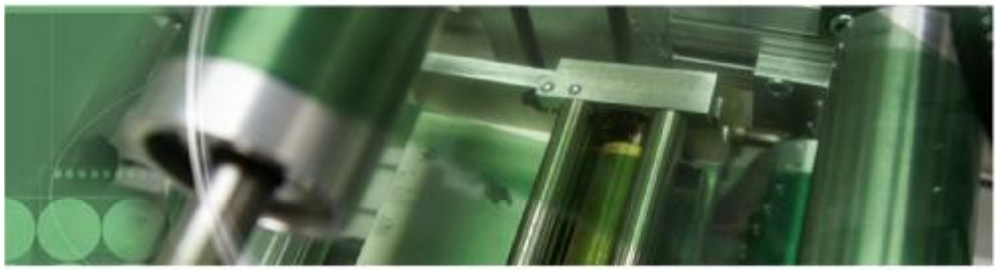


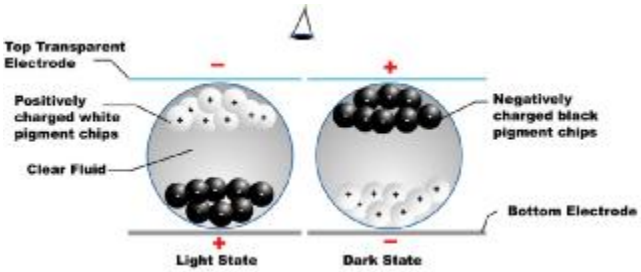
Paper Electronics

Roger Bollström[1], Daniel Tobjörk[3], Peter Dolietis[1], Anni Määttänen[2], Petri Ihalainen[2], Jouko Peltonen[2], Ronald Österbacka[3] and Martti Toivakka[1]

[1]Paper Coating and Converting
[2]Physical Chemistry
[3]Physics/Organic Electronics
Åbo Akademi University, Turku, Finland

Paper Electronics is not Electronic Paper!

Amazon Kindle

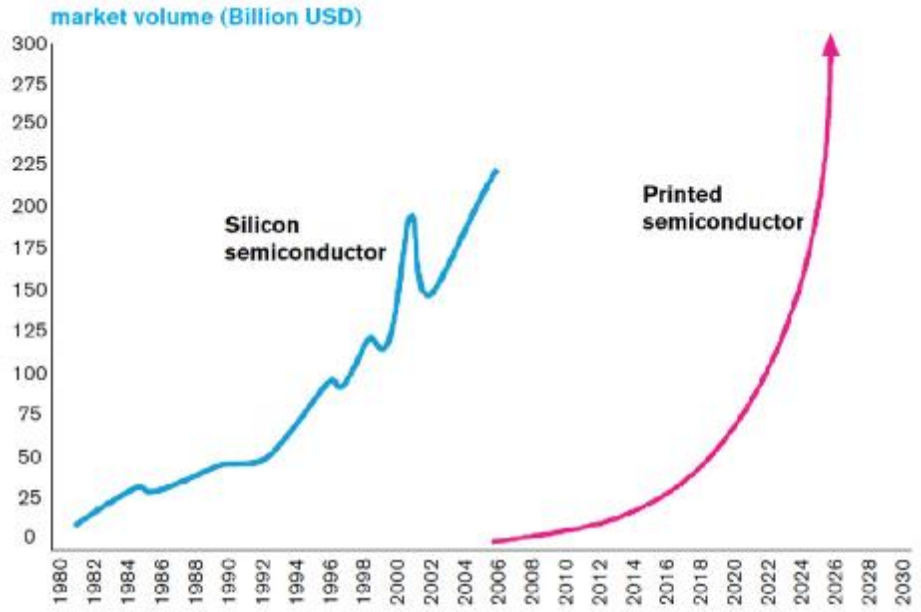


E Ink

Fulton Innovation

Paper Electronics = Printed Electronics on Paper

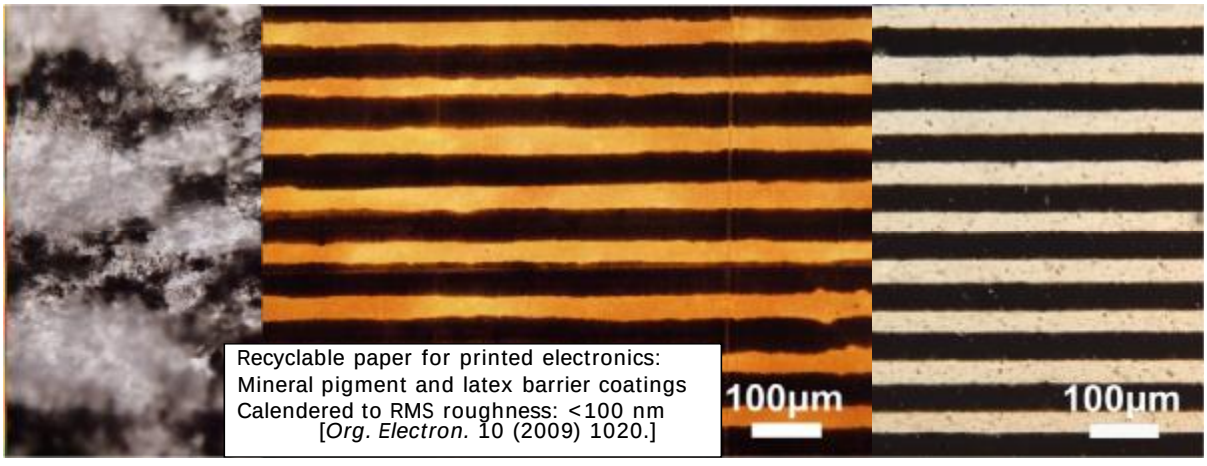
Market Prediction for Printed Electronics



IDTechEx

Challenges of Printing Electronics on Paper

- Paper & printing not developed for electronics
- Optical vs. electrical print



Recyclable paper for printed electronics:
Mineral pigment and latex barrier coatings
Calendered to RMS roughness: <100 nm
[*Org. Electron.* 10 (2009) 1020.]

