Centre for Nanotechnology and Smart Materials

Development of printed capacitive sensors

From R&D to Process and Product Engineering

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Summary

- About CeNTI
- Printed electronics: From R&D to Product Engineering
- Technologies: Printed and Embedded Electronics
- R&D and Product Development
- Printed capacitive sensors

High Level Shareholders

universidade de aveiro

citeve

Universidade do Minho

CTIC

U.PORTO

CEiiA

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Technology Campus

Figures & Facts

- Brainware
  - 45 FTE (Full-time equivalent) high skilled professionals
  - > 10 Students
  - >15 Patent submissions in the last 4 years
- Ongoing collaborations
  - > 20 w/ R&D Centers
  - > 50 w/ Companies

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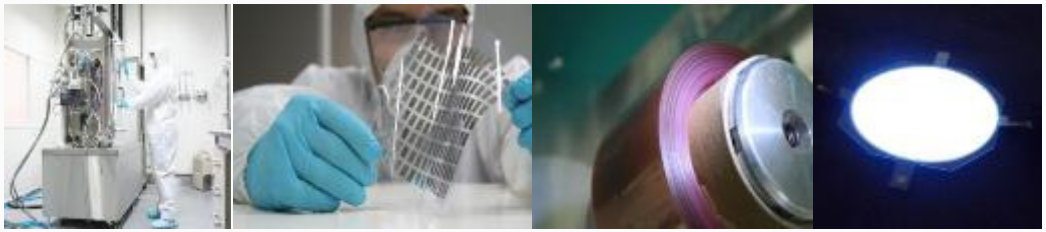
R&D Services

Functional Materials & Solutions

Smart Materials & Systems



Solutions Design & Engineering

Main Applications

Health, Protection & Well-being

Automotive & Aeronautics

Architecture & Construction

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Several Substrates

Outputs

- **Ultra high barrier films**
- **Gas barrier**
- Conductive fibres and films
- Super-hydrophobic and super-oleophobic
- Biocolouring
- High insulation

Outputs

- Selfcleaning
- Abrasion resistant & anti-scratch
- Anti-Slip & Grip-Enhanced Surfaces
- Low weight thermoplastic materials
- High performance adhesives

Outputs

- Drug release materials
- Chemical agents release
- Flame retardant
- **Organic solar cells**
- **Organic LEDs**
- **Electrochromic materials**
- **Heating bands**

Outputs

- Supercapacitors
- Biometric sensors:
  - temperature, heart-rate, motion and touchpads/keypads
- Integrated gas sensors
- Wireless data communication to mobile platforms

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PRINTED ELECTRONICS

From R&D to Product Engineering

Scalability: from Demonstrator to Pre-Series

R&D Project

- **Proof-of-concept;**
- **Final Prototype;**

Process Development

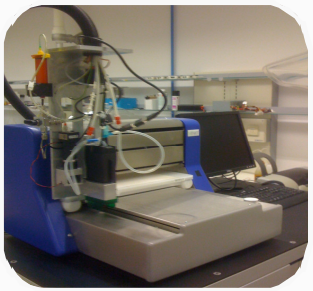
- **Process development;**
- **Product Design;**
- **Production Cost Assessment**

Pre-Series;

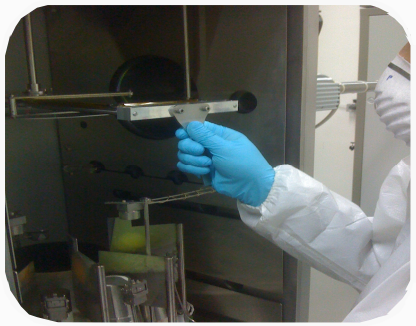
- **Small Scale Manufacturing;**
- **Market Test;**
- **Logistics**

Lab scale Printing Technologies

Screen Printing (Sheet and Rotary)

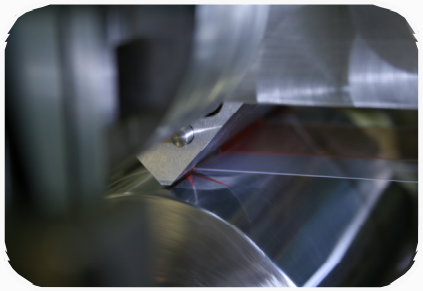


Inkjet Printing



LTE thermal evaporation

Sheet/Sample

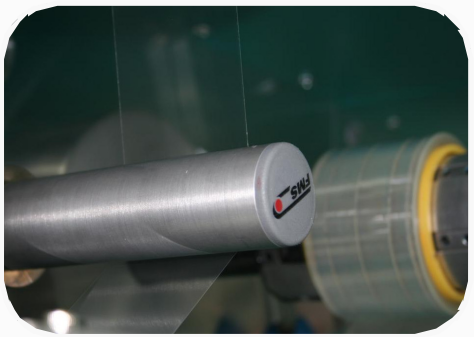


Slot die Coating;

