Functional material engineering: From printed interconnects to functional coatings

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INSTITUUT VOOR MATERIAALONDERZOEK

IMO **IMOMEC**

Research mission: New and innovative materials for a sustainable and healthy future (energy production, energy storage, healthcare …)

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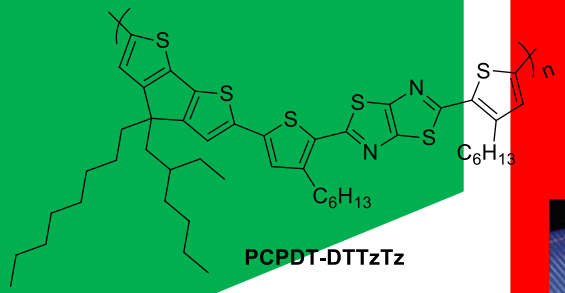
The Printed Electronics Value-Chain

Materials

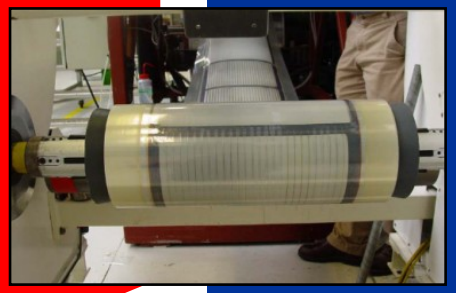
- Polymers
- Small molecules
- Metal oxides
- Nanostructures
- Diamond
- …



PCPDT-DTTzTz

Physics

- Characterization
- Device Physics
- Prototypes
- Modelling



Processing & Reliability

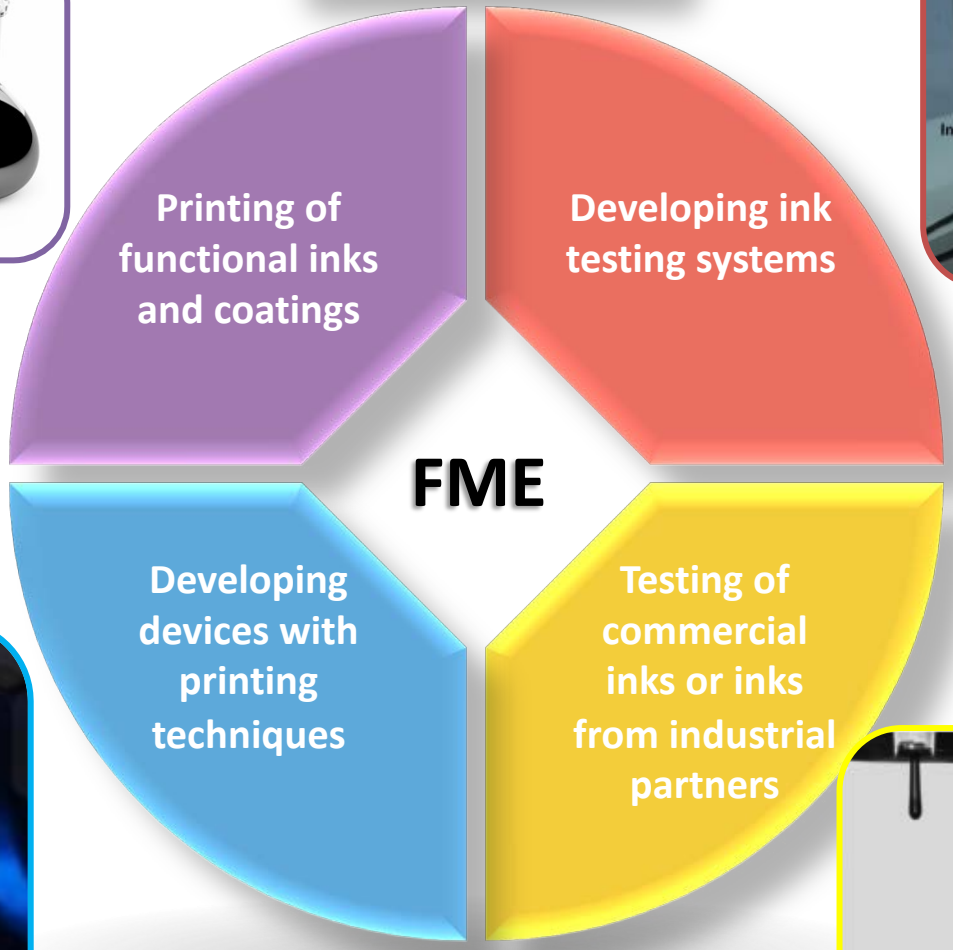
- Printing
- Lifetime

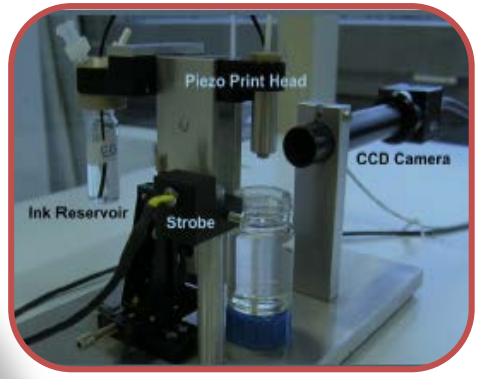
Valorization:

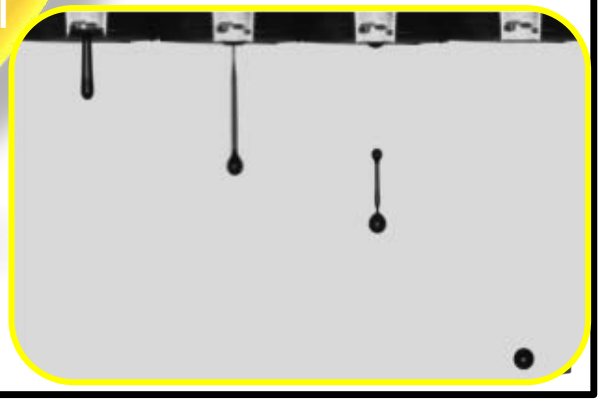
- Innovative clean-tech region
- Science parks
- Tech.Transfer Office

Functional Materials Engineering Group

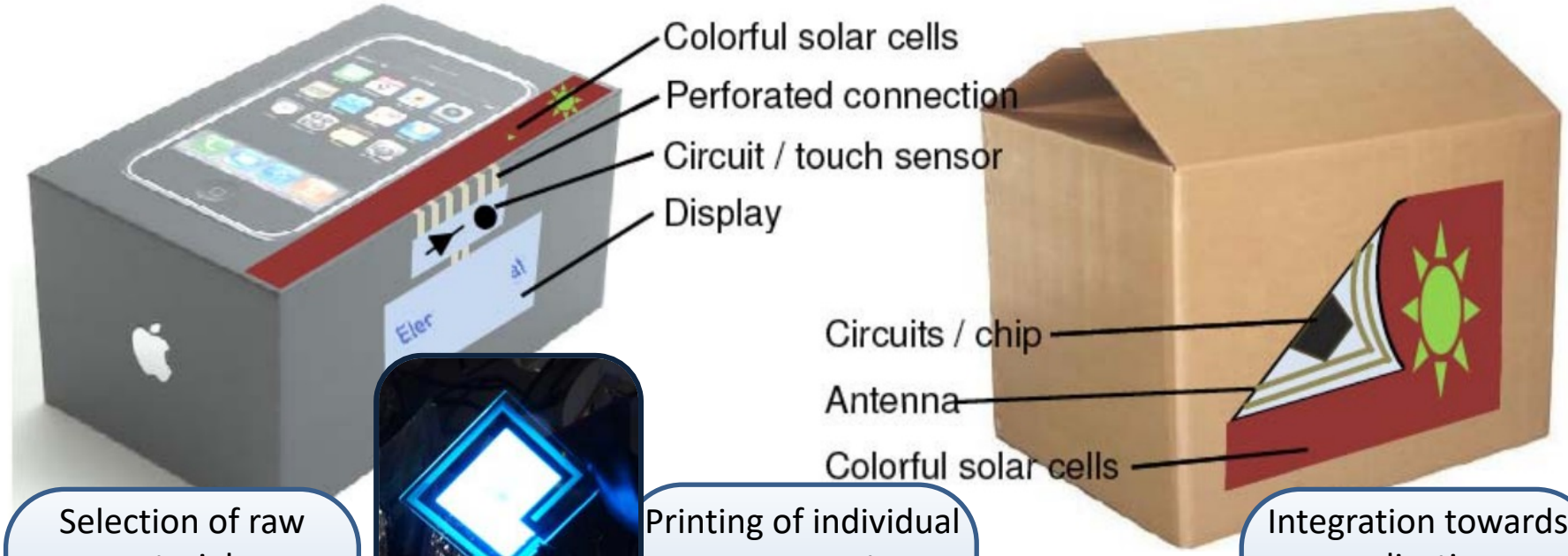
Activities







Outline

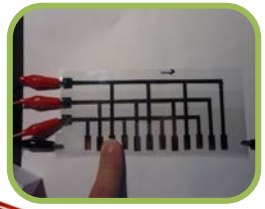


Selection of raw materials:

- Substrate: fiber-based, foil
- Functional ink: conductive, light emitting, barrier …

Printing of individual components:

- Sensor: T(°C), pH, R (Ohm)
- Energy: solar cell + battery
- RFID
- Actuator
- Protective layer



Integration towards application:

- Track and trace
- E-commerce and advertisement
- Safety

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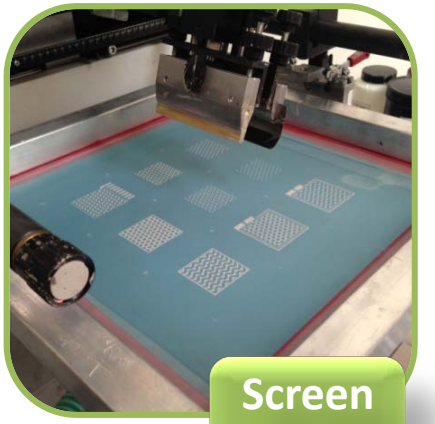
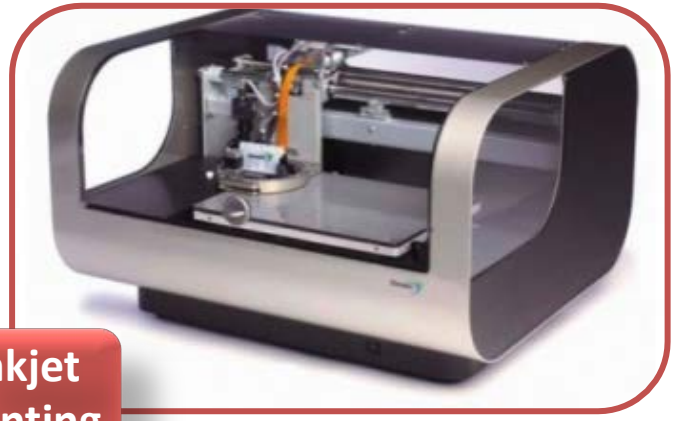
Techniques

Spin coating



Screen printing



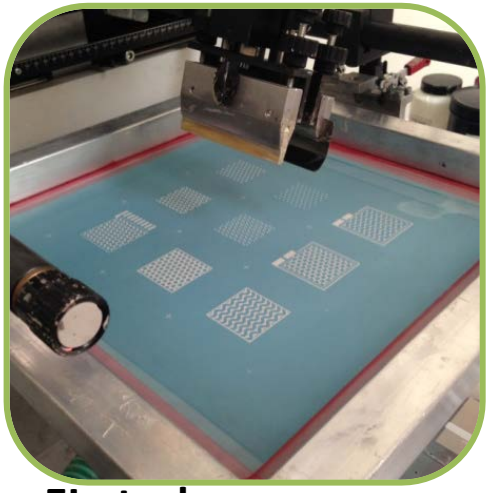
Inkjet printing

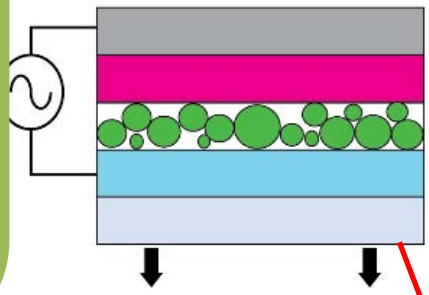
Thermal evaporation

Ultrasonic Spray coating

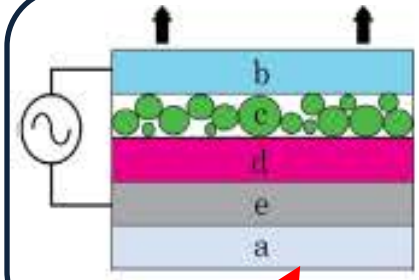
Screen Printing

Screen printing is a technique whereby a mesh is used to transfer ink onto a substrate, except in areas made impermeable to the ink by a blocking stencil. A blade or squeegee is moved across the screen to fill the open mesh apertures with ink, and a reverse stroke then causes the screen to touch the substrate momentarily along a line of contact. This causes the ink to wet the substrate and be pulled out of the mesh apertures as the screen springs back after the blade has passed.

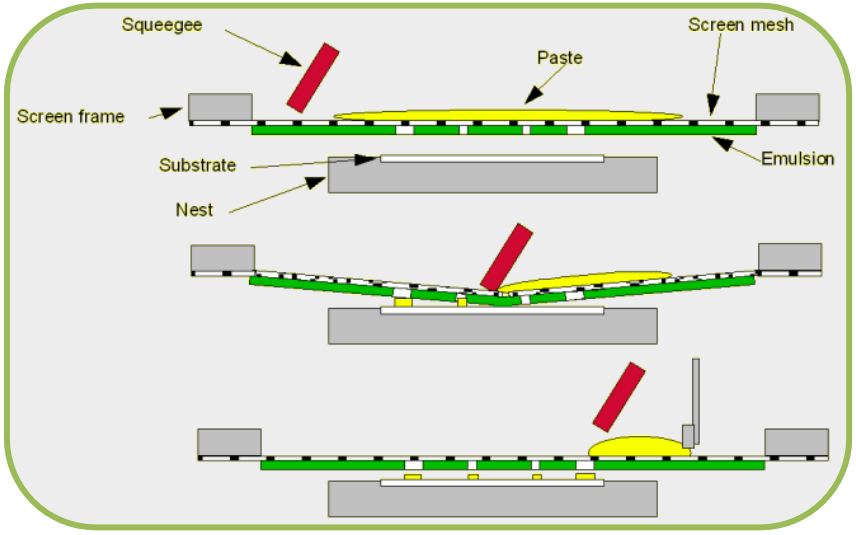




EL stack



PEDOT PSS
Phosphor layer
Dielectric
Ag layer
Textile



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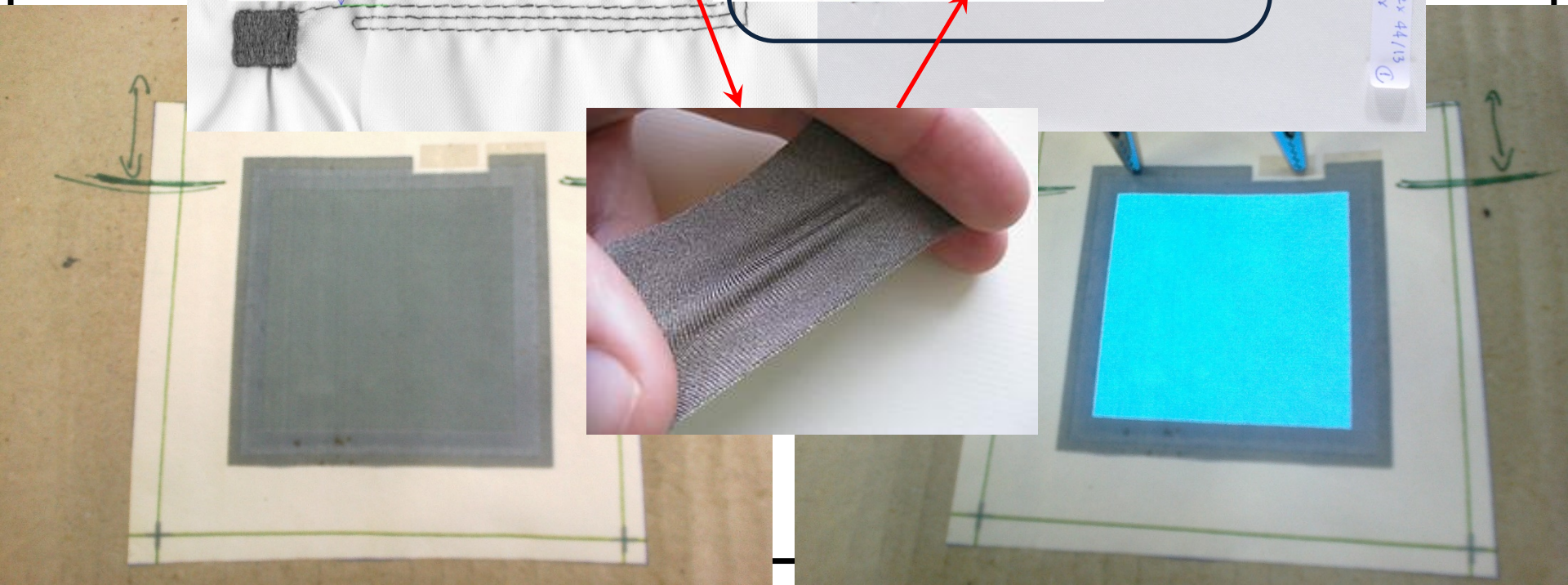
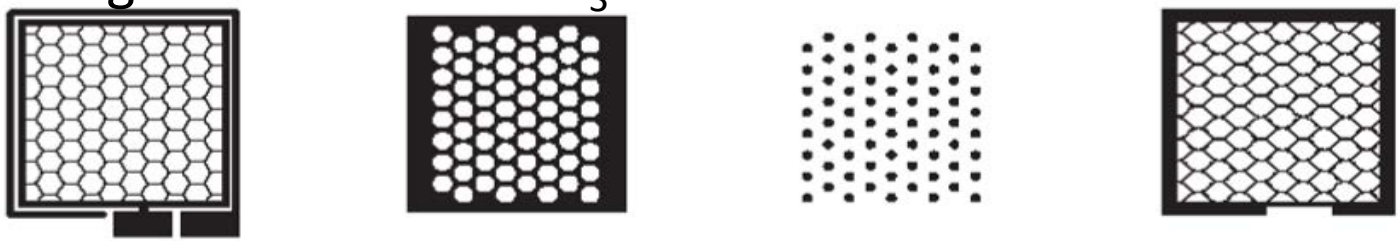
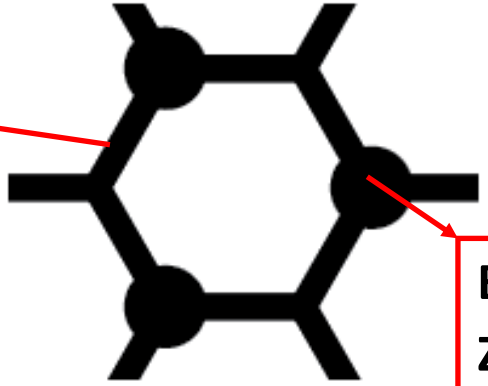
Screenprinting ACPEL