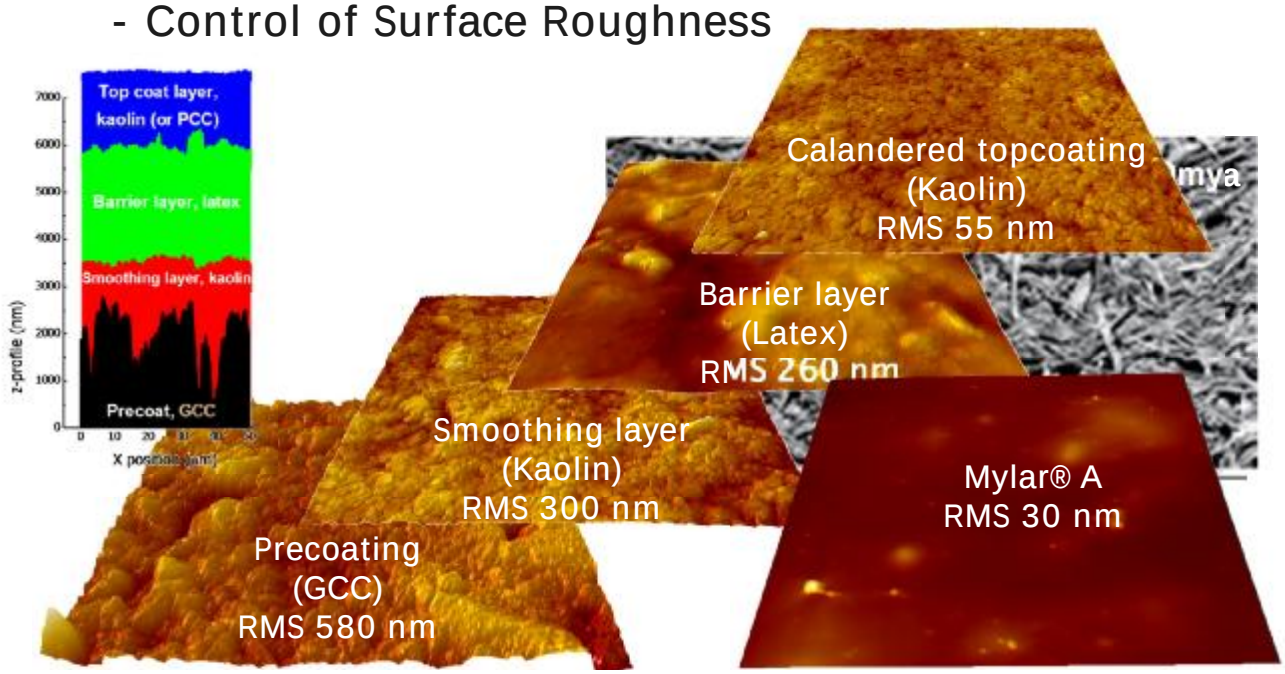
Making Paper Compatible with Printed Electronics

- Printability determined by compatibility of ink – substrate – printing method
- We need to measure and control surface properties: roughness, porosity, wettability, chemical activity/inertness, barrier properties, mechanical properties

- Surface treatment methods to improve printability:
  - Existing:
    - surface sizing
    - pigment coating
    - dispersion coating
    - extrusion coating
    - corona
  - Novel methods:
    - plasma activation
    - plasma coating
    - nanoparticle deposition
    - sol-gel coating
    - atomic layer deposition

