
P3
save energy
keep track
anticipate
lower cost
save time
stay tuned
improve performance
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Holst Centre
Open Innovation by IMEC and TNO

**Manufacturing for PE**

**Cambridge, UK**

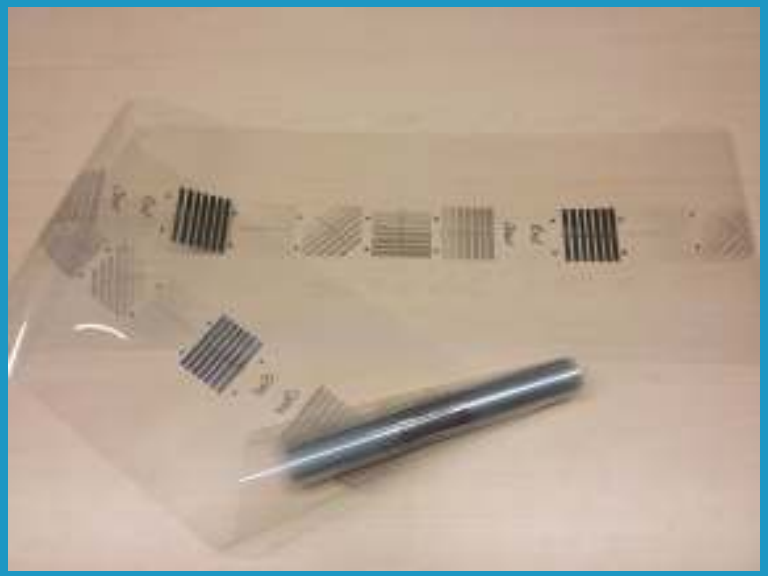
**March 20th , 2014**

Holst Centre

Open Innovation by IMEC and TNO

spgprints

# Technology transfer from S2S to R2R processing for industrial scale printed electronics manufacturing




Pit Teunissen - Holst Centre

Eric Rubingh – Holst Centre

Tim van Lammeren – Holst Centre

Robert Abbel – Holst Centre

Rob Hendriks – Holst Centre

Sjoerd van de Geijn – Stork Prints BV

Pim Groen – Holst Centre / Delft University of Technology

# Presentation overview

**Conductive structures for plastic electronics**

**Photonic sintering**

**Way of working**

**Experimental results**

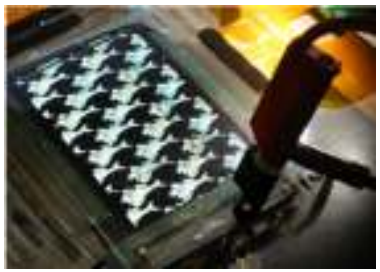
**Summary & Conclusion**

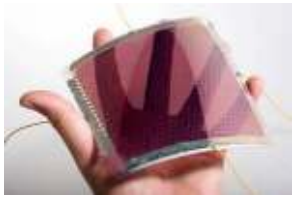
# Conductive structures for plastic electronics - Examples

Flexible displays

Plastic solar cells

Touch screens



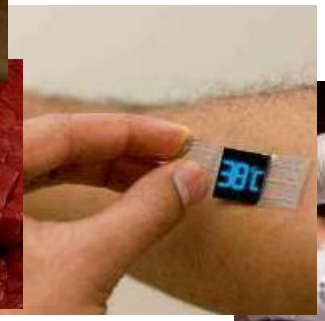
Plastic batteries

Smart packaging

Signage


RFID tags


Sensors




OLEDs

Disposable bio-sensors

Smart bandage

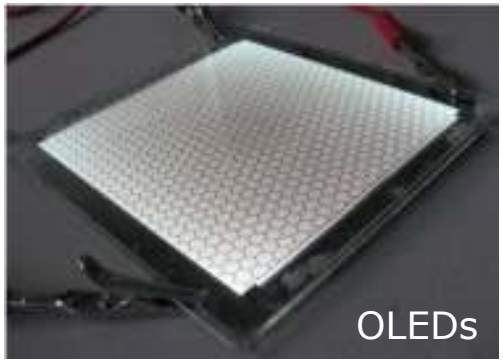
Electronic textiles

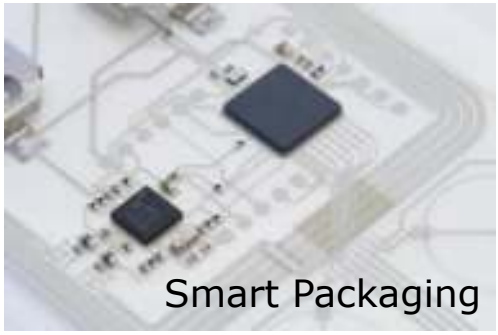
# Introduction – General goal printed functional structures

