Holst Centre

Open Innovation by IMEC and TNO

Printed electronics – from simple circuitry to integrated devices

Daniella Deutz, Robert Abbel, Erik Tempelman and Pim Groen

Holst Centre

TU Delft

an open innovation research institute, focusing on technologies for flexible electronics ('system-in-foil') and ultralow power wireless sensors

Holst Centre: partner in research

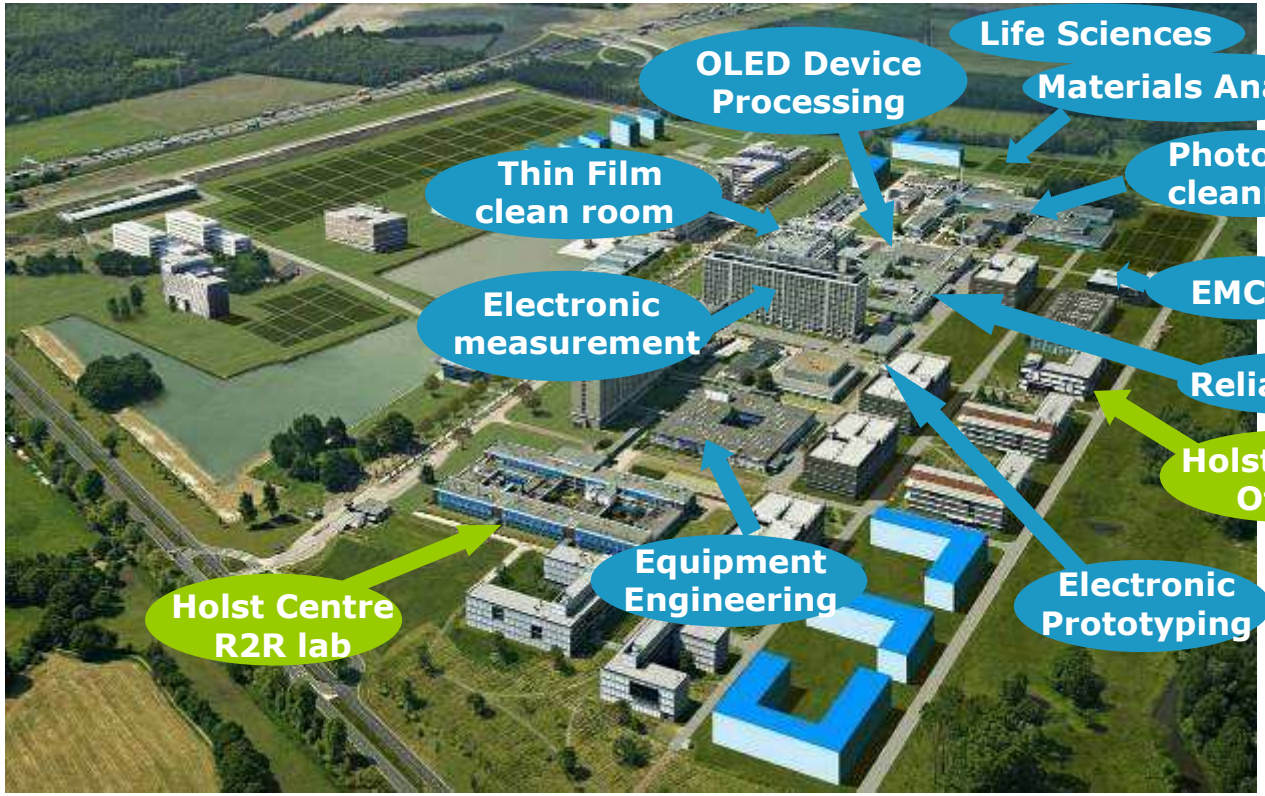
- **Independent, with reputed parents**
  - founded by imec (1300 fte, Belgium) and TNO (3500 fte, The Netherlands)
  - established in 2005
- **Critical mass**
  - own staff 210; 25 nationalities
  - 70 'resident' researchers
- **Characteristics**
  - bridging gap between industry and academia: working on technologies that will reach market in 3-5 years
  - perform joint research **with** industrial partners in Shared Research Programs
- **Funding**
  - supported by both Dutch government and industrial partners

NL Agency
Ministry of Economic Affairs

Industrial partners from across the value chain

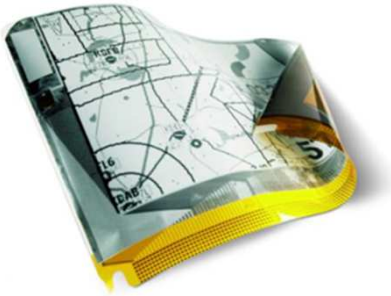
At the hotspot of human-focused innovation

- Located at the High Tech Campus in Eindhoven (previous Philips Natlab)
- Access to on-site shared facilities (MiPlaza)
- Holst also has its own labs, mainly focussing on R2R technologies

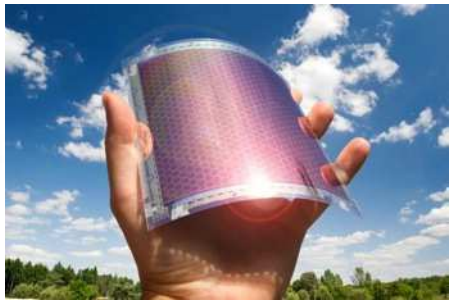


Our field: next generation electronics

flexible displays



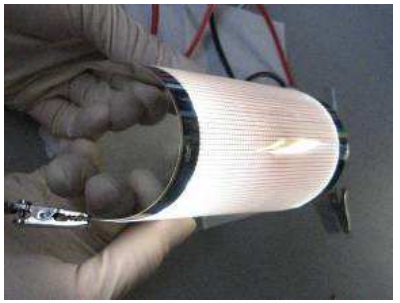
flexible solar cells



touch screens

flexible lighting devices (OLEDs)

key differentiators:
ultralow power electronics &
thin and flexible
('system-in-foil')



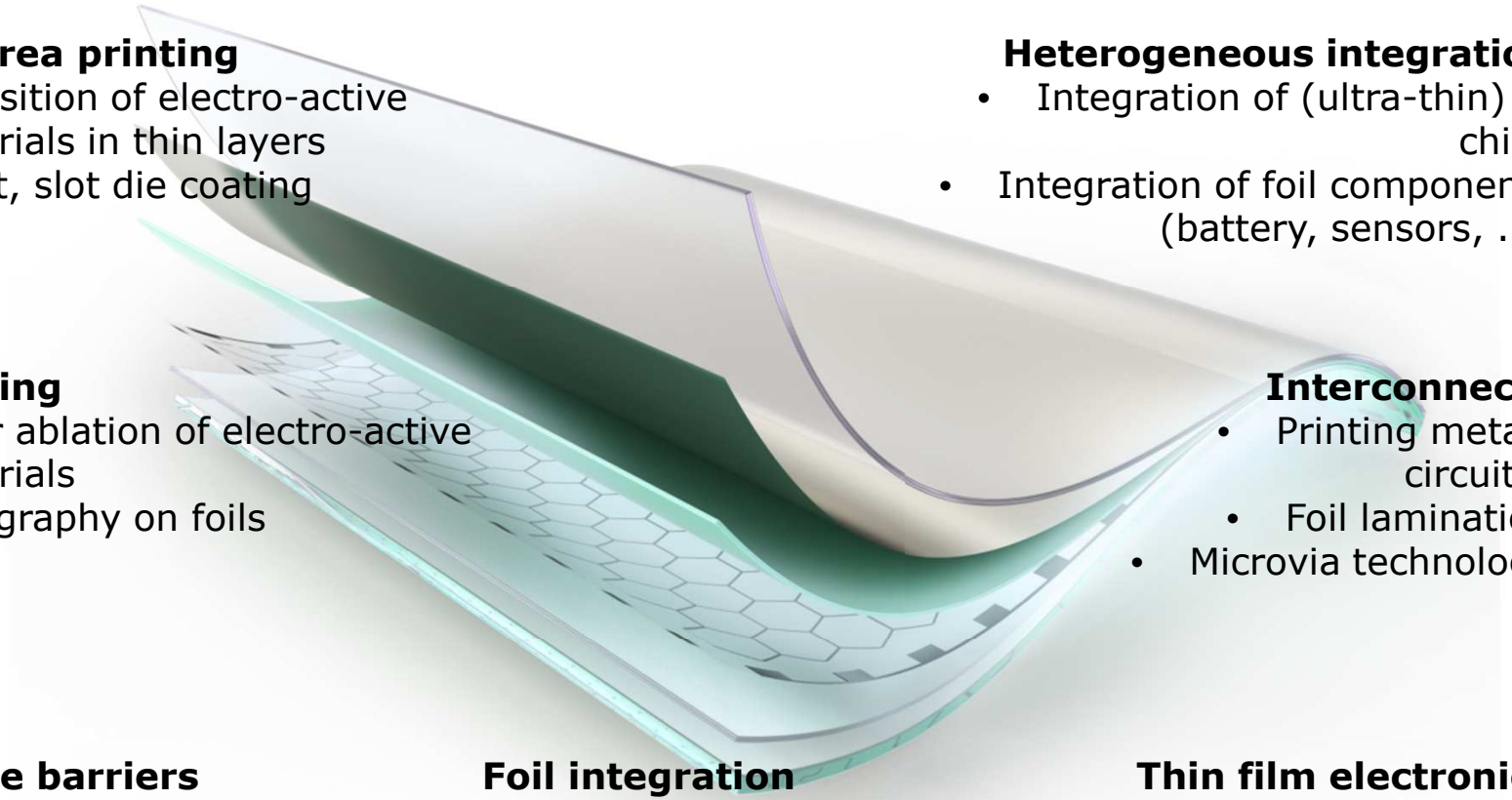
food and medicine monitoring sensors

health patches

Our offering: a set of techno's for systems-in-foil

Large area printing
- Deposition of electro-active materials in thin layers
- inkjet, slot die coating

Heterogeneous integration
- Integration of (ultra-thin) Si chips
- Integration of foil components (battery, sensors, ...)



Patterning
- Laser ablation of electro-active materials
- Lithography on foils

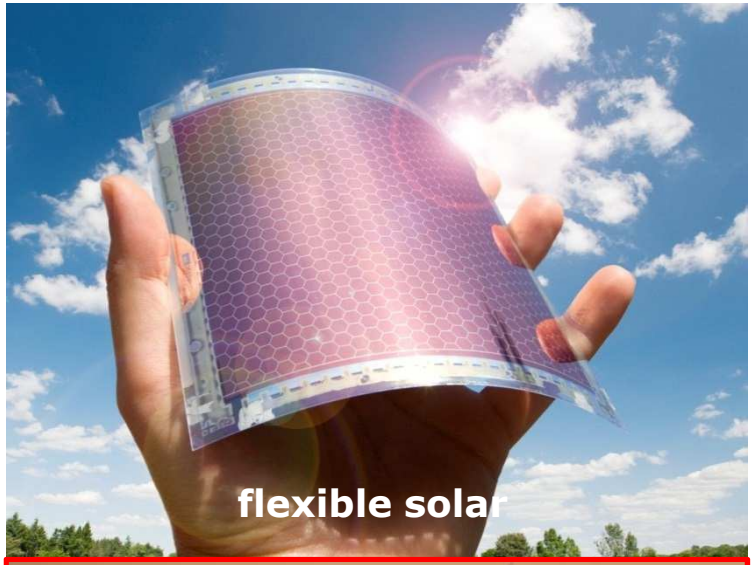
Interconnects
- Printing metals circuitry
- Foil lamination
- Microvia technology

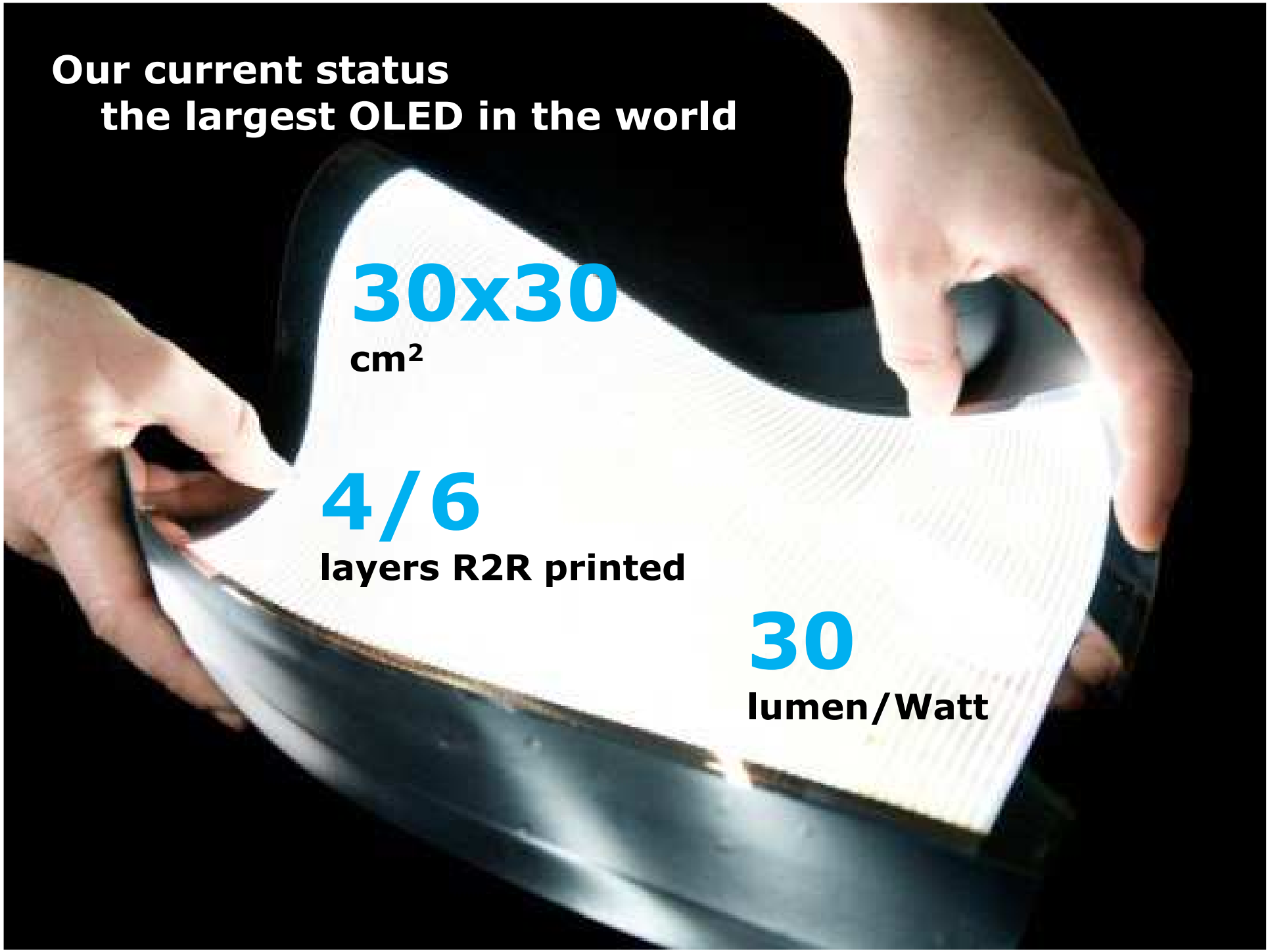
Moisture barriers
- Technologies for thin, transparent moisture barriers on foil
- For OLED, OPV, displays