Knife/Doctor blade;

Spray and Dip coating

R2R Gravure



Lamination& Encapsulation

R2R

R2R at pilot and semi industrial scale

3DMM Microflex Print Line 300mm

Multi tech print unit

R2R 12m print line:

- Rotary Screen;
- Slot die coating;
- In-line corona and cleaning;
- 3m N2 thermal treatment;
- Double lamination;

Multi-technology print unit:

- Foulard;
- Gravure printing;
- Knife coating;
- Doctor Blade;
- Slot die coating;
- Micro-roller coating;
- Thermal curing (1m);
- Lamination;

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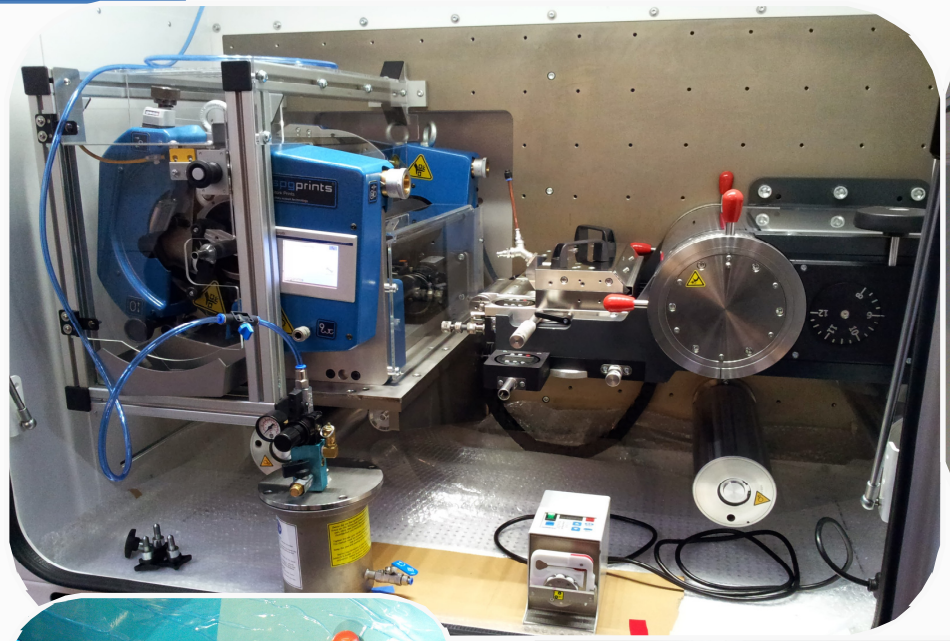
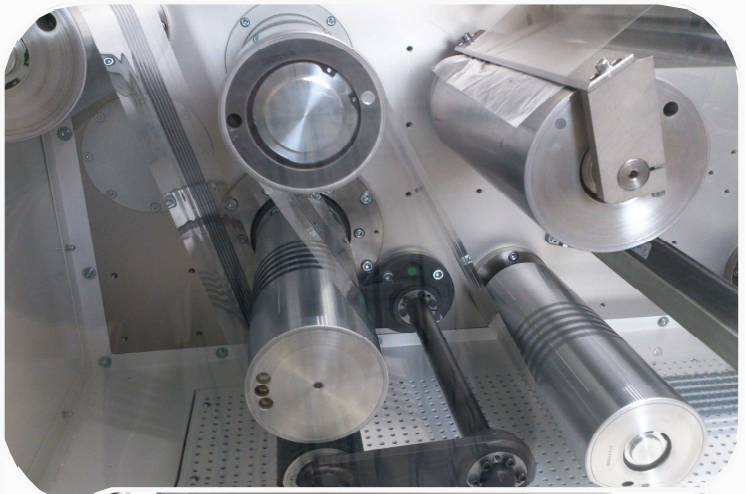
R2R at pilot and semi industrial scale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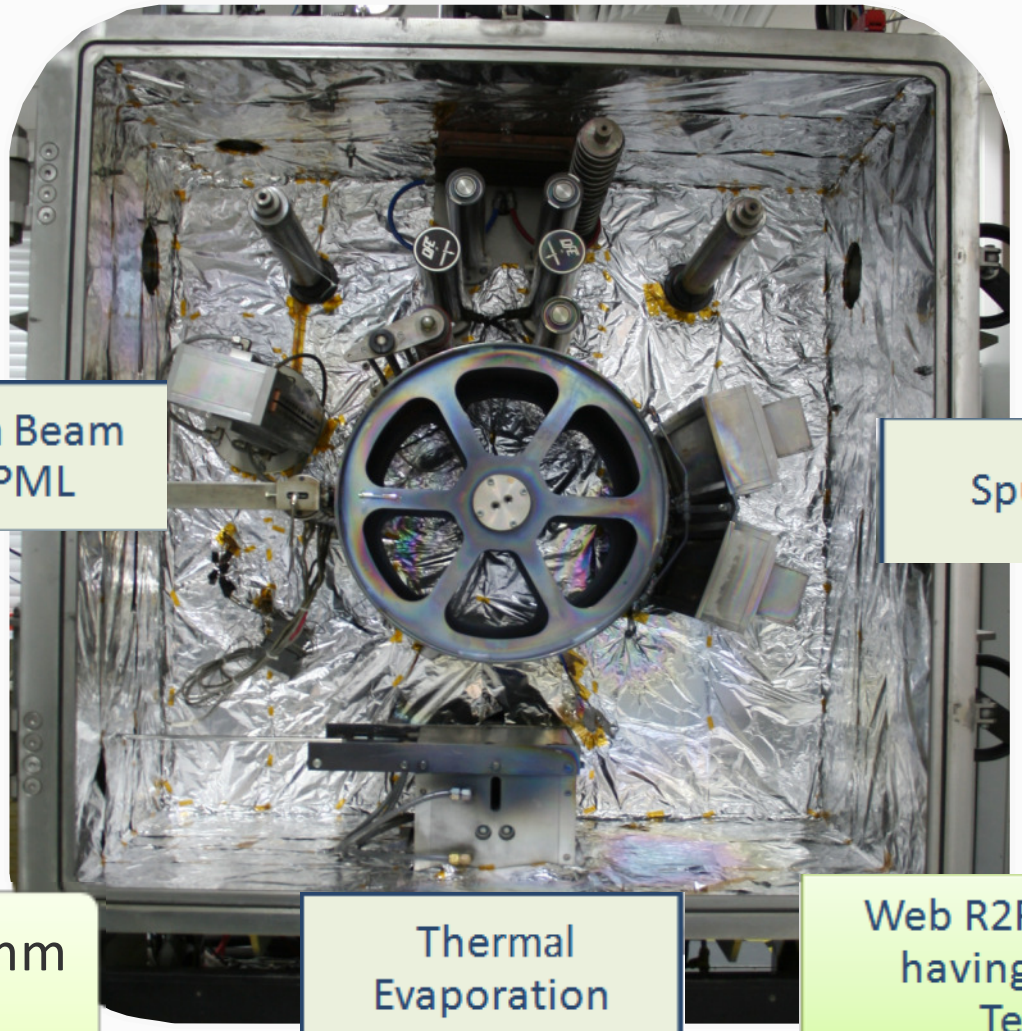
Synergy with R2R Vacuum Coating



Electron Beam with PML

Sputtering

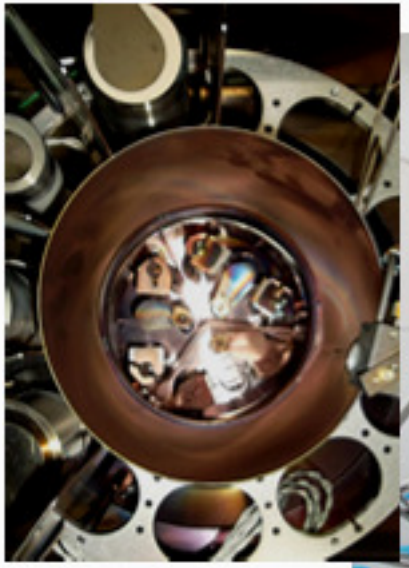
100-500mm R2R

Thermal Evaporation

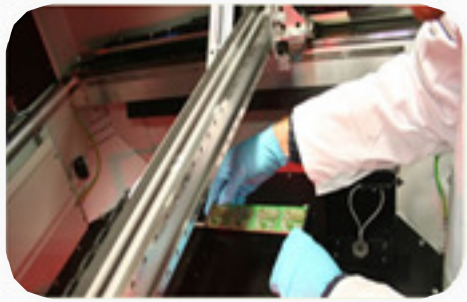
Web R2R vacuum system having 3-line Coating Technologies