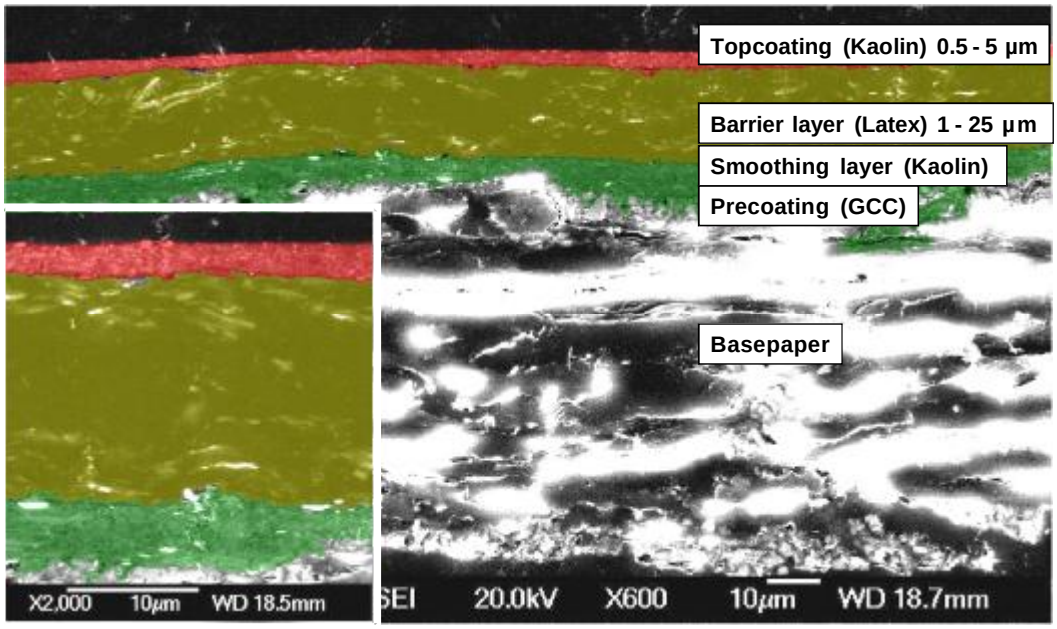
Paper for Printed Electronics

- Control of Surface Roughness



J. Järnström, P. Ihalainen, K. Backfolk, J. Peltonen: Applied Surface Science 2542 (2008) 5741
R. Bollstrom, D. Tobjörk, A. Määttänen, P. Ihalainen, R. Österbacka, J. Peltonen, M. Toivakka,: Org. Electronics, 10, 1020 (2009)
R. Bollström, A. Määttänen, P. Ihalainen, M. Toivakka, J. Peltonen: Patent application PCT/FI2010/050056

Example Substrate Concept For Paper Electronics



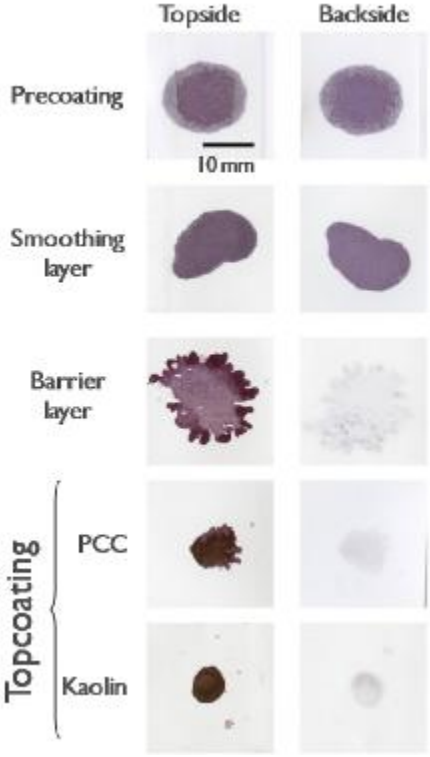
Bollström, R., A. Määttänen, D. Tobjörk, P. Ihalainen, N. Kaihovirta, R. Österbacka, J. Peltonen, and M. Toivakka. "A multilayer coated fiber-based substrate suitable for printed functionality." *Organic Electronics* 10, no. 5 (2009): 1020–1023.

Barrier Properties and Solvent Resistance

Acetone
Toluene
IPA
CB
DCB
THF
DMSO
DMF
Xylene
Acetic acid
HCL
NaOH

Drop size 5µl

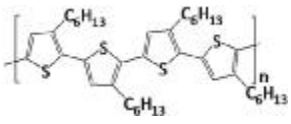
P3HT in DCB

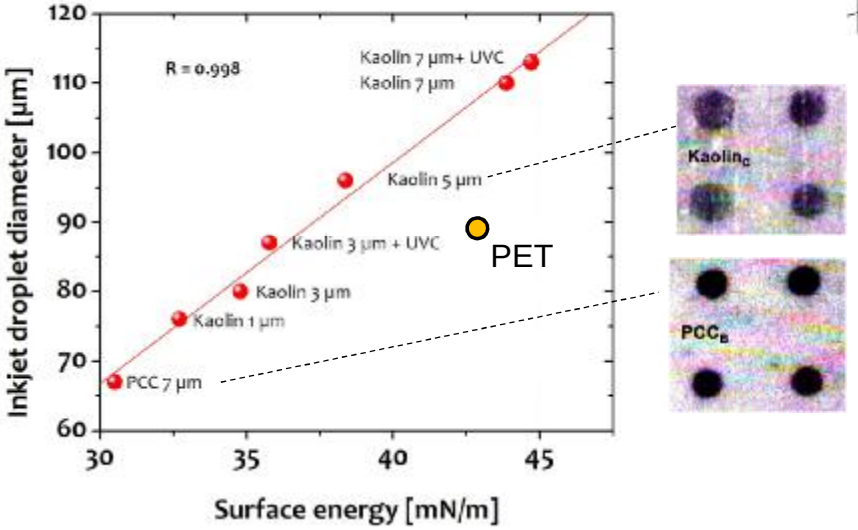


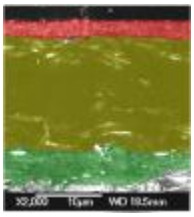
Mylar® A

Improved Inkjet Printability Through Control of Wettability

Ink: 0.5 wt.% P3HT in o-dichlorobenzene (o-DCB),V = 10 pl

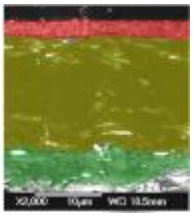






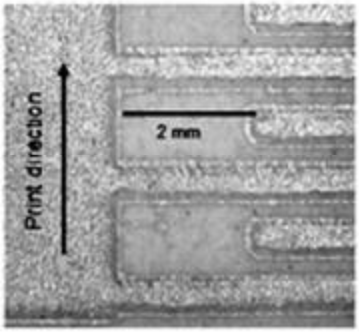
Määttänen, A., Ihalainen, P., Bollström, R., Toivakka, M., & Peltonen, J. (2010). *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *367*(1-3), 76–84.

