



Paper as a Substrate for (Active and) Intelligent Packaging

Martti Toivakka
Laboratory of Paper Coating and Converting
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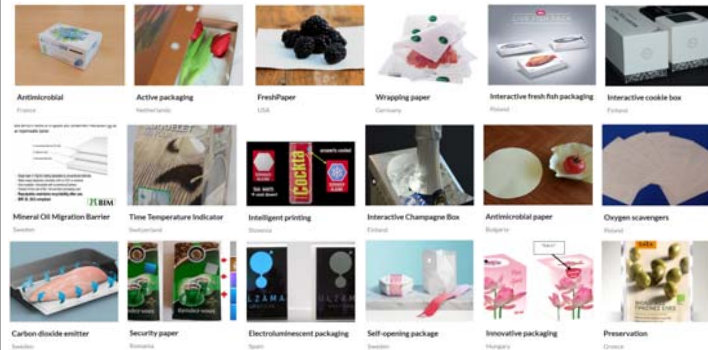






Active and Intelligent Packaging

www.actinpak.eu



cost ActInfak

Martti Toivakka, 2012



AIPIA – Active & Intelligent Packaging Industry Association (www.aipia.info)

Active Solutions

- Bio-Chemical active films
- Antimicrobial packaging
- Oxygen, CO₂, Gas-scavenging
- Moisture control
- Anti-Oxidation
- Temperature Controlled Packaging
- Active labels
- Nano-technology enabled packaging

Intelligent Solutions

- Sensors and Tags
- NFC Technology in packaging
- Printed Electronics
- RFID Technology
- Track, Trace and Control Systems
- Telecommunications
- IT solutions, software
- Time- and temperature indicators
- Hardware (logistical)
- Supply chain order-, control- and information systems
- Anti-theft devices
- Tamper proofing and Anti Counterfeit Systems
- Mobile Commerce
- Transport & Logistics

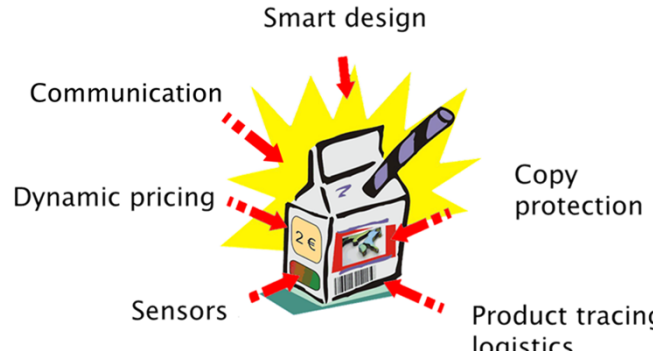




Martti Toivakka, 2012



Intelligent Packaging



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Modified from www.attophotonics.com

Martti Toivakka, 2012

Fortune-magazine:
"McDonalds Unveils 'McBike'
Bicycle-Friendly Bic Mac Packaging"



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cost Ac infak Fulton Innovation Martti Toivakka 2017

Hype and Unreasonable Expectations...



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Communicative Packaging –
Bar- and QR(Quick Response)-codes

<http://www.abo.fi/lpcc>



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Fordom odlade man vindruvsranka
av vars frukt man gjorde ädelt vin.
Nu man pressar saften ur en plank,
doftande av äkta terpentin.
Höj nu bågaren o broder, syster.
Låt den finska skogen rinna kall.
Ner i strupen
och om du är dyster,
låt oss dricka upp en liten tall.

g -
nse)-codes
o.fi/lpcc

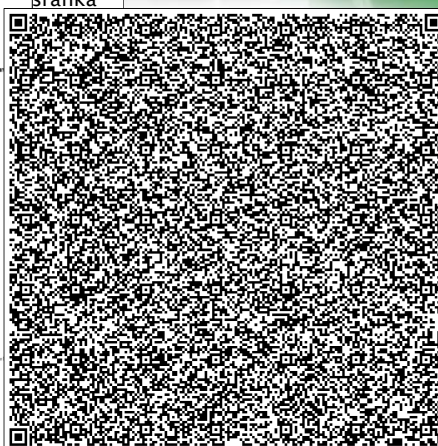




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sranka



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www.huhtamaki.com/adtone

Adtone
a cup with digital content

Huhtamaki Adtone™ is our smartest cup yet. It's made the cup interactive with a heat sensitive label and a Quick Response (QR) code that links it to digital content.