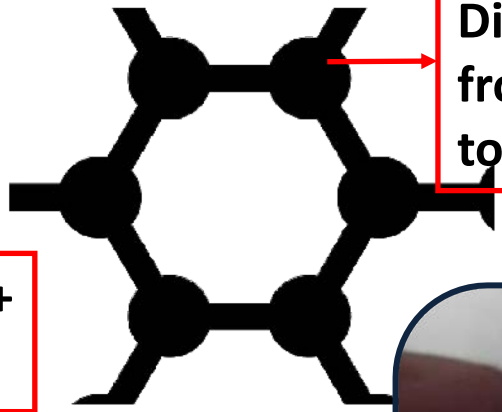
Screenprinting ACPEL

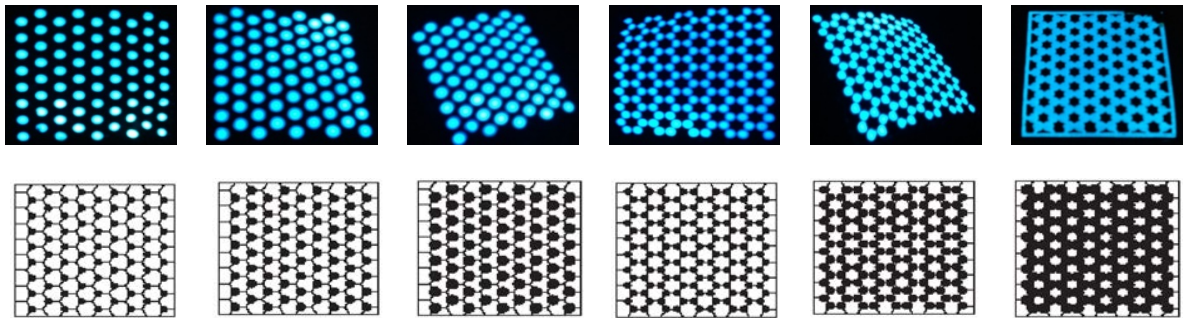


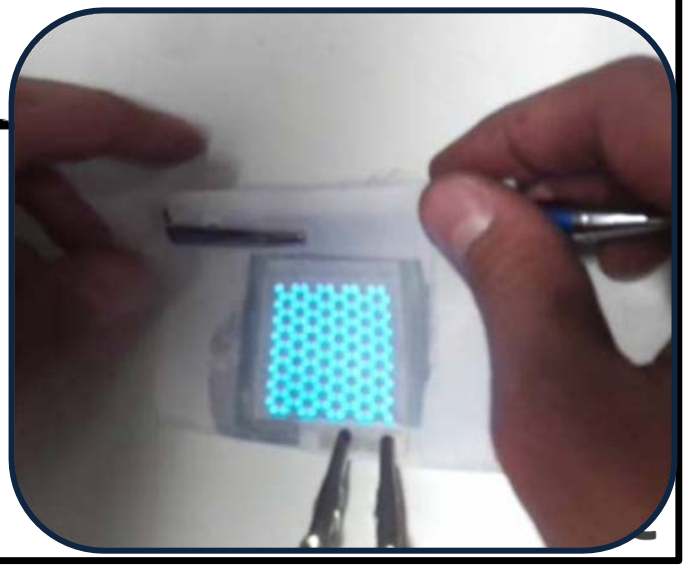
Single (3 EL dots)



Dual (6 EL dots)



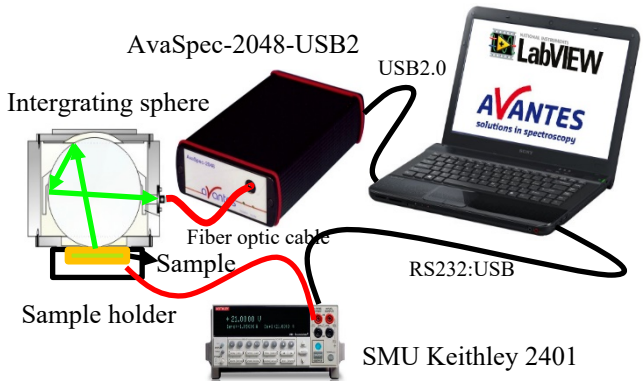




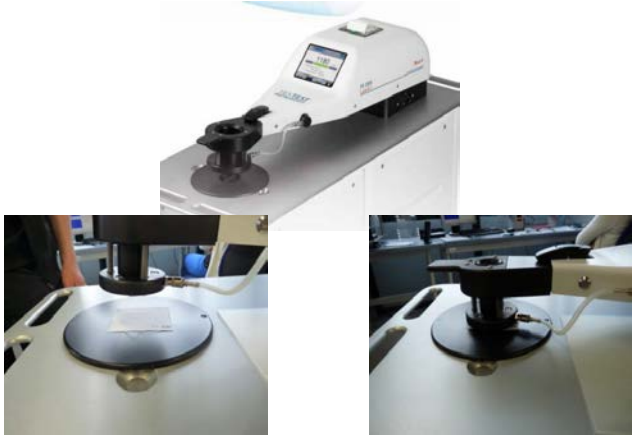
Deferme et.al. – in publication

Screenprinting ACPEL

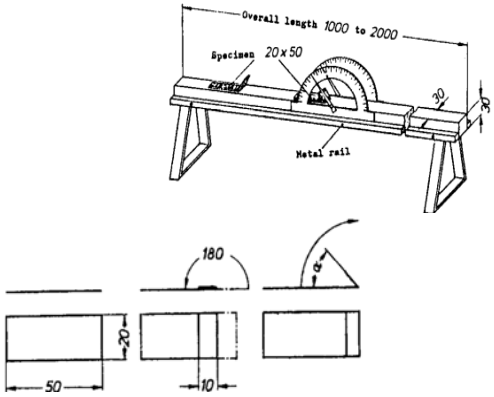
Light Output

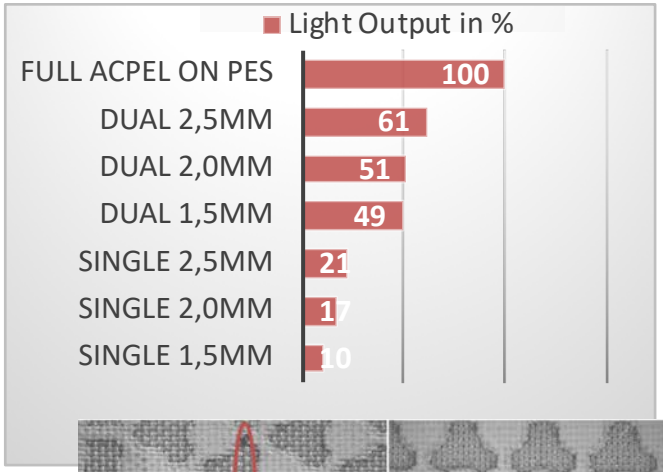


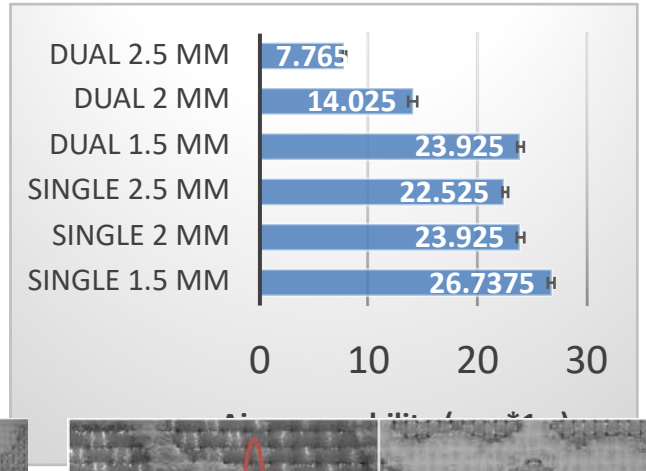
Air Permeability

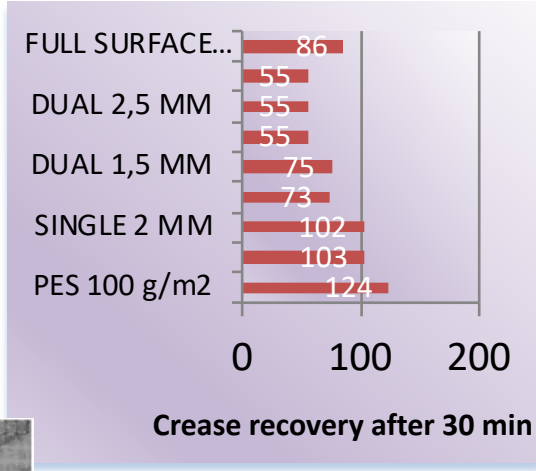


Crease Recovery

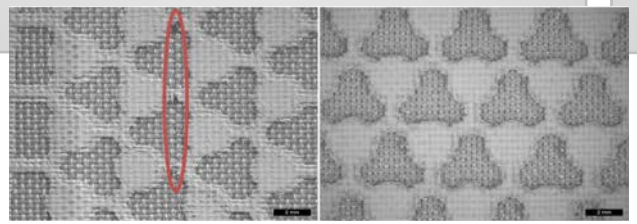


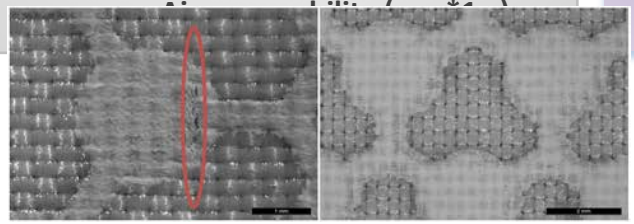






Crease recovery after 30 min





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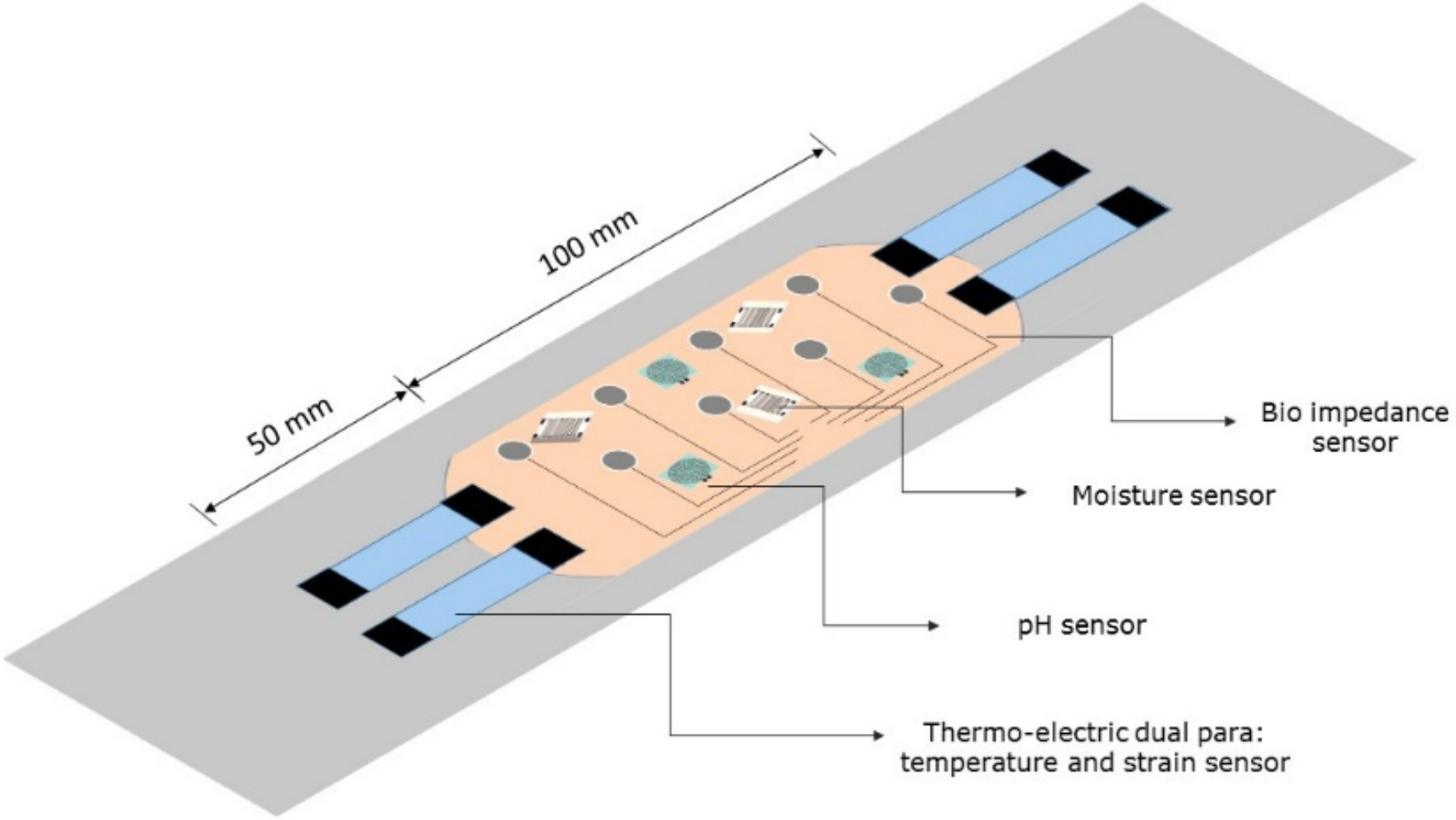
Multi-sensory array for Wound Management