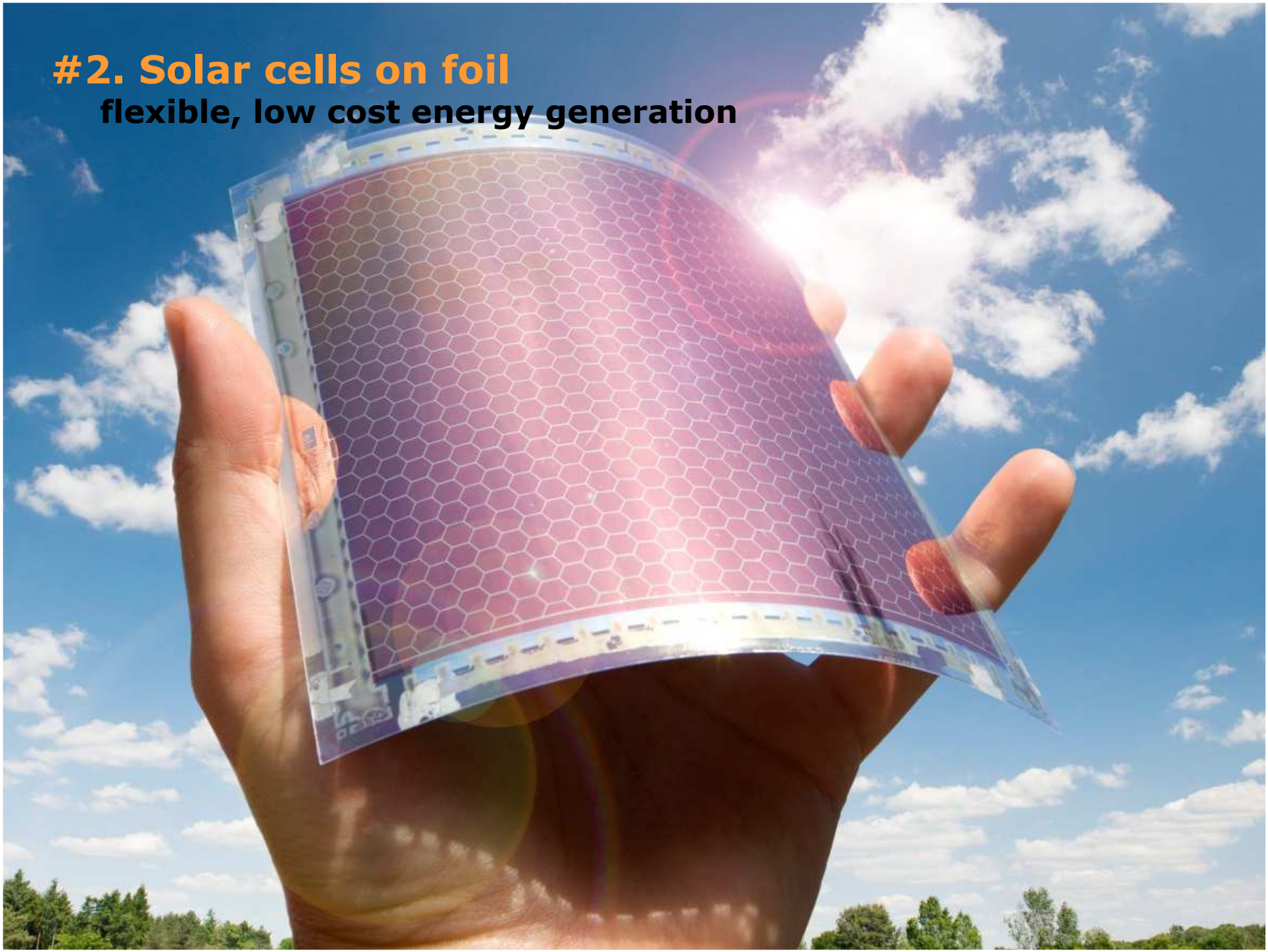
Foil integration
- stretchable electronics
- textile integration

Thin film electronics
- TFT circuits
- Non-volatile memory
- Diodes and rectifiers

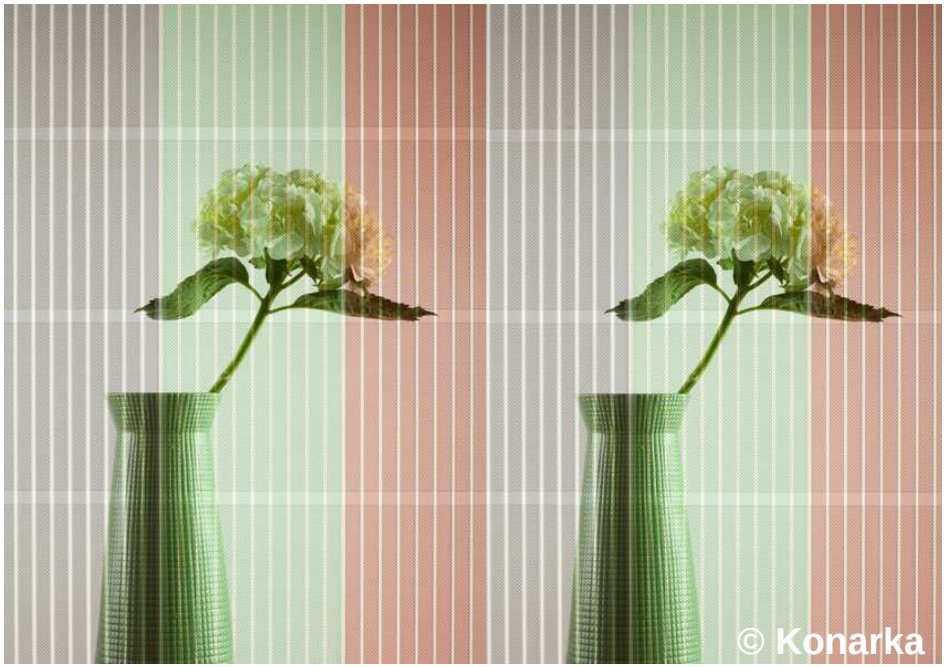
… proven to work in actual applications




Our current status
the largest OLED in the world
30x30
cm²
4/6
layers R2R printed
30
lumen/Watt


#2. Solar cells on foil
flexible, low cost energy generation


© Solliance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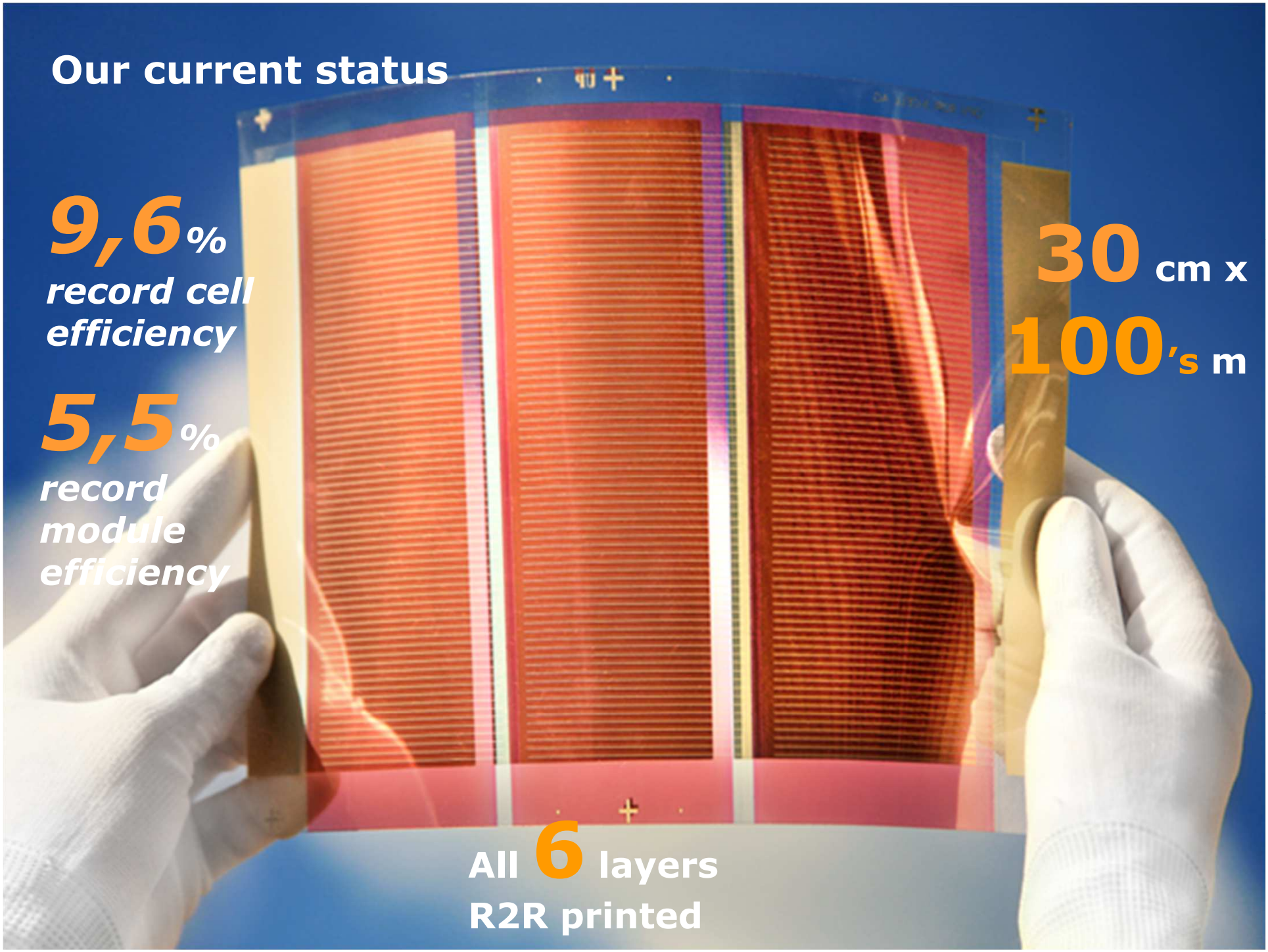
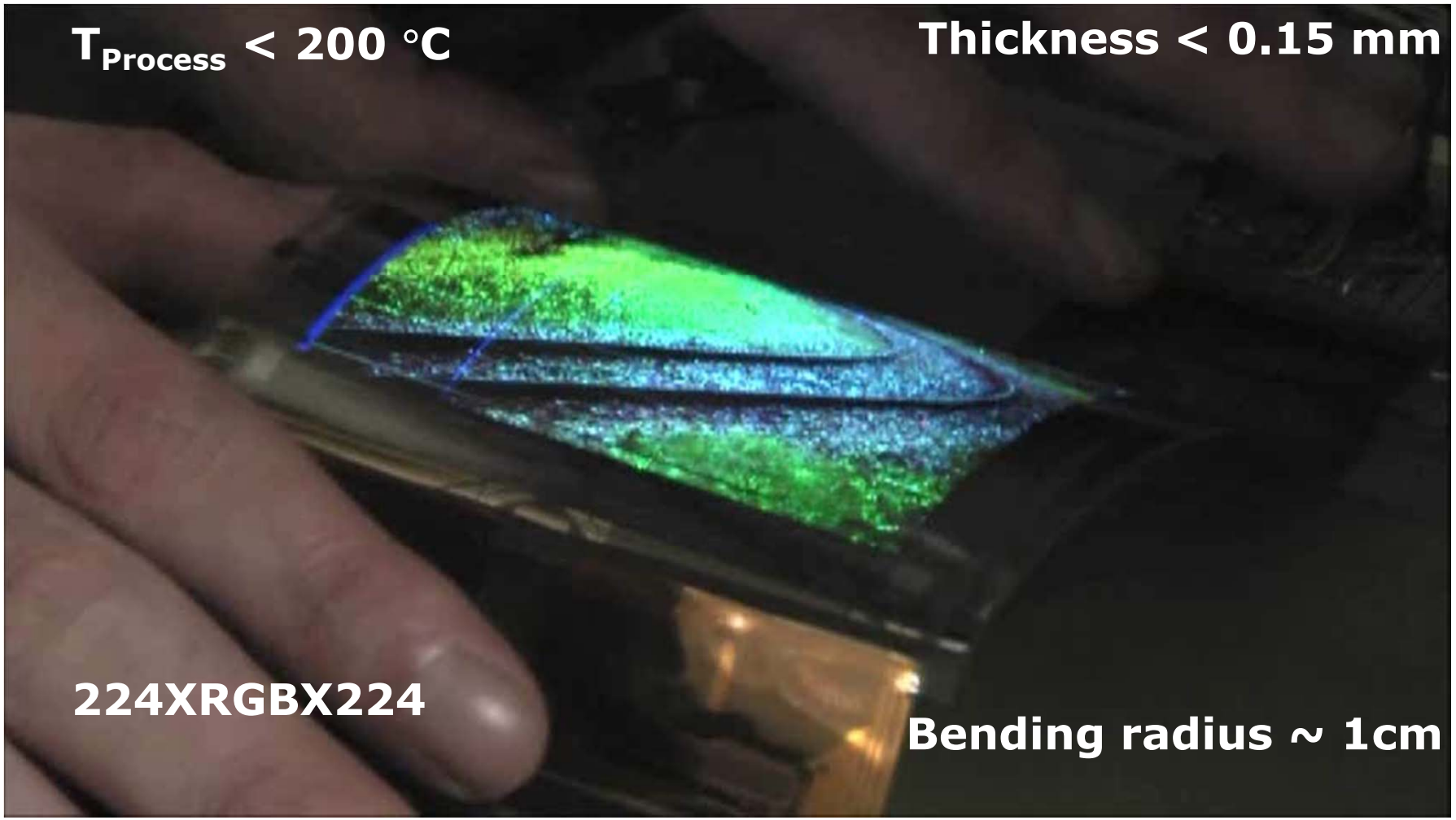

Our current status
9,6%
record cell efficiency
5,5%
record module efficiency
30 cm x
100's m
All 6 layers
R2R printed