The new Adtone cup gives consumers something they actually want, through something they use every day, delivering your message in a unique and memorable way.

WATCH VIDEO

discover new way
engage customers



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www.huhtamaki.com/adtone



Adtone cup is a perfect way to deliver your message in a unique and memorable way.

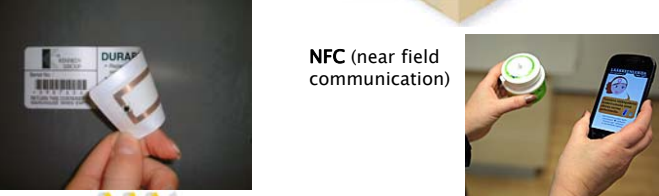
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Electronically Readable Communicative Packaging



RFID (Radio Frequency Identification)



NFC (near field communication)

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Communicative Packaging for Medicine



Data from package #259

System time: Sun Oct 14 16:24:16 UTC+0300 2007
 Device time: Sun Oct 14 16:30:12 UTC+0300 2007
 Device uid time: Fri Jun 15 14:14:41 UTC+0300 2007
 Max number of events: 10
 Events triggered: 3

Event #	Event time	Q1
1	Fri Oct 12 11:47:00 UTC+0300 2007	2
2	Thu Oct 4 10:04:00 UTC+0300 2007	1
3	Fri Oct 12 11:55:00 UTC+0300 2007	2

Stora Enso Pharma DDSi Wireless

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Communicative Packaging for Medicine



Stora Enso Pharma DDSi Wireless

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Paper Electronics = Disposable Printed Electronics on/in Paper with Commercial Potential

Incontinence detection, Sensible Solutions Sweden AB



Electro-magnetic blocking, De Barros et al.

Self-cooking soup packaging, Fulton Innovation

Patient adherence tracking, Pharma DDSi, StoraEnso

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Product Concepts Based on Electrochemistry

"Zero-Cost Diagnostics"
G.M. Whitesides

Li-ion paper-batteries,
Jabbour et al.

Printed system
www.acree.se

Printed battery
Printed display driver logic
Printed sensor
Sample here
37.6
Sensor logic
Printed display

Gas sensor on paper,
Peltonen et al., FunMat/FlexSens

cost Actin/ak Martti Toivakka 2012

Hybrid Products

- Combine, e.g. silicon-based RFID-chips with printed antenna:
 - Contactless smartcards and tickets
 - Product tracing and copy protection

Confidex

Walki* Pantenna

Powercoat Alive

Ultra thin chips
unigartar

NDSU

Laser-enabled advanced packaging (LEAP)

Printable LEDs
rohinni

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Embedding Intelligence in Paper-based Products

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Functional Printing on Paper

200 μm

Inkjetted Particulate Silver Ink
R. Bollström et al., 2013.

inked region
50 μm
(b)

Inkjetted PEDOT:PSS-SWCNT Ink
P. Angelo et al. NPPRJ 27(2):486, 2012

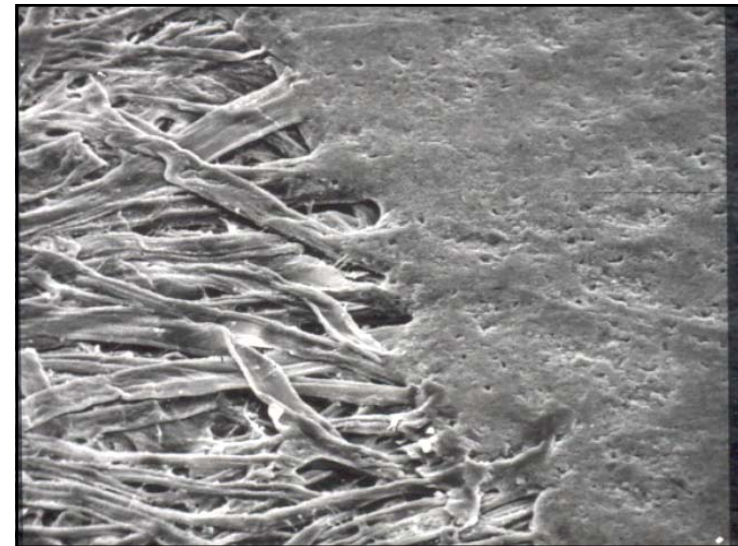
- Poor performance due to:
 - high surface roughness
 - uncontrolled spreading
 - uncontrolled absorption