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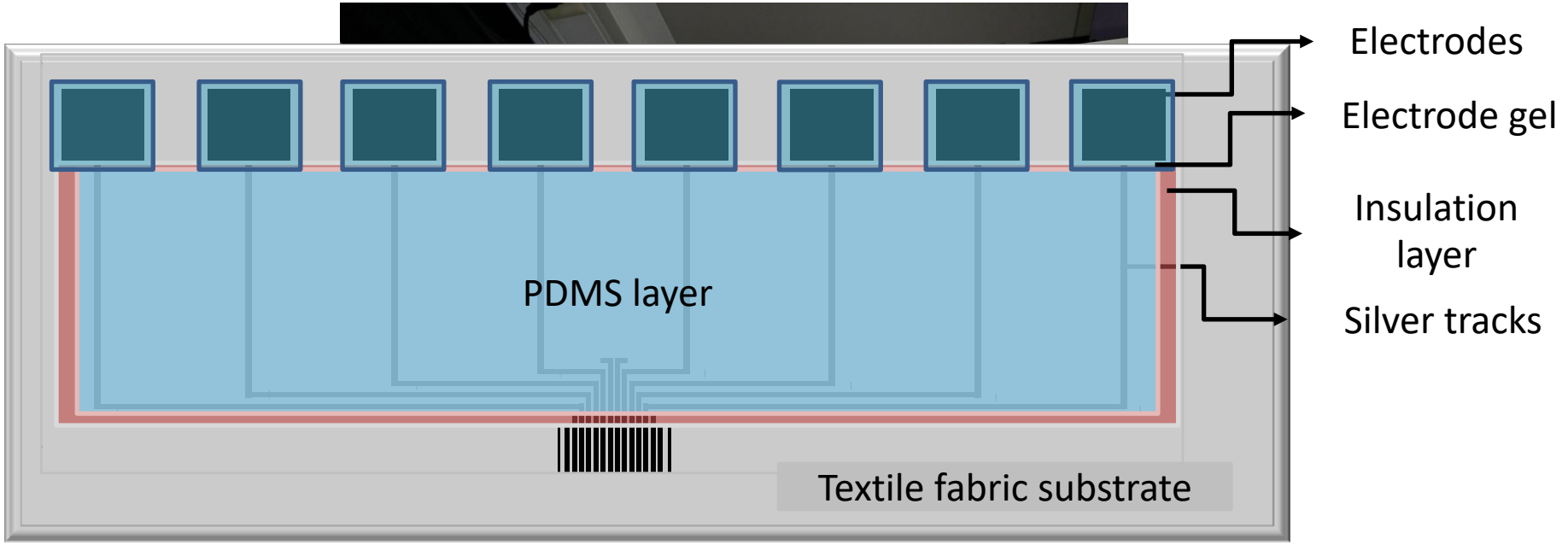
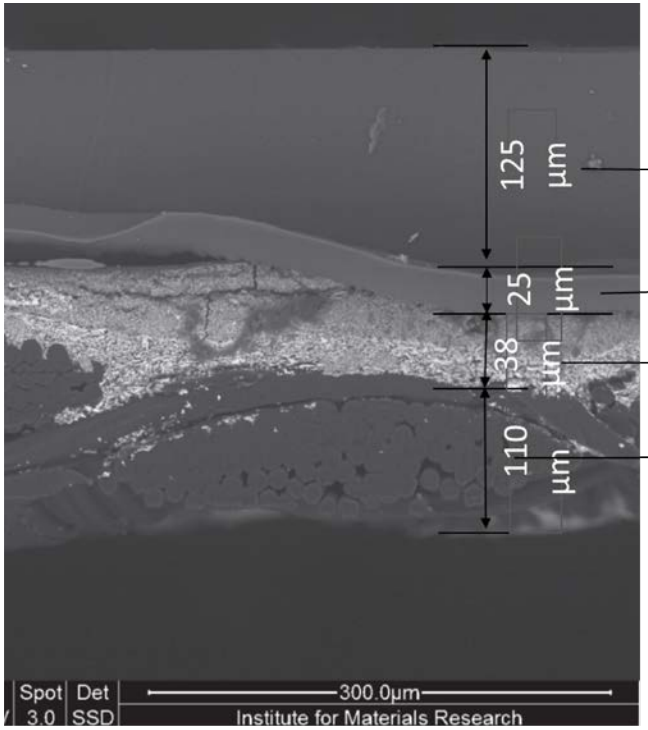
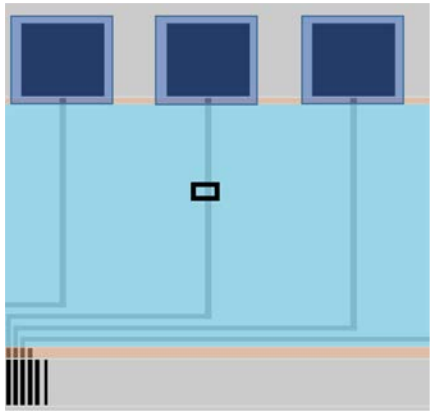
Bio-impedance sensor



Bio-impedance sensor

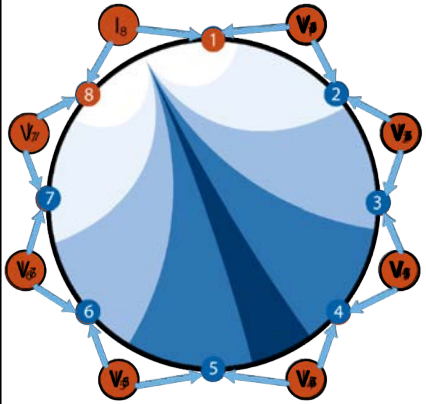


SEM image of the cross section

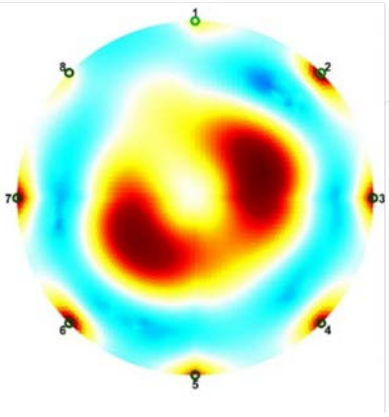


Bio-impedance sensor

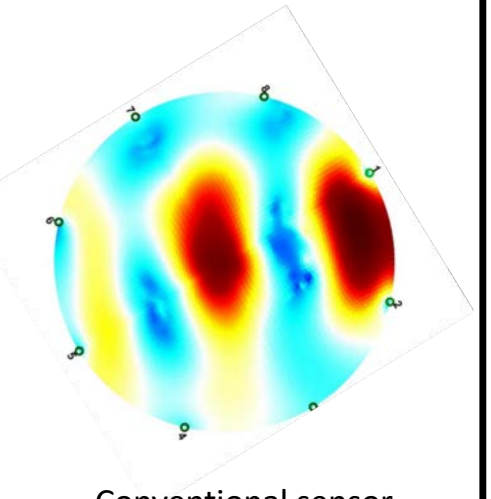
Measurements used MUSEIC V2.0 board and an algorithm based on EIDORS software base under the GNU public licence



Cross section of human forearm

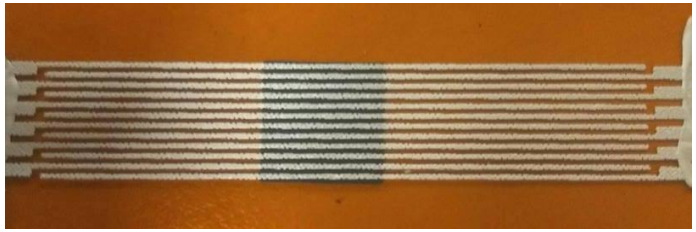


Printed sensor, 8 KHz

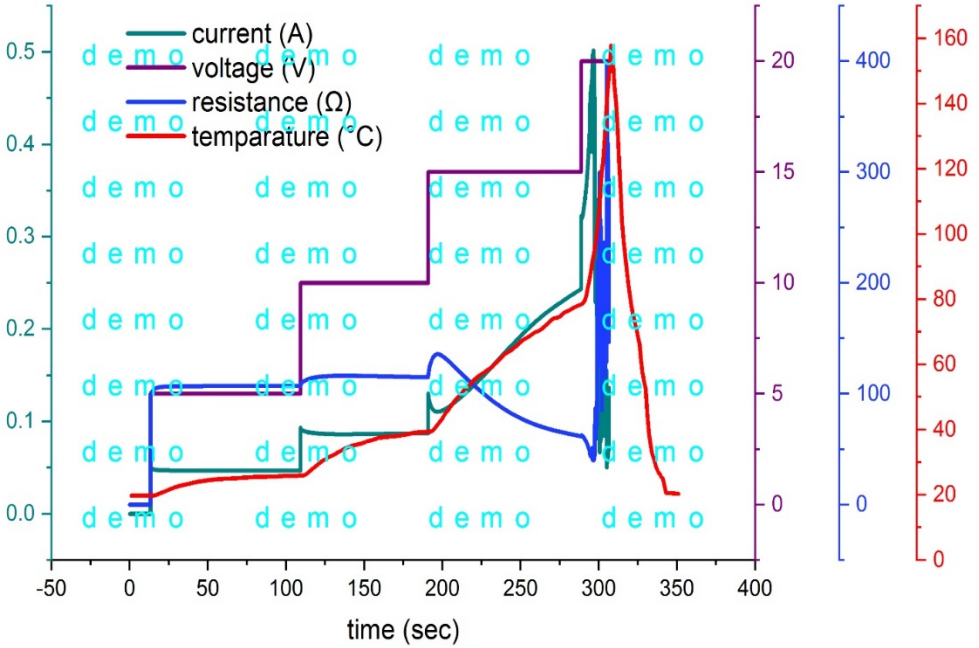


Conventional sensor based on ECG patches, 8KHz

Moisture sensor: self regulating heaters



- Interdigitated Silver supporting structures with self regulating carbon coating (Loctite ECI 8000 PTC) designed for the temperature of around 60 °C
- Self regulating property by adjusting resistance in the carbon layer
- It can be seen between 200 sec to 300 sec



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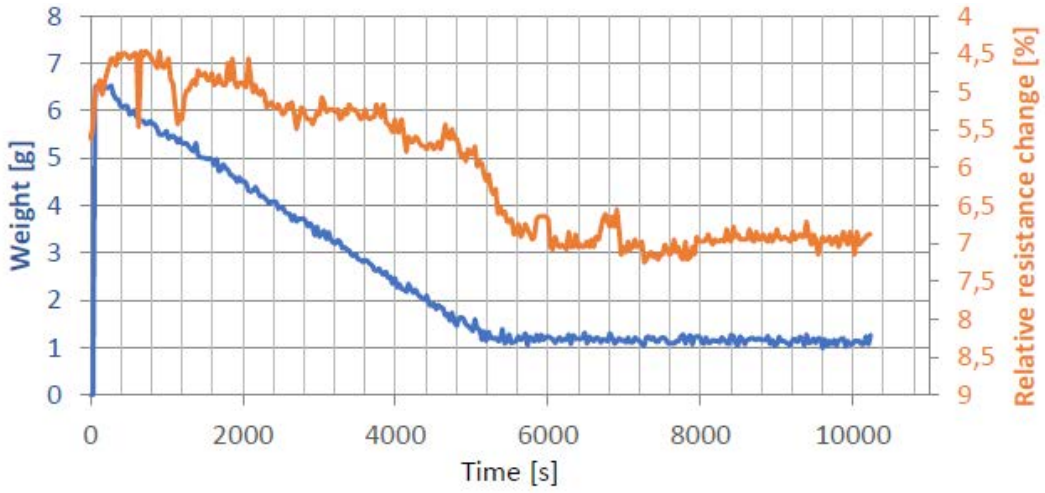
Moisture sensor

Moisture content measurement using self regulating heaters for wearable applications



Moisture content (in grams) measurement with relative resistance change over time

Self regulating heaters printed on the polyamide foil to monitor the moisture content induced changes in the resistance .

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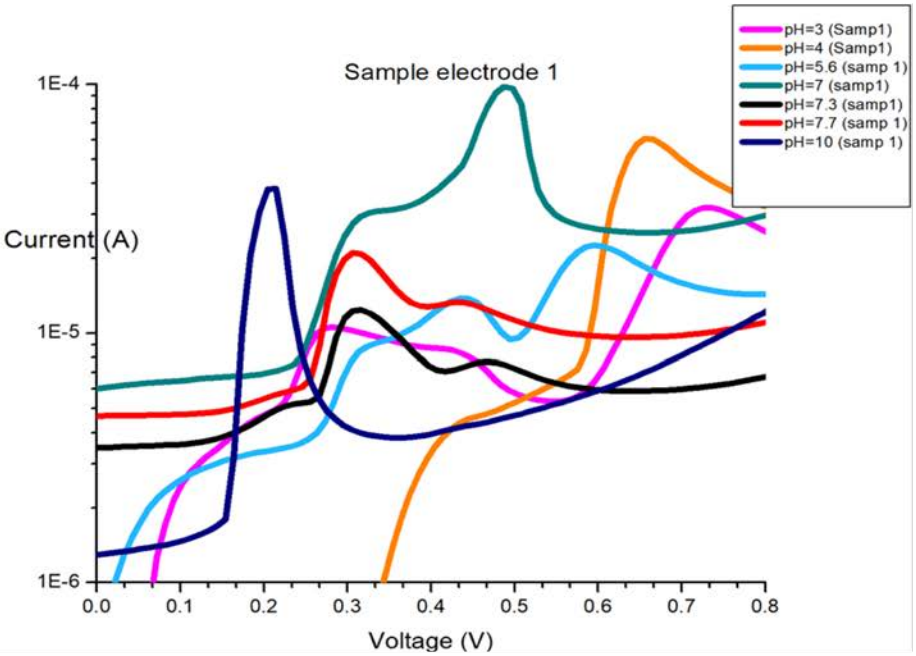
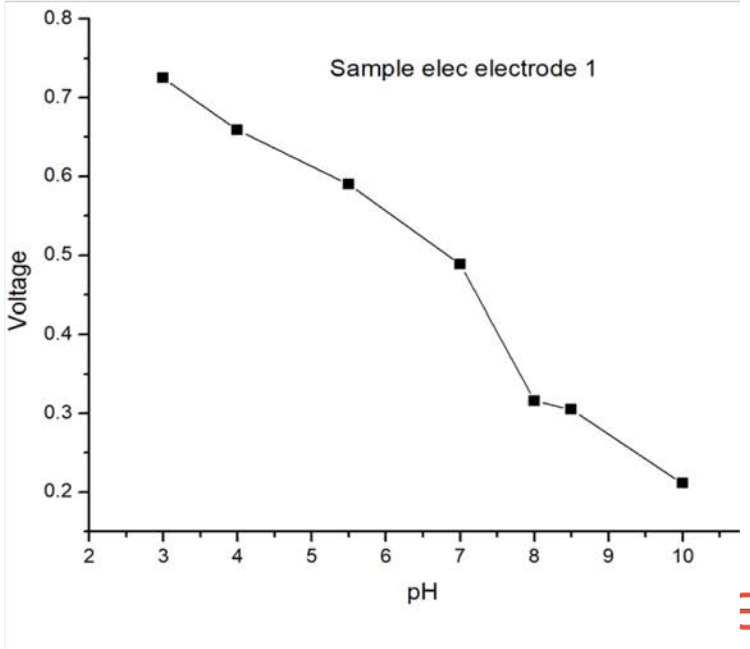
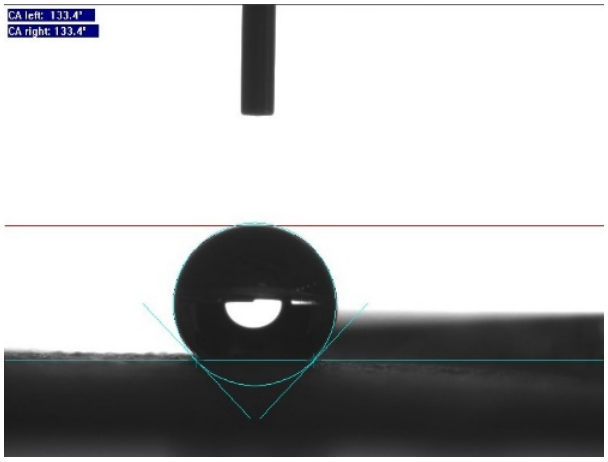
pH sensor

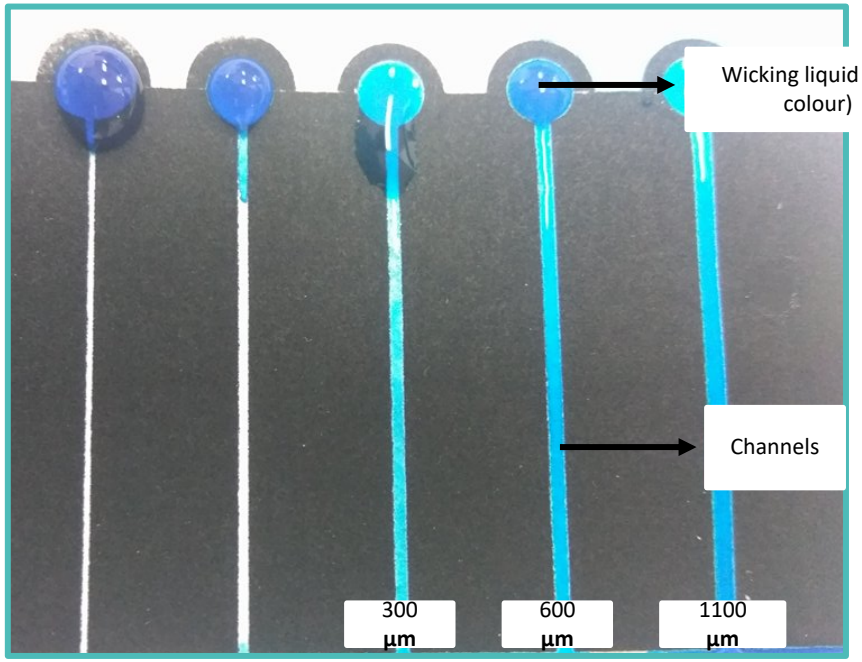
- Cyclic Voltammetry
- PF-407 Carbon paste milled with Alizarin
- Milling procedure is most important
- Yet to make completely printed (Reference and counter electrode need to be printed)





Printed functionality- microfluidic channels





- Microfluidic channels on paper (1 mm X 50 mm)
- Screen printed with conductive carbon paste
- Contact angle above 130 degrees
- Need to improve the print line definition
- Printing channels back to back on a wicking paper?