#3. Flexible AM OLED displays

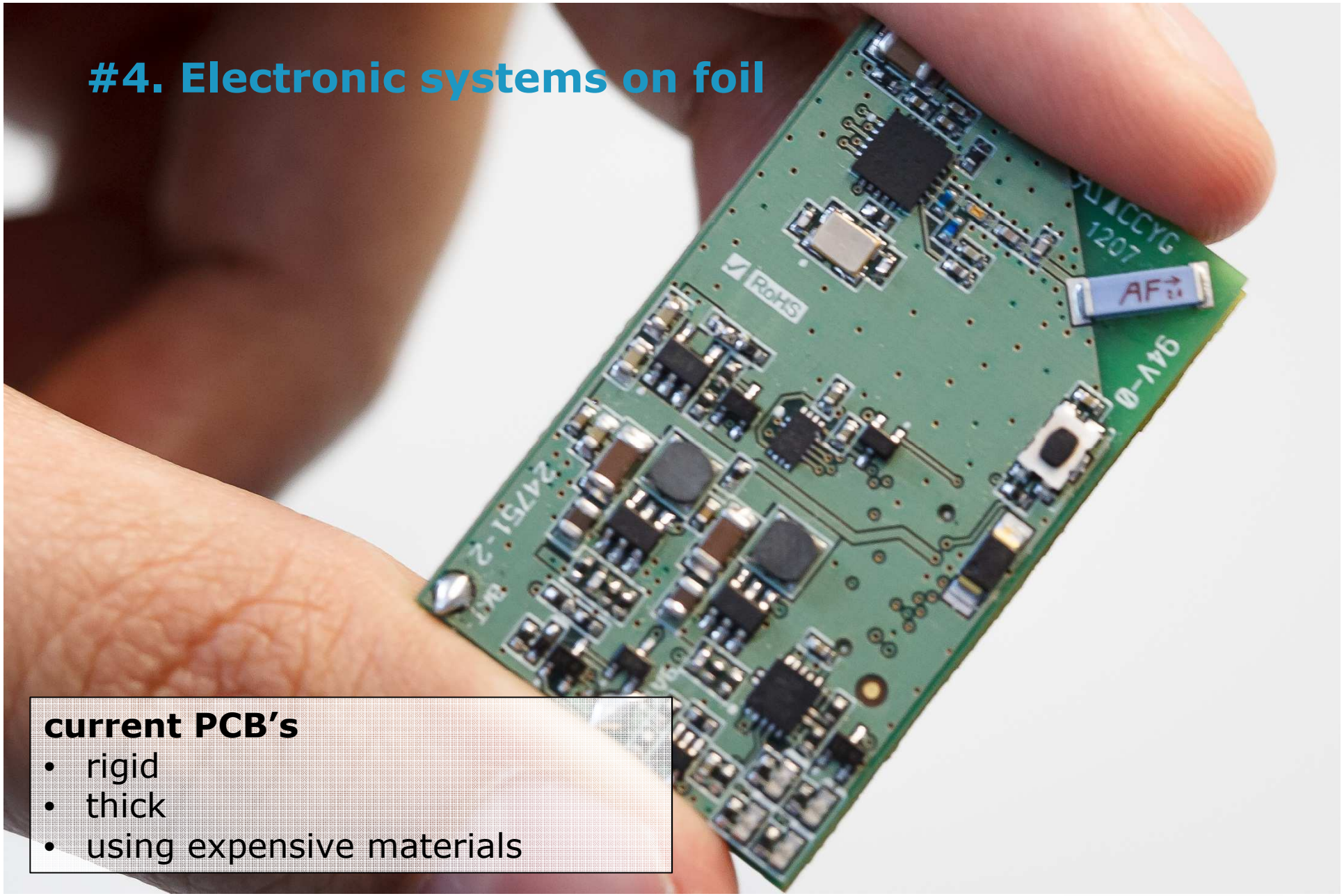
Vision on displays

Full color AMOLED display on PEN



Together with Panasonic (SID' 2013)
More upcoming developments @ SID' 2014 (3 accepted) and 2 ISSCC accepted papers

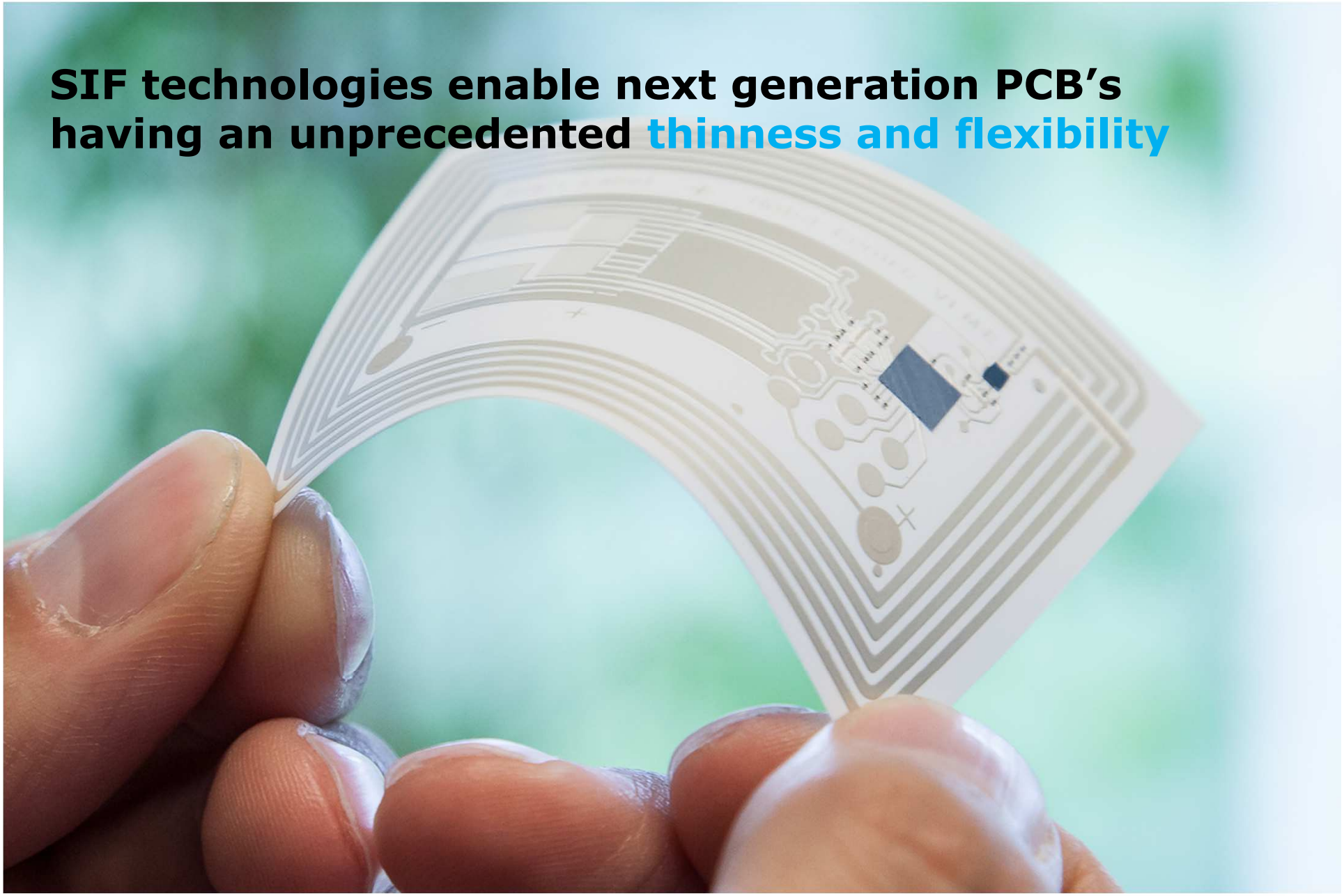
#4. Electronic systems on foil



current PCB's

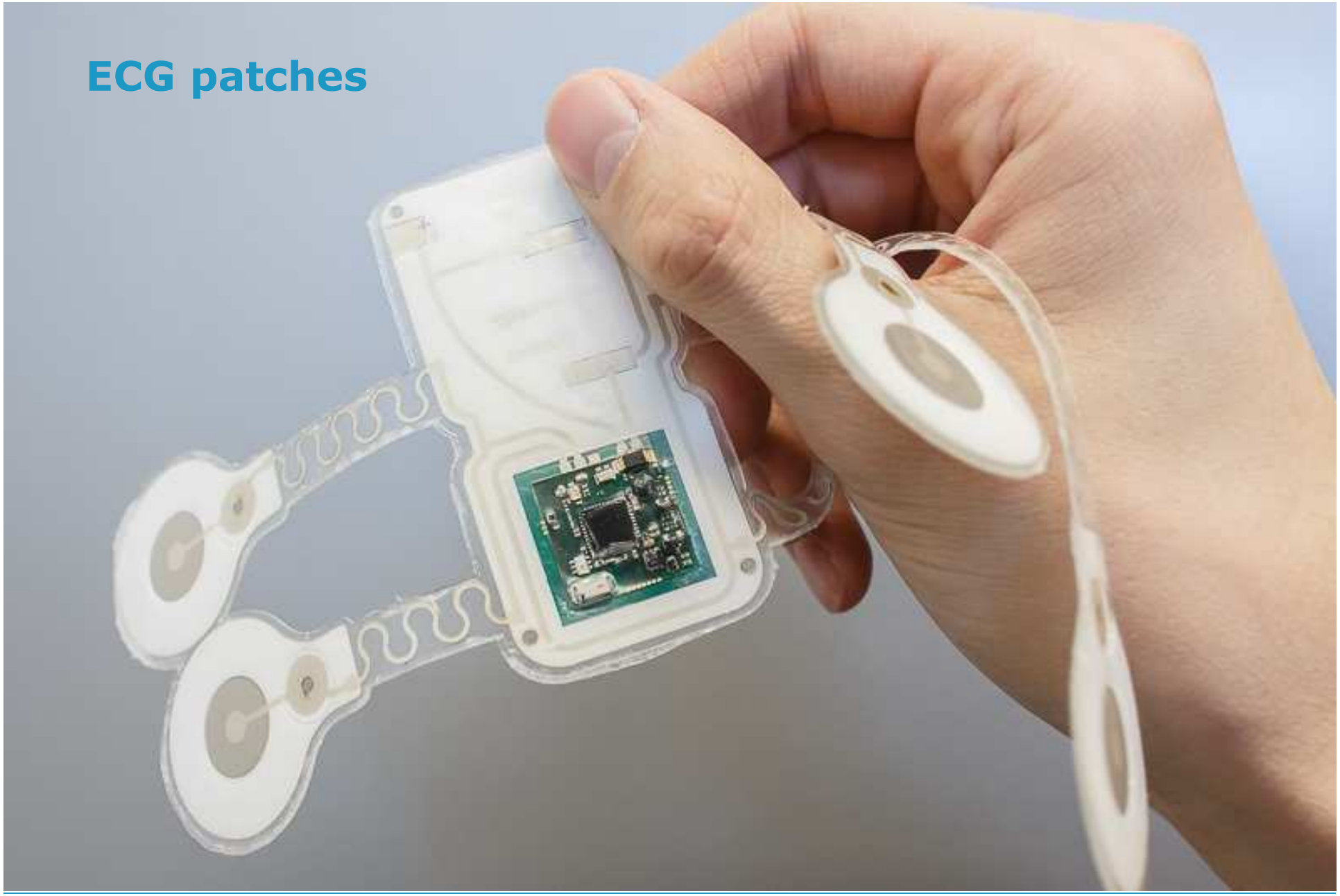
- rigid
- thick
- using expensive materials

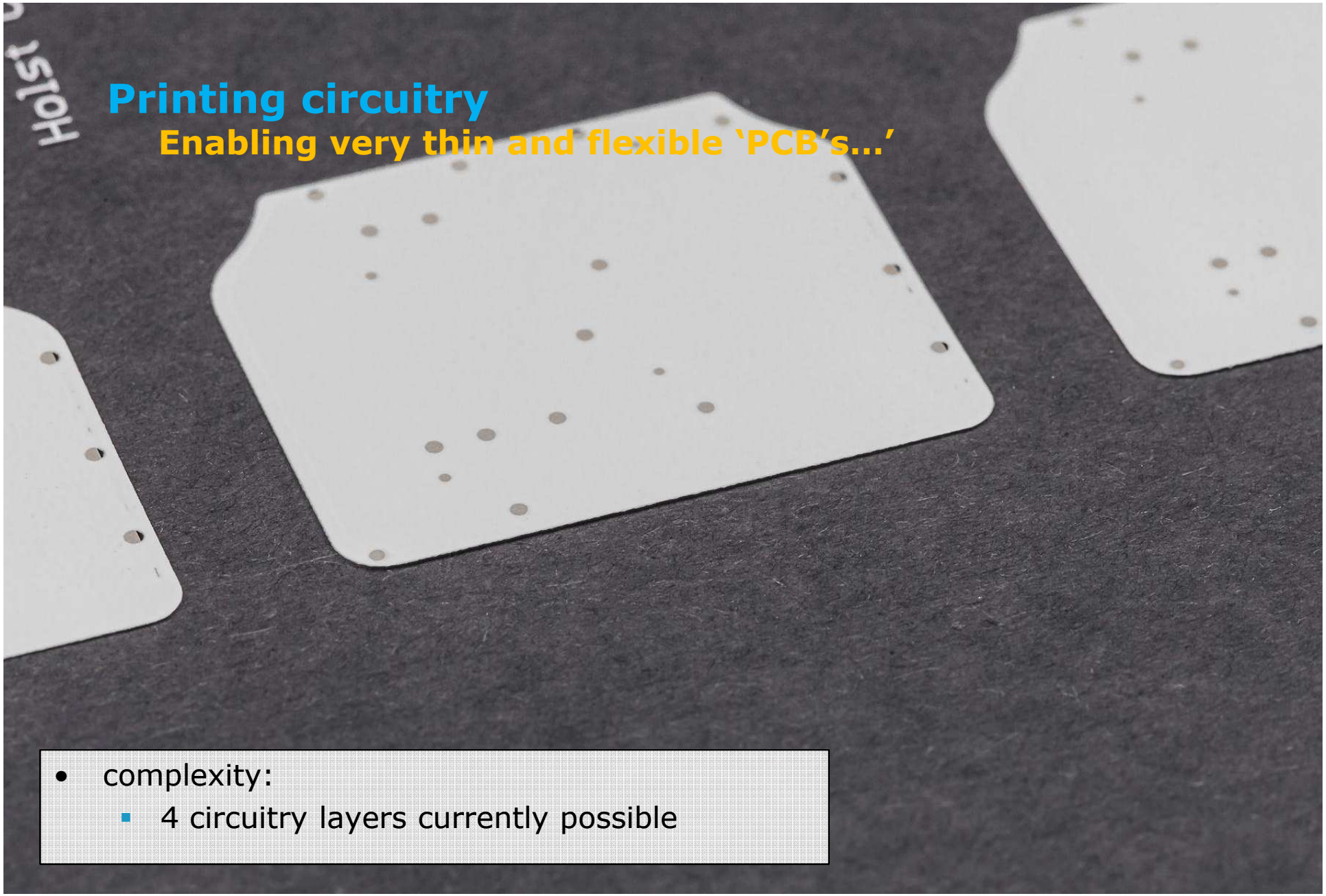
SIF technologies enable next generation PCB's having an unprecedented thinness and flexibility