Synergy with R2R Vacuum Coating

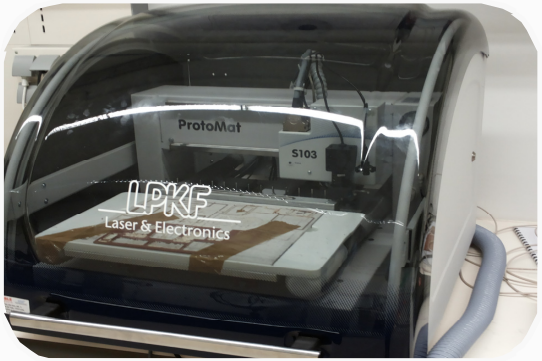
- **Lab-scale research** needs to consider the **process requirements** given by the 2nd step up-scaling;
- **Pilot scale** is required to **assess the feasibility of the printing/processing** of a given device and the final product (assembling and integration step);
- Assessing the **viability of intermediate assembling steps** is key for determining the **feasibility of the process** as whole.



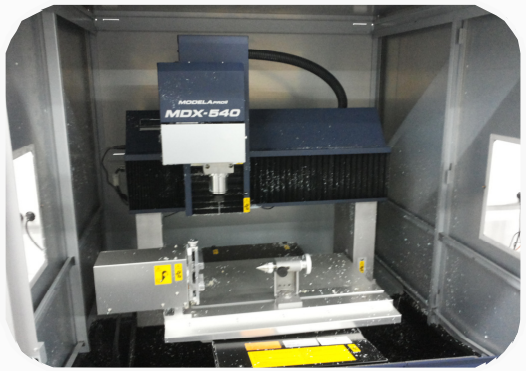
Process development



SMT
Technologies



FABLAB



Machining and Finishing

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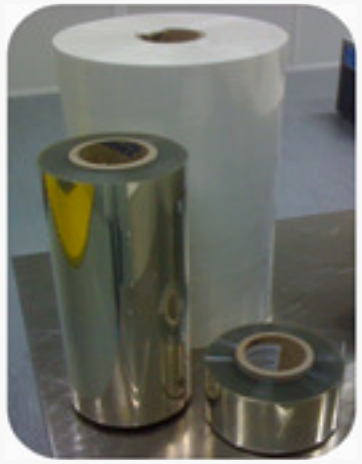
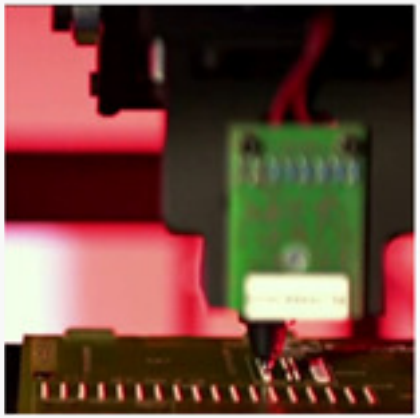
Scalability: sample to product