Adjusting Printability by Top Coating Formulation



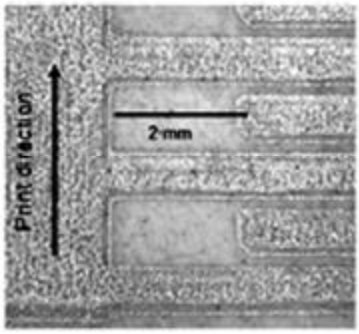
Flexo printability of Ag ink

100pph PCC
10pph SB latex
Coating thickness 3µm



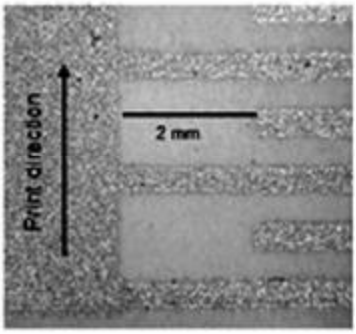
Surface energy ~30mN/m
Medium pore volume

100pph kaolin
10pph SB latex
Coating thickness 3µm



Surface energy ~40mN/m
Low pore volume

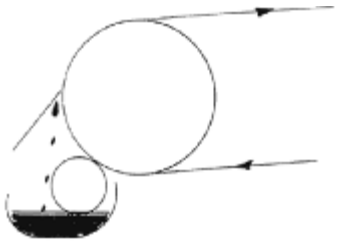
70pph kaolin 30pph PCC
4pph SB latex
Coating thickness 6µm



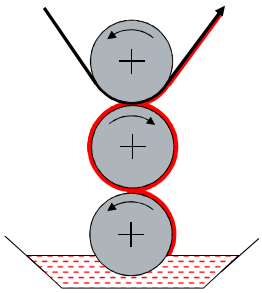
Surface energy ~40mN/m
High pore volume

Coating Methods

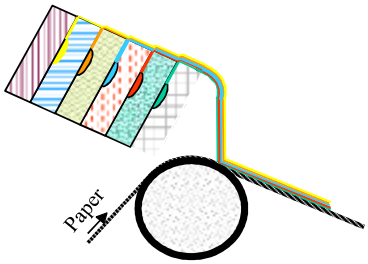
Blade coating



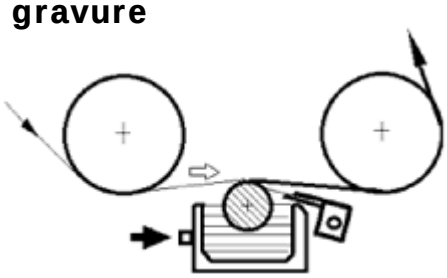
Gravure offset coating



Curtain coating

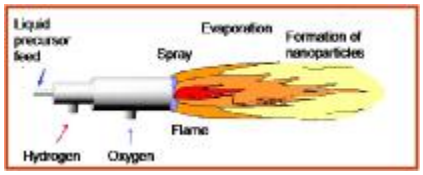


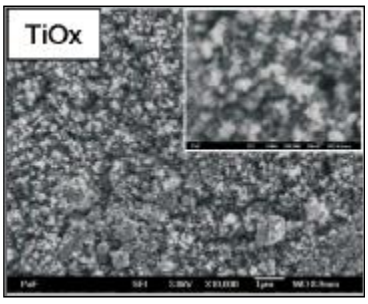
Reverse gravure



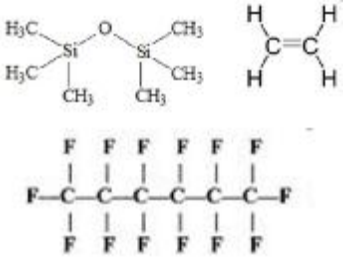
Novel Surface Treatment Methods for Paper