Disposable skin temperature patch

ECG patches

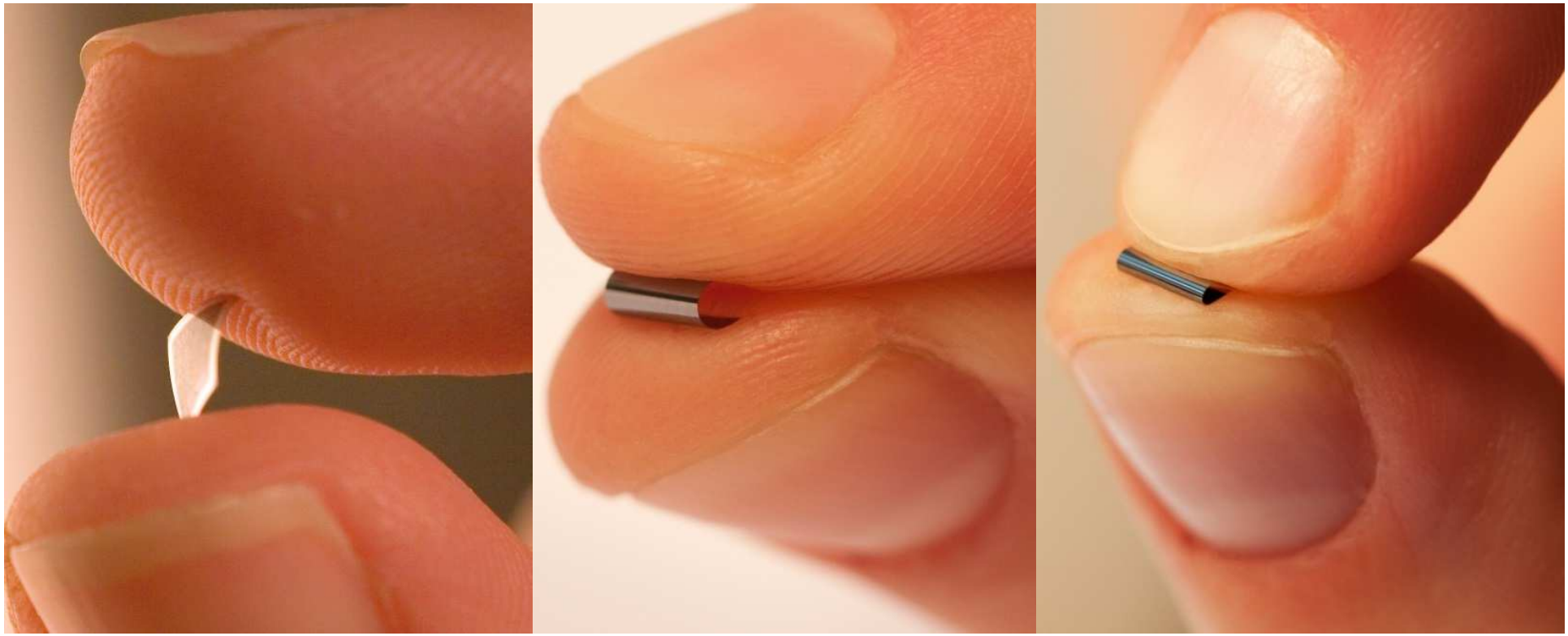




Printing circuitry

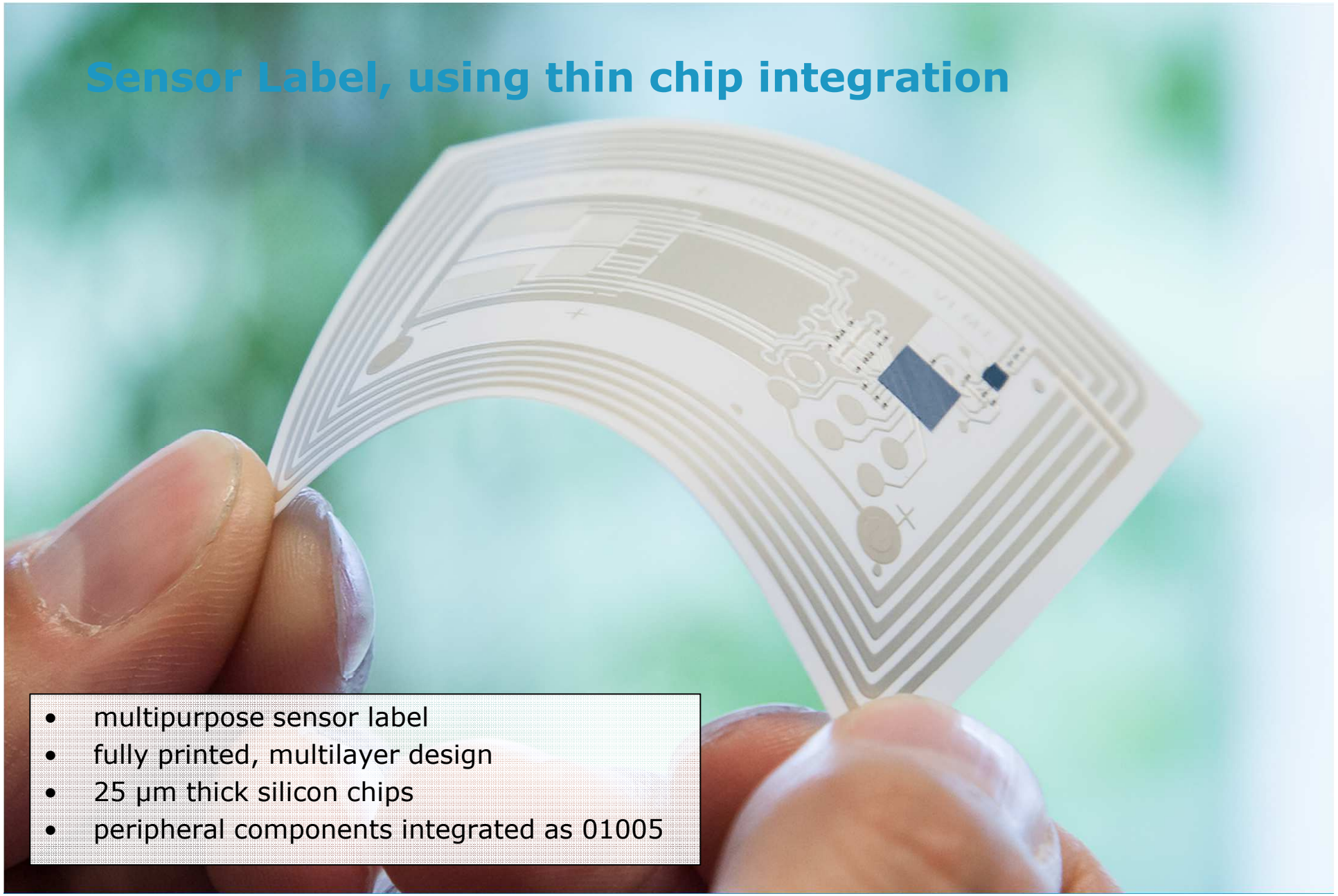
Enabling very thin and flexible 'PCB's…'

- complexity:
  - 4 circuitry layers currently possible



we develop key enabling technologies to integrate silicon chips as thinned, bare die components

Sensor Label, using thin chip integration



- multipurpose sensor label
- fully printed, multilayer design
- 25 µm thick silicon chips
- peripheral components integrated as 01005

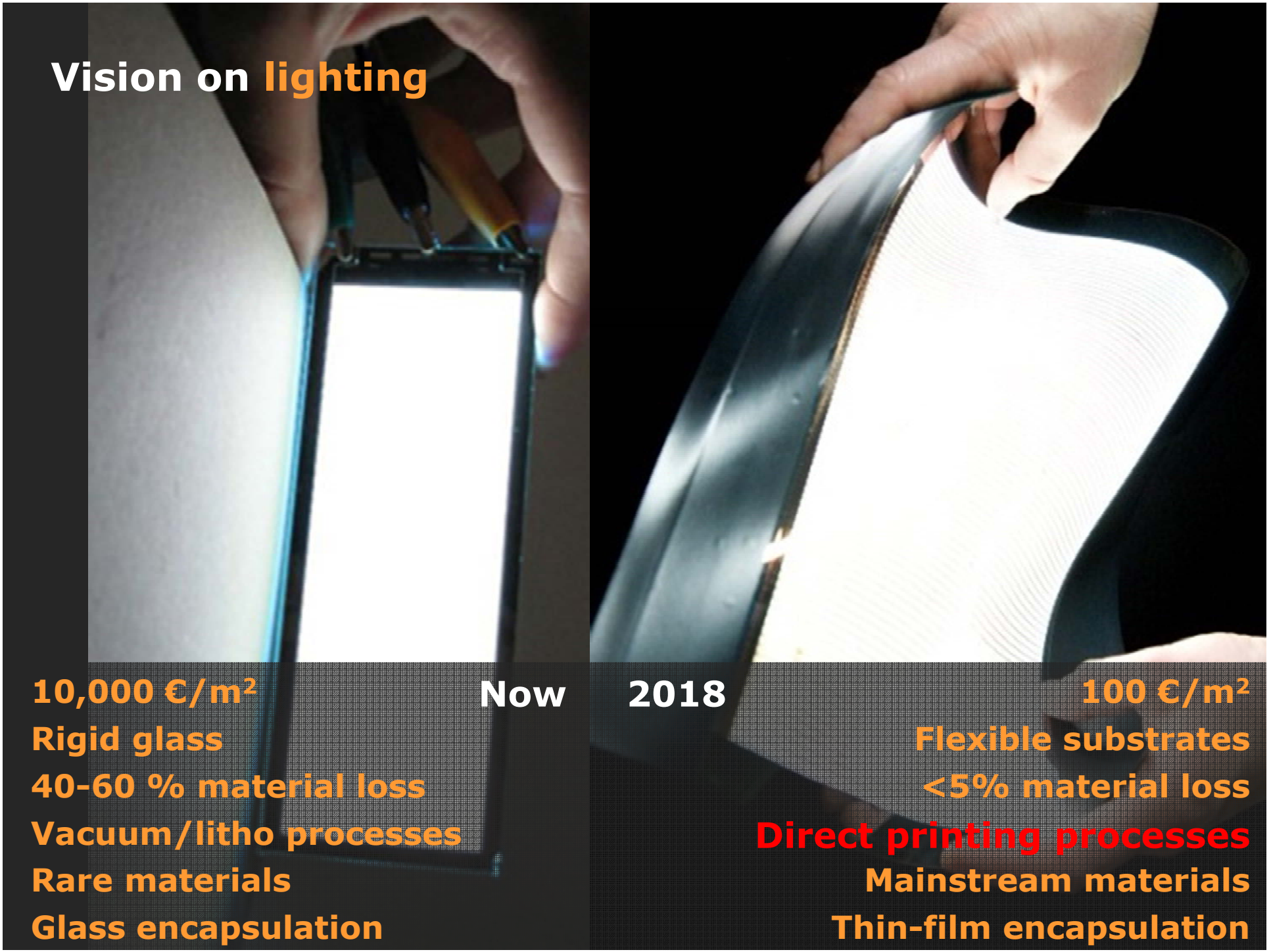
Holst Centre

Open Innovation by IMEC and TNO

R2R processing

An Open-Innovation Initiative by imec and TNO

Vision on lighting



Now	2018
10,000 €/m²	100 €/m²
Rigid glass	Flexible substrates
40-60 % material loss	<5% material loss
Vacuum/litho processes	Direct printing processes
Rare materials	Mainstream materials
Glass encapsulation	Thin-film encapsulation

R2R Printing & Coating technology

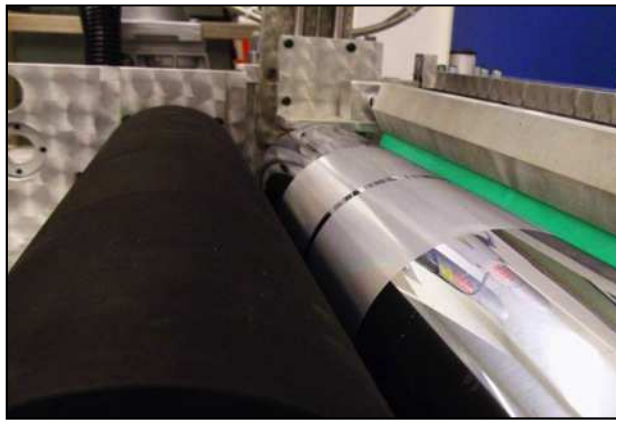
Why?