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Challenges of Using Paper as Substrate for Printed Electronics

- High surface roughness and porosity, large pore size
- Hygroscopicity and poor dimensional stability
- Poor long time heat resistance
- Complex surface chemistry
- Poor barrier properties
- Dusty material not allowed in clean room environment used by printed electronics manufacturers

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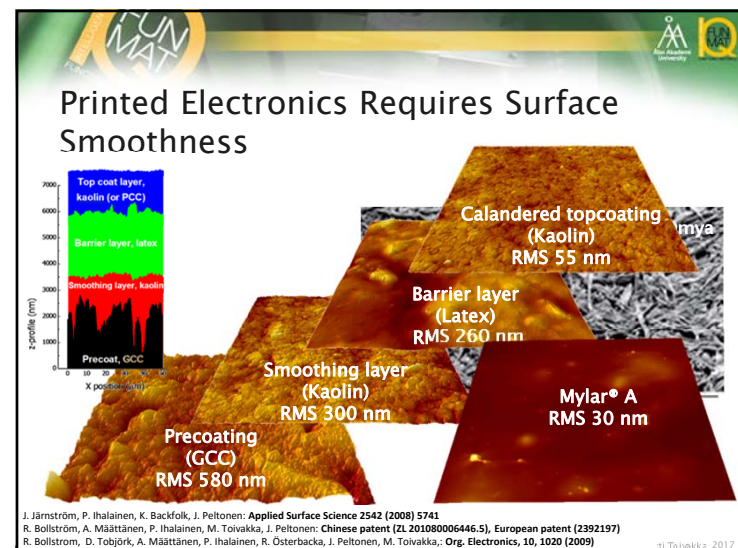