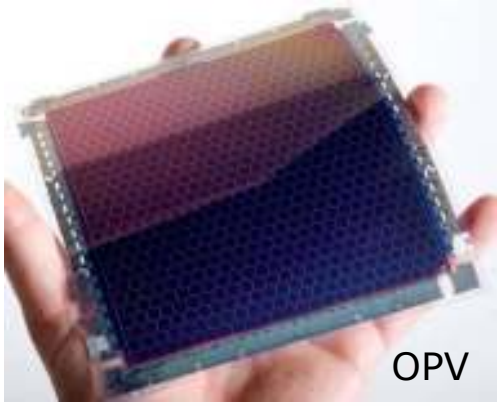
- **Research objective**
  - Develop R2R compatible printing and sintering technology for functional structures on flexible substrates

- **Applications targeted**
  - OLEDs: Anode structure
  - OPV: Electrodes
  - Smart blisters/packaging: Circuitry
  - RFID: Antenna structures
  - Touch panel: Driving lines

- **General requirements**
  - Low resistivity: ≤ 5 X bulk silver
  - Low sintering temperature: ≤ 150ºC, foil compatible
  - Short sintering time: <(<) 1 min, R2R compatible
  - Compatible with device stack
  - Focus on industrialization and cost reduction

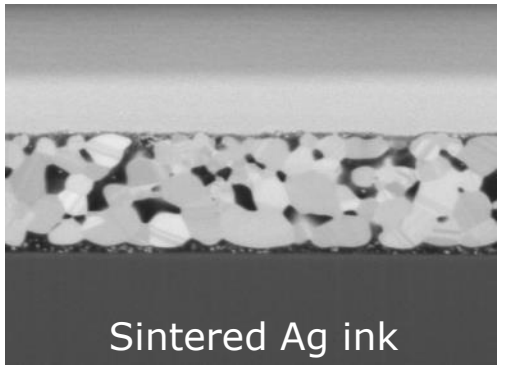

OLEDs


Smart Packaging


OPV

# Introduction – Themes printed functional structures

- **Conductive materials:**
  - Development of conductive inks
  - Evaluation of commercial and development inks
- **High resolution printing techniques:**
  - Inkjet, (rotary) screen and flexo printing
  - Sheet-to-sheet and roll-to-roll
- **Low-temperature sintering technologies:**
  - Photonic, laser, plasma and microwave sintering
  - Sheet-to-sheet and roll-to-roll
- **Integration in devices:**
  - Migration, topology, material interaction, life time


Sintered Ag ink


Roll-to-roll processing

Integration in devices

# Presentation overview

**Conductive structures for plastic electronics**

**Photonic sintering**

**Way of working**

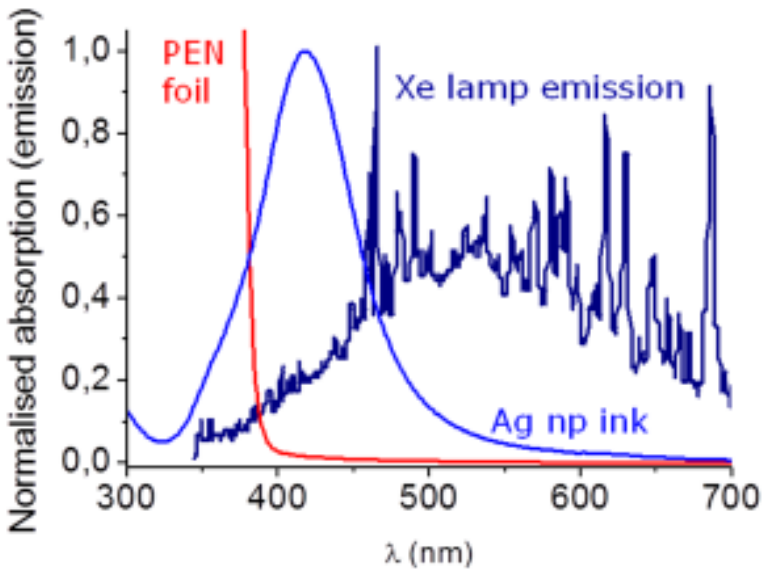
**Experimental results**

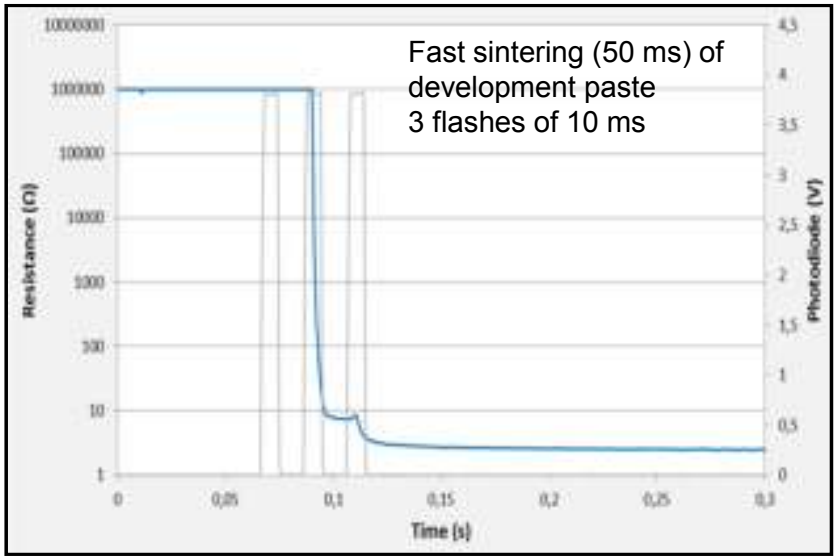
**Summary & Conclusion**

# Photonic sintering – principle

- **Principle of photonic drying/sintering**
  - Light is absorbed in the printed structures, not substrate
  - Elliptical reflectors focus the light in narrow lines
  - High frequency flashing > no stitching effect
  - Short light pulses > limited heat flow into the substrate
  - Top and bottom illumination
  - "Off the shelf" lamps and electronics > inexpensive
  - Inline resistance and temperature monitoring possible