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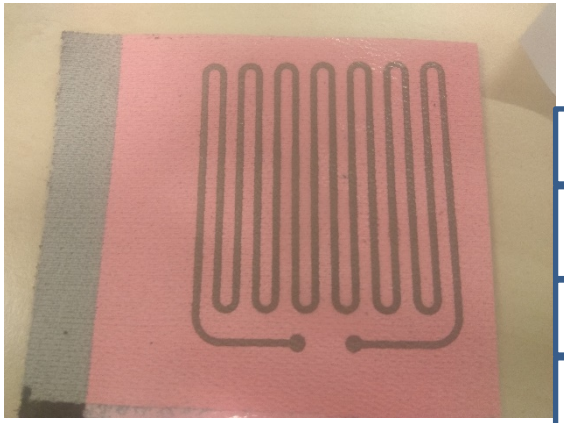
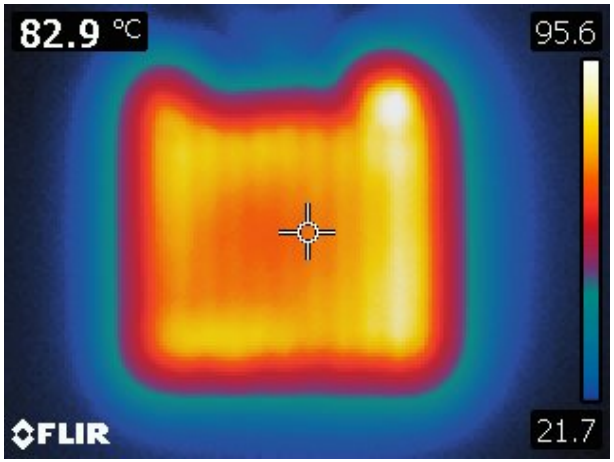
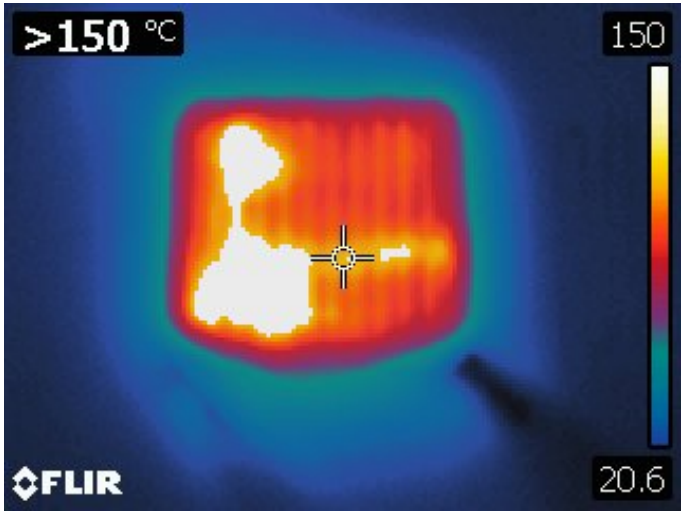
Printed heater



Layer stack

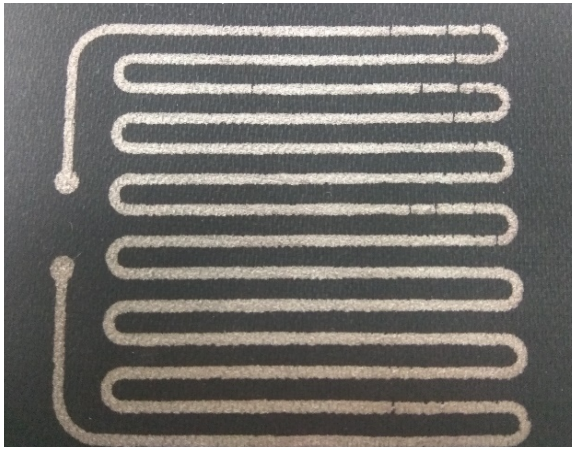
- PDMS coating
- Silver screen printed
- Dielectric layer
- Substrate





Layer stack

- PDMS coating
- Silver screen printed
- Low conductive carbon paste coating
- Substrate



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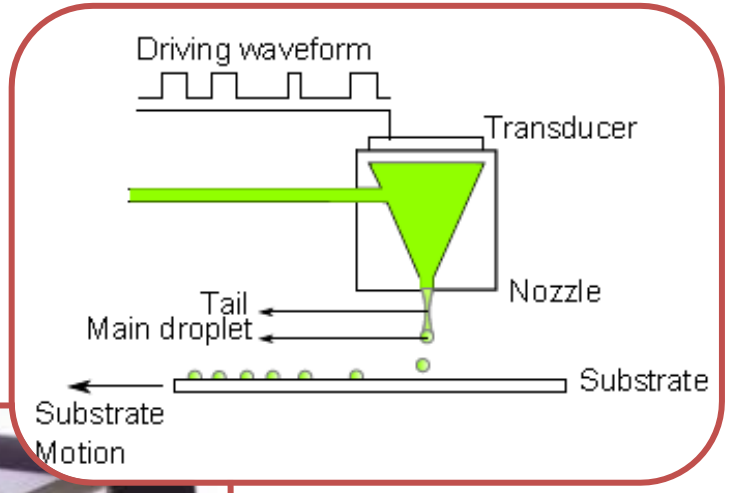
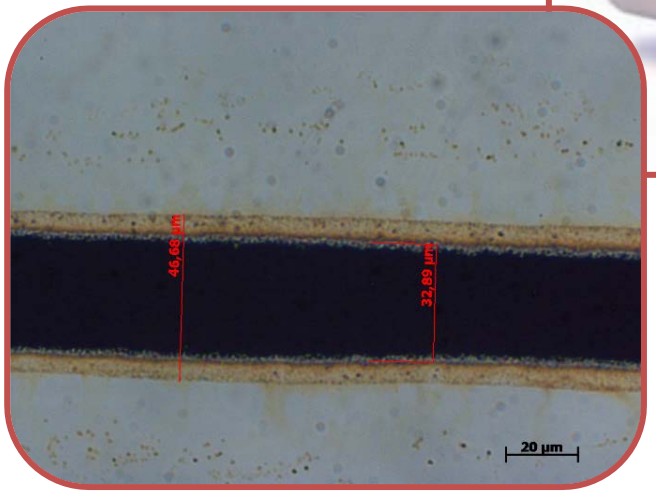
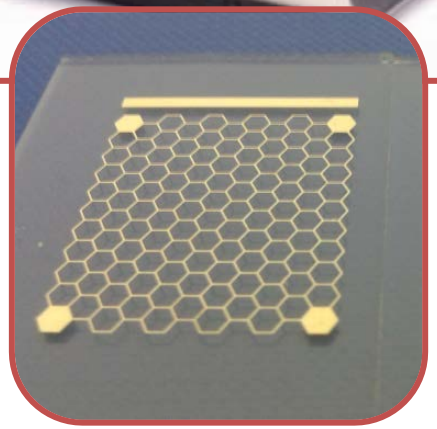
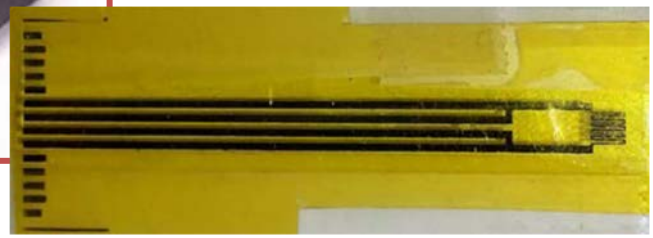
Drop-on-demand Inkjet Printing

The Dimatex ink jet printer uses a piezoelectric drop-on-demand ink jet technology.
This technology uses a piezoelectric material that is placed at the back of the ink reservoir of each nozzle. When a voltage is applied the material changes shape, resulting in a pressure wave forcing the droplets to eject the nozzle.









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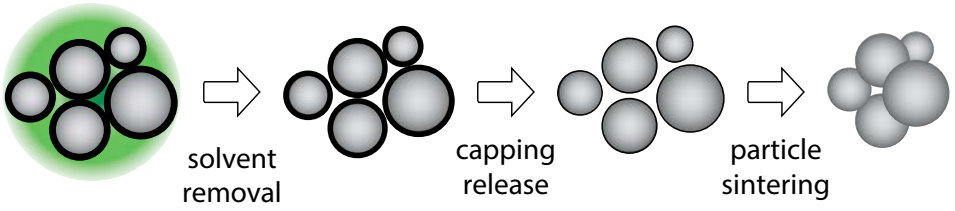
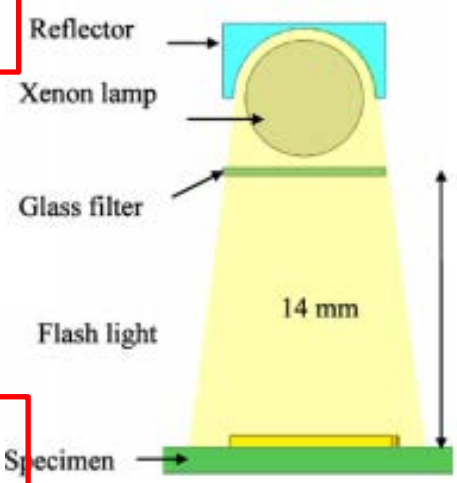
Met@lInk: Nanoparticle vs. MOD inks

Nanoparticle based inks

Ag nanoparticles capped with a polymer layer



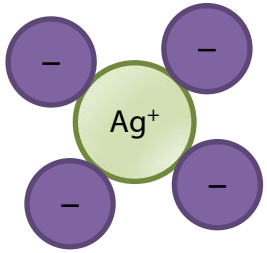
"high" temperature
> 200 °C



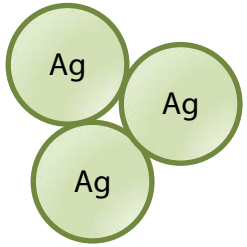
low temperature
60 °C

Molecular precursor inks

Ag molecules stabilised with counterions



counterion removal



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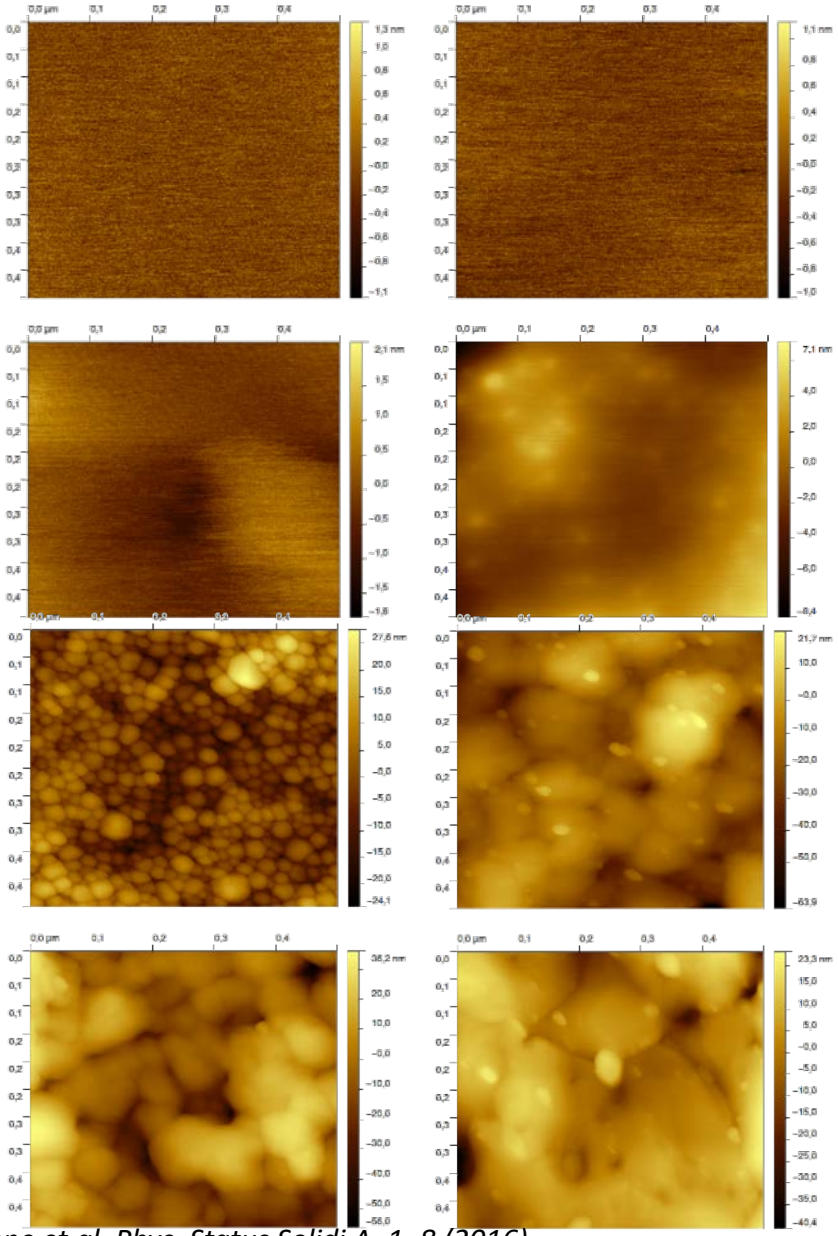
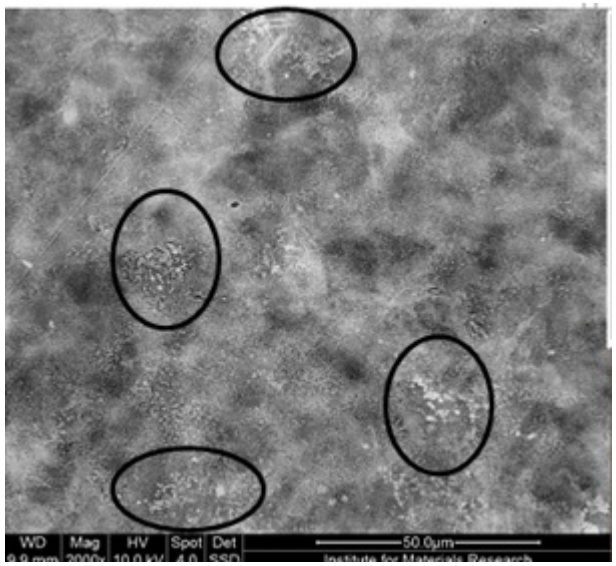
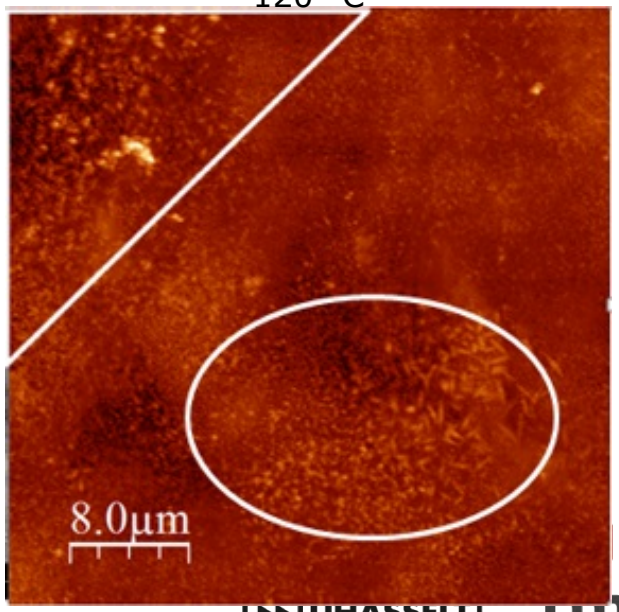
Nanoparticle vs. MOD inks