Printing/casting preferred over lithographic patterning

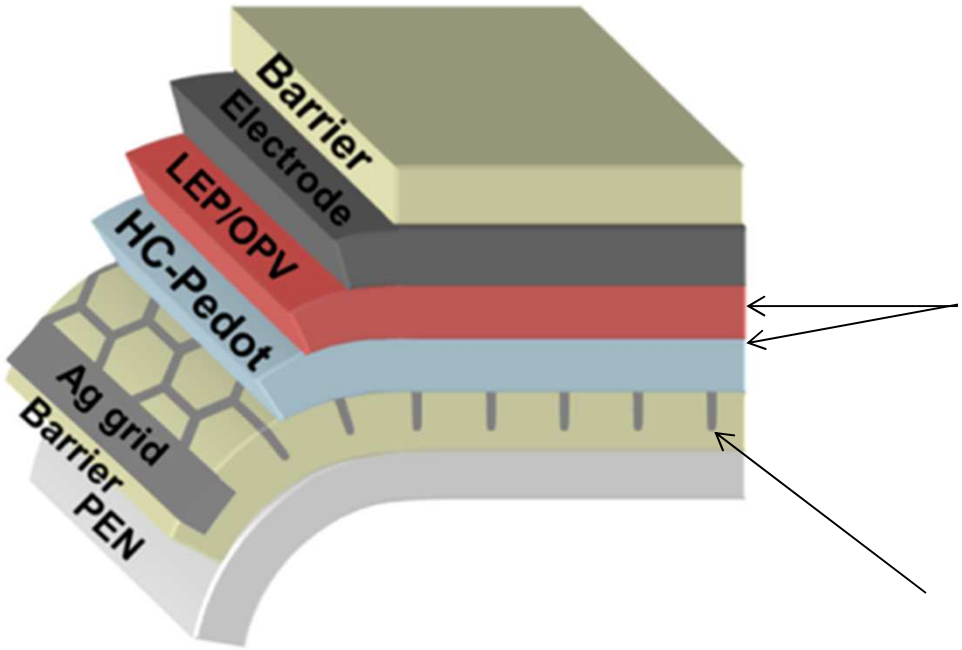
- easier for large scale processing
- fine features/patterning without complicated masks
- higher materials utilisation → lower cost

Topics:

- ✓ **S2S upscalable to R2R**
- ✓ **Multilayer coating**
- ✓ **Patterning & alignment**
- ✓ **Prevention of contamination – yield control**



Schematic of R2R solution processed OLED (ITO free)

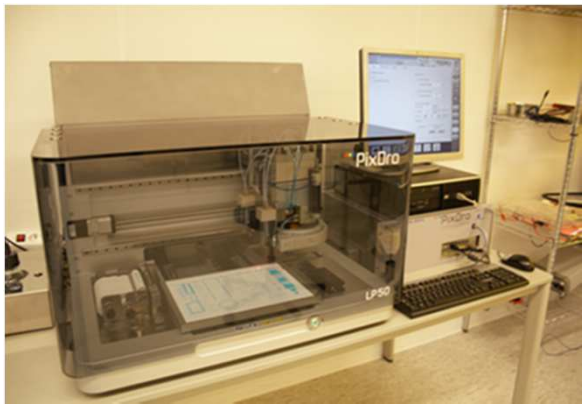


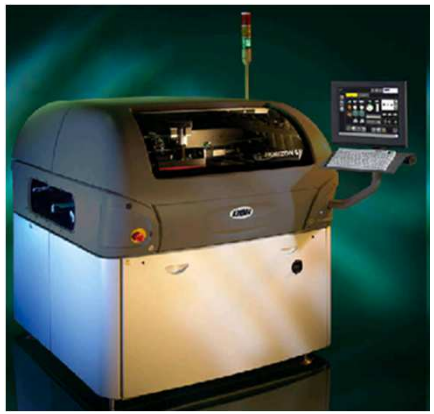
2. Large area coating

1. Printing and sintering of silver grids (anode)

Printing & Sintering

- **Printing silver: Ink jet – Screen printing**



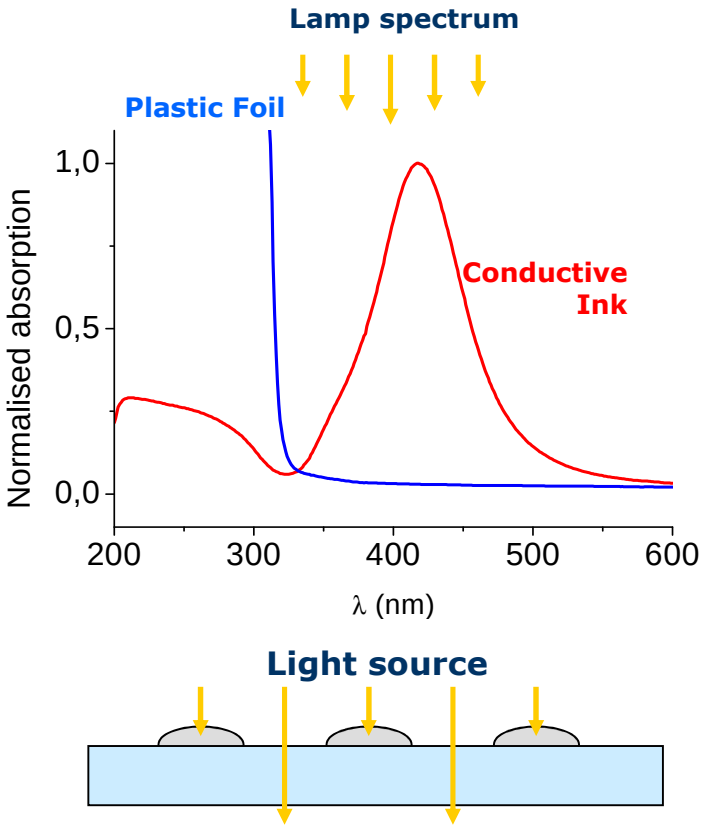


- **Baseline Process: Thermal Sintering in furnace at high temperatures (30 min./>150 ^{o}C)**
  - Limited to T_g of polymer foils
  - Slow and inefficient process
  - In R2R line with 6 m/min a furnace of 60 m needed

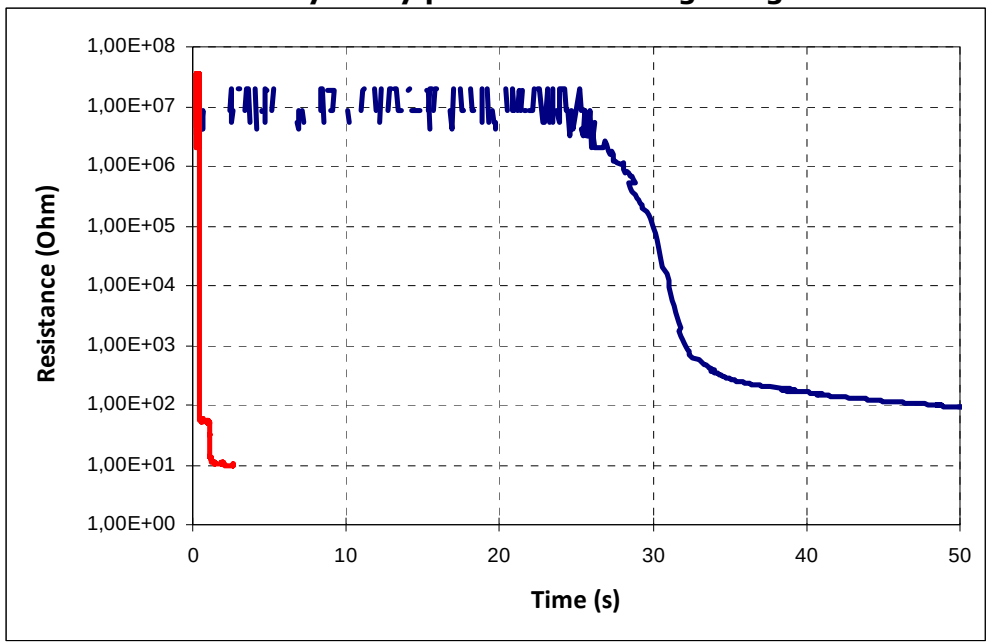
- **Photonic Flash Sintering**

Photonic sintering principle

- The principle of photonic sintering is the selective heating of the ink
- Lamps are chosen such that the light is mainly absorbed in the printed structures, not substrate



Result feasibility study photonic sintering of Ag-based inks



Oven sintering (130°C)

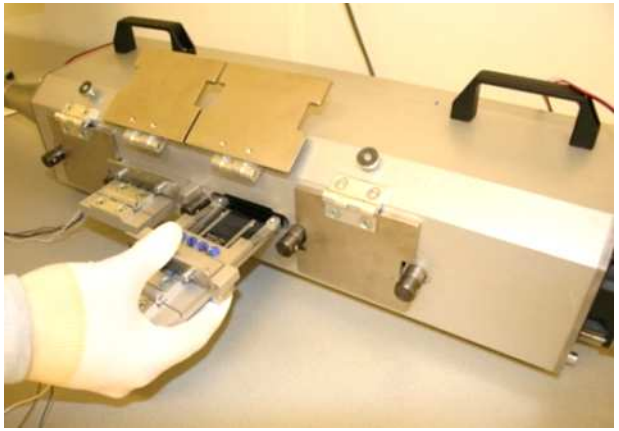
Optimized Flash sintering

Achievements:

- Sintering time reduced from minutes to few seconds!

Photonic sintering equipment

- **Photonic sinter equipment**
  - A good understanding of the sinter behavior of materials is essential
  - Measuring real-time in-line resistance and temperature necessary



Stage 1: Research tool

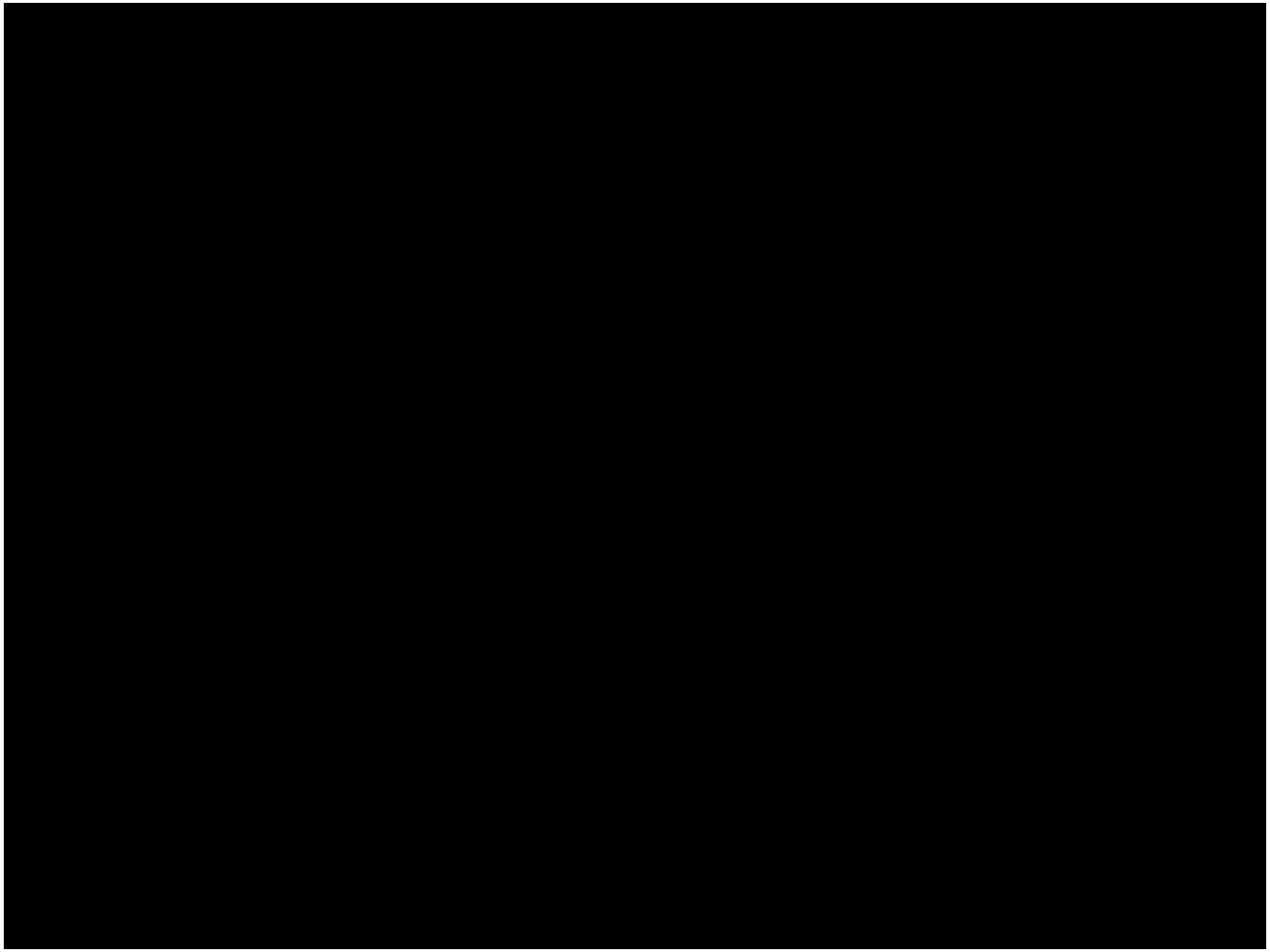
- Single lamp system
- Sintering of lines
- In-line measurements
  - Resistance
  - Temperature
- Inert atmosphere capable

Stage 2: S2S tool

- Novacentrix 1300
- Working on inline measurements of temp. + resistance

Stage 3: R2R tool

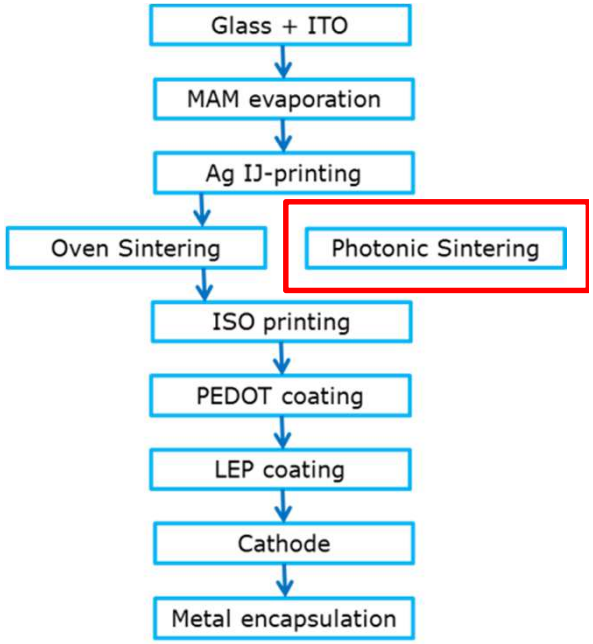
- Up to 6 lamps
- Xenon Sinteron 500
- NIR pre-drying 5.8 kW
- 1 meter footprint

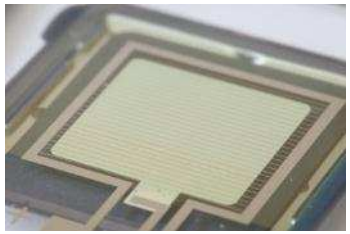


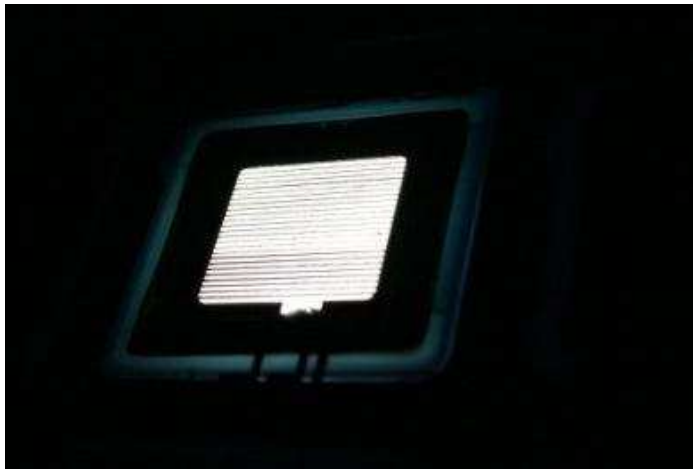
Device integration in OLED:

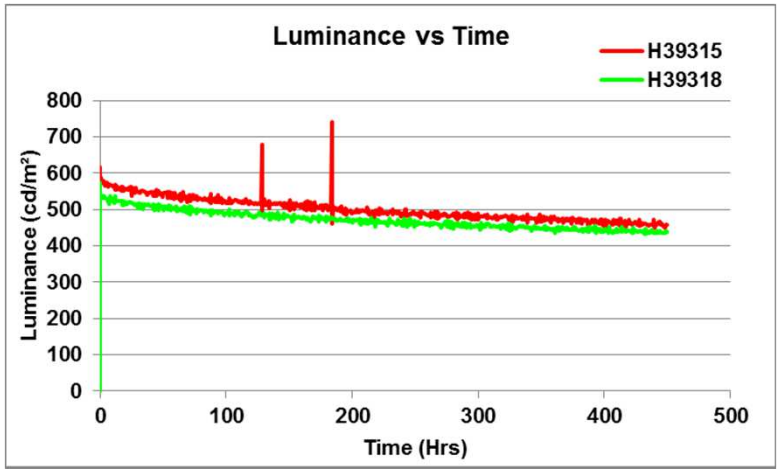
Ink Jet Printing S2S + photonic sintering