Reflector geometry



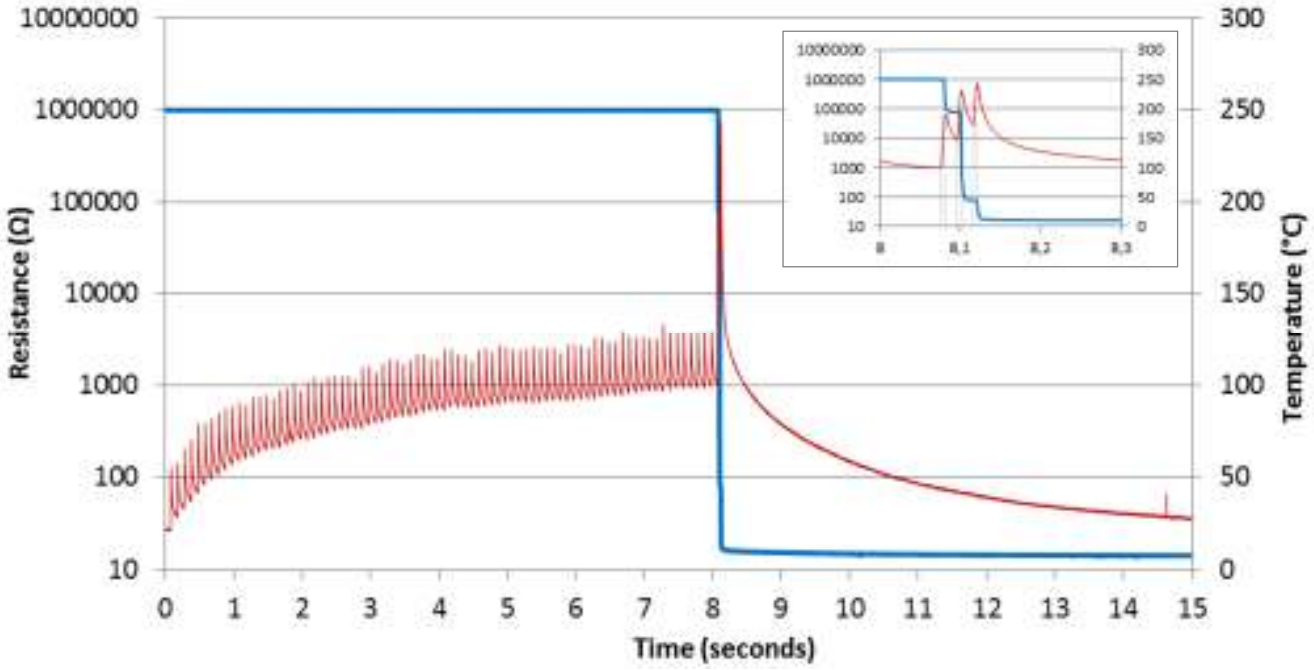

**Ref: Abbel et al., MRS Commun., 2012, 2, 145.**

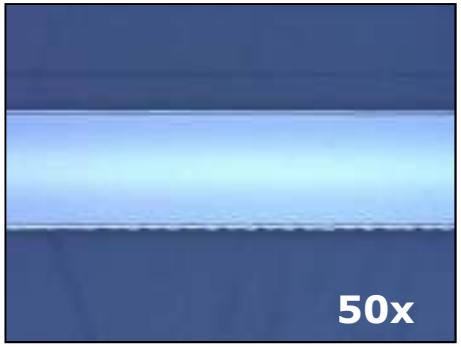
# Photonic sintering – process study

- **Sequence flash sintering** (Silver np ink)
  - To achieve highly conductive structures without deforming the temperature-sensitive substrate, two flash settings are used

| Process | Time | Temperature | Pulse settings |
|---|---|---|---|
| Solvent evaporation | seconds | < Tg | low intensity, high frequency |
| Sintering | milliseconds | >(>) 250°C | high intensity, short pulse(s) |