Liquid Flame Spray nanoparticle deposition

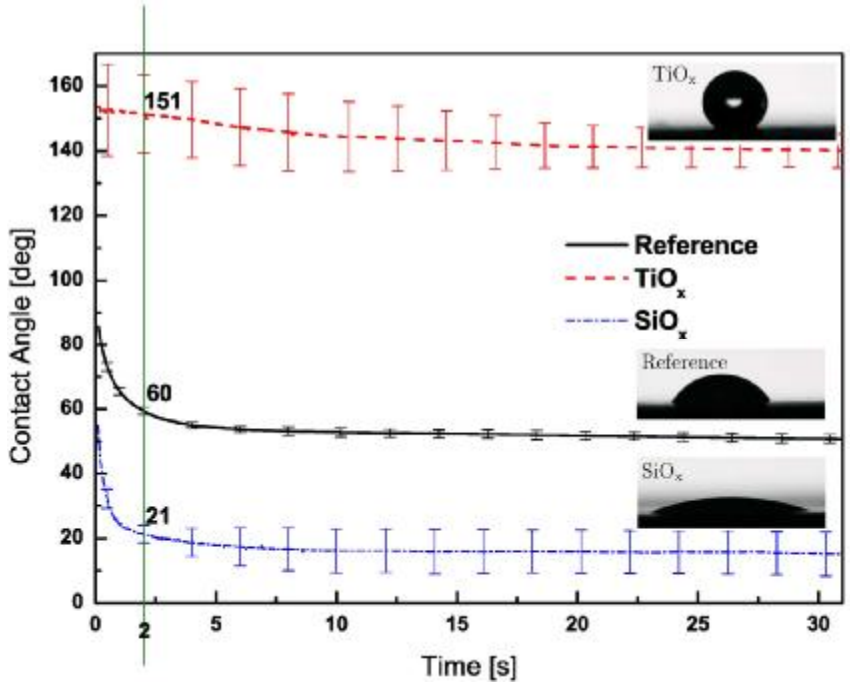




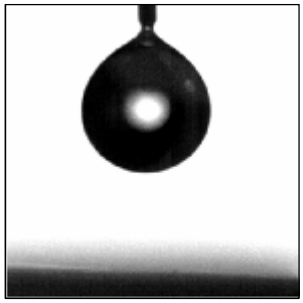
Plasma Deposition



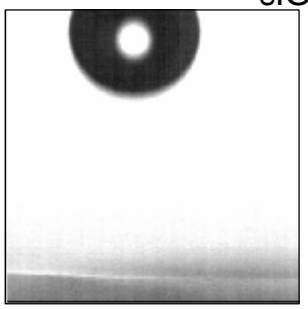
Water Contact Angle on Nanoparticle Coated Paperboard



TiOx



SiOx



Paper Electronics Platform

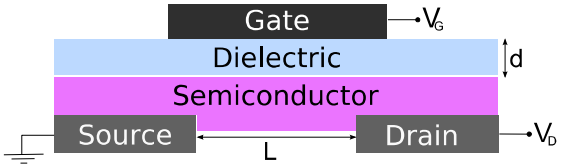
- Novel device concepts needed:
  - › Solution processable (preferably without clean-room)
  - › Simple design
  - › Avoid critical alignments, linewidths of >10 µm, etc.
  - › Low-voltage operation needed
  - › Recyclable or disposable

- Components needed for stand-alone operation:
  - › Input/Output device – e.g., electrochromic inks, color indicators
  - › Logic device – transistor, e.g., Hygroscopic Insulator FET
  - › Memory device – e.g., fullerenes + polymers
  - › Power Supply – e.g., printed battery, solar cell, fuel cell

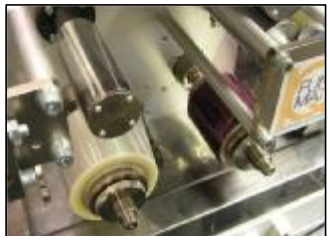
Low-voltage Organic Field Effect Transistor (OFET) on Paper

HIFET:

- Source and drain
  - › AgNP-ink: Inkjet printed and IR-sintered (10 s)
- Organic semiconductor
  - › P3HT: Inkjet printed
- Dielectric (hygroscopic insulator)
  - › PVP: Reverse gravure coated
- Gate contact
  - › PEDOT:PSS: Inkjet printed or drop cast

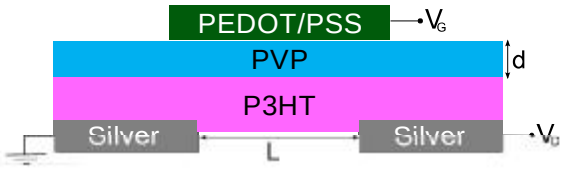


FUJIFILM Dimatix, Inc

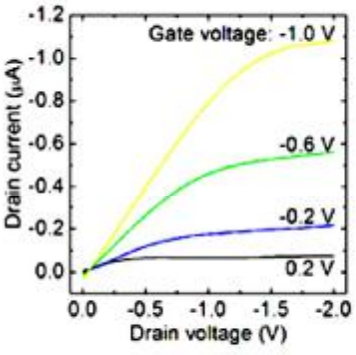


Mini-Labo, Yasui Seiki Co.