- Functional OLED's IJ-printed Ag grid lines covered with IJ-printed ISO
  - No difference between oven and flash sintered samples
  - Still surviving operational life time experiments: >1500h
  - Operational life time of non ISO coated Ag devices: 80h



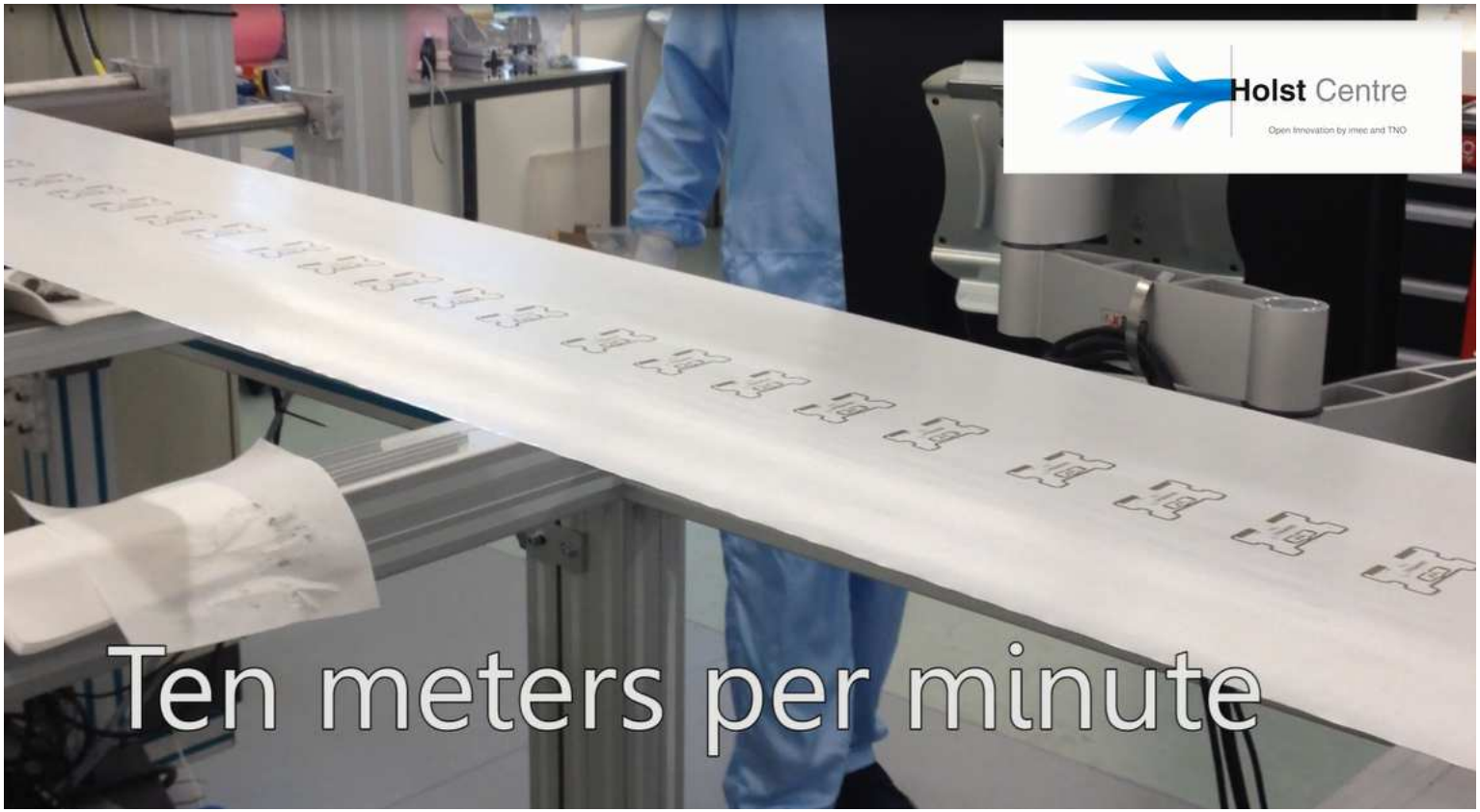






Lifetime - 20°C / 50% Humidity

Smart card (smartrac / Lotus Eu FP7 project)



Large area coating (using solution processing)

Large variety of deposition techniques to choose from:
Slot-die coating, Ink Jet Printing, Flexo/gravure/rotary screen……

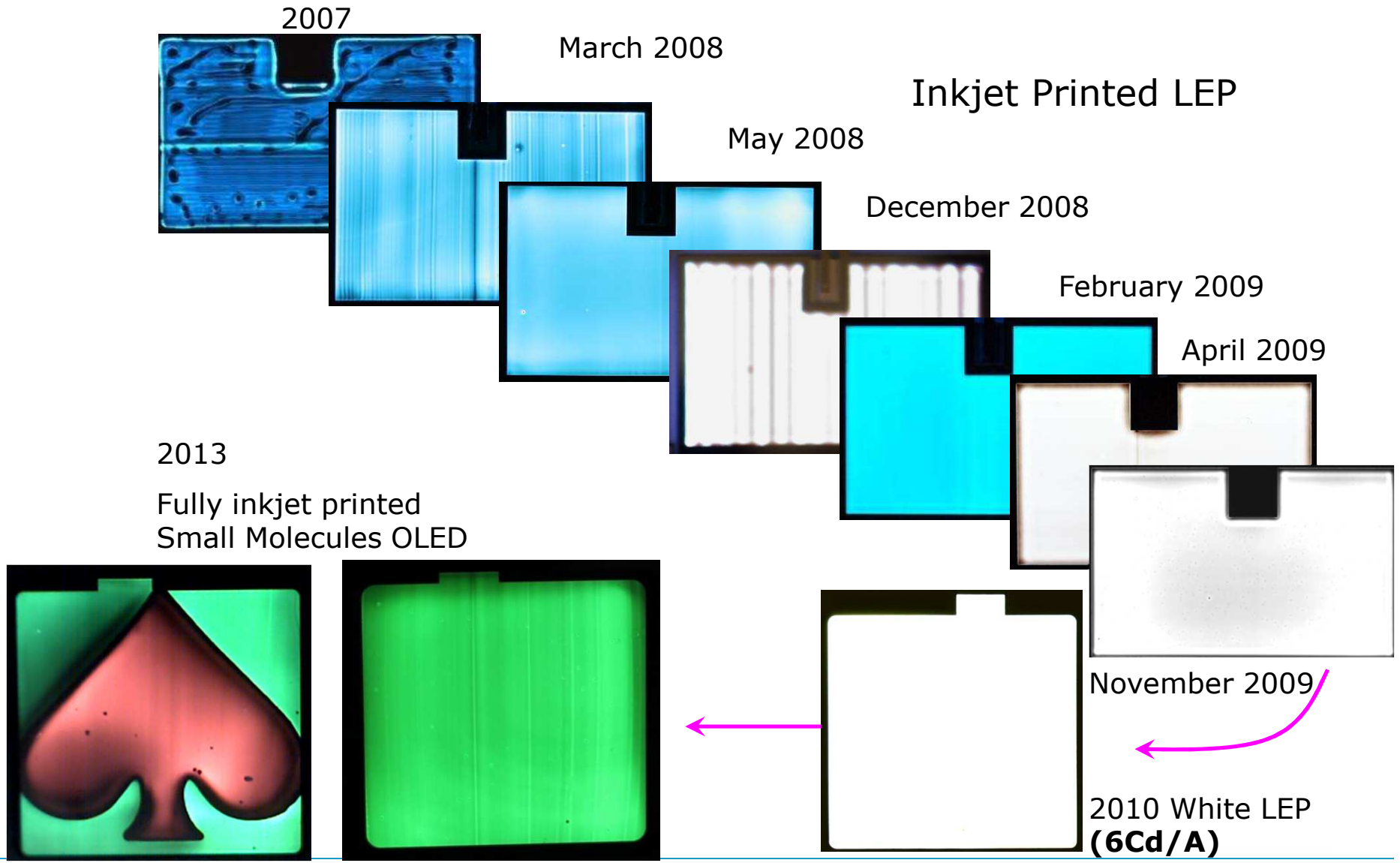
Holst Centre's Approaches:

0) Spin coating: simple, no patterning

1) Ink-jet printing: non-contact, patterning is easy
- *Homogeneity over large areas needs to be investigated*

2) Slot-die coating: non-contact, large area blanket coating
- ***Pattering:*** *stripe coating and intermittant coating*

Evolution of Inkjet printing of OLEDs



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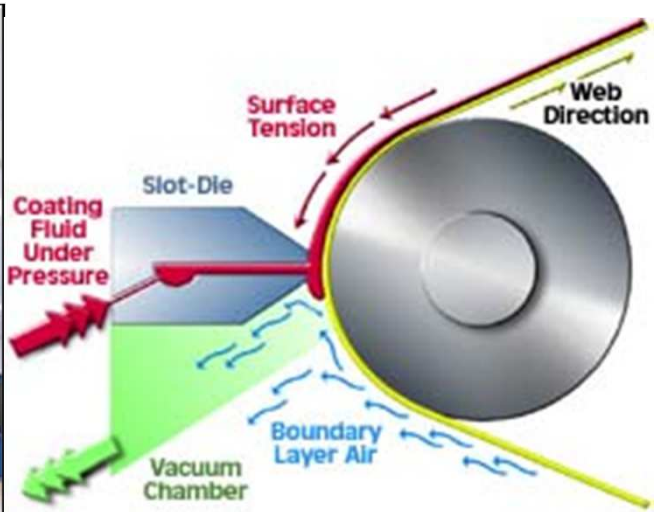
*- **Pattering:** stripe coating and intermittant coating*

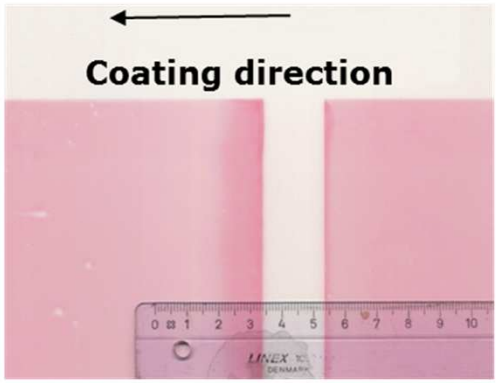
Slot die coating at Holst



Pattering !!!