1st step

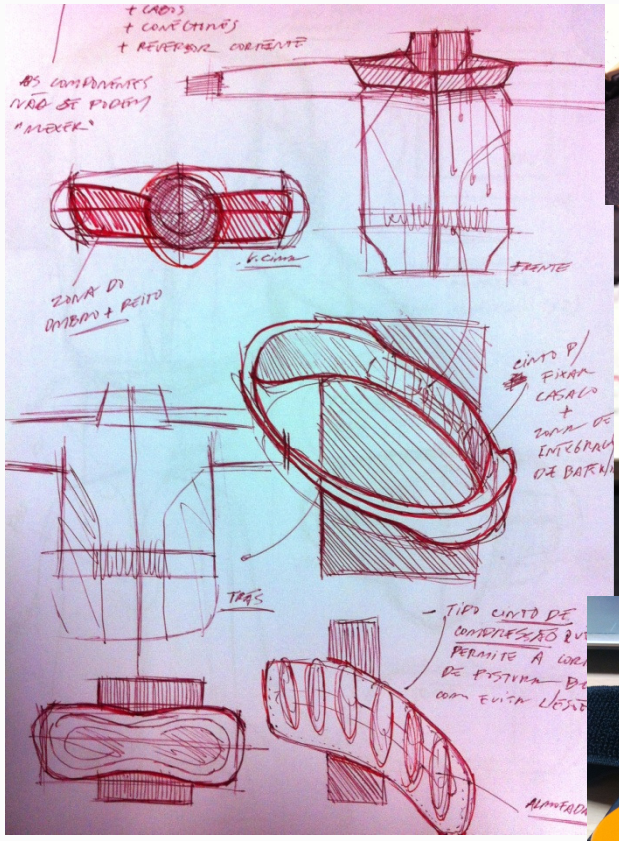


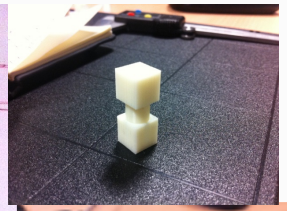
2nd step

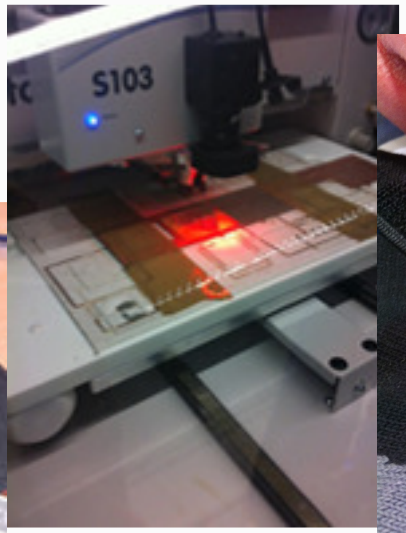


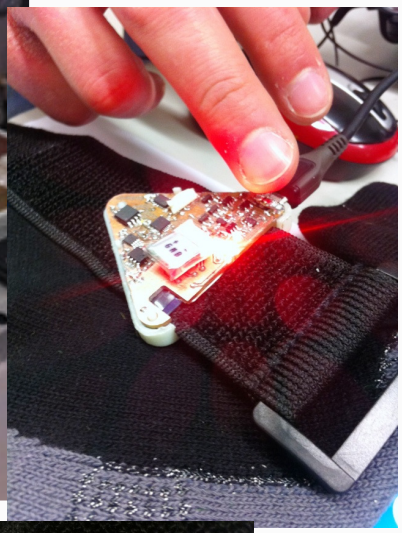
TP LEDs
Smart Pillow

Scalability: sample to product









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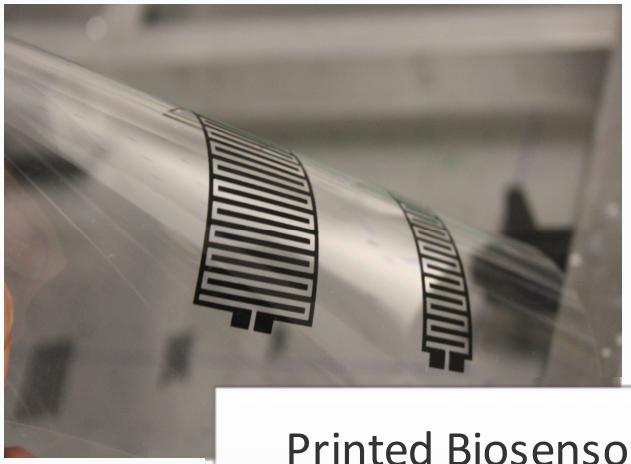
TECHNOLOGIES

