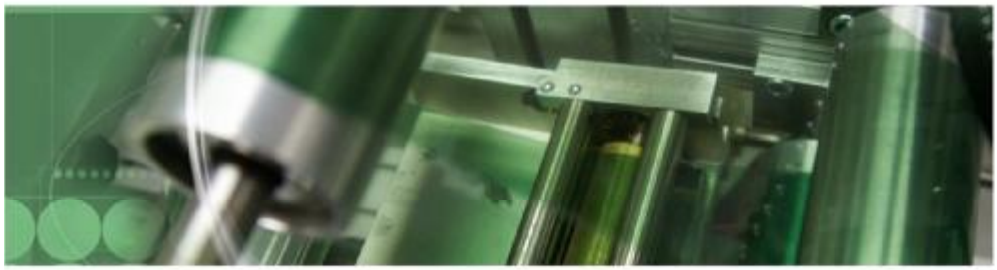


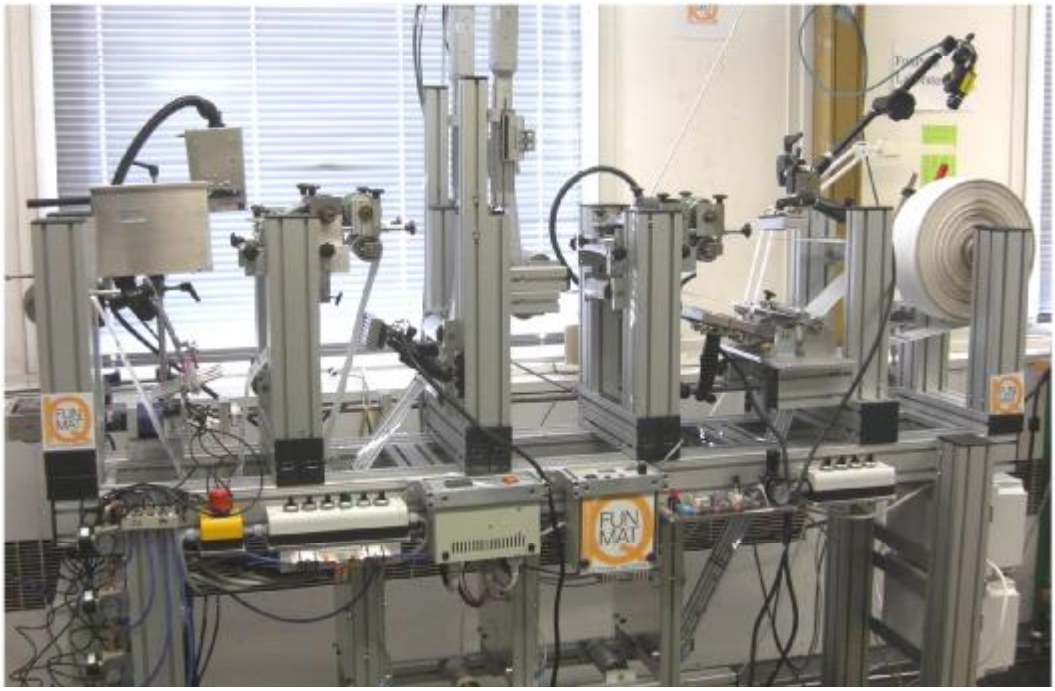
High volume printing of devices and sensors on paper

Roger Bollström
Functional Printing Laboratory
Center for Functional Materials
Åbo Akademi University