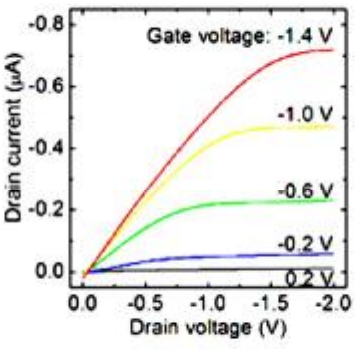
Printed Transistor on Paper



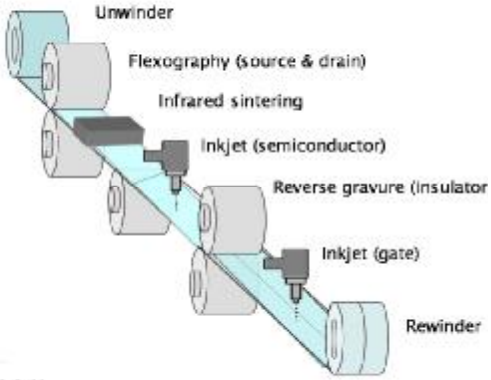
I-V Characteristics



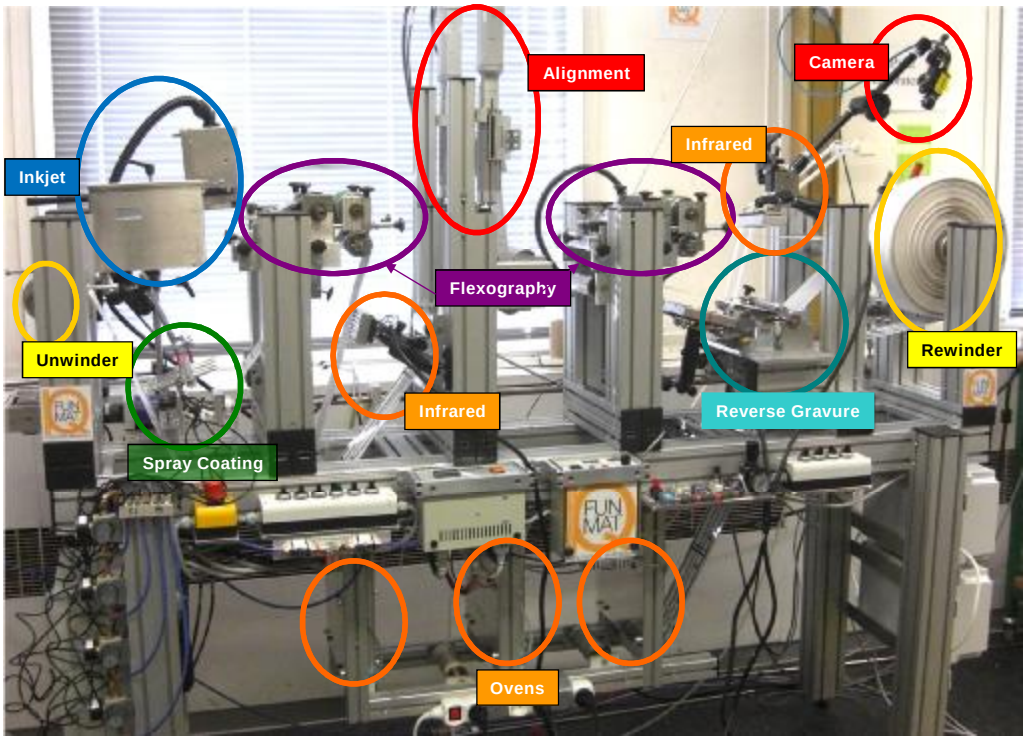
Immediately after manufacturing



After 4,5 months of storage in room atmosphere



“FunPrinter” - Custom-built Hybrid Printer

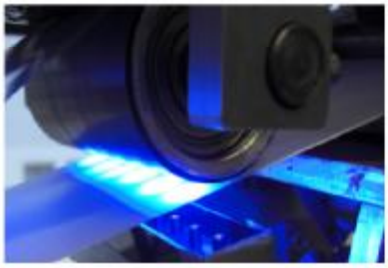


FunPrinter: Roll-to-roll Prototypes and Demonstrators

FLEXO

INKJET

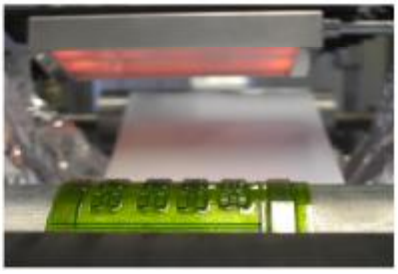
HOT EMBOSSING



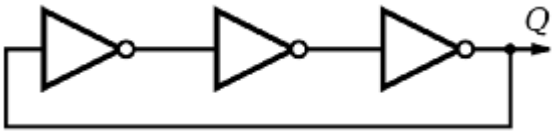
Ultraviolet (UV)

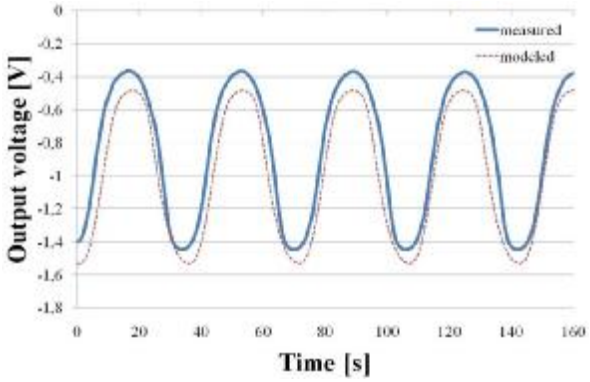
Infra red (IR) curing

(also 3 x hot air)