  - Using NIR pre-drying is a good alternative for the first stage



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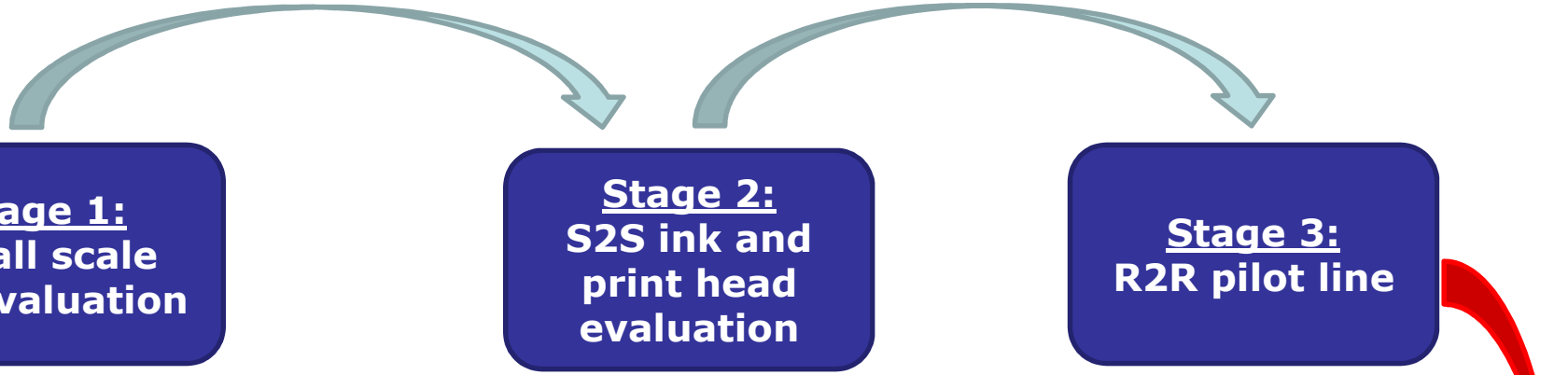
# Way of working – General




**Stage 1: Ink testing**

- Ink evaluation
  - Printability
  - Substrate compatibility
  - Wetting behavior
- Small ink volume
- Single lines and simple patterns
- Oven & photonic sintering

**Stage 2: Head evaluation**

- Ink compatibility with industrial print head
- Ink evaluation
  - Printability
  - Wetting behavior
- Medium ink volume
- Up to 30x30 cm high resolution patterns
- Oven & photonic sintering

**Stage 3: R2R pilot**

- Continuous production
- Head stacking
- Ink evaluation
- Large ink volume
- IR & photonic sintering

**Stage 4: Outsourcing to production line**

Not applicable at this moment

# Way of working - Equipment

- **Stage 1: Small scale ink evaluation**
  - Evaluation of commercial and development inks
  - A good understanding of the sinter behavior of materials is essential
    - Measuring real-time in-line resistance and temperature necessary

**Printer: Fujifilm Dimatix**

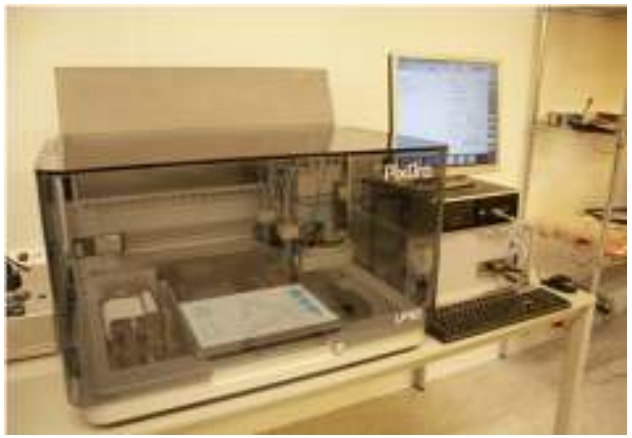
- Easily replaceable and inexpensive print head
- Good for initial printability tests; 1-3 ml volume
- Drop volume 1 & 10 pL
- Only 16 nozzles
- Good access to waveform

**Sinter set-up: Research tool**

- Single lamp system
- Sintering of lines
- In-line measurements
  - Resistance
  - Temperature
- Inert atmosphere capable

# Way of working - Equipment

- **Stage 2: S2S ink and print head evaluation**
  - Ink evaluation in an industrial print head
  - Printing of high resolution test patterns up to A4 size
  - Sintering is optimized in a S2S photonic sintering tool



**Printer: Roth&Rau PixDro LP-50**

- Konica Minolta print head
- Volume 10-20 ml
- Drop volume 4 pL
- 512 nozzle 360 DPI - nozzle pitch 70.5 µm
- 36.1 mm print width

**Sinter set-up: S2S tool**

- Up to 8 lamps
- Xenon Sinteron 2000
- Substrates: 300x300 mm²
- In-line measurements
  - Resistance

# Way of working - Equipment

- **Stage 1 & 2: S2S photonic sintering**

## NovaCentrix PulseForge 1300

- Max radiant energy delivered
  - 45 (J/cm2)
- Peak radiant power delivered
  - 24 (kW/cm2)
- Effective max linear processing speed
  - 30 (meters/min)
- Curing dimension per pulse
  - 75 x 150 (mm)
- Max area cured per sample
  - 300 x 150 (mm)
- Output spectrum
  - 200-1500 (nm)

## Additional functionality developed at Holst

- Inline measurement at 10,000 samples/s
  - Resistance
  - Temperature

# Way of working - Equipment

- **Stage 3: R2R pilot line**
  - Continuous inkjet printing and photonic sintering on a roll-to-roll line

