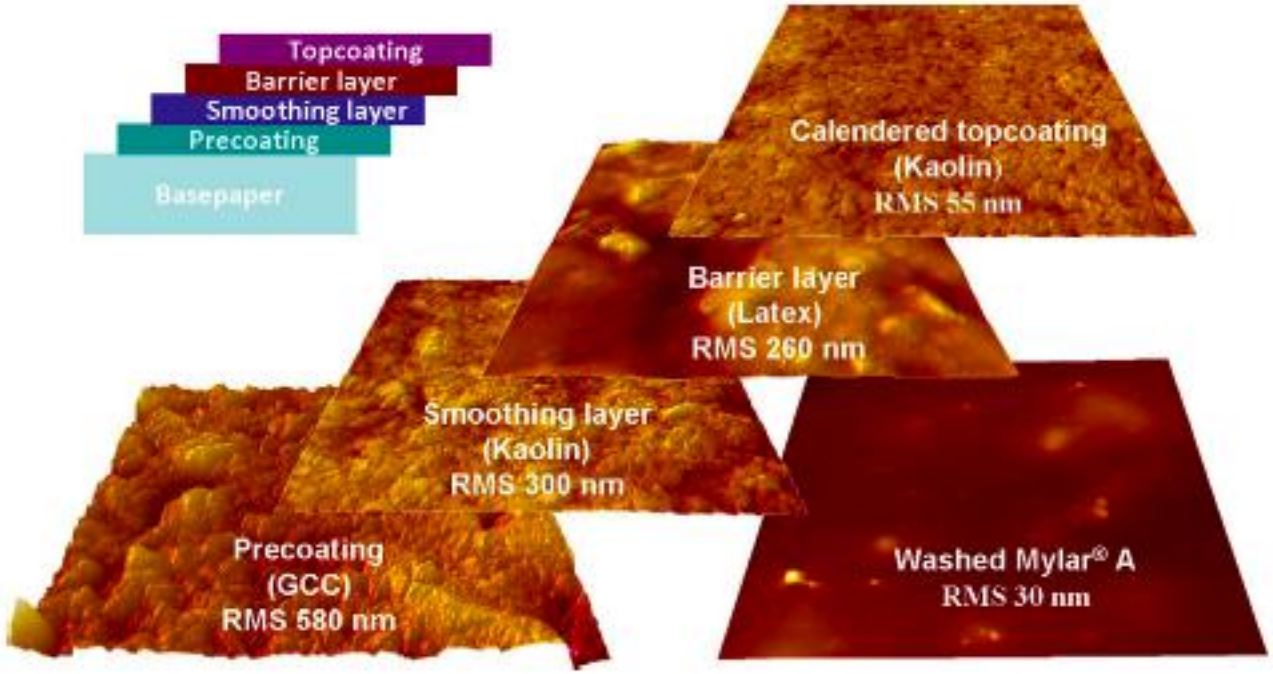
Multi-layer coated paper for PE

- 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)



Roger Bollström, Anni Määttänen, Daniel Tobjörk, Petri Ihalainen, Nikolai Kaihovirta, Ronald Österbacka, Jouko Peltonen, Martti Toivakka, "A multilayer coated fiber-based substrate suitable for printed functionality", Organic Electronics, 10 (2009) pp. 1020–1023.

Surface topography of layers



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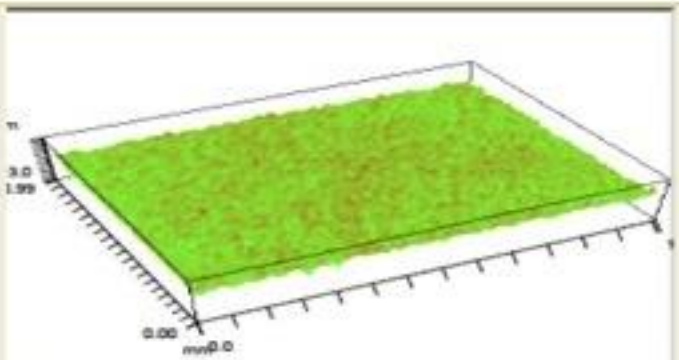
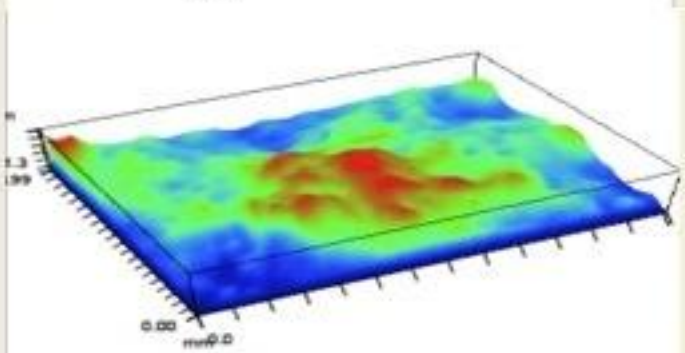
New coated paper

Samples	Average of Roughness (µm)	Scanned Images
PET	0.147	
New Paper	0.367	

Thermal Properties (important for sintering)

Material	Thermal conductivity (W/mK)	Heat Capacity (J/g/K)	Density (g/cm^3)	Melting Temp. ($^{\circ}C$)
Copper	170	0.386	8.71	1084
PET	0.14	1.3	1.39	255
Glass	0.01	0.768	2.38	1500-2300
Paper	0.05	1.4	0.25-1.50	does not melt

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.

Questions

Thank You!

Center for the Advancement of Printed Electronics

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