Towards Logic Circuits Using HIFETs





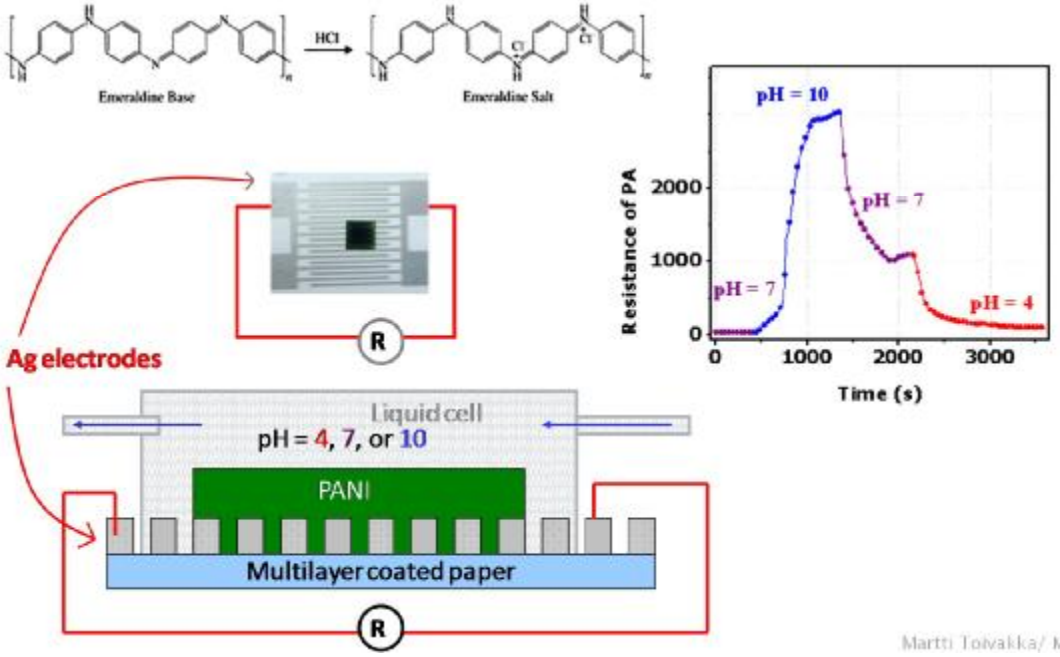
Development and integration of printed paper-based electronics

OULUN YLIOPISTO
UNIVERSITY of OULU

Oscillation @ f=28mHz

J. Koskela, A. Kilpelä, N. Björklund, R. Österbacka, submitted

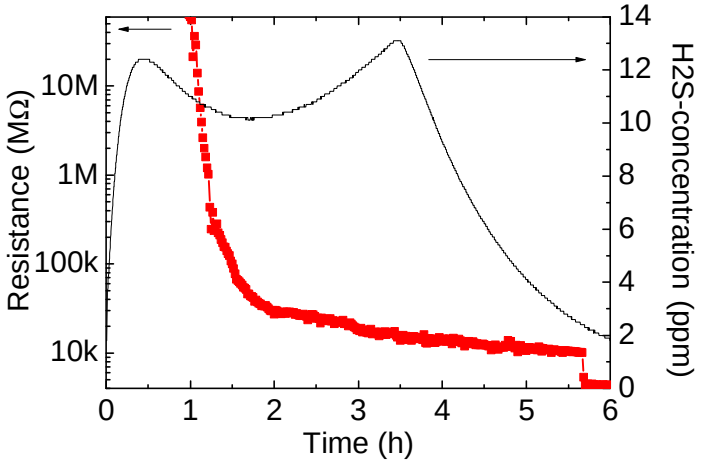
Electronically Readable, Printed pH Sensor on Paper

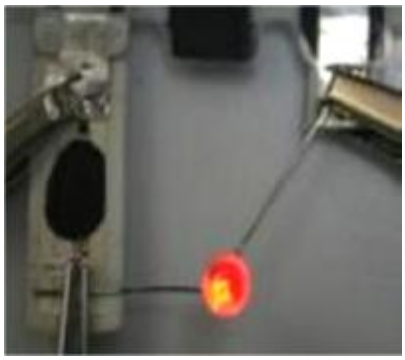


Gas Sensors on Paper (H_2S)

Polyaniline with copper salt

› E.g. $CuCl_2 + H_2S \rightarrow Cu_xS + HCl$
=> protonation of polyaniline-EB





J. Saraf, D. Tobjörk, A. Määttänen, et al., submitted

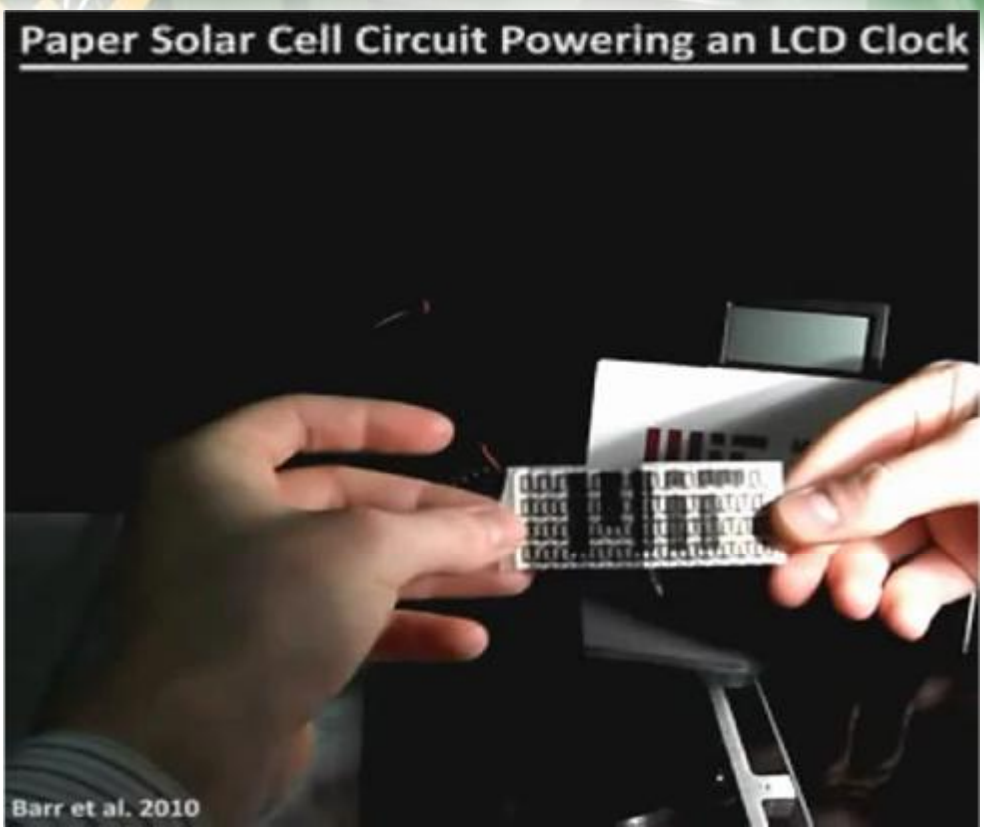
Adjustable Packaging Line for the Future