Paper electronics platform

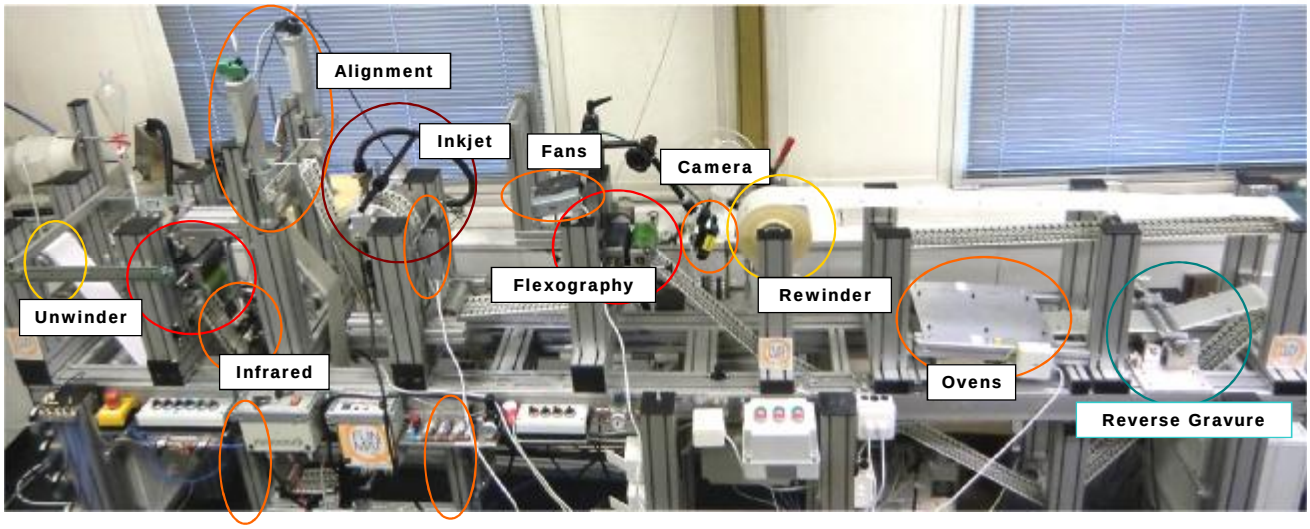
- Novel device concepts needed:
  - Solution processable
    - Preferably without clean-room
  - Simple design
  - Linewidths of >10 µm
    - To avoid critical alignments etc.
  - Low-voltage operation needed
  - Recyclable or disposable substrate

Custom built hybrid printer



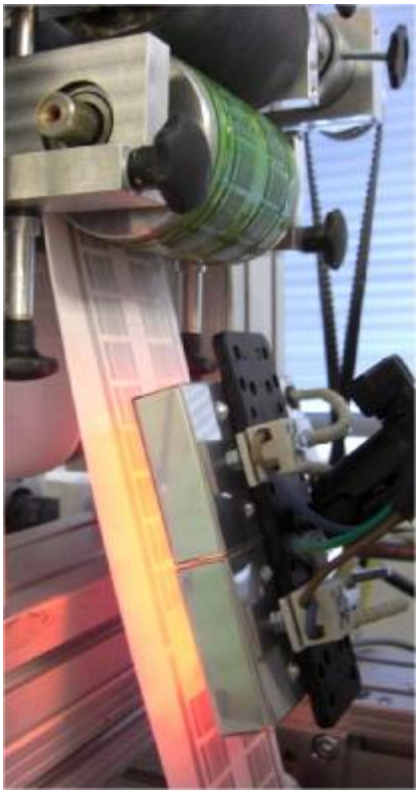
The “FunPrinter” a year ago

Custom built hybrid printer



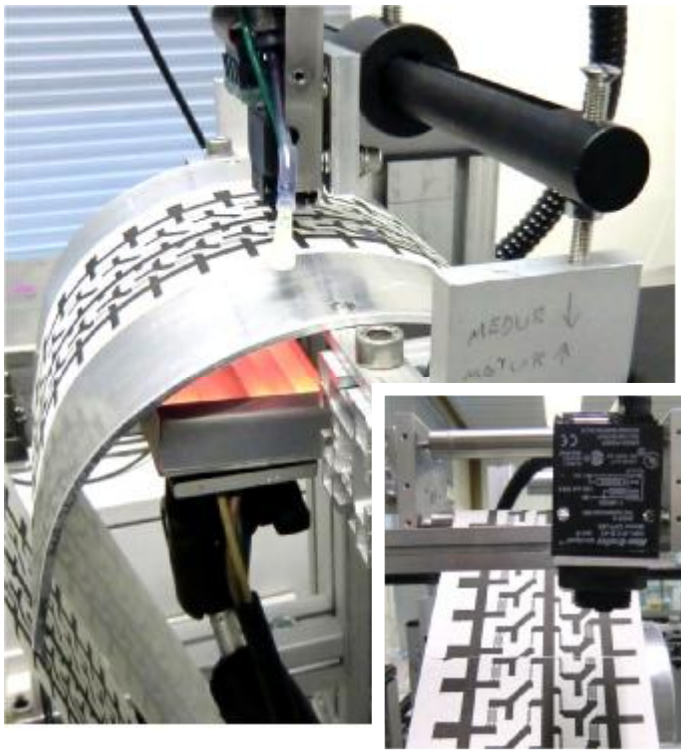
- UVA/UVC lamps
- Spray coating unit
- Gravure unit
- Laminator/embossing unit