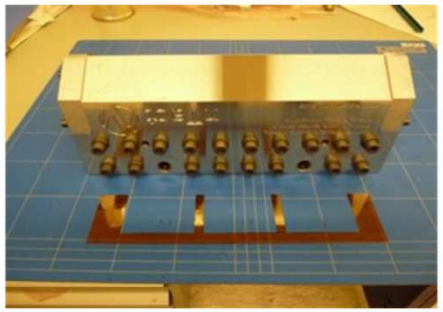
nTact

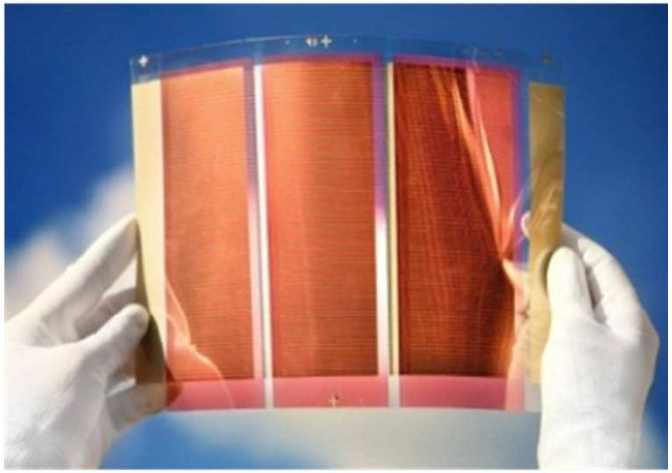
Patterning slot die

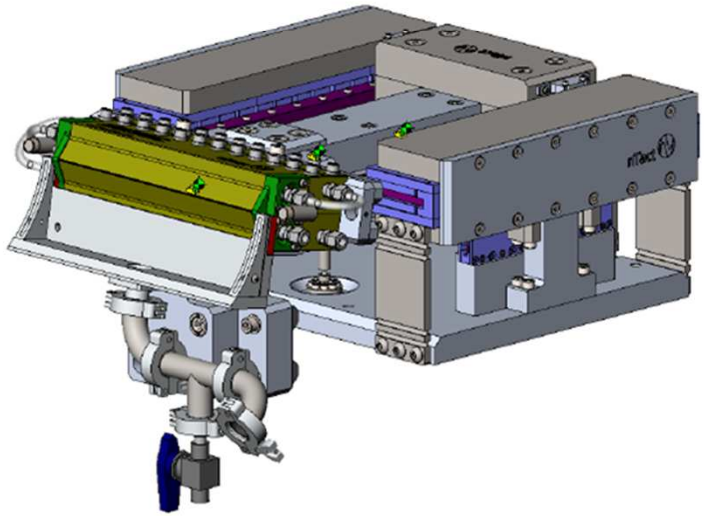


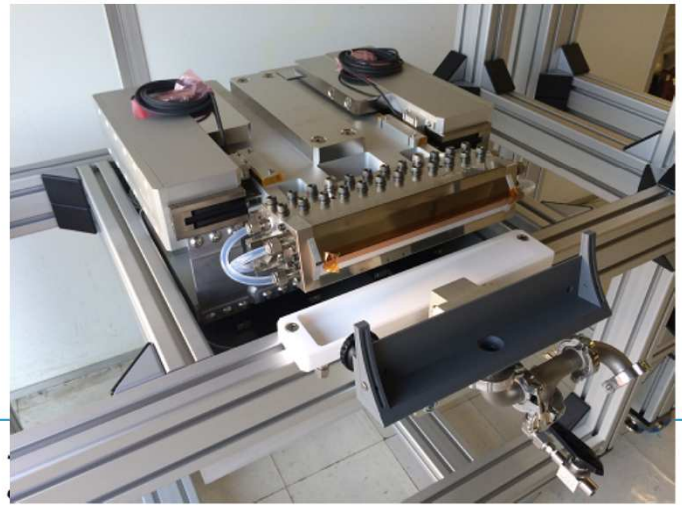
Intermittent coating with slot-die

Stripe Coating



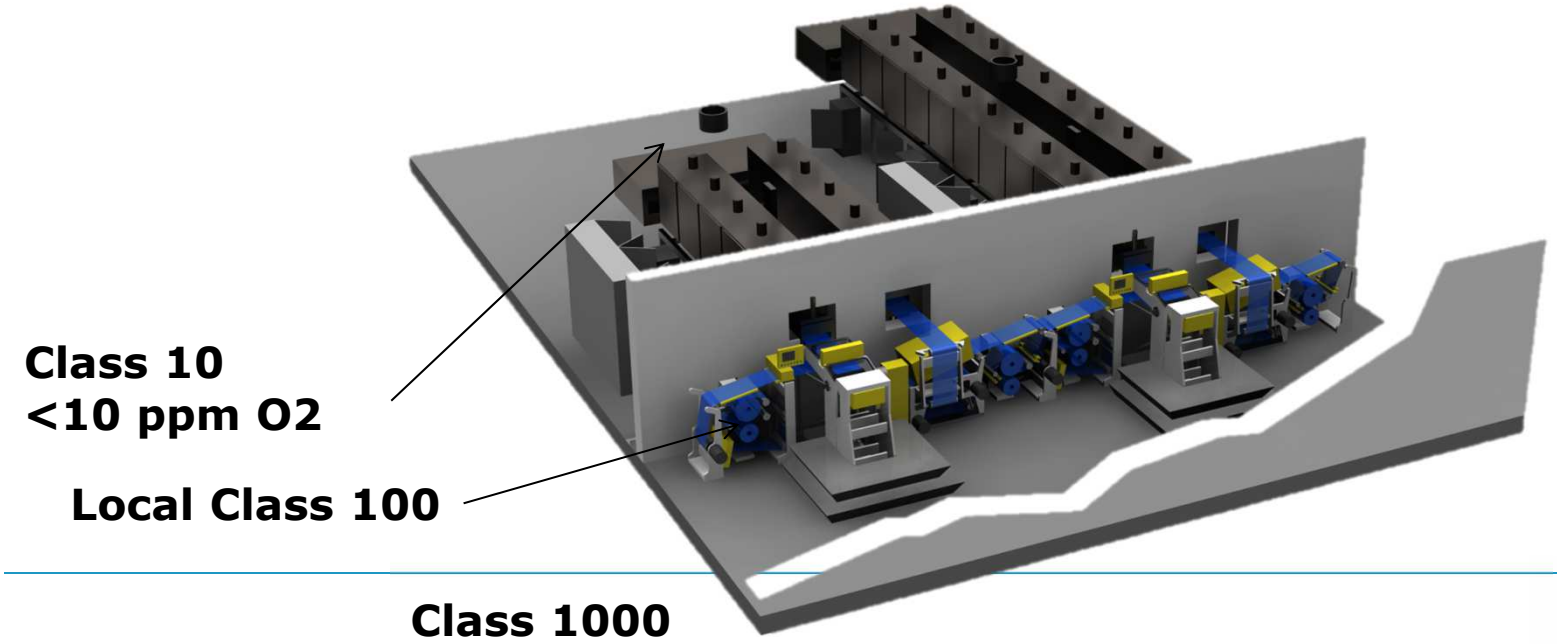






Holst Centre multicoat (2 x slot coating) pilot production line

- **Unique concept where web is never touched on topside essential for Oled production.**
- **Concept makes very efficient use of cleanroom space.**
- **Slot die coating in controlled atmosphere (all coating and drying in Nitrogen environment if needed).**
- **Closed furnace (class 10 + < 10 ppm O_2/H_2O)**
- **Possibilities for intermittant slot die (patterning with unique high speed moving slot die).**

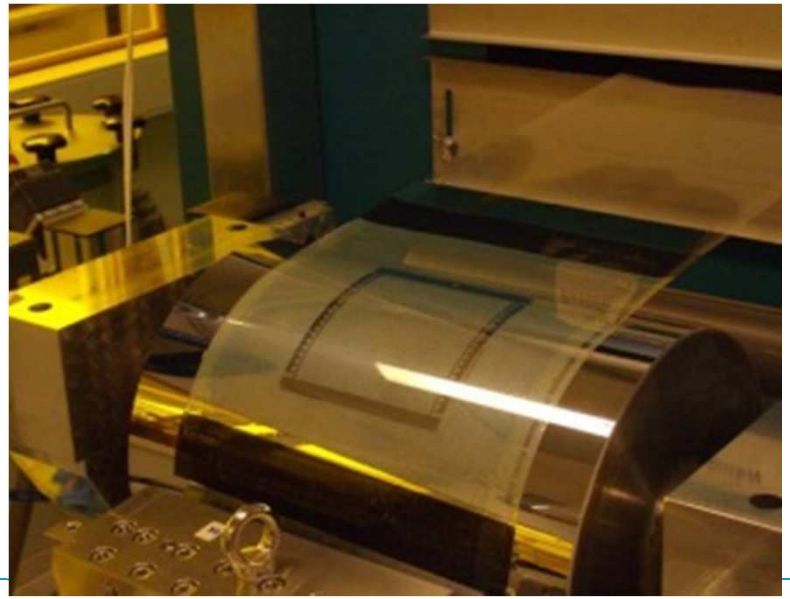



Development
of new Multi
R2R Process.

Solliance R2R line

OLEDs: Large area slot die coated flexible demonstrators

- Slot-die coated layers of **100 - 30 nm** with thickness **variation only ± 2 nm**
- Sequential coating of up to **3 organic layers** on **plastic and metal foil** proven



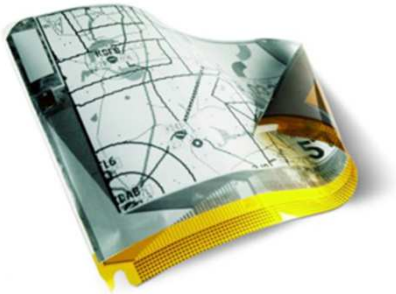
Holst Centre

Open Innovation by IMEC and TNO

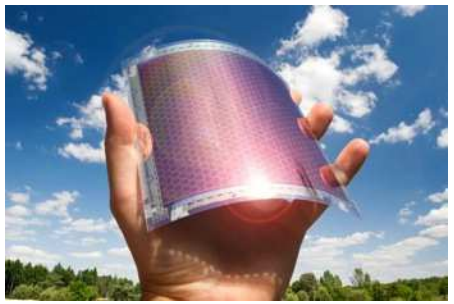
Flexible sensors

Holst Centre: Large area flexible electronics

flexible displays

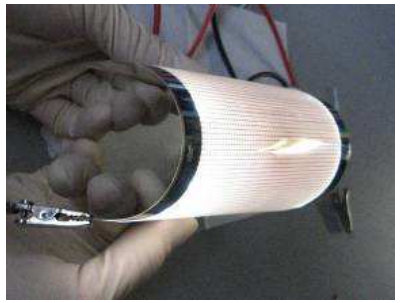


flexible solar cells



flexible lighting devices (OLEDs)

Future: add sensors



food and medicine monitoring sensors

health patches

Flexible Sensors

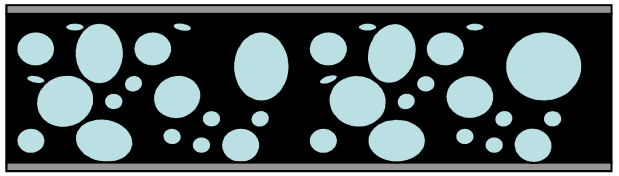
Holst Centre
Open Innovation by IMEC and TNO

- Polymer based:
    - PVDF family (processing – T range)
- Semiconductor based:
    - Limited functionality / temperature range
    - Complex / fragile
    - Limited flexibility
- Ceramic based:
    - Expensive – difficult to produce
    - Fragile – low shock resistance - flexibility
    - Difficult to integrate in product

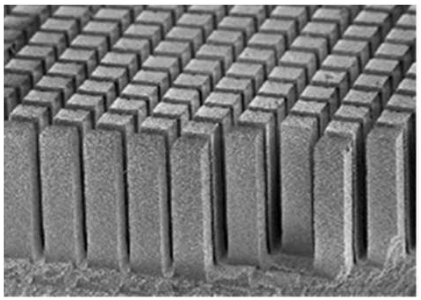
- **Need for flexible sensors → functional electroceramic material composites**

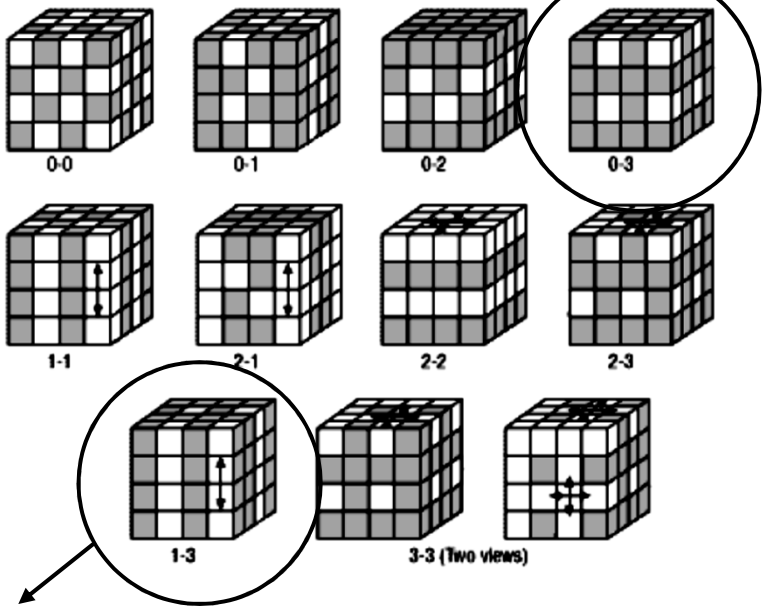
Types of composites

- Ceramic – Polymer composites



0-3, Sensors

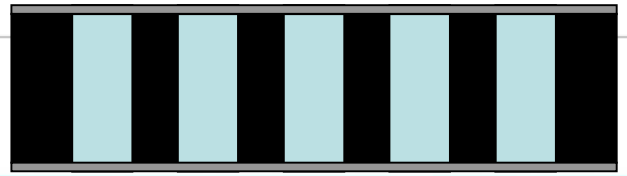




Ceramic

Polymer matrix

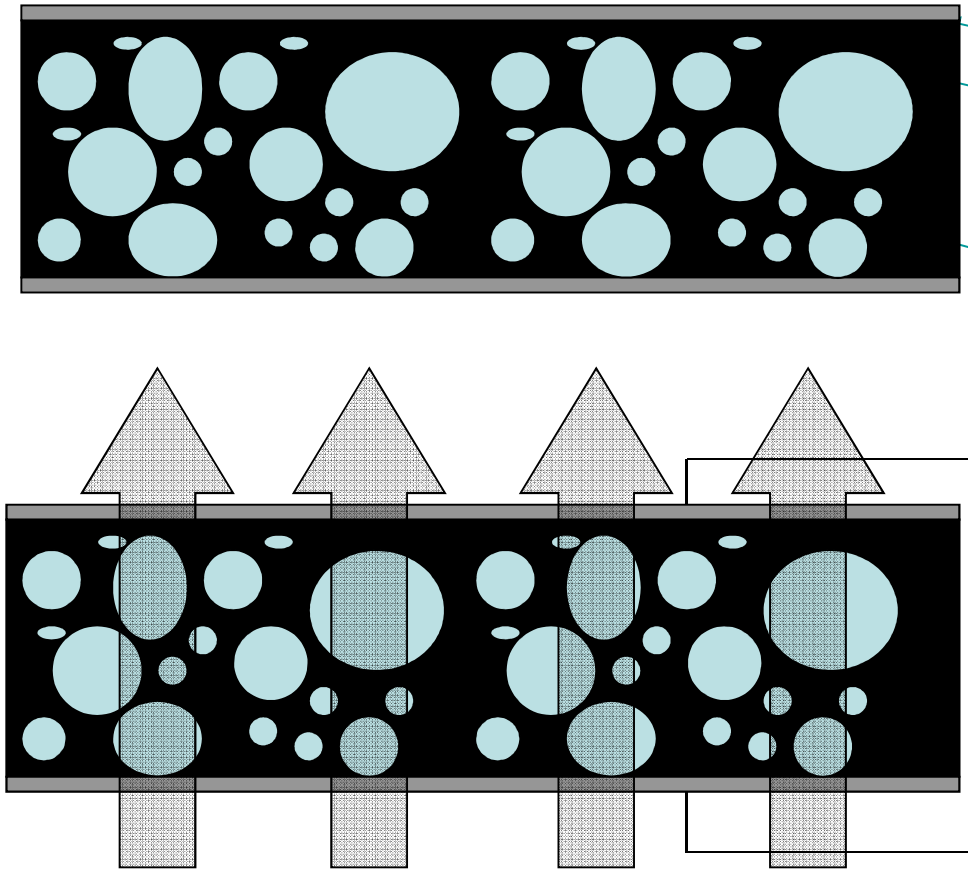
Electrode



1-3, Transducers

RE Newnham, DP Skinner, LE Cross, Mat. Res. Bull, 1978

Dielectrophoresis in piezoelectric composites



Electrode

PZT Particle

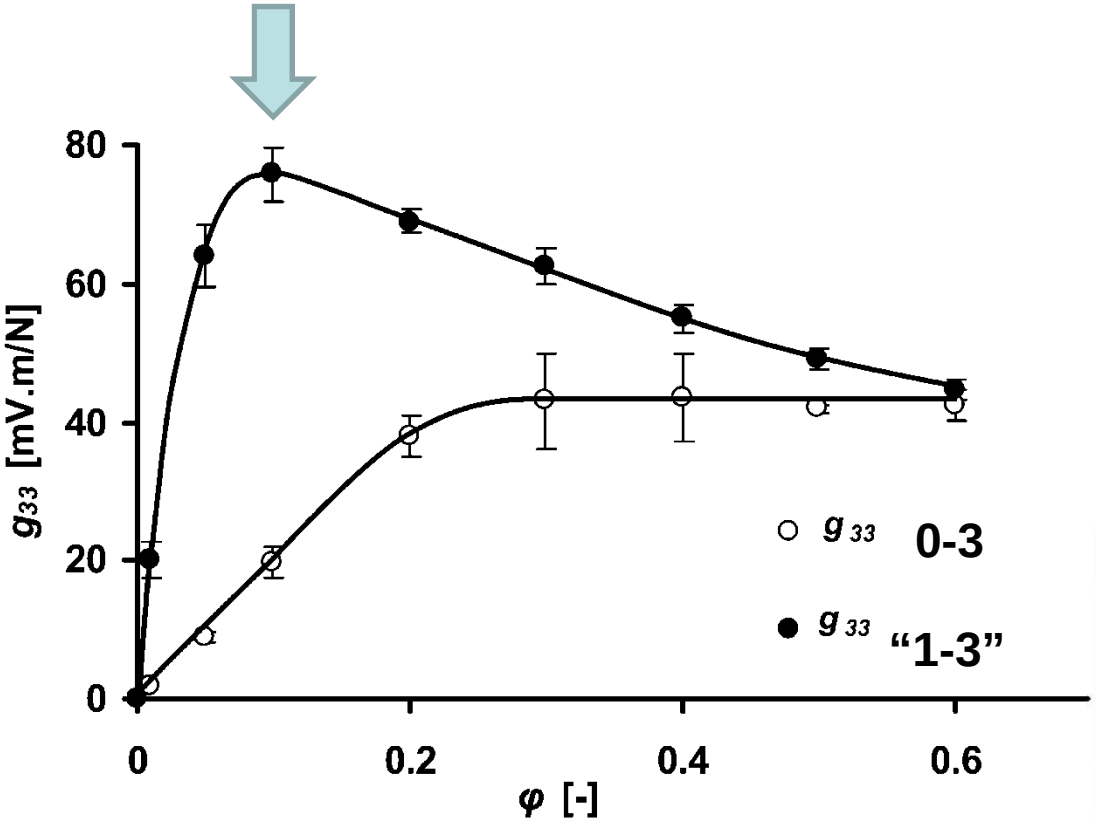
Polymer Matrix
(Uncured Thermoset)