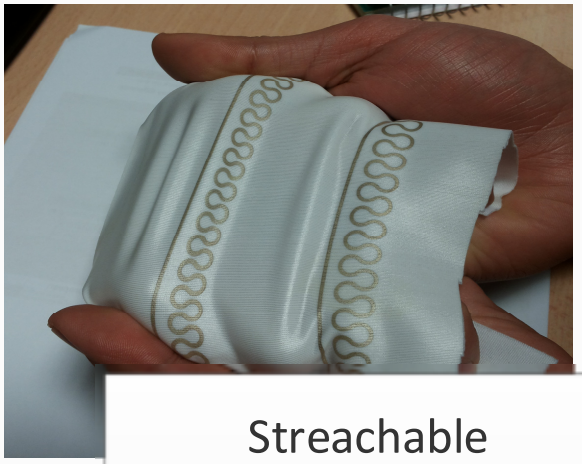
Printed and Embedded Electronics

Printed Circuitry/Elements

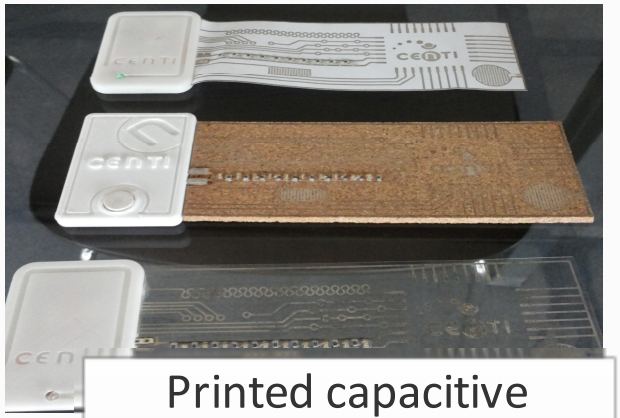
Printed circuitry (touchpads)



Printed Biosensors



Streachable



Printed capacitive sensors

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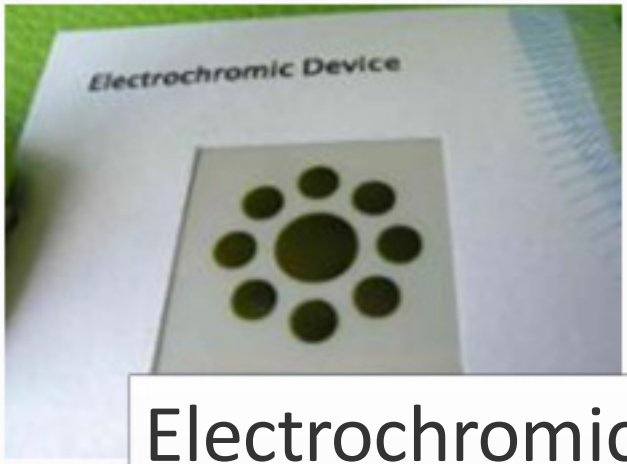
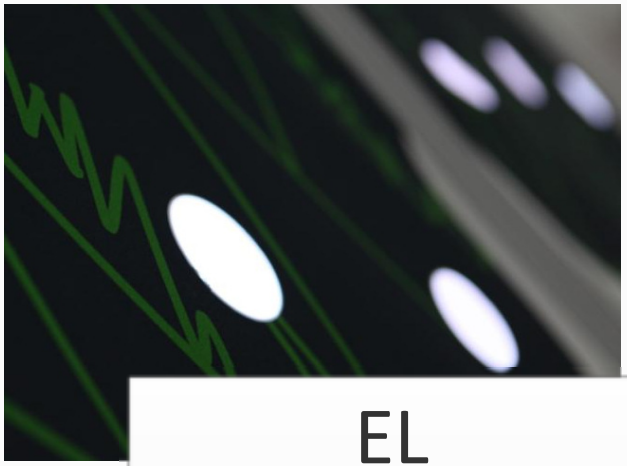
Devices