**Printer: SPGPrints setup**

- 1 (to 5) Xaar1001 print heads
- Drop volume 6-42 pL; 7 grey-scales
- 1000 nozzles; 360 dpi; nozzle pitch 70.5 µm
- >100 ml volume needed

**Sinter set-up: R2R tool**

- Up to 6 lamps
- Xenon Sinteron 500
- NIR pre-drying 5.8 kW
- 1 meter footprint

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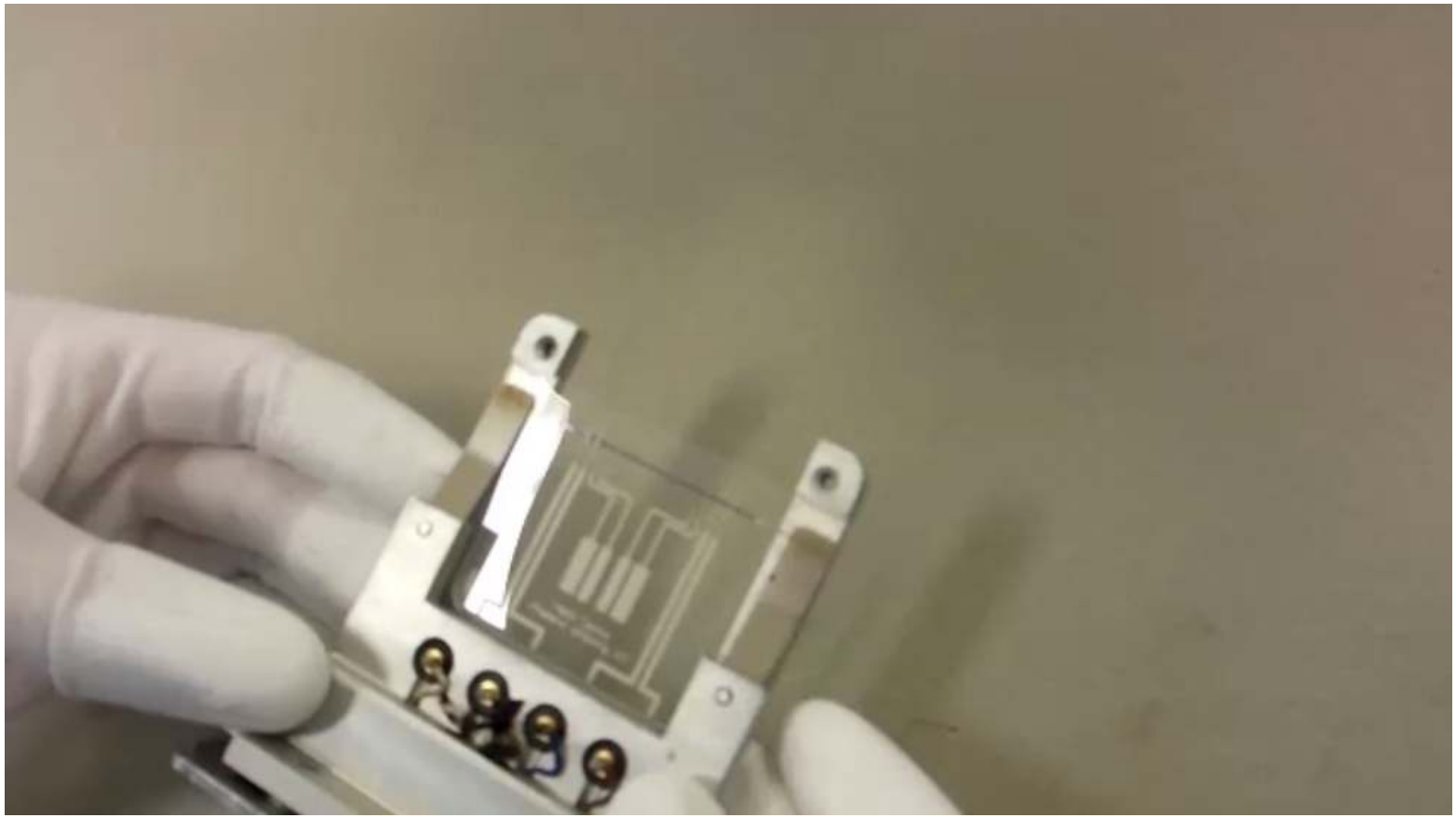
# Results – Stage 1: Material selection

## Evaluation of commercial and research conductive inks

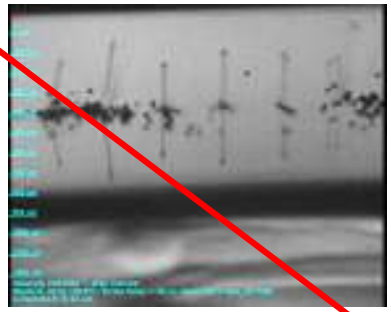


**Movie: Dimatix inkjet printing and photonic sintering**

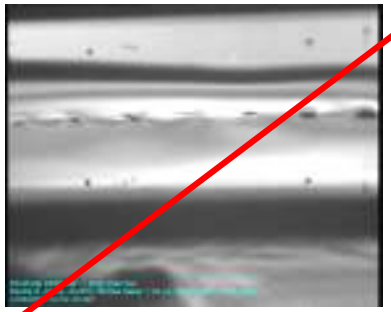
# Results – Stage 1: Material selection

- **Typical resistivity for Silver nano-particle ink**
  - Oven 130°C/30 min: 12x Bulk Ag
  - Oven 150°C/30 min: 9x Bulk Ag
  - Photonic sintering: 6x Bulk Ag