120 °C



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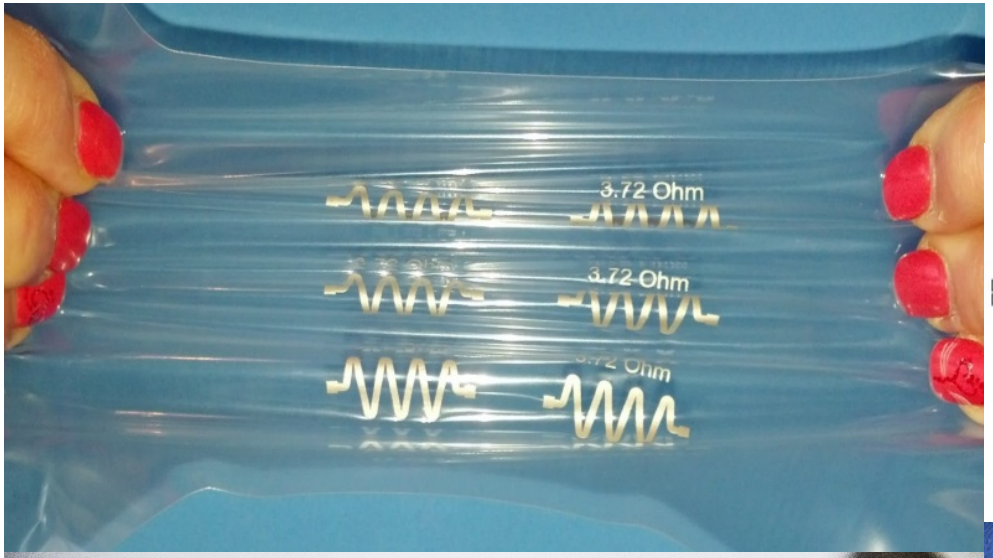
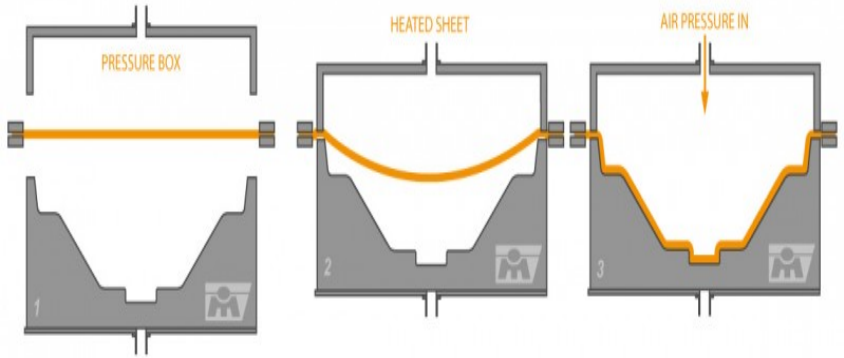
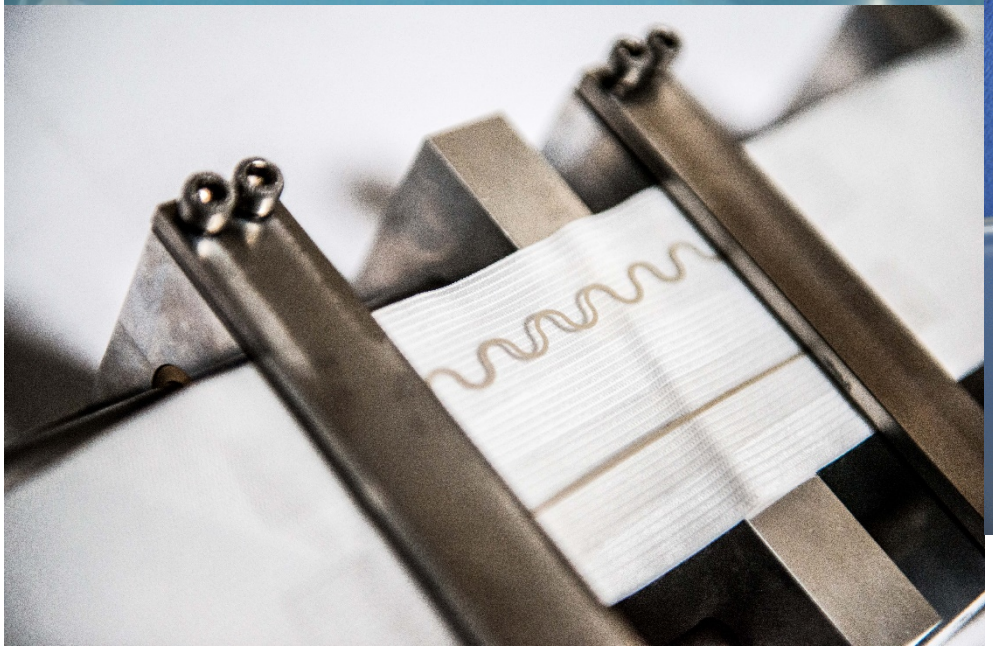
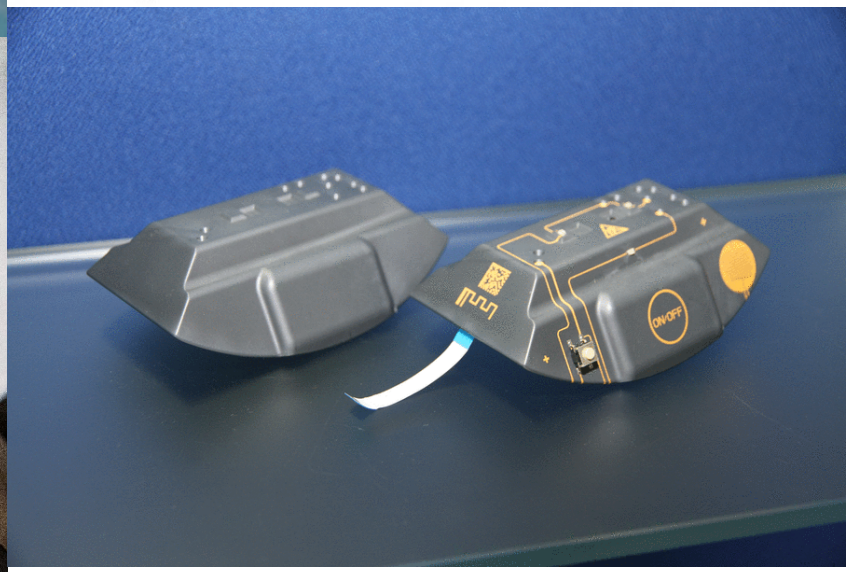
3D-Elektroprint: One-time deformable









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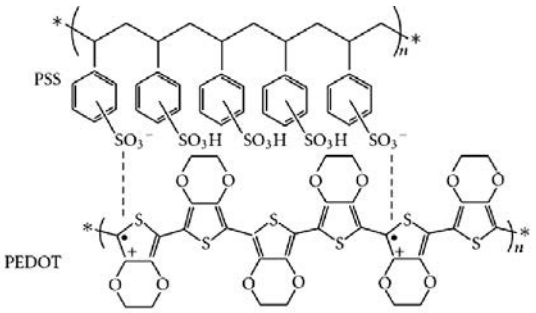
3D-Elektroprint: One-time deformable

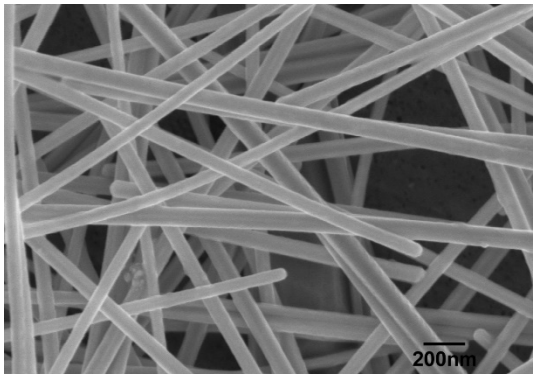
- PEDOT:PSS

Conductive polymer



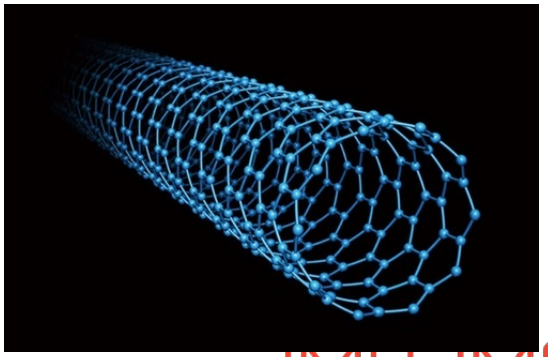
- Silver nano-wire

Nano-structure

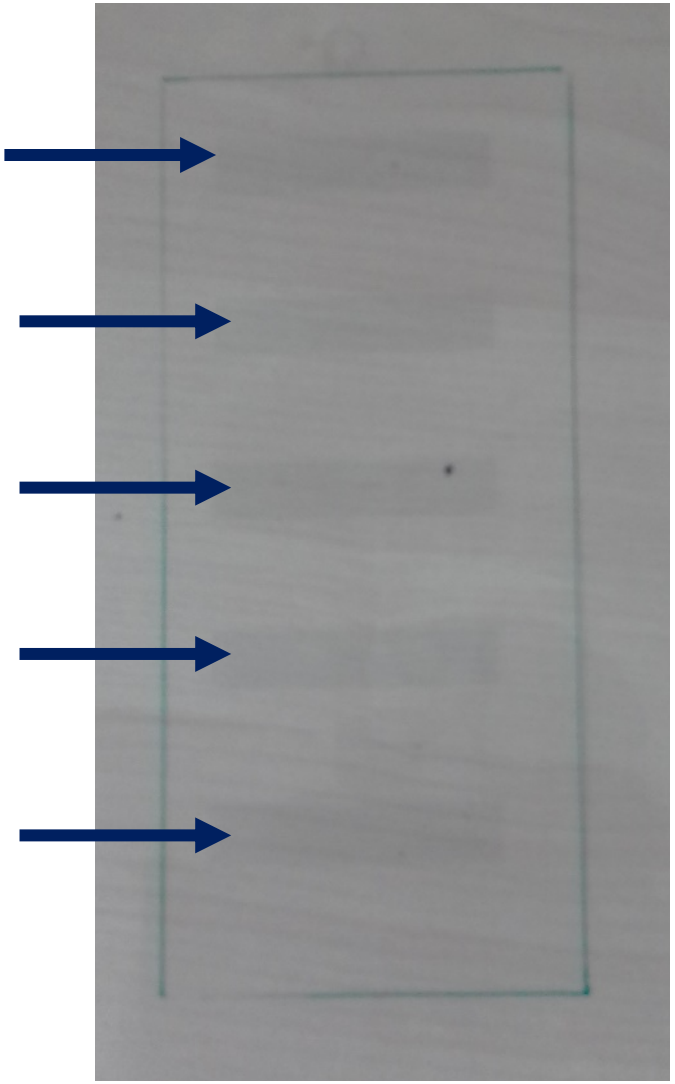


- Carbon nano-tube

Allotropes of carbon with a cylindrical nano-structure



3D-Elektroprint: One-time deformable



50X10 mm^2 rectangle was printed with our developed PEDOT:PSS and sintered within oven at 100^0C for 10 minutes.

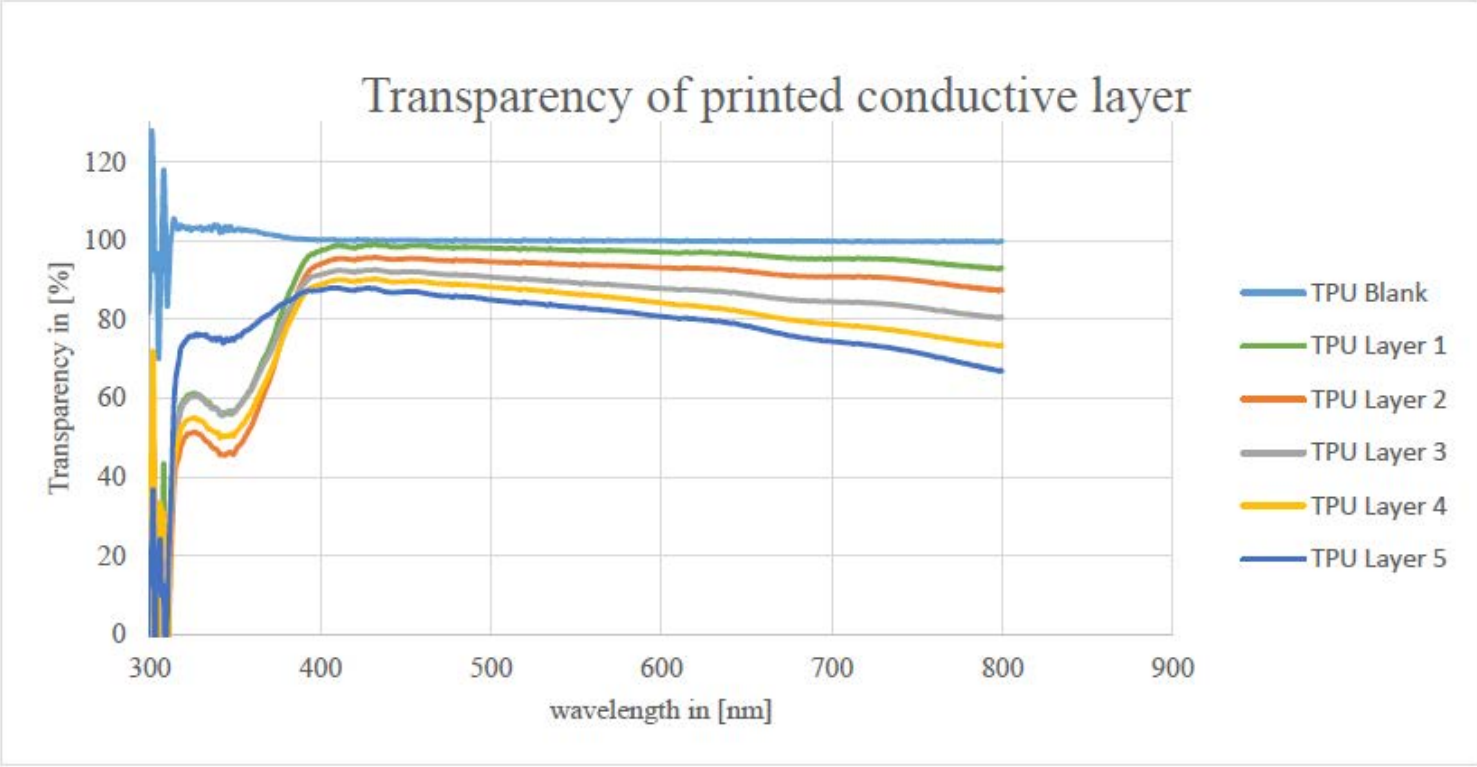
Characterization of the printed layer

- Conductivity
- Surface morphology
- Transparency
- Conductivity after stretching

Integrate on cone by vacuum forming method

3D-Elektroprint: One-time deformable

Layer Number	Sheet resistance in [Ω/sq] (Van der Pauw)	Surface Roughness (R_q) in [nm]
1	1100	6.41
2	500	10.68
3	300	13.14
4	200	12.38
5	150	11.62