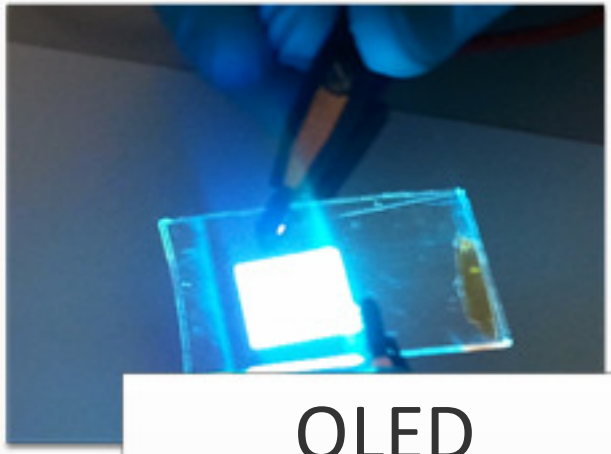
OPVs



Electrochromic



EL



OLED

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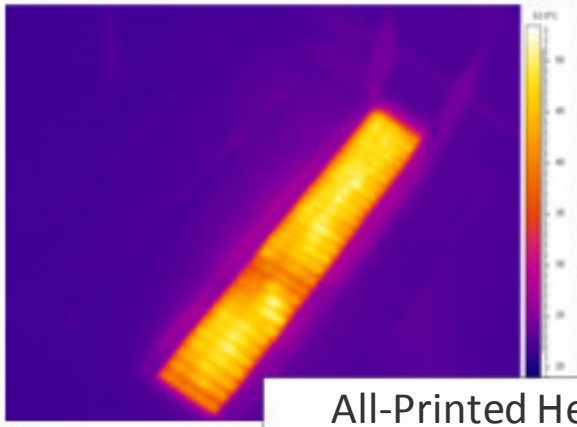
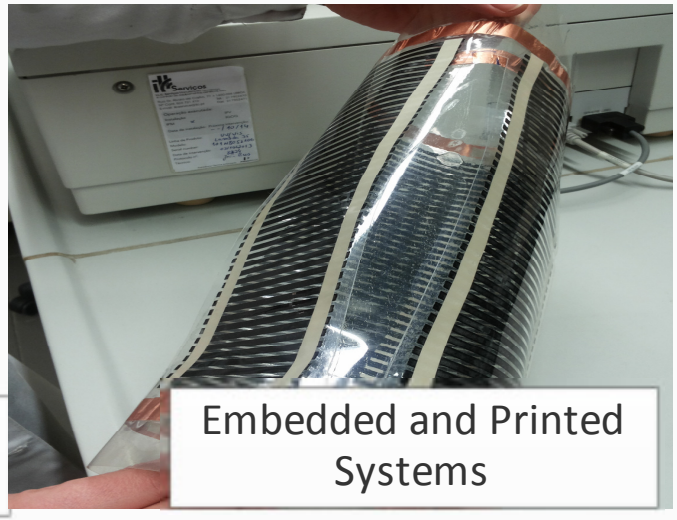
Devices

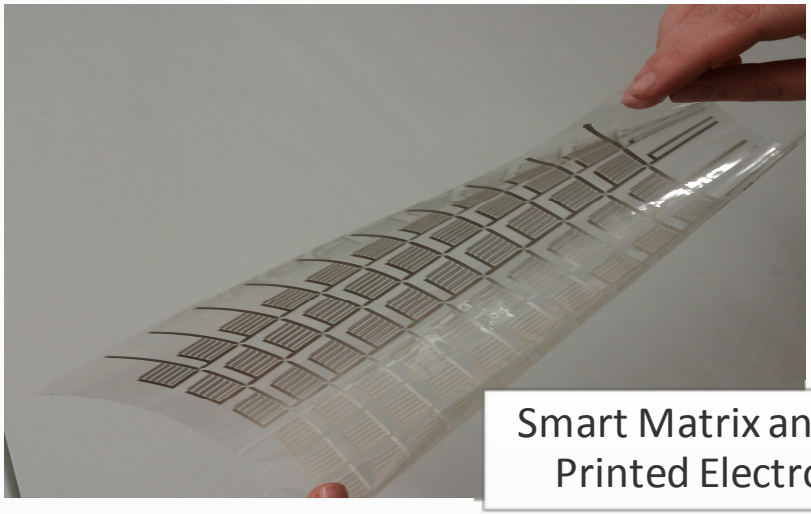


All-Printed Heating Elements



Embedded and Printed Systems

Software and Hardware Development



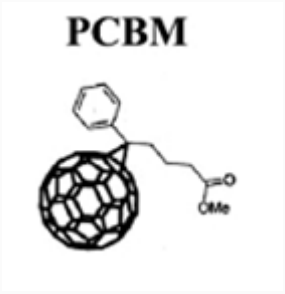
Smart Matrix and Fully Printed Electronics