Flexography + infrared



- Wide viscosity range
  - › 100 mPas – 1000mPas
- Cheap layouts
  - › ~30€
- Relatively small ink amount
  - › <20 ml
- Three aniloxes (volumes)
  - › 12, 17 and 30 cm^3/m^2
- Online drying / sintering
  - › Infrared
  - › Ovens
  - › Air fans
  - › Ultra Violet (UVA and UVC)

Current inkjet setup with hotplate drying



- Possibilty to test printing with very small ink amount
  - › ~5 ml
- Low viscosty required
  - › <10mPas
- Preferably solvent based inks
  - › DCB
  - › CB
  - › Xylene
  - › Toluene
  - › Oil

New four-printhead setup

XAAR

To be assembled in 2012

Available printheads

Physical Attributes	Xaar 128/80	Xaar 128/80-W	Xaar 128/40 - 8.3	Xaar 128/40-W	Unit
Colour of insulator					—
Active nozzles	128	128	128	128	—
Print swathe width	17.4	17.4	17.4	17.4	mm
Nozzle pitch	137.3	137.3	137.3	137.3	µm
Nozzle density (nozzles per inch)	185	185	185	185	npi
Drop velocity *	5	5	6	6	m/s
Printhead weight (dry)	15.5	15.5	15.5	15.5	g
Dimensions (WxDxH)	38 x 12 x 41	38 x 12 x 41	38 x 12 x 41	38 x 12 x 41	mm
Ink type	Approved range **	Approved range **	Approved range **	Approved range **	—
Binary					
Drop volume *	80	80	40	40	pl
Typical firing frequency *	4.25	5.5	8.3	8.3	kHz

Physical Attributes	Xaar 126/80	Xaar 126/50	Xaar 126/35	Unit
Active nozzles	126	126	126	—
Print swathe width	17.2	17.2	17.2	mm
Nozzle pitch	137.3	137.3	137.3	µm
Nozzle density (nozzles per inch)	185	185	185	npi
Drop velocity *	6	6	6	m/s
Printhead weight (dry)	22	22	22	g
Dimensions (WxDxH)	45x13x43	45x13x43	45x13x43	mm
Fluid types	Approved range **	Approved range **	Approved range **	—
Binary				
Drop volume *	80	50	35	pl
Typical firing frequency *	5.2	7.5	9	kHz

Dimatix DMP-2800

Type: Piezo-driven jetting device with integrated reservoir and heater

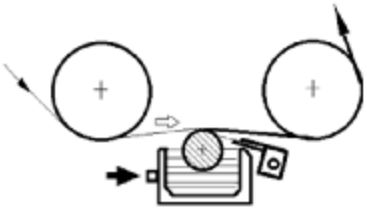
Usable Ink Capacity: Up to 1.5 ml (user-fillable)

Number of Nozzles: 16 nozzles, 254 µm spacing, single row

Drop Volume: 1 (DMC-11601) and 10 (DMC-11610) picoliter nominal

XAAR

Reverse gravure



- Very flexible coating method
- Required material amount
  - >20 ml
- Wide viscosity range
  - 10 mPas – 1000mPas

Spray coating

- Four nozzles
- Can be used independently
  - Feeding from same or separate containers
- Possibilty to coat with relatively small ink amount
  - › ~10 ml
- Relatively low viscosity required
  - › <50mPas

Printing in reality

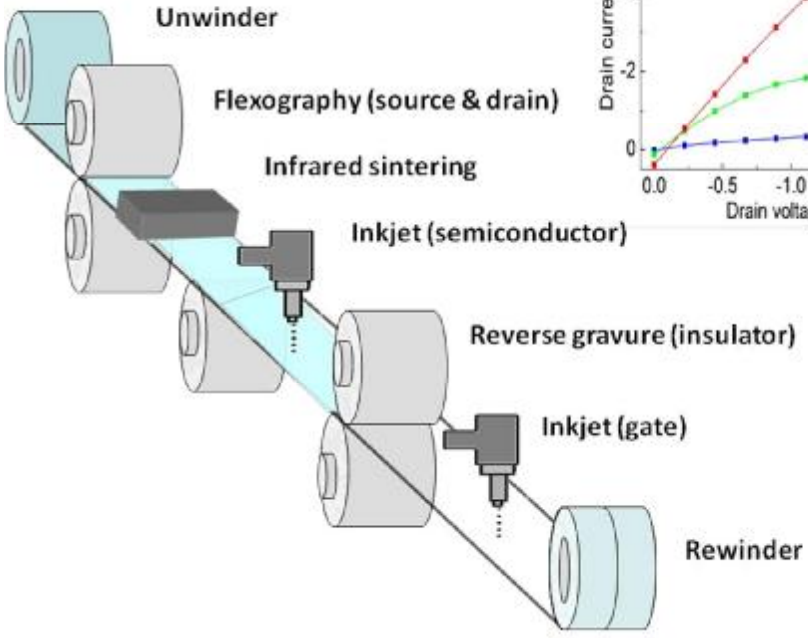
Filmed by Turku TV (edited)