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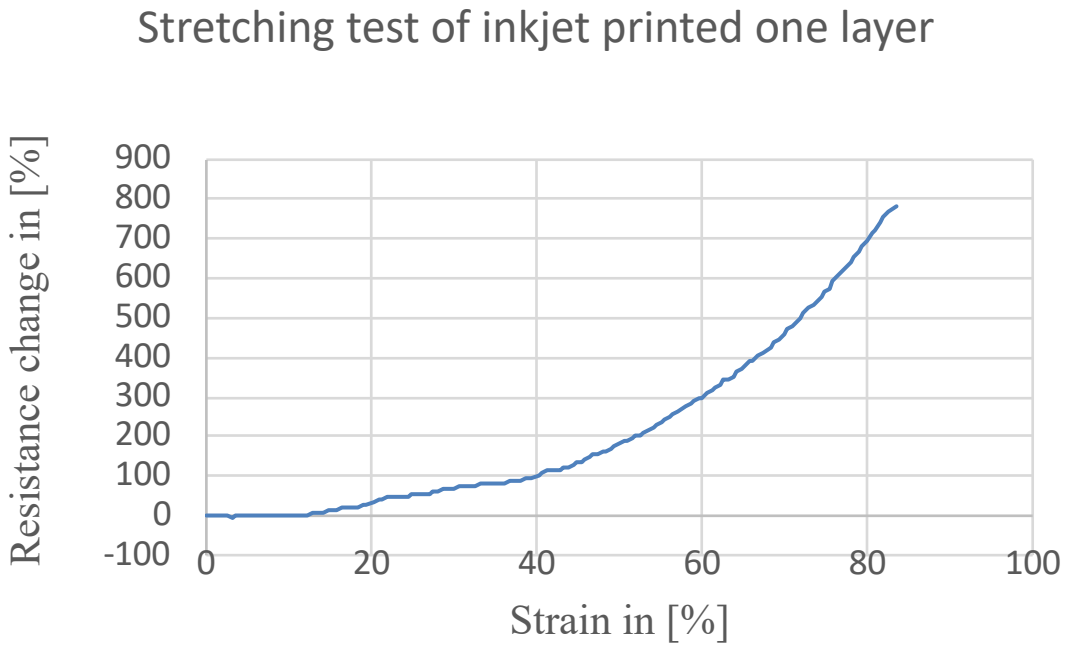
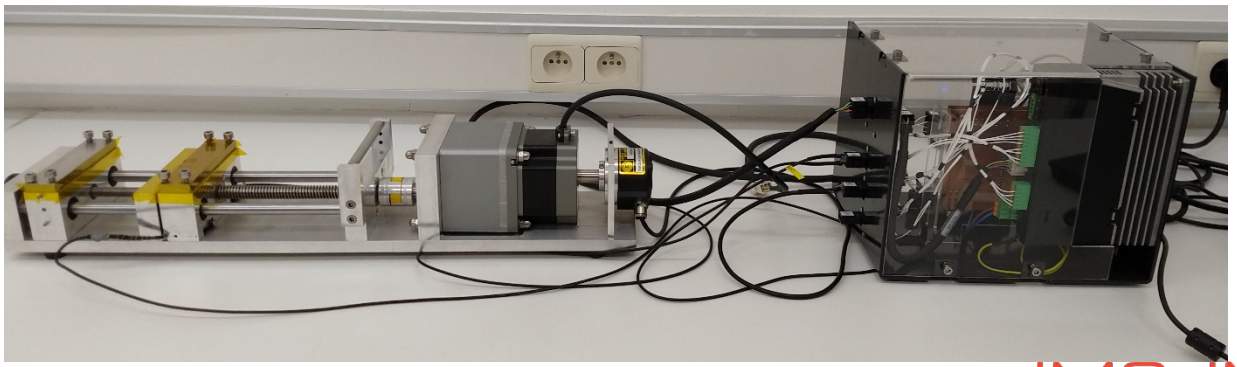
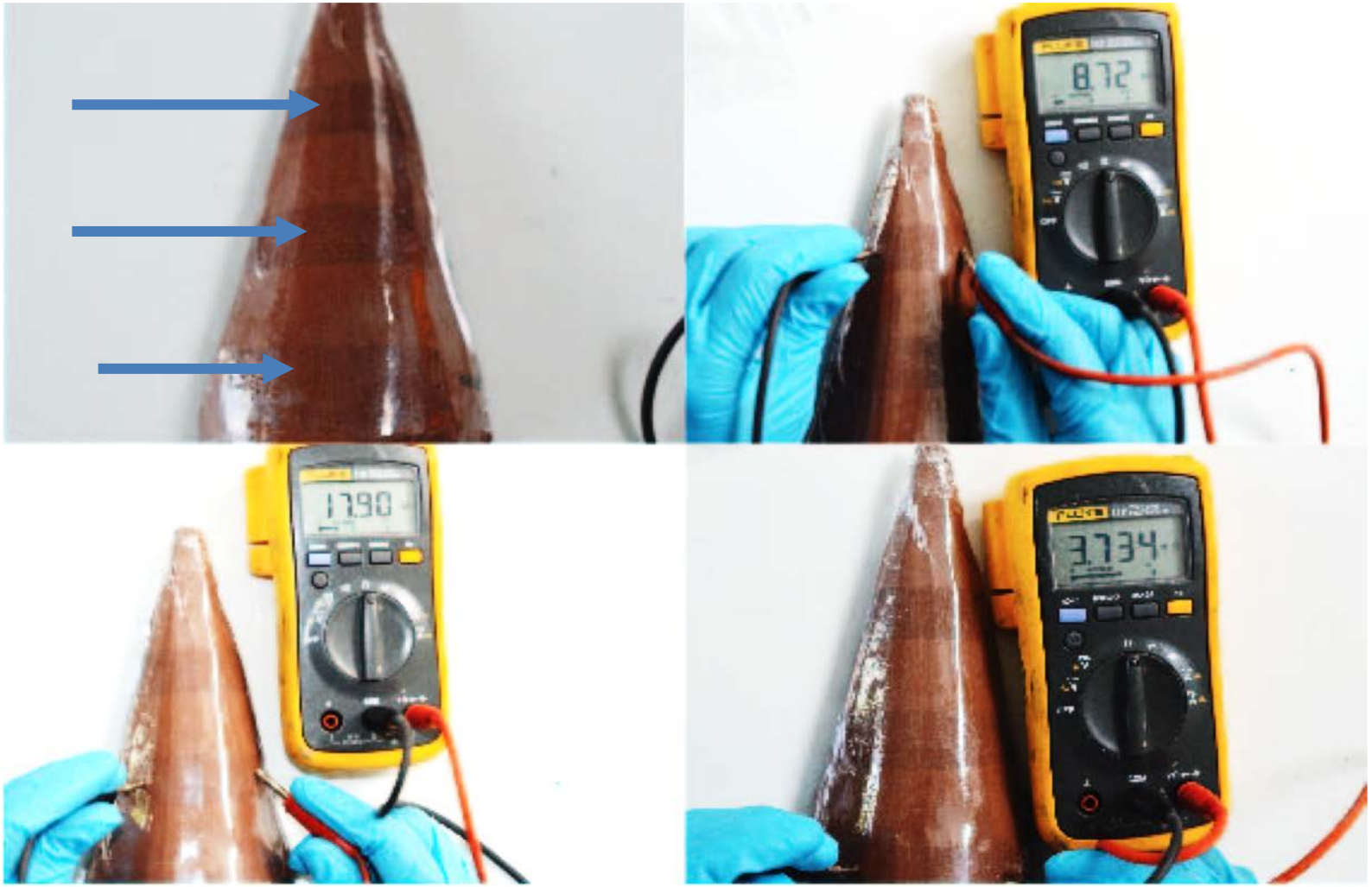
3D-Elektroprint: One-time deformable





3D-Elektroprint: One-time deformable



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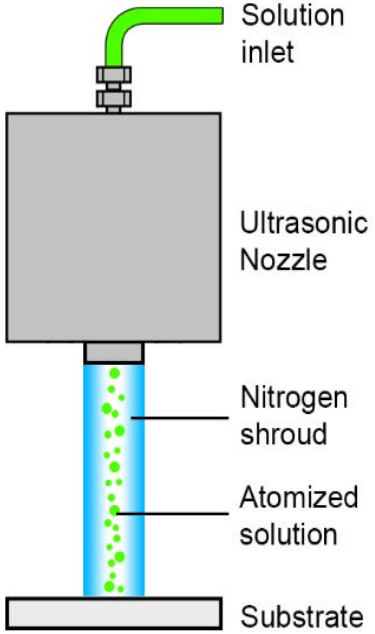
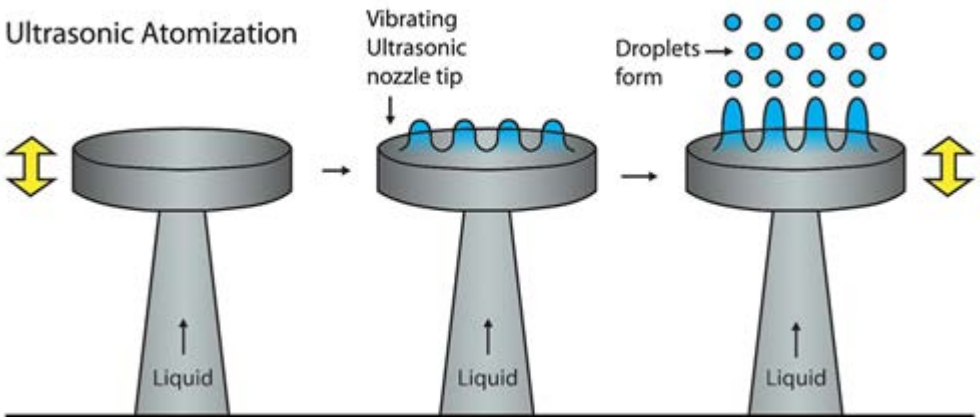
Ultrasonic Spray Coating

The Sono-Tek spray coater uses an ultrasonic atomization technology to deposit very small droplets gently on a substrate. A high frequency electrical signal causes the mechanical expansion and contraction of two piezoelectric transducers, resulting in vibrations that are sent down the nozzle's horn, ultrasonically vibrating at the nozzle's atomizing tip. The functional solution traveling down the center of the nozzle forms capillary waves due to this vibrational energy. When the solution emerges onto the atomizing surface, it reaches a critical wave amplitude and is broken into a spray of tiny drops by the ultrasonic energy concentrated there.





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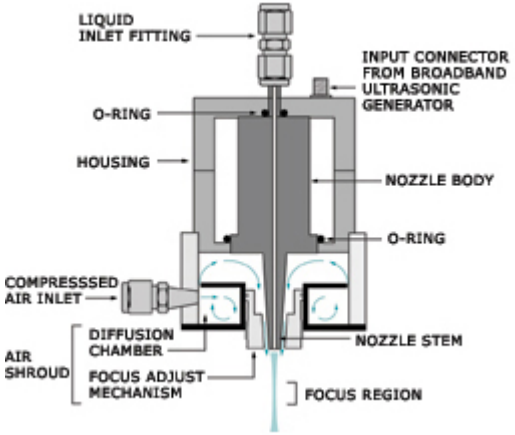
Ultrasonic Spray Coating

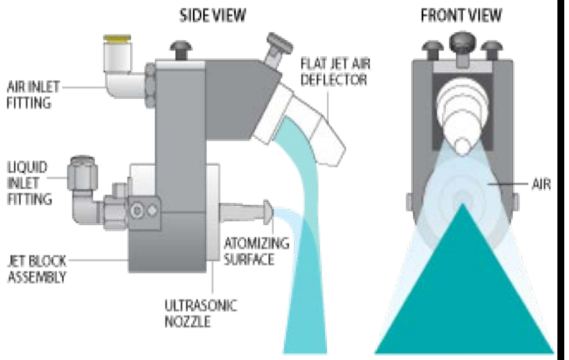
Accumist

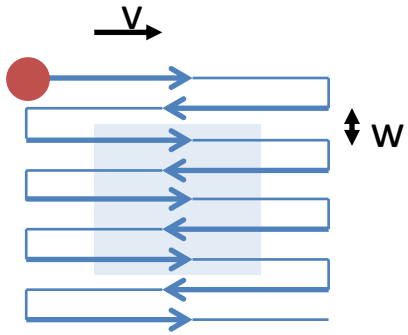


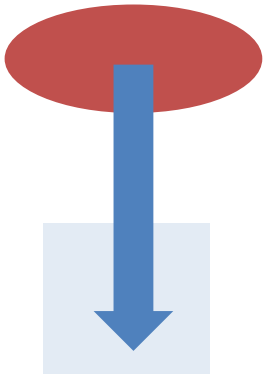
Spray Coating Parameters

- Ink / NP-content
- w = area spacing (mm)
- Nozzle velocity (mm/ s)
- Flow rate (ml / min)
- Nozzle atomizing power (W)
- z = distance to substrate (mm)
- T= Temperature of substrate (°C)
- Accumist shroud pressure (psi)
- # layers

Widetrack







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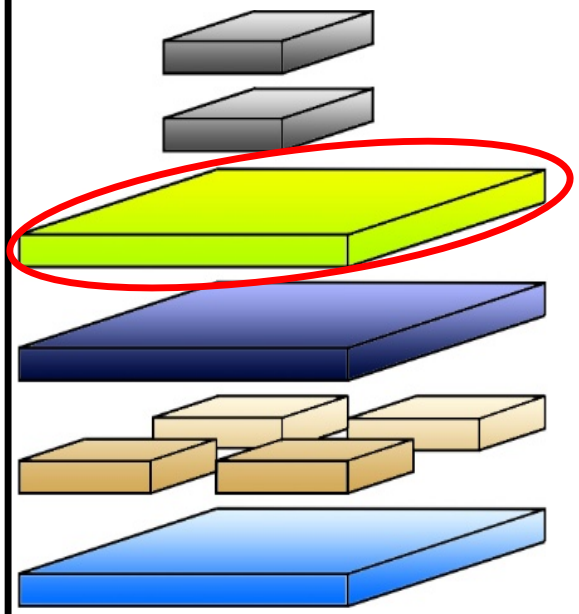
Ultrasonic Spray Coating – OLED active layer



Al Evaporated (100nm)

Ca Evaporated (30nm)

Super Yellow (80nm)

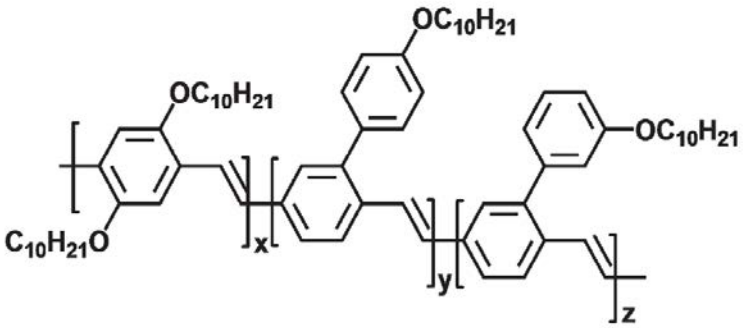
PEDOT:PSS (40nm)

ITO

Glass substrate

Conjugated polymer:

'Superyellow'



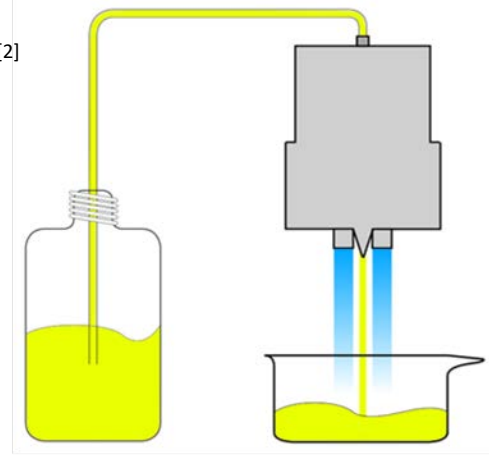
x=0.04, y=0.48, z=0.48

phenyl substituted PPV OLED material [1][2]

Effect of ultrasonication on polymer chain:

side-chain scission?

backbone cleavage?



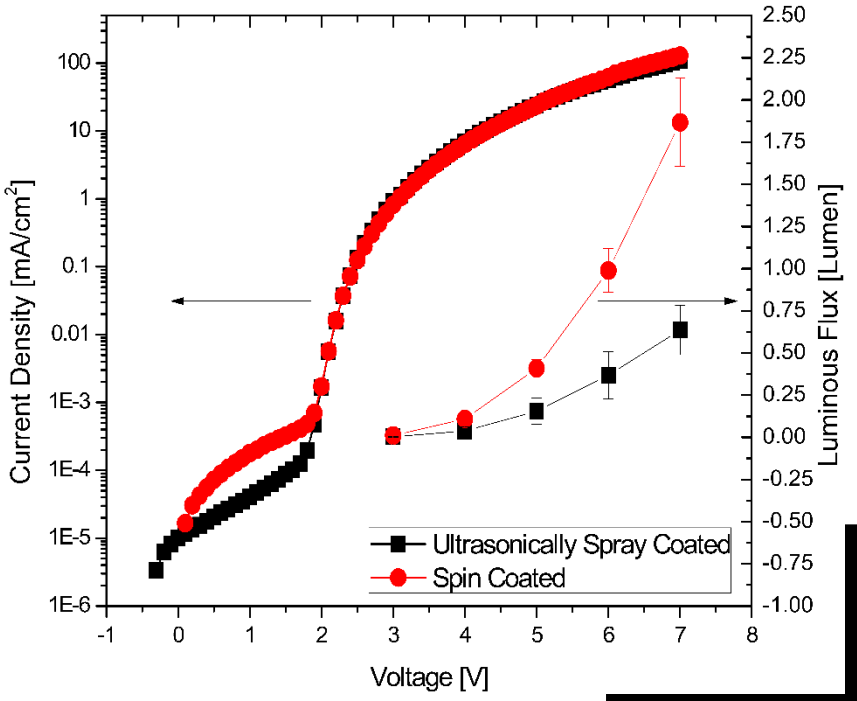
Pristine solution prepared in N2

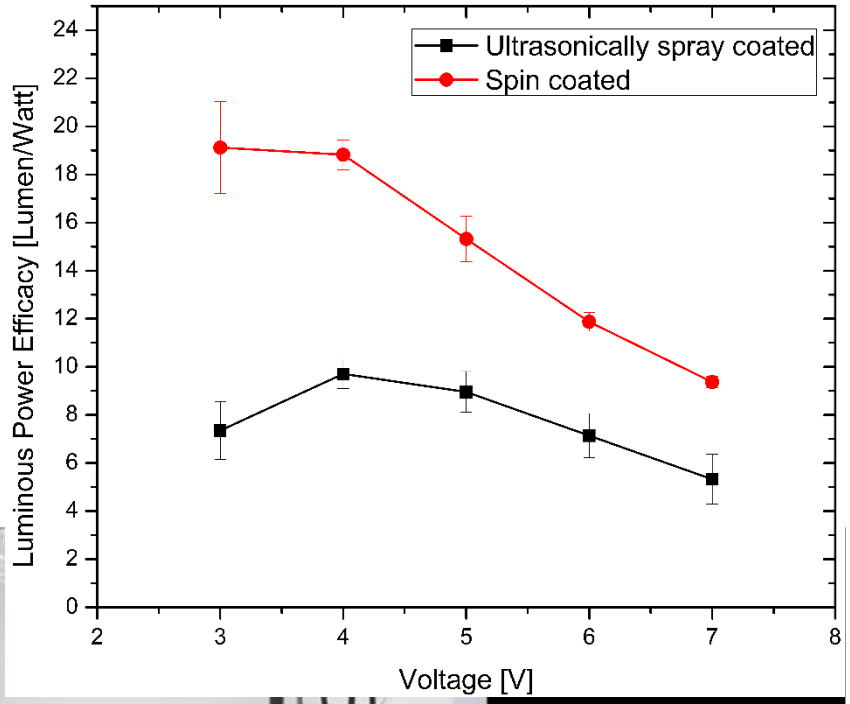
Ultrasonic atomized solution in atmospheric conditions

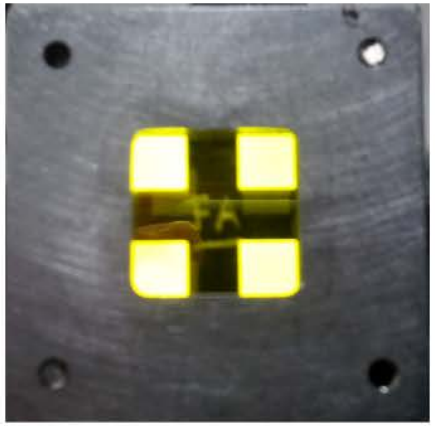
[1] Gambino, S., et. al., "Comparison of hole mobility in thick and thin films of a conjugated polymer", Organic Electronics 11(3), 467–471 (2010).