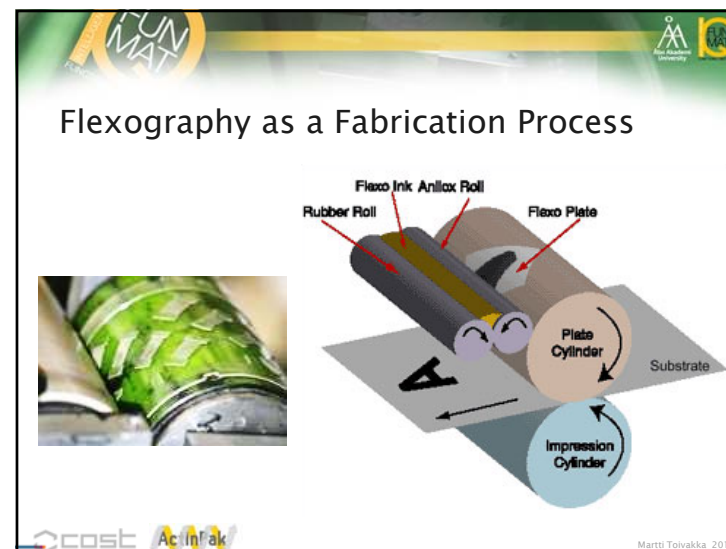
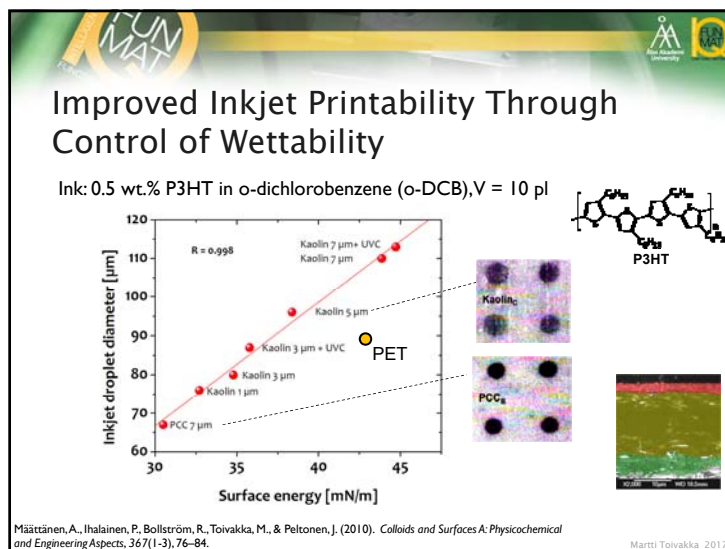
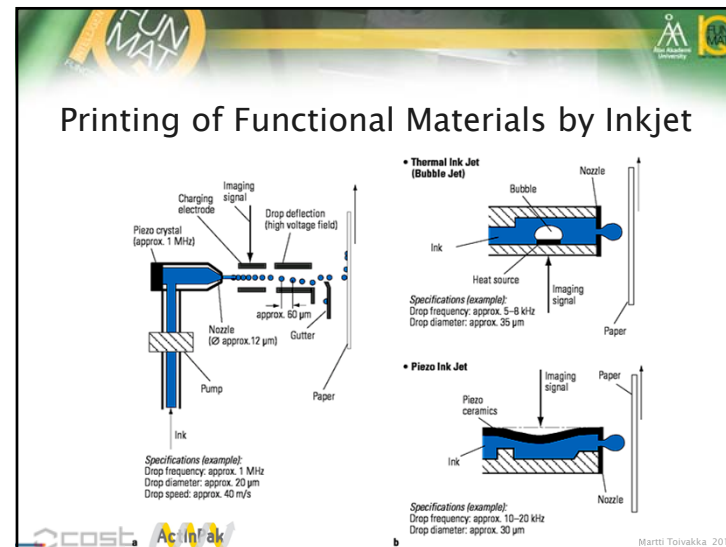
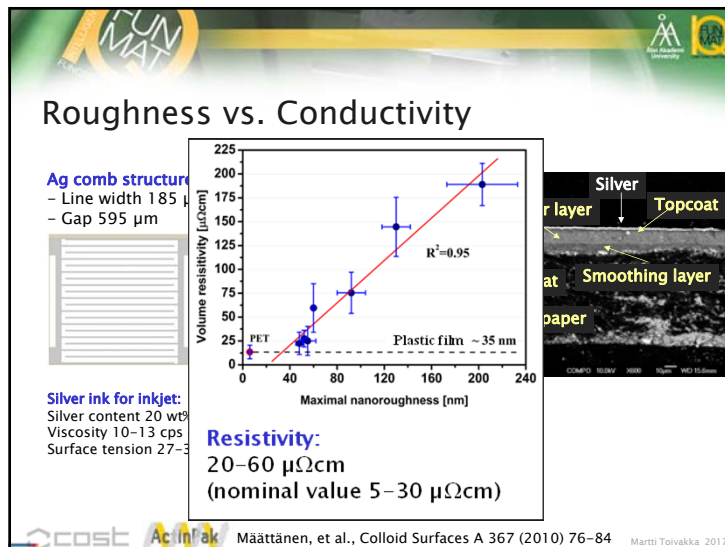
Example Substrate Concept for Paper Electronics