Good wetting

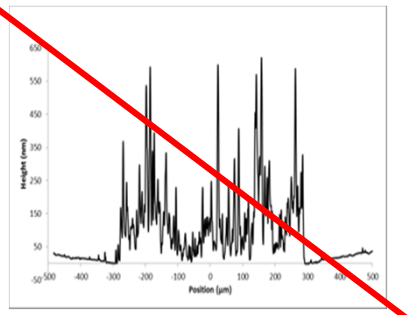


Instable jetting

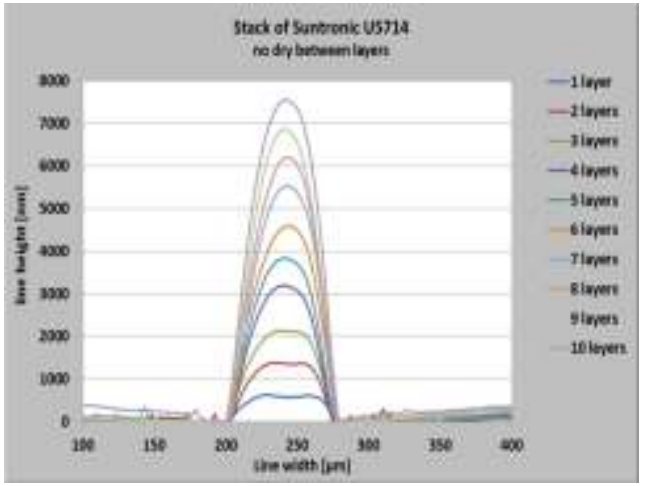


Nozzle plate wetting

Extreme wetting



Rough profile




Smooth & well defined profile

# Results – Stage 2: Up-scaling to S2S

## Up-scaling to 30X30 cm

**Movie: S2S IJP using PixDro LP50**

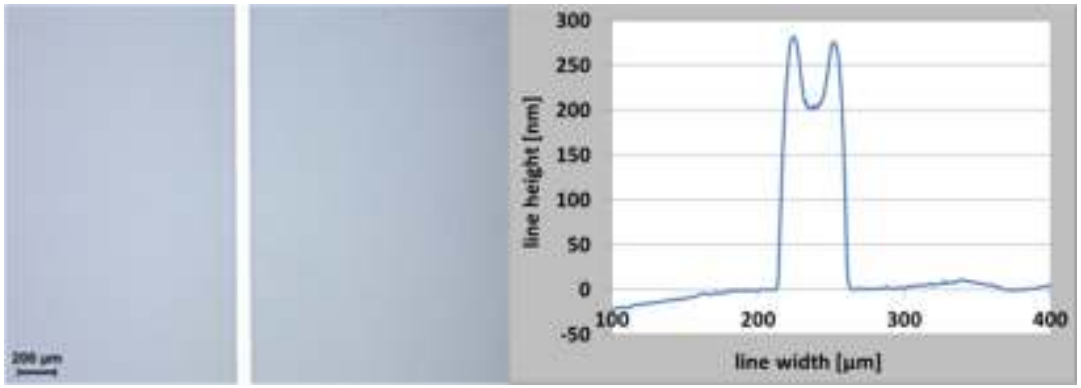
**S2S photonic sinter tool**

**Movie: S2S photonic sintering**
**Movie courtesy of Philips**

# Results – Stage 2: Up-scaling to S2S

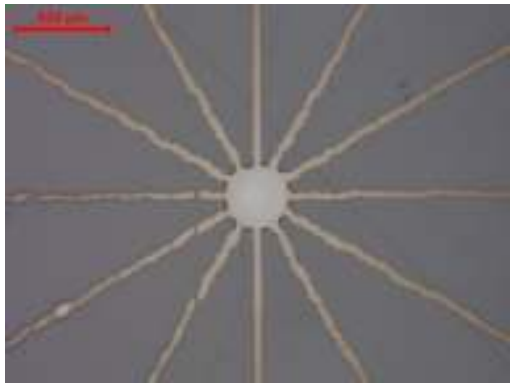
- **Typical conductivity for S2S sintered Silver nano-particle ink**
  - Oven 130°C/30 min: 12x Bulk Ag
  - Oven 150°C/30 min: 9x Bulk Ag
  - Photonic sintering S2S: 8x Bulk Ag