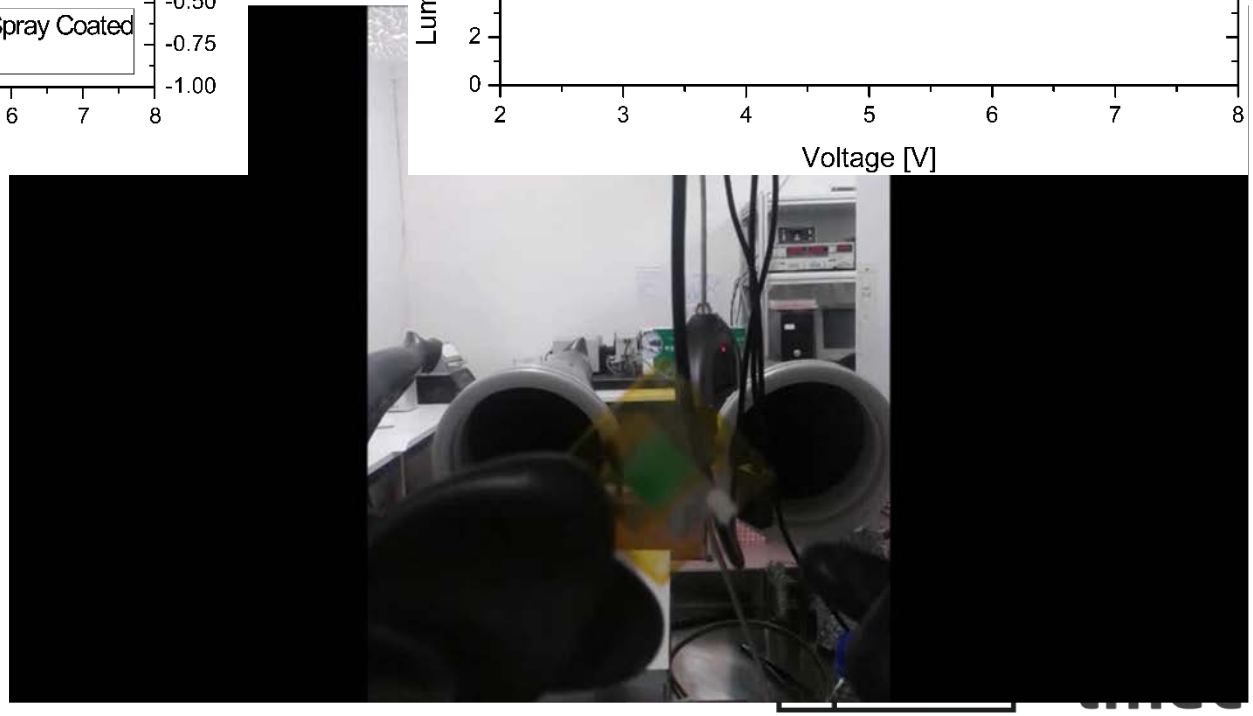
[2] Spreitzer, B.H., et. al., "Soluble Phenyl-Substituted PPVs New Materials for Highly Efficient Polymer LEDs ", Advanced Materials 10(16), 1340–1343 (1998).

Ultrasonic Spray Coating – OLED active layer







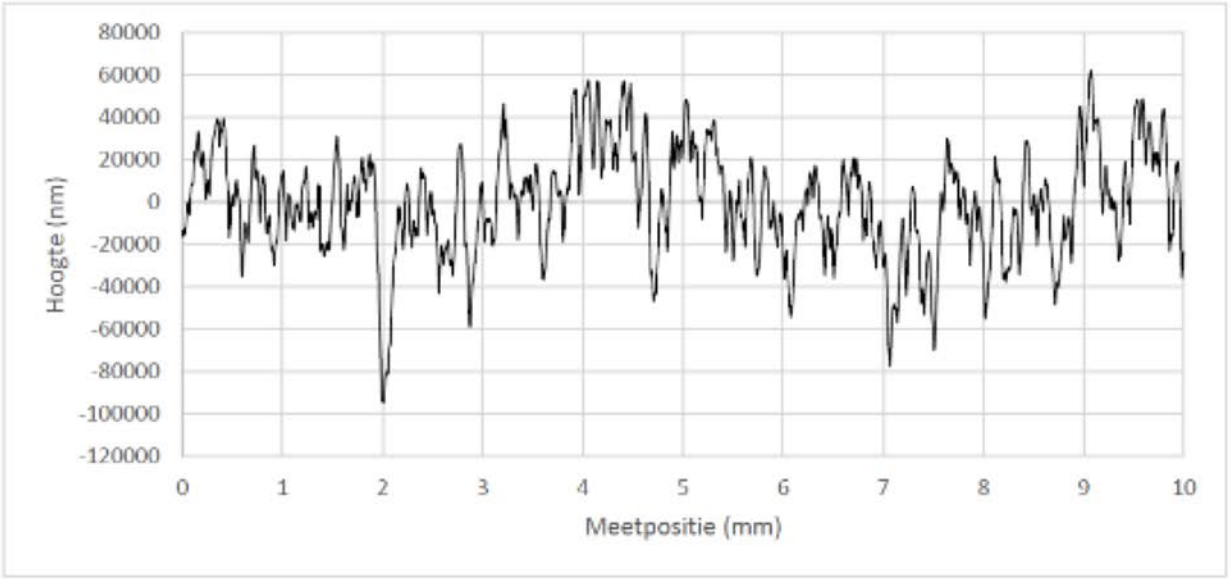


Gilissen et.al. Organic Electronics, vol 20 (2015)

Functional Coatings on non-flat surfaces

- PA-12 (nylon) from Selective Laser Sintering

$$R_a = 19{,}7 \pm 5{,}3\ \mu m$$



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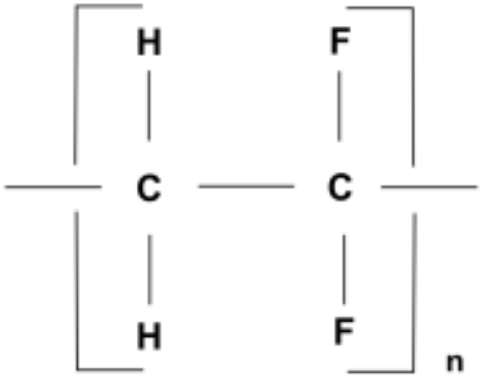
Functional Coatings on non-flat surfaces

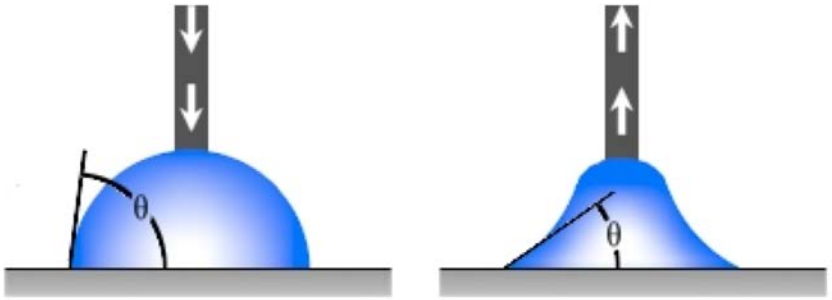
1) Polyvinylideenfluoride (PVDF)
2) Aceton
3) Silica nanoparticles



To achieve:

Roughness reduction + functionality
(superhydrophobicity – easy to clean)

- Pa < 2 µm
- WCA > 150°



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Functional Coatings on non-flat surfaces

- Ink (wt%) and # layers:
  Amount of deposited material
- Volume flow + Nozzle Speed:
  V% ink/Area/time
- Hotplate temperature and Spraying height:
  Drytime

Parameters	Optimal Value
Nozzle frequency (kHz)	120
Power (W)	2.5
Pressure (bar)	0.13
Amount of layers	30
Ink (wt %)	4.5
Volume flow (mL/min)	1.9
Nozzle speed (mm/s)	10
Hotplate temperature (°C)	30
Spraying height (cm)	6

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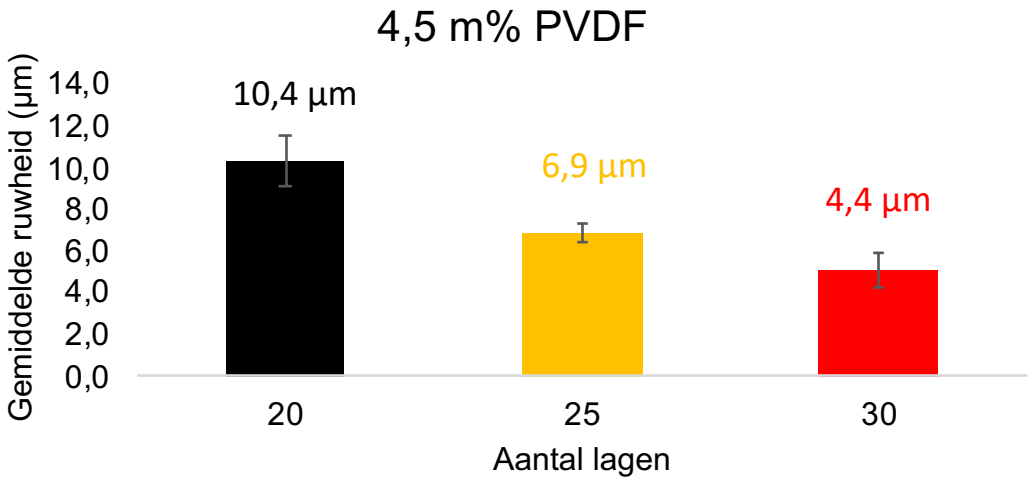
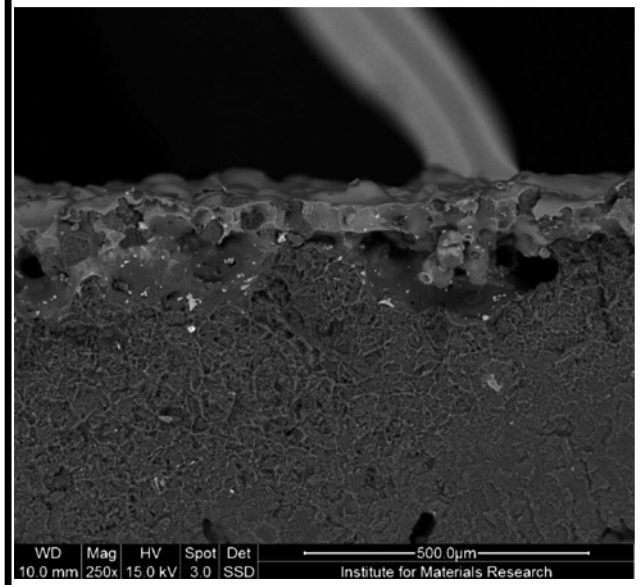
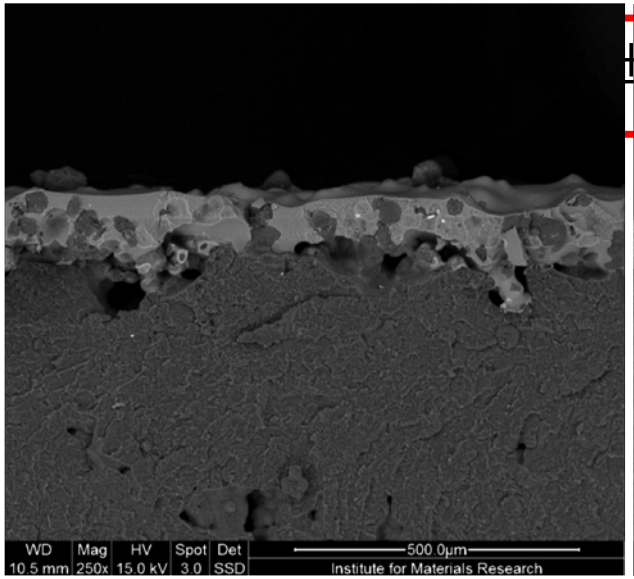
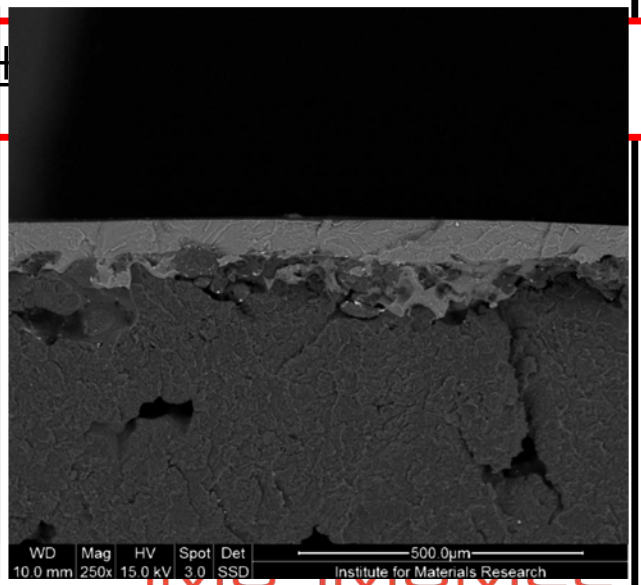
Functional Coatings on non-flat surfaces









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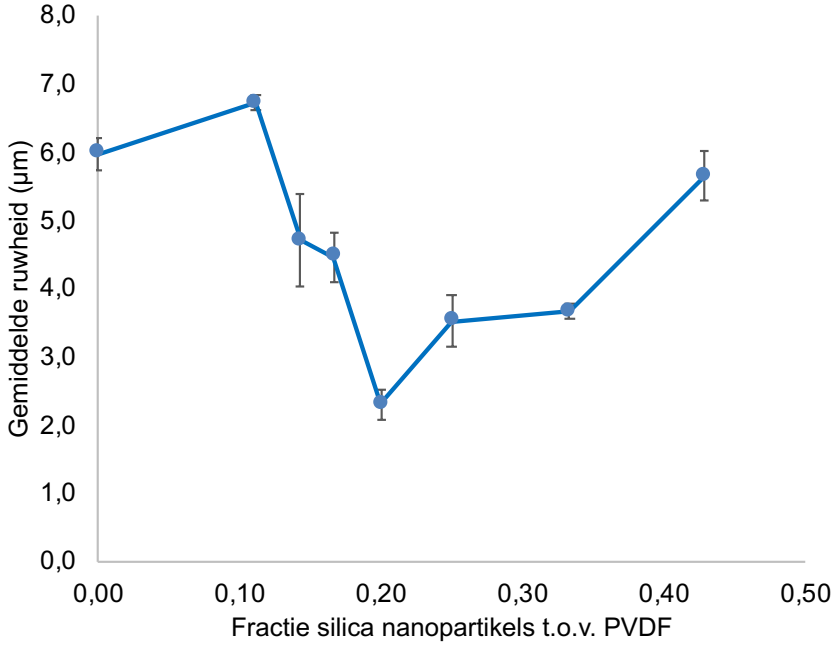
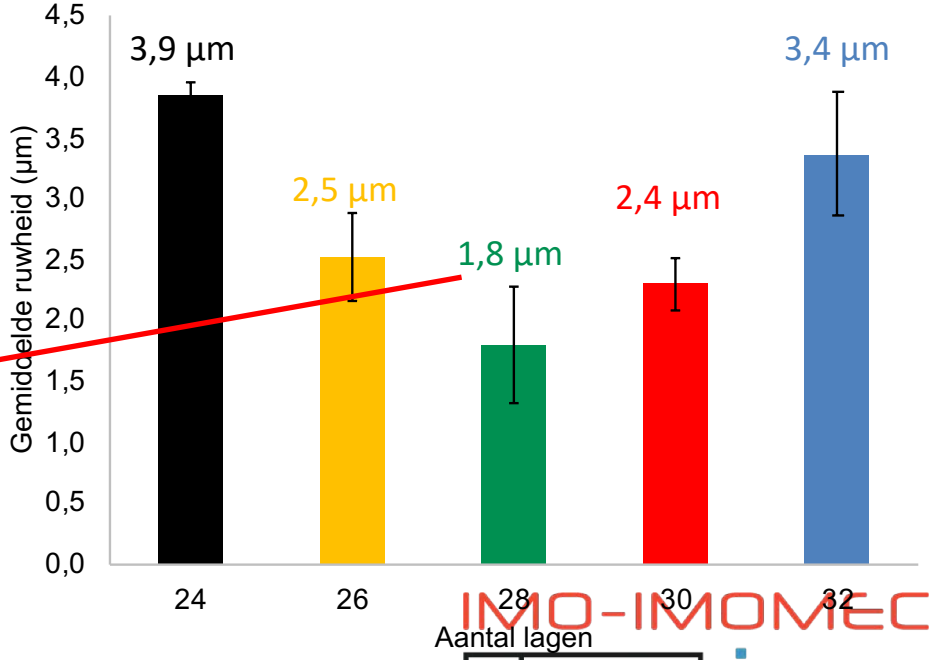
Functional Coatings on non-flat surfaces