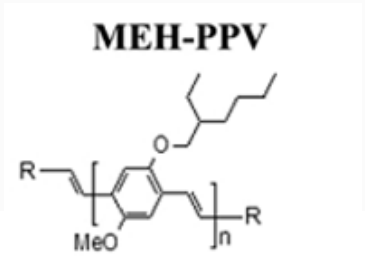
R&D PROJECTS

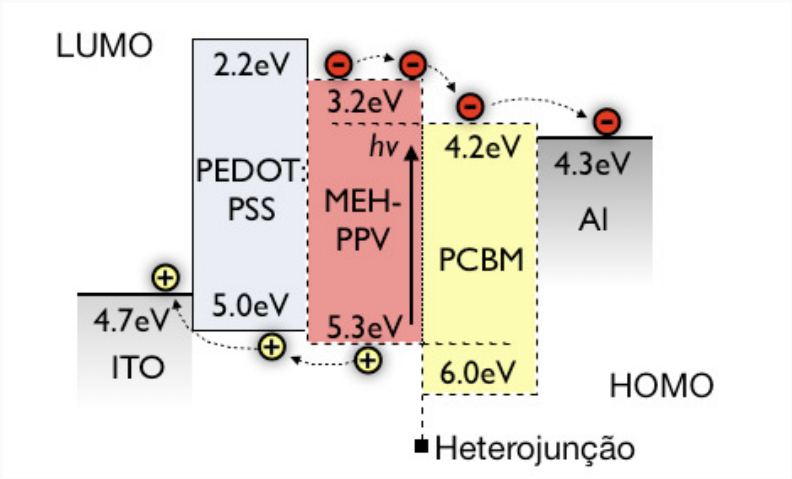
R&D Organic and Printed Photovoltaic

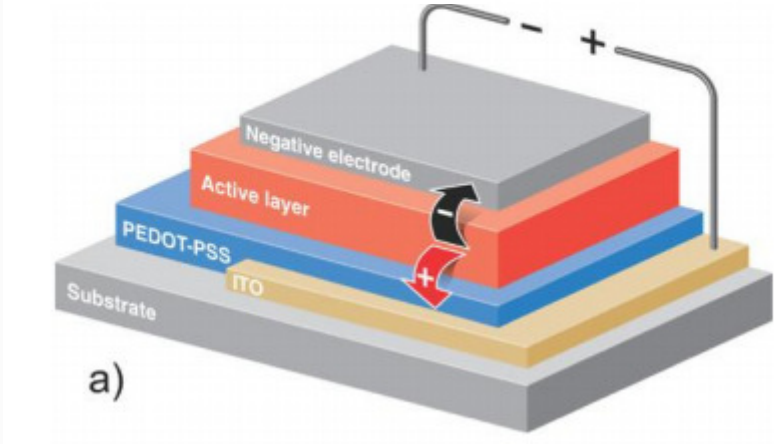
Cooperation with University of Aveiro

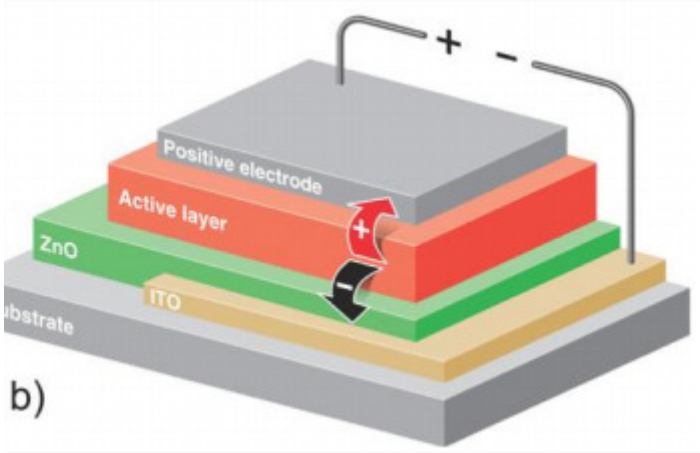
Organic Photovoltaic Devices



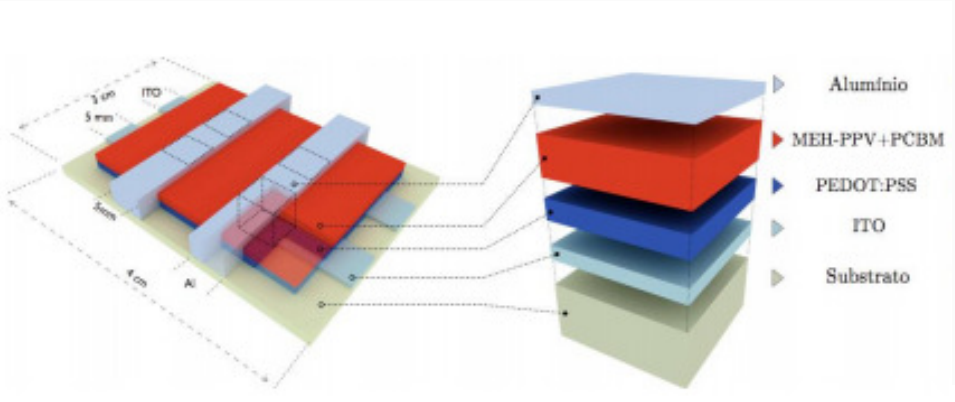