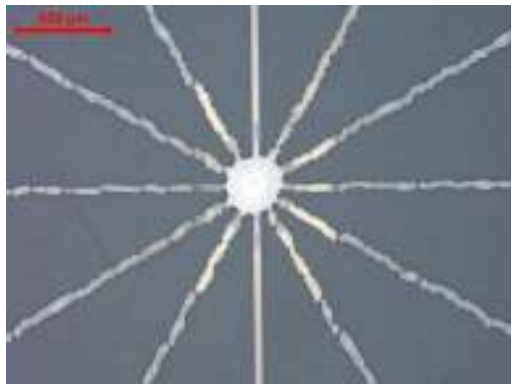
Nozzle check: all 512 nozzles active




Good line definition in print direction

Typical S2S test pattern



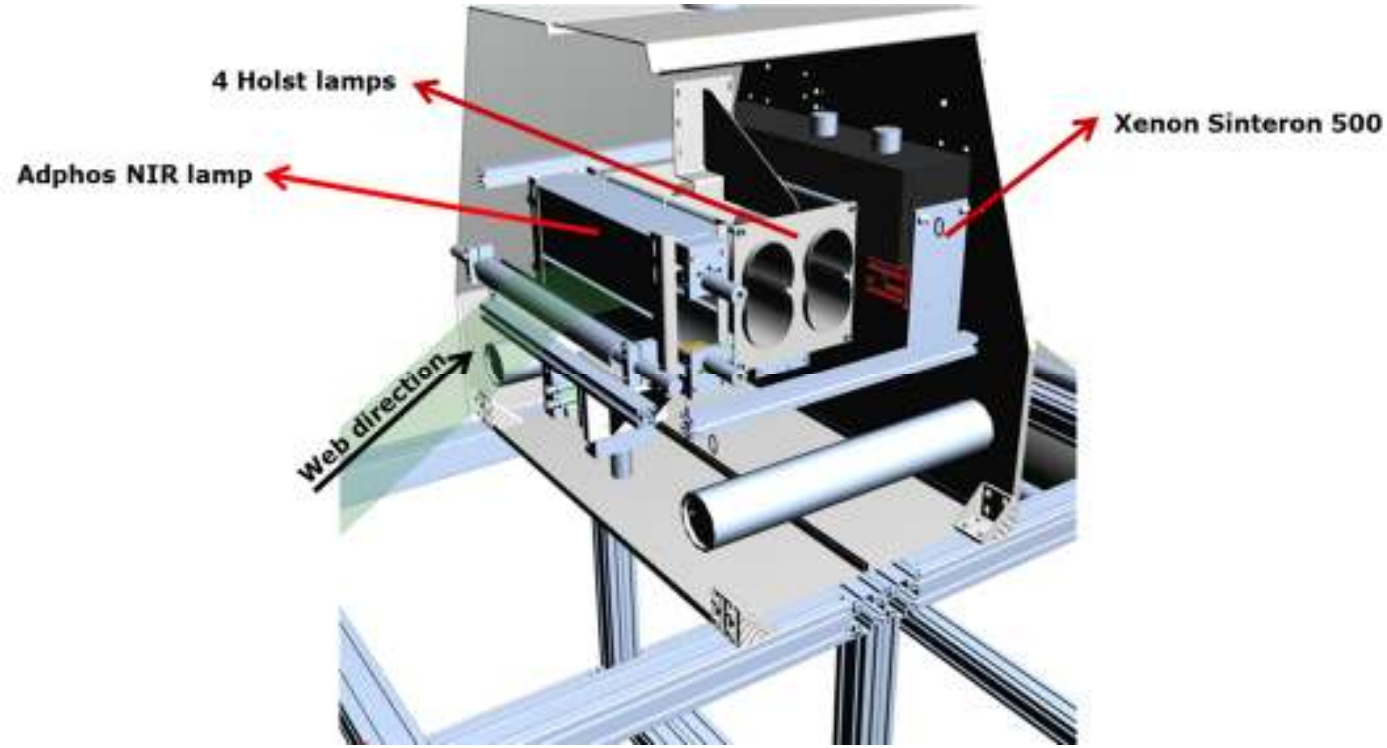


Some optimization necessary in other directions

# Results – Stage 3: Up-scaling to R2R

**Up-scaling to continuous production process**

- **Requirements**
  - Reliable ink supply in large volumes and with reproducible/stable quality
  - Fast drying and sintering
  - Compatible with industrial print heads
  - Stable printing with all nozzles