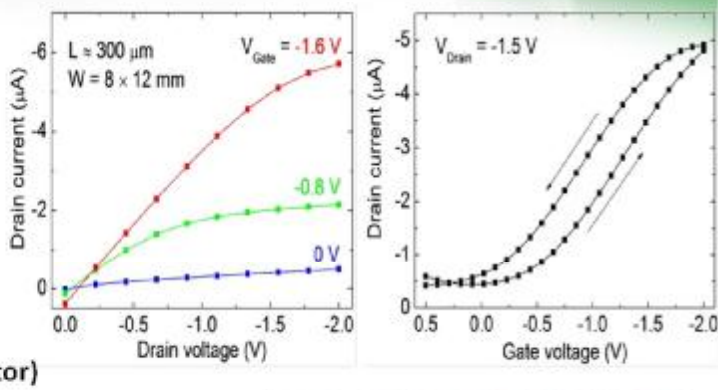
Source: Åbo akademin uusi pääaine vastaa kestävän kehityksen vaatimuksiin
http://www.ts.fi/tstv?v=1.2&id=1890036&type=recordvideo

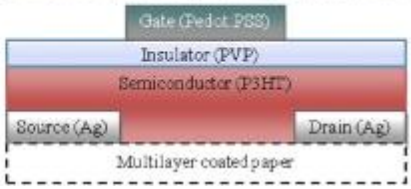
Roll to roll printed devices
-proof of concept

- Transistor
- Electrochromic pixel
- Hydrogen sulfide sensor
- Oxygen sensor
- Ion-selective electrode
- Reaction array

Transistor

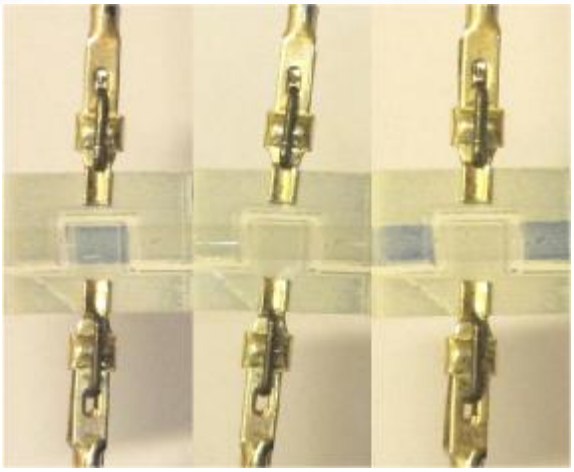




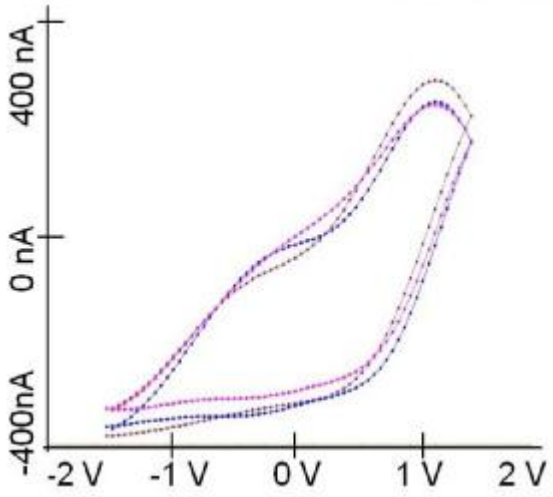


R. Bollström, D. Tobjörk, P. Dolietis, P. Salminen, J. Preston, R. Österbacka and M. Toivakka, Printability of functional inks on multilayer curtain coated paper, Chemical Engineering and Processing (Submitted)