Apply AC field

Cure Thermoset matrix

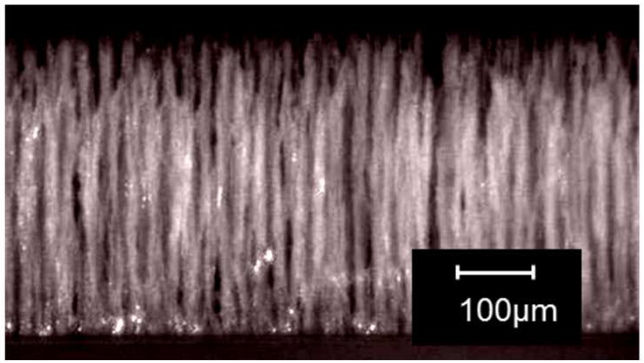
Poling (DC)

Piezoelectric composites
31 composites: DEP results, g_{33}



$$g_{33} = \frac{d_{33}}{\varepsilon_0 \varepsilon_r}$$

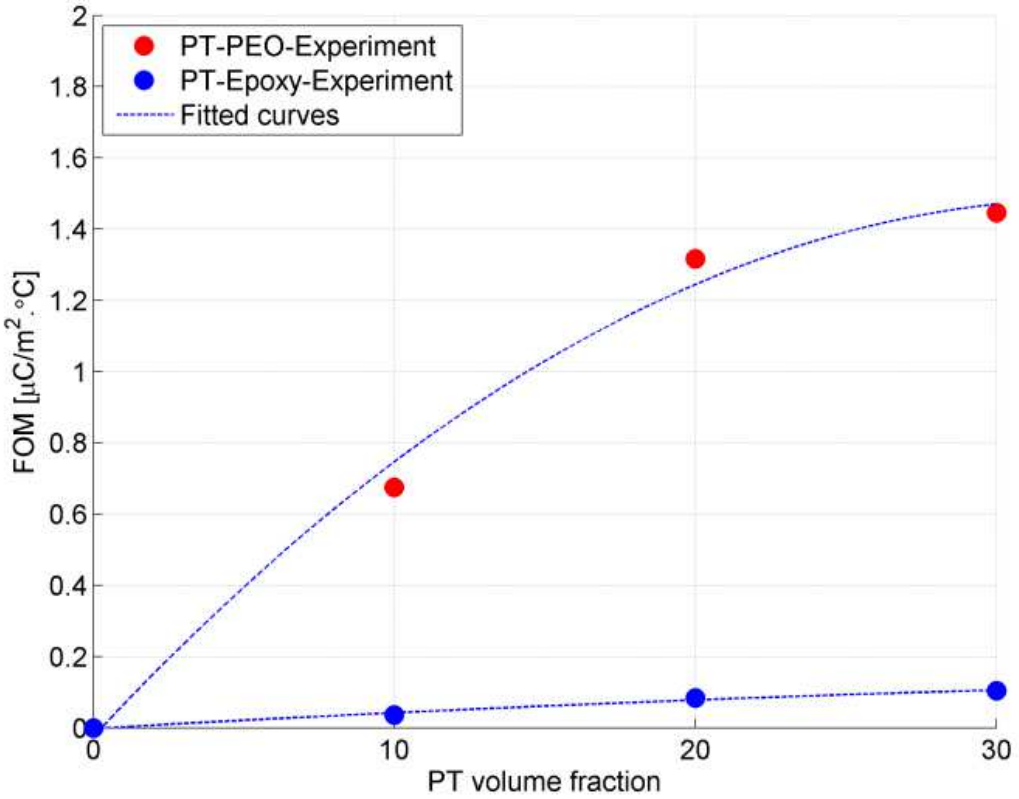
5vol% PZT – Epoxy
(stereo optical Microscope image)



Van den Ende et al., Appl. Phys. 2009

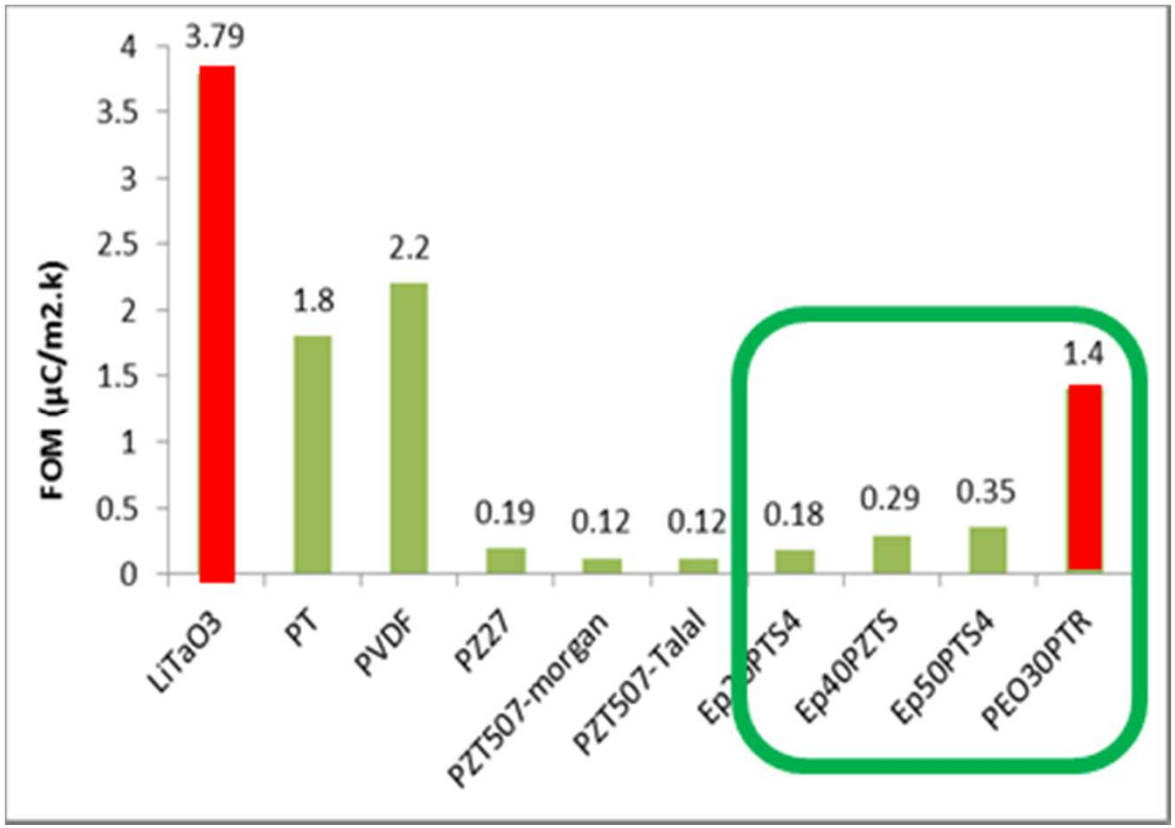
Pyroelectric properties

PT-Epoxy vs PT-PEO composites

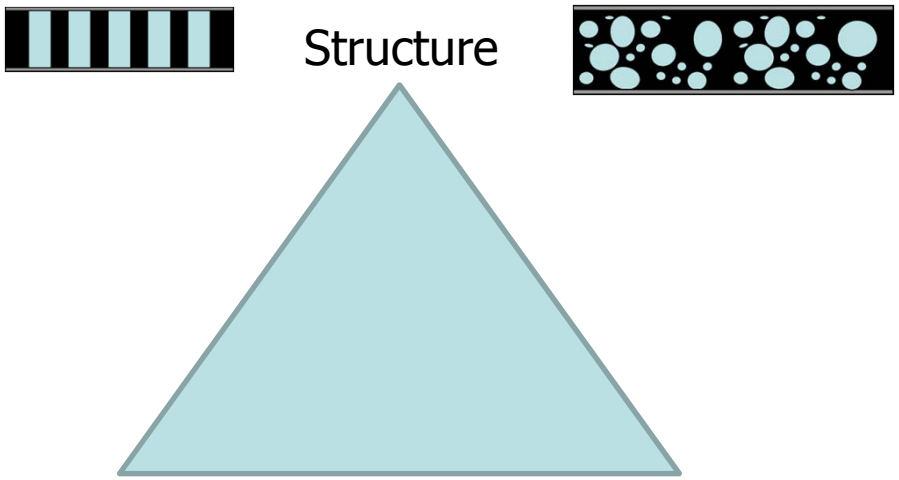


Pyroelectric properties

PT-Epoxy vs PT-PEO composites



- Flexible functional composite materials can be made with wide range of properties

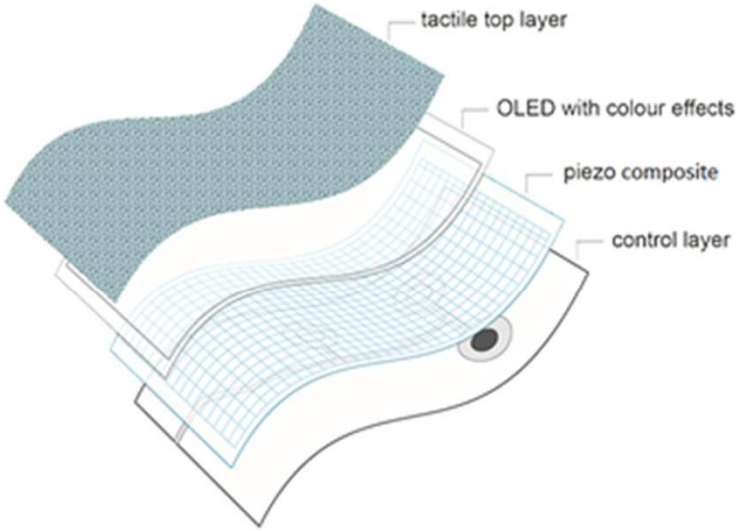


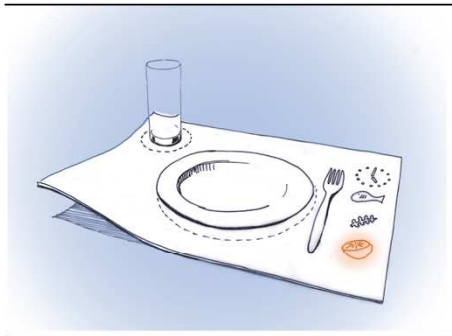
Holst Centre

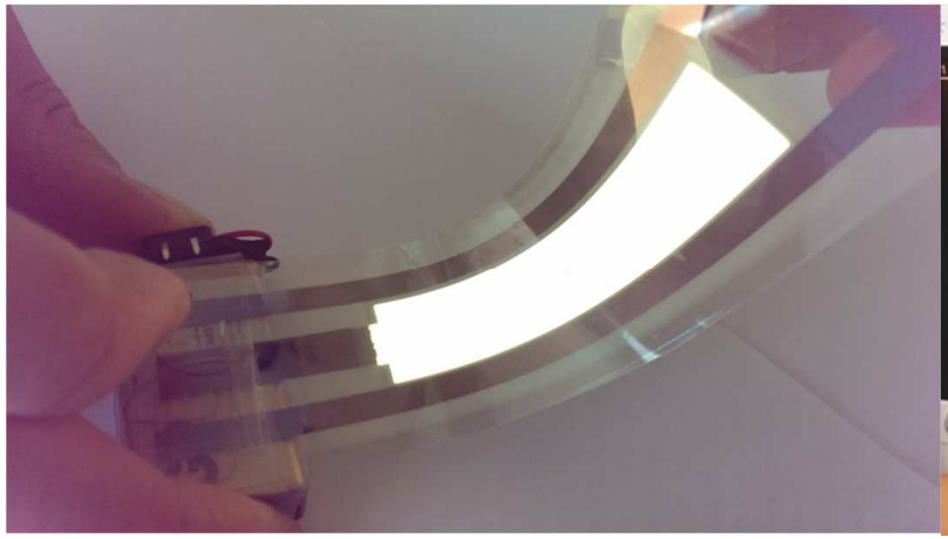
Open Innovation by IMEC and TNO

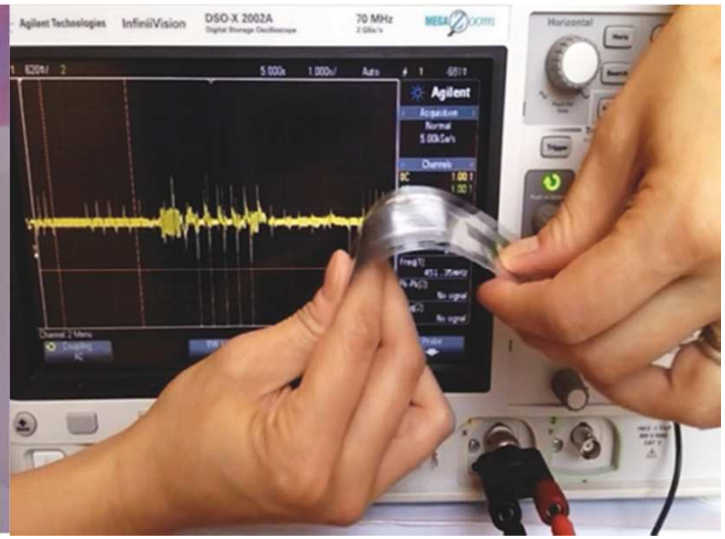
More integration

EU project:
4 materials partners +
12 design companies



			
Smart placemat to improve people's diet	Wristband for reminders and feedback	Force-sensitive grip for expressing anxiety	Intuitive interface for Emergency defibrilator





Conclusion

Printed electronics:

exciting field growing from simple printed PCB's

to integrated complex products

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no 281027 and 310311

CLEAN4YIELD
DETECTION • CLEANING • PREVENTION • REPAIR

light.touch.matters
the product is the interface