Schematic of sinter setup in R2R line

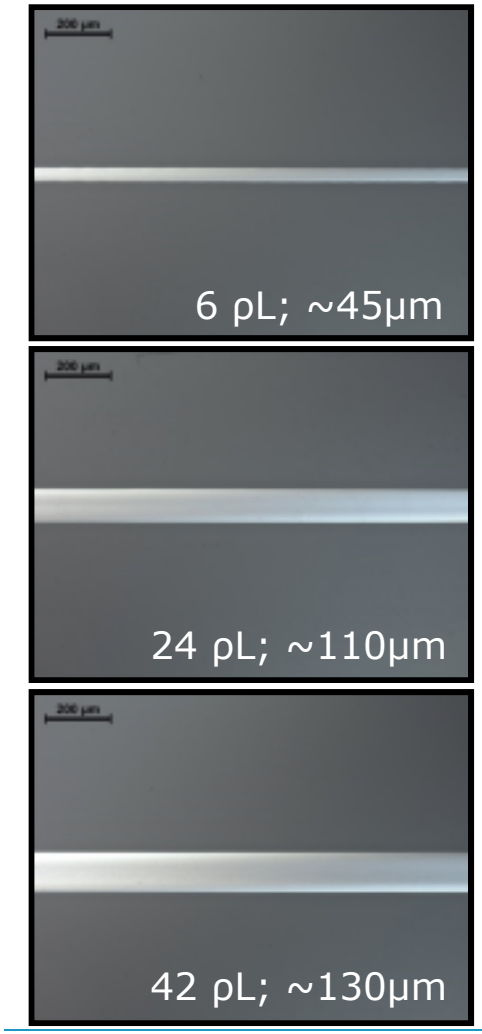
# Results – Stage 3: Up-scaling to R2R

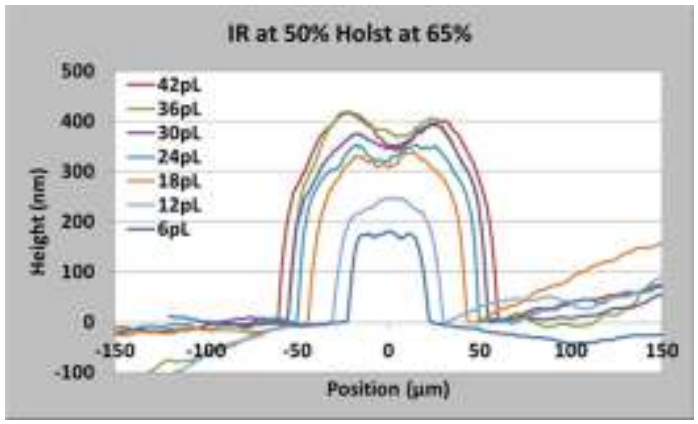
**In-house record of R2R printing and sintering on plastic film at 12 m/min using SPGPrints tool and 60cm wide sinter setup (IR + Photonic)**

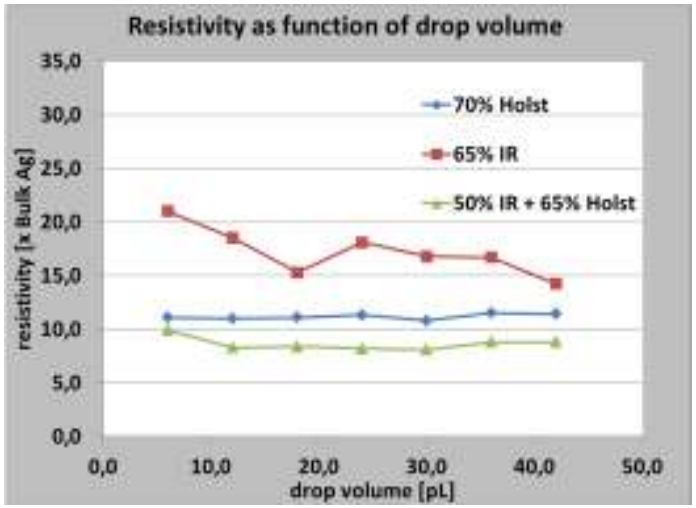

**Movie can be found on you-tube:**
**Roll-to-roll inkjet printing and sintering at Holst Centre**

# Results – Stage 3: Up-scaling to R2R

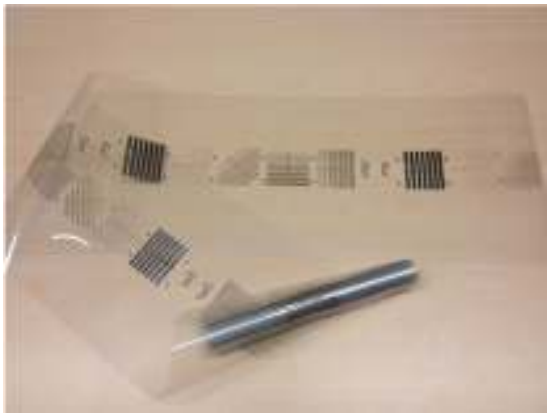
- **R2R results Suntronic EMD5603 on PEN (3 m/min)**




- Very good line definition
- Best result at 720dpi
- Smallest line width ~45µm
- Best sinter results with combination of NIR + Holst lamps
- Resistivity 8.5x Bulk Ag



R2R printed and sintered structures on foil

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# Summary & Conclusion

- **An efficient route from batch to roll-to-roll production was shown**
  - Small scale material testing and evaluation using Dimatix printer
  - Up-scaling to S2S processing using PixDro LP-50 inkjet printer
  - R2R printing using SPGPrints inkjet printer

- **Dedicated photonic sinter equipment for each stage**
  - Inline temperature and resistance measurement reveal best sinter settings
  - Photonic sintering gives better conductivity compared to oven sintering

- **R2R inkjet printing and sintering at 10 m/min was demonstrated**
  - 45µm resolution on PEN
  - No foil deformation
  - Resistivity of 8.5x bulk Silver
  - 60cm sinter footprint

# Acknowledgements

## Industrial partners








## Academic partners






Holst Centre

Open Innovation by IMEC and TNO


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