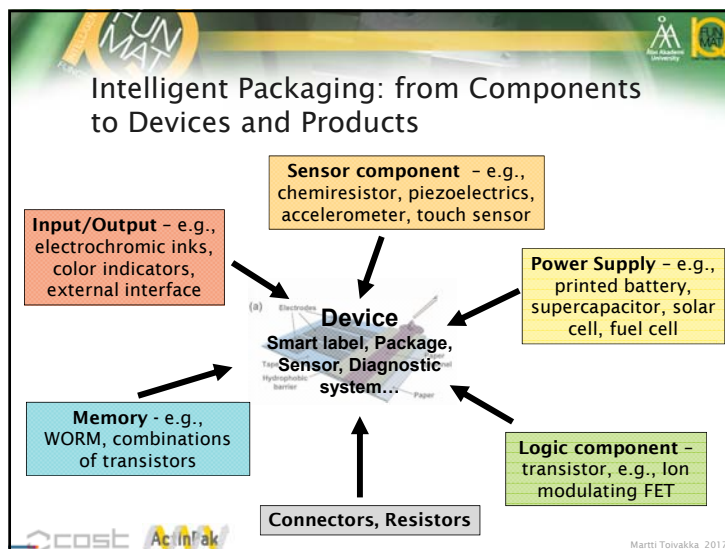
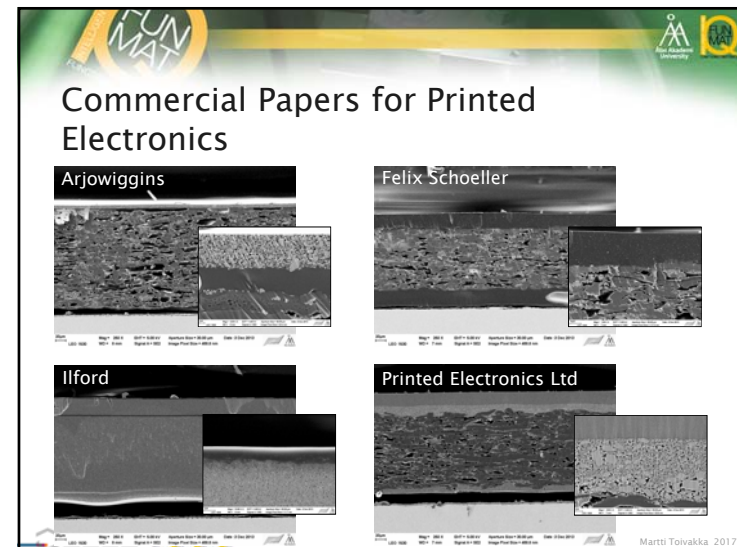
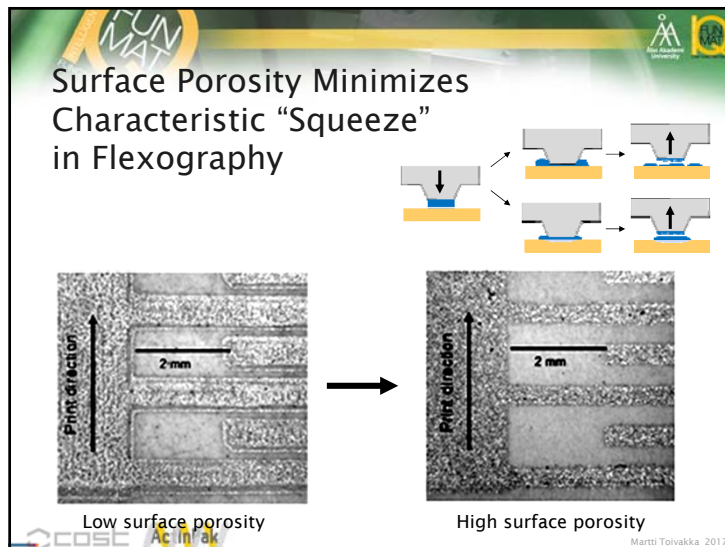
- A combination of:
 - › sufficient **smoothness** (~50nm RMS),
 - › solvent **barrier/sealing** properties (DCB, acids, bases etc.),
 - › adjustable **printability** for given functional ink through control of surface energy and surface porosity,
 - › **thermal performance** allowing for IR sintering
- Roll-to-roll processable, recyclable and compostable

20.0kV X600 10µm WD 18.7mm

Bollström, R., A. Määttänen, D. Tobjörk, P. Ihalainen, N. Kaihoviirta, R. Österbacka, J. Peltonen, and M. Toivakka. "A multilayer coated fiber-based substrate suitable for printed functionality." *Organic Electronics* 10:1020-1023. Bollström et al. "Method for creating a substrate for printed or coated functionality, substrate, functional device and its use", EPO Patent: EP2392197, Chinese Patent ZL 201080006446.5







Low-voltage Printed Transistor on Paper

HIFET (Hygroscopic Insulator FET):