Electrochromic pixels



-1.5 V **0 V** **+1.5 V**

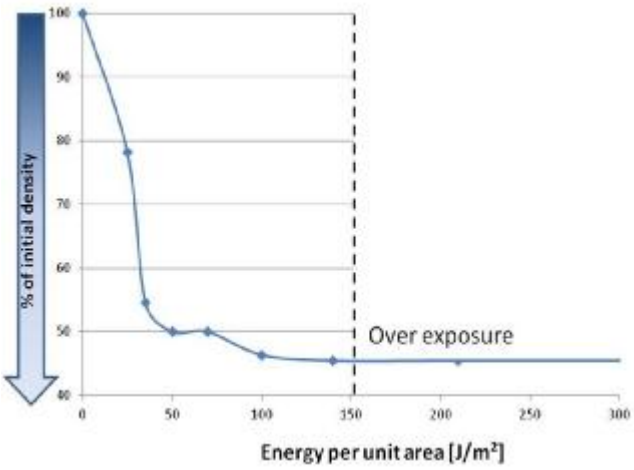


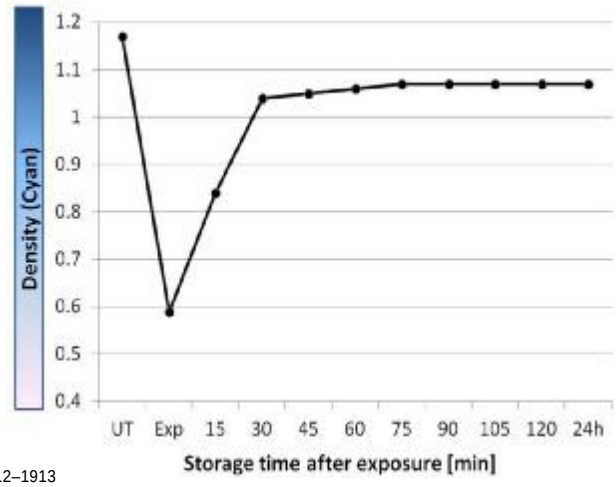
P. Andersson, D. Nilsson, P. O. Svensson, M. X. Chen, A. Malmstrom, T. Remonen, T. Kugler, M. Berggren, "Active matrix displays based on all-organic electrochemical smart pixels printed on paper", Advanced Materials 2002, 14, 1460

P. Andersson, R. Forchheimer, P. Tehrani, M. Berggren, Printable all-organic electrochromic active-matrix displays, Adv. Funct. Mater. 17 (2007) 3074–3082.

Oxygen sensor

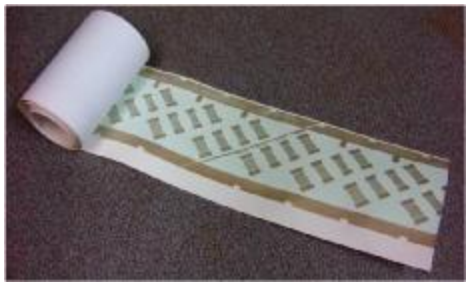
Mylar **Polyolefine** **Barrier** **MLC**



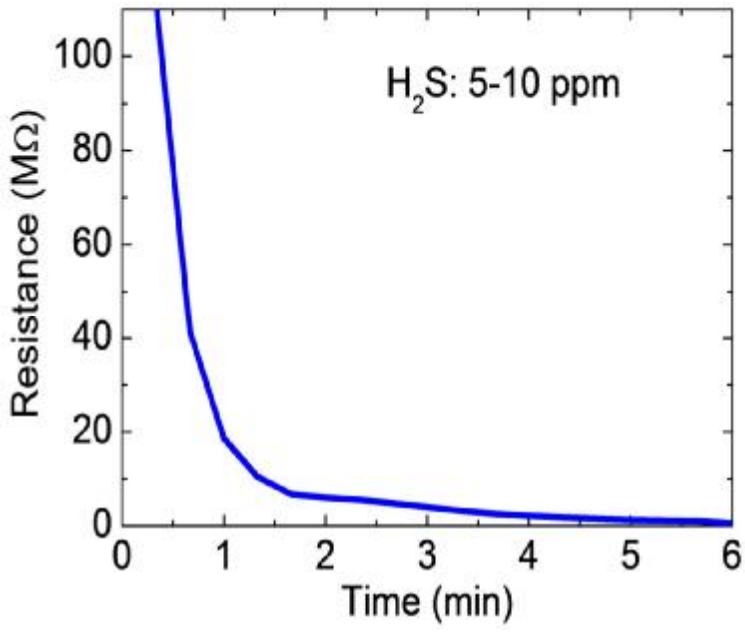


S.-K. Lee, A. Mills and A. Lepre, An intelligence ink for oxygen, *Chem. Commun.* (2004) 1912–1913