- Sensors and indicators for modified atmosphere packages
  - › E.g. for oxygen and hydrogen sulfide

LAPPEENRANNAN TEKNILLINEN YLIOPISTO

LAHDEN AMMATTIKORKEAKOULU
Lahti University of Applied Sciences

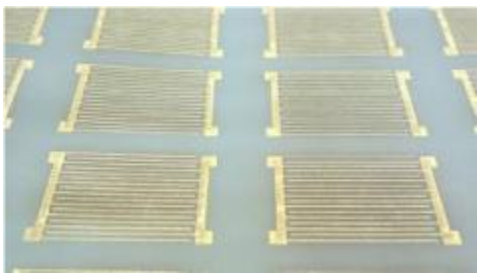
European Union
European Regional Development Fund



Barr et al., *Direct Monolithic Integration of Organic Photovoltaic Circuits on Unmodified Paper,* Adv. Mat. 2011

Paper Electronics – Summary

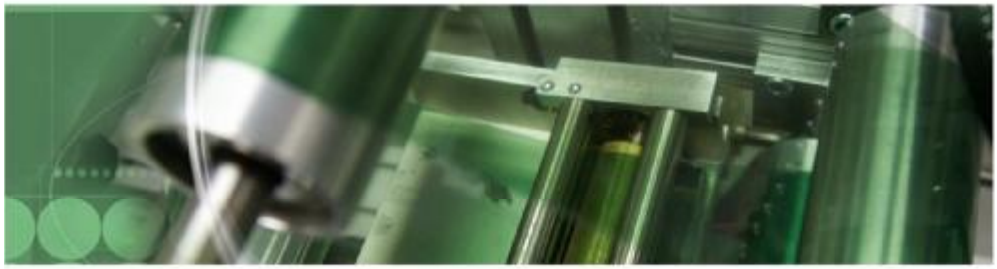
- ”Paper electronics” is attracting interest due to numerous business opportunities
- It is possible to print electronics on paper
- Åbo Akademi has demonstrated printed transistors and other components on paper
- First products will be simple sensors for biological, biomedical and chemical applications



Recent Publications

- Bollström, R., M. Tuominen, A. Määttänen, J. Peltonen, and M. Toivakka. "Top layer coatability on barrier coatings." *Progress in Organic Coatings* 73, no. 1 (2012): 26–32.
- Bollström, R., J. J. Saarinen, J. Päty, and M. Toivakka. "Measuring solvent barrier properties of paper." *Measurement Science and Tec*
- Tobjörk, D., H. A … en, M. Toivakka, H. Tenhu et al. "IR- … no. 7 (2012): 2949–2955.
- Ihalainen, P., A. Määttänen, U. Mattinen, M. Stepien, R. Bollström, M. Toivakka, J. Bobacka, and J. Peltonen. "Electrodeposition of PEDOT-Cl film on a fully printed Ag/polyaniline electrode." *Thin Solid Films* 519 (2011): 2172–2175.
- Saarinen, J. J., P. Ihalainen, A. Määttänen, R. Bollström, and J. Peltonen. "Printed … wetting on a natural fibre based substrate." *Nordic Pulp and Paper Research Jou*
- Määttänen, A., D. Fors, S. Wang, D. Valtakari, P. Ihalainen, and J. Peltonen. "Pap … printed diagnostics." *Sensors and Actuators B: Chemical* 160, no. 1 (2011): 140
- Määttänen, A., P. Ihalainen, R. Bollström, M. Toivakka, and J. Peltonen. "Wetting … printed poly(3-hexylthiophene) on pigment coated papers." *Colloids and Surfac … ring Aspects* 367, no. 1-3 (2010): 76–84.
- Määttänen, A., P. Ihalainen, R. Bollström, S. Wang, M. Toivakka, and J. Peltonen. … ent Coated Paper by UVC Irradiation." *Industrial & Engineering Chemistry Research …*
- Pykönen, M., K. Johansson, R. Bollström, P. Fardim, and M. Toivakka. "Influence … on UV-Varnish Absorption into Permeable Pigment-Coated Paper." *Industrial & Eng … o. 5* (2010): 2169–2175.
- Bollström, R., A. Määttänen, D. Tobjörk, P. Ihalainen, N. Kaihovirta, R. Österbac … multilayer coated fiber-based substrate suitable for printed functionality." *Organic Electronics* 10, no. 5 (2009): 1020–1023.

http://www.abo.fi/lpcc



INTELLIGENT PRINTING FUN MAT FUNCTIONAL MATERIALS

Thank You!

Financing:

ACADEMY OF FINLAND
RESEARCH FUNDING AND EXPERTISE

STIFTELSEN FÖR ÅBO AKADEMI

Åbo Akademi University

Tekes

European Union
European Regional Development Fund