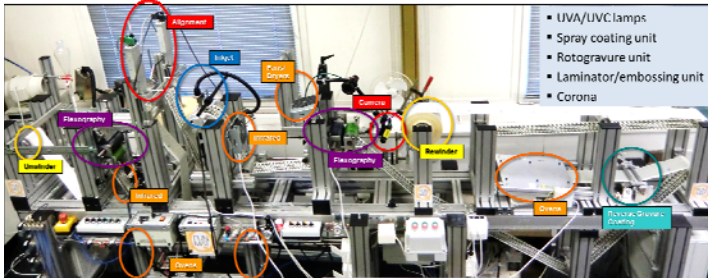
- **Source and drain**
 - › AgNP-ink: Inkjet printed and IR-sintered (10 s)
- **Organic semiconductor**
 - › P3HT: Inkjet printed
- **Dielectric (hygroscopic insulator)**
 - › PVP: Reverse gravure coated
- **Gate contact**
 - › PEDOT:PSS: Inkjet printed or drop cast

FUJIFILM Dimatix, Inc

Mini-Labo, Yasui Seiki Co.

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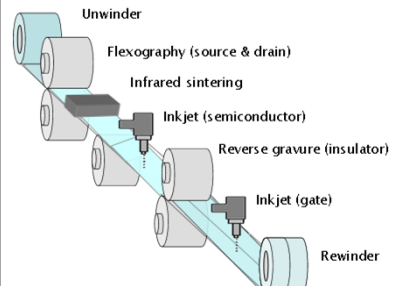
"FunPrinter" – Custom-built Hybrid Printer for Functional Materials



- UV/UVI lamps
- Spray coating unit
- Rotogravure unit
- Laminator/embossing unit
- Corona

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R2R-printed Transistors on Paper



Unwinder
Flexography (source & drain)
Infrared sintering
Inkjet (semiconductor)
Reverse gravure (insulator)
Inkjet (gate)
Rewinder

Immediately after manufacturing

After 4.5 months of storage in room atmosphere

I-V characteristics

Gate voltage: -1.0 V, -0.6 V, -0.2 V, 0.2 V

Drain current (μA) vs Drain voltage (V)

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Towards Logic Circuits on Paper

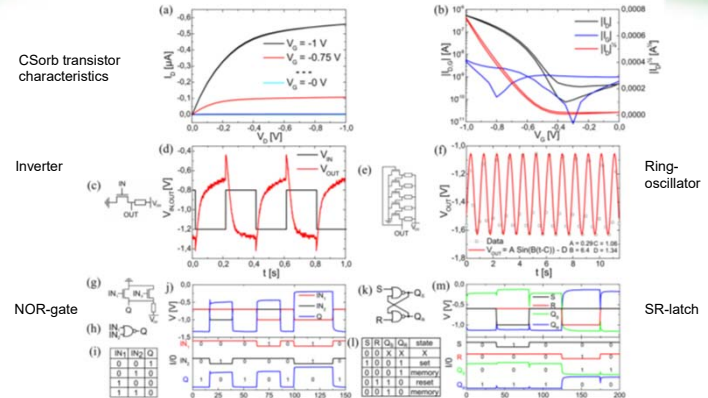
CSorb transistor characteristics

Inverter

NOR-gate

Ring-oscillator

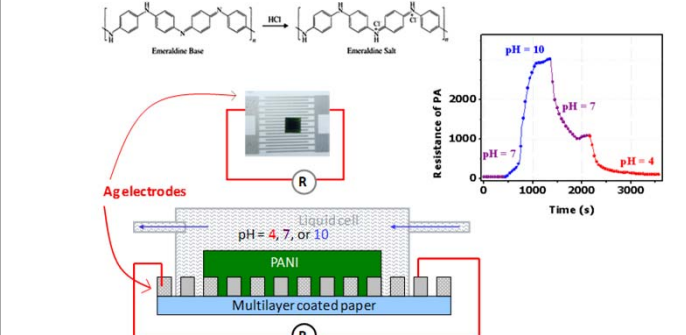
SR-latch



Petterson, F., Paper- and Membrane-Based Ion-Modulated Electronics, 2015, PhD thesis, Åbo Akademi

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Electronically Readable, Printed pH Sensor on Paper