Hydrogen sulfide sensors

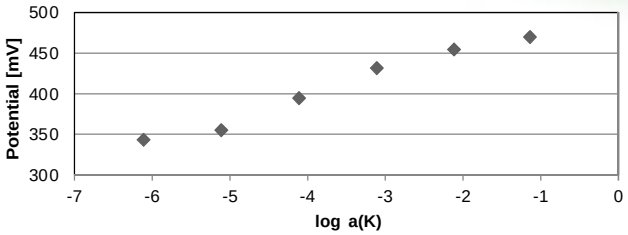


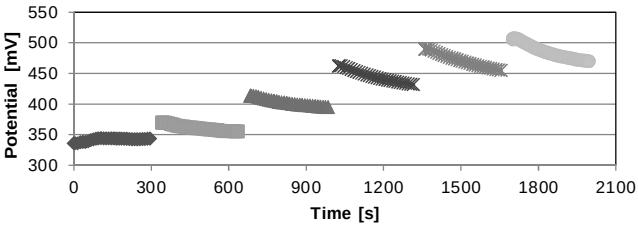
- Flexography
  - Silver electrodes
- Spray / reverse gravure
  - Copper cloride
  - Copper acetate



J. Sarfraz, D. Tobjörk, R. Österbacka, M. Lindén, "Low-Cost Hydrogen Sulfide Gas Sensor on Paper Substrates; Fabrication and Demonstration", IEEE sensors conference, Limerick 2011

Ion-selective electrodes





- Flexography
  - Carbon electrodes
  - UV-laquering as insulator
- Membrane added by drop cast

- Extremely high barrier properties required
  - 10 minutes against tetrahydrofuran
  - 1 hour against 1M KCl

Sari Viljanen, Undersökning av jonselektiva elektroder tryckta på papper som substrat, M. Sc. Thesis, 2012

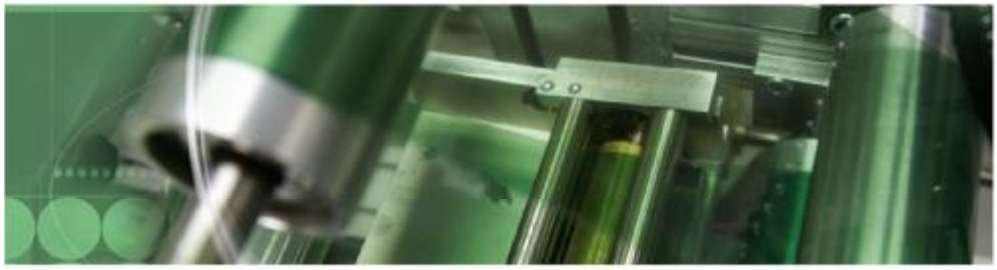
Paper-based planar reaction arrays

- Flexography
  - › PDMS Hydrophobic ink
  - › Well structure
- Hydrophilic wells and hydrophobic barrier walls

Anni Määttänen, Daniela Fors, Shaoxia Wang, Dimitar Valtakari, Petri Ihalainen, Jouko Peltonen, Paper-based planar reaction arrays for printed diagnostics, *Sensors and Actuators B: Chemical, Volume 160, Issue 1, 15 December 2011, Pages 1404-1412*

Concluding remarks

- Combination of suitable coating and printing methods enables for roll to roll manufacturing of functional devices
- Printing/coating method to be chosen depending on material properties and available amount
- Several devices demonstrated as proof of concept
- Future work
  - › Challenges in alignment control to be solved
    - Software development
    - Development of printer electronics (interference problems)
  - › New inkjet setup to be assembled



INTELLIGENT PRINTING FUN MAT FUNCTIONAL MATERIALS

Thank You!

D. Tobjörk, P. Dolietis, J. Kniivilä, A. Määttänen, T. Remonen, C-J. Wikman, S. Viljanen, J. Sarfraz, P. Ihalainen, T. Mäkelä, M. Lindén, J. Peltonen, C-E. Wilén, J. Bobacka, R. Österbacka, M. Toivakka

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