Influence on roughness of fraction nanoparticles



4,2 wt% PVDF and 0,8 wt% silica nanoparticles



Industrial standard

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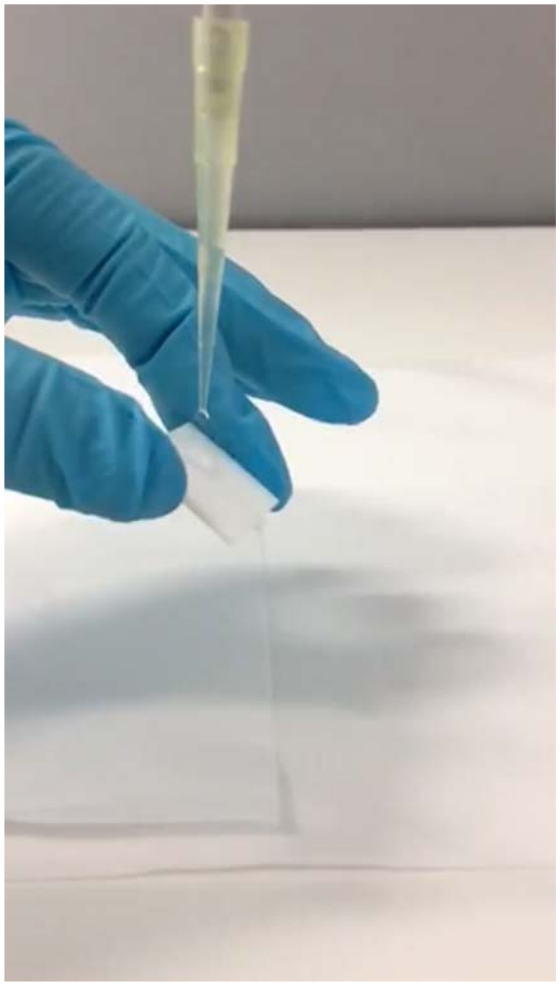
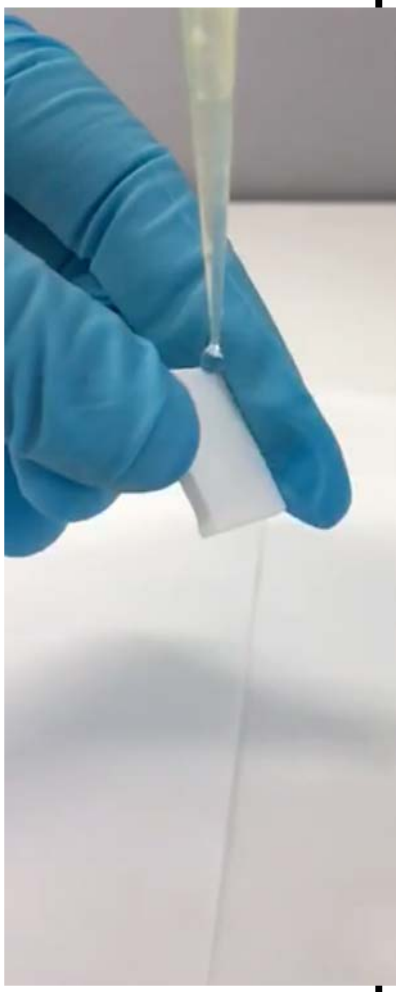
Functional Coatings on non-flat surfaces: superhydrophobicity





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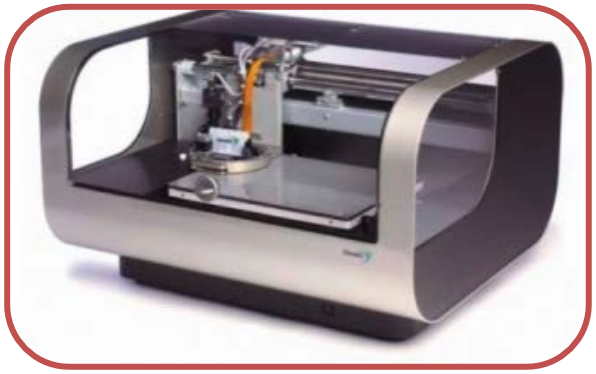
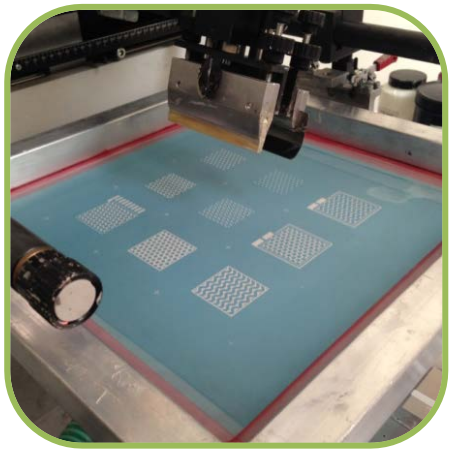
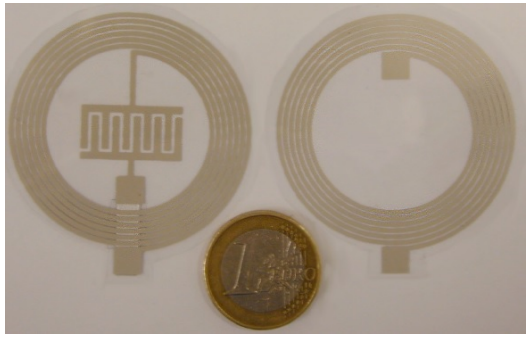
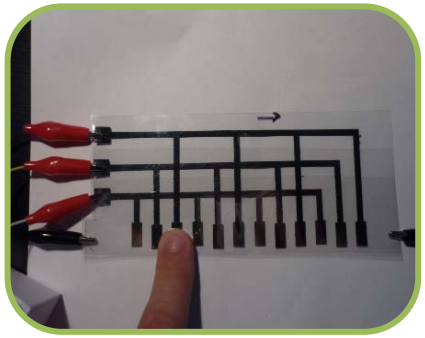
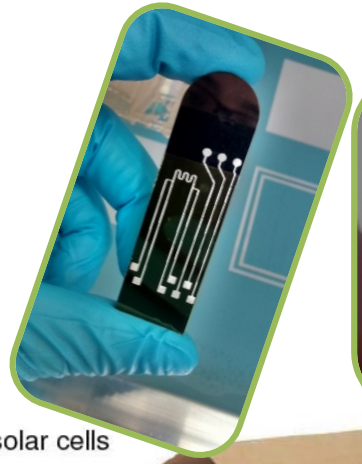
Conclusion

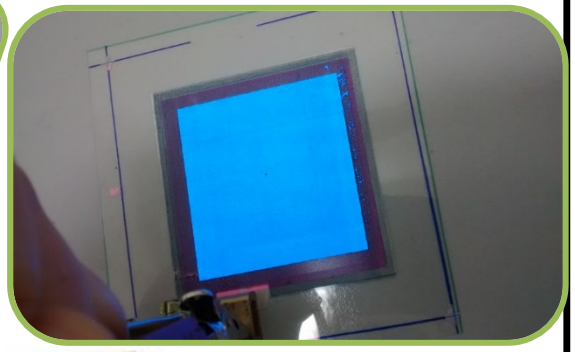


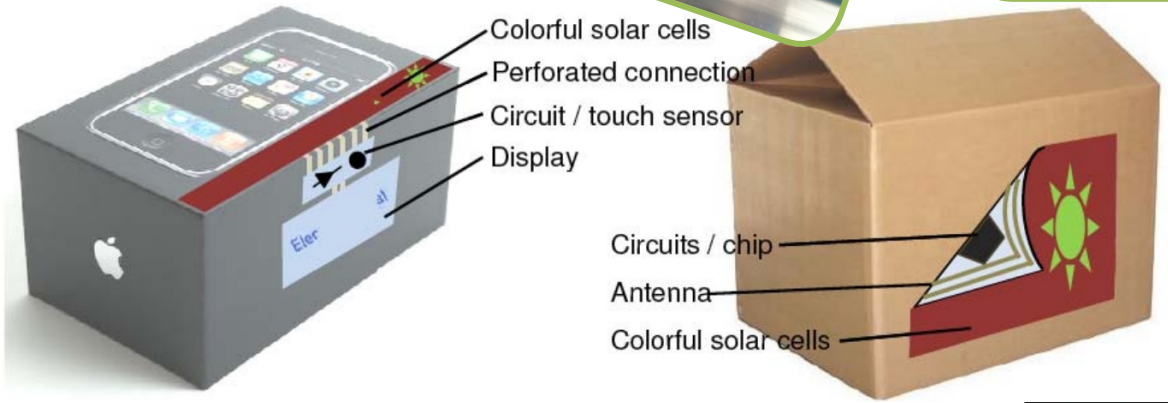












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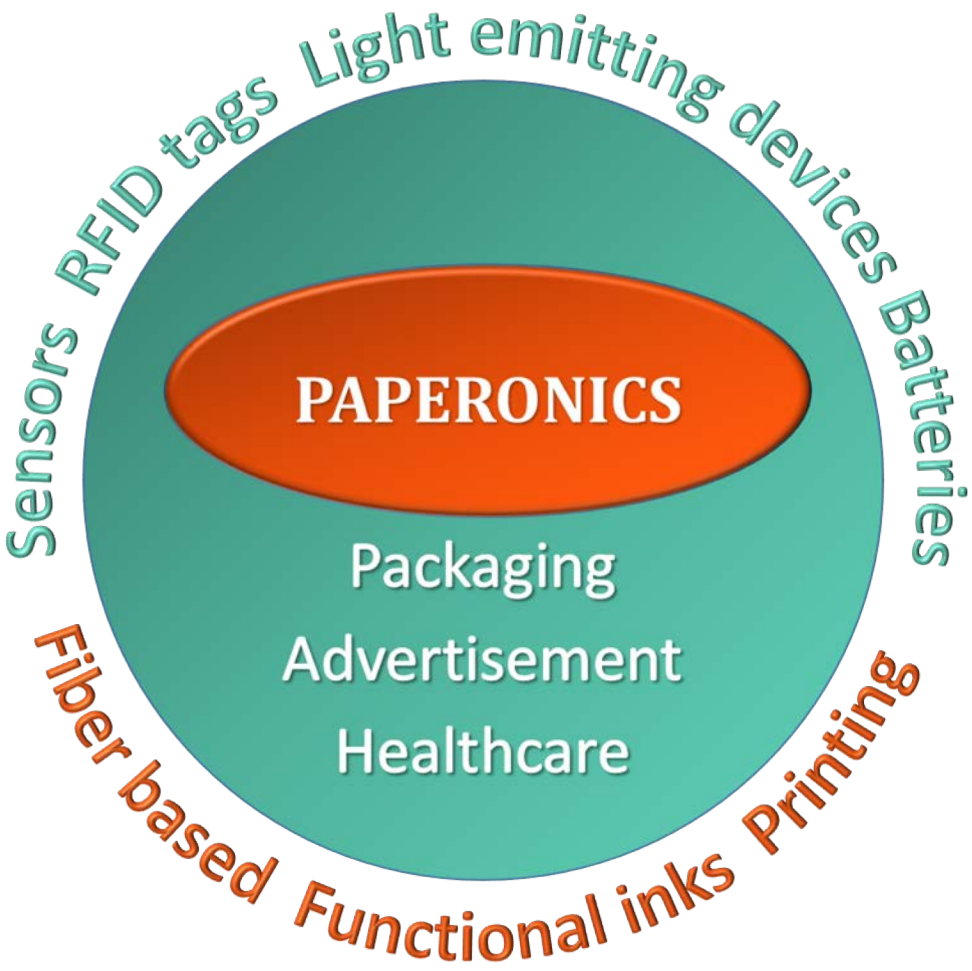
PAPERONICS - Project



Research institutes

- Fraunhofer IVV: encapsulation materials with oxygen and water vapour scavengers

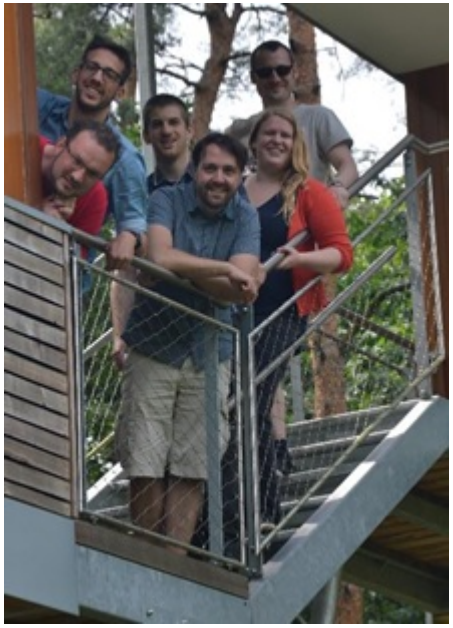
- University Hasselt: printed sensors and light emitting devices on paper, functionality and shelf-life testing

- IMEC: RFID circuits to be embedded in or added on paper

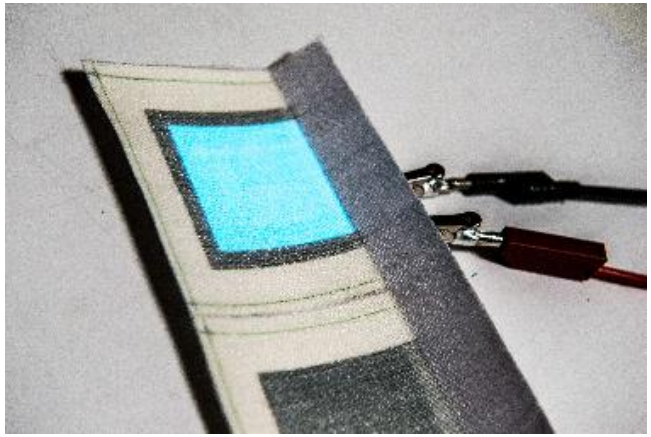
- University Chemnitz: printed solar cells on paper and integration of all technologies

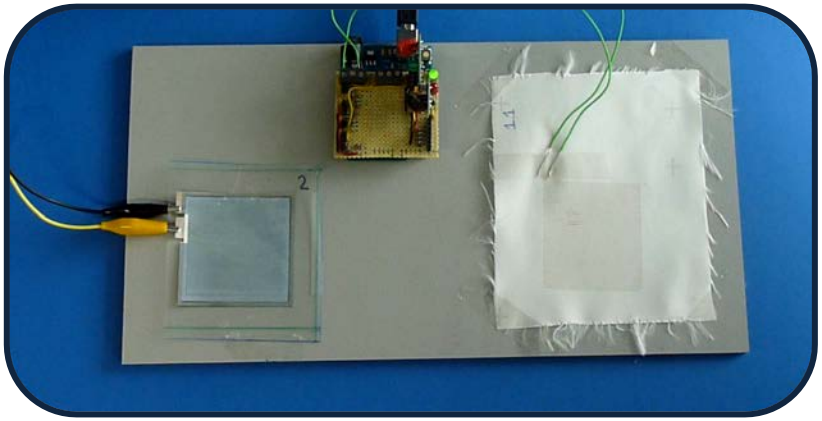
Companies involved in
Paper – cardboard – Printing – Electronics
Packaging & other Paper applications …

Acknowledgement



Functional Materials Engineering (FME) Research Group:
Dr. ir. Jeroen Drijkoningen, Dr. Koen Gilissen, Ing. Jeroen Stryckers, Ing. Glen Vandevenne, Ing. Inge Verboven, Ing. Steven Nagels, Ing. Manoj Jose, Ing. Indranil Basak, Ing. Dieter Reenaers





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