Emeraldine Base + HCl → Emeraldine Salt

Ag electrodes

Liquid cell

pH = 4, 7, or 10

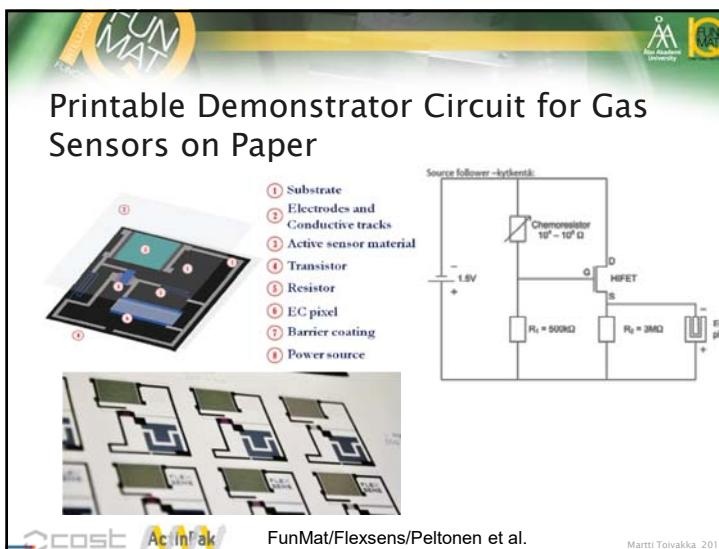
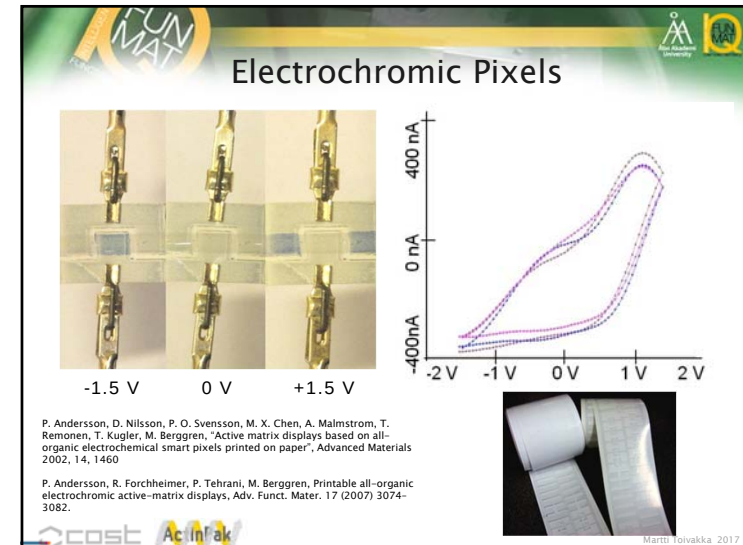
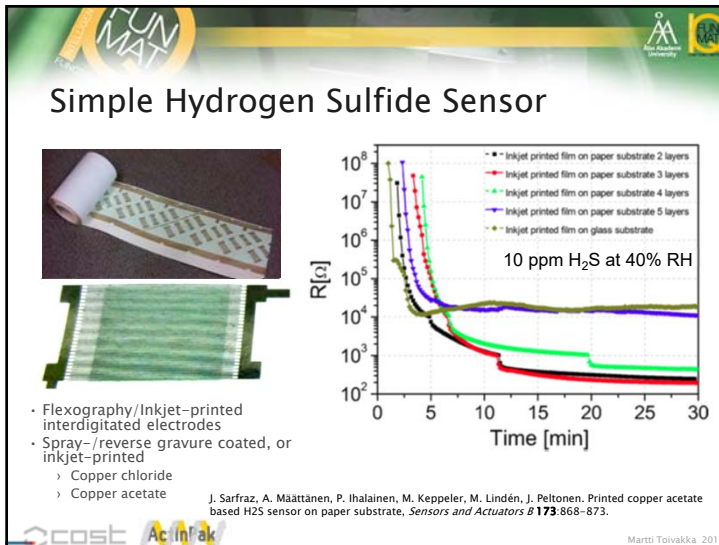
PANI

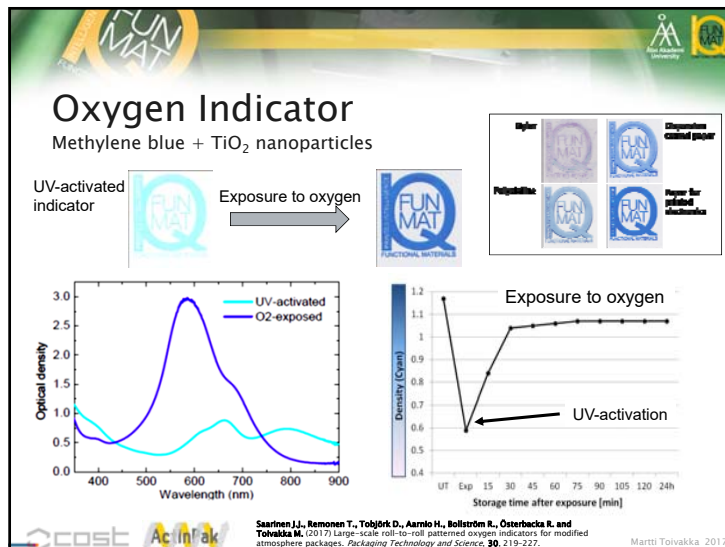
Multilayer coated paper

Resistance of PA vs Time (s)

pH = 10, pH = 7, pH = 4

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Proof-of-concept Devices on Paper

- Transistors
- Ring oscillators
- 1-bit memory
- Electrochromic pixels
- Light-emitting electrochemical cell
- Ion-selective electrodes
- Hydrogen sulfide sensors
- Oxygen sensors
- Printable circuit for gas sensors
- Reaction arrays
- Digital microfluidics

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Fabrication of Solution Processable Devices on Paper

• Success of fabrication (printability) is determined by compatibility of ink – printing method – substrate:

- › **Inks (solution processable functional materials):**
 - Conductive particulate inks, e.g. nanoparticle/micron-size silver, carbon, gold, copper...
 - Conductive polymer inks, e.g. PEDOT:PSS, PANI...
 - Semiconducting inks, e.g. P3HT, PQT...
 - Insulators, e.g. PVP, PMMA...
- › **Printing / coating method:**
 - Inkjet, flexography, rotogravure, screen printing...
 - Reverse gravure, spray, slot, curtain...
- › **Substrate:** Paper/paperboard/nanocellulose film with adjustable physico-chemical surface properties

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Advantages of Using Paper as Substrate for Printed Intelligence/Electronics

- Low cost and large existing product base
- Biodegradability, compostability, ease of disposal → one-time use, "throw-away electronics"*
- Controllable mechanical properties: stiffness, flexibility, foldability
- Adjustable printability of functional materials
- High temperature tolerance → inexpensive infrared sintering of functional inks
- Transparency by using nanopaper (=nanocellulosic films)
- Biocompatibility beneficial for biological applications

* Aliaga et al., The influence of printed electronics on the recyclability of paper: a case study for smart envelopes in courier and postal services. *Waste Management* 38:41-48, 2015

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Paper as a Substrate for Printed Electronics and Intelligent Packaging

- Devices often need to be adapted for paper
- Device(s) to be fabricated, i.e. end-use application, determine which paper properties must to be measured and controlled:
 - › Barrier properties, surface roughness, surface energy, surface porosity, dimensional stability, thermal resistance...
 - › ...while maintaining the low cost and recyclability
- No universal “Paper for printed electronics” exists (excluding perhaps plastic coated paper → plastic)



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Conclusions and Outlook

- Printed transistors, simple circuits and numerous other devices as well as sensors can be fabricated on specialty papers/paperboards
- However, fabrication of complex devices directly in/onto paper challenging in existing large volume converting and printing processes:
 - Separate production of devices/components (on paper/ plastic/ silicon)
 - Integration in/onto products, e.g., as stickers/labels
- Active packaging solutions relatively easy to implement on absorptive & porous paper: emitters, scavengers, absorbers, antioxidation agents, functional coatings etc.



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<http://www.abo.fi/lpcc>

<http://www.funmat.fi/>





Toivakka M., Peltonen J. and Österbacka R. (2017) Paper electronics. In Irimia-Vladu, M., E.D. Glowacki, N.S. Sariciftci and S. Bauer, eds. *Green materials for electronics*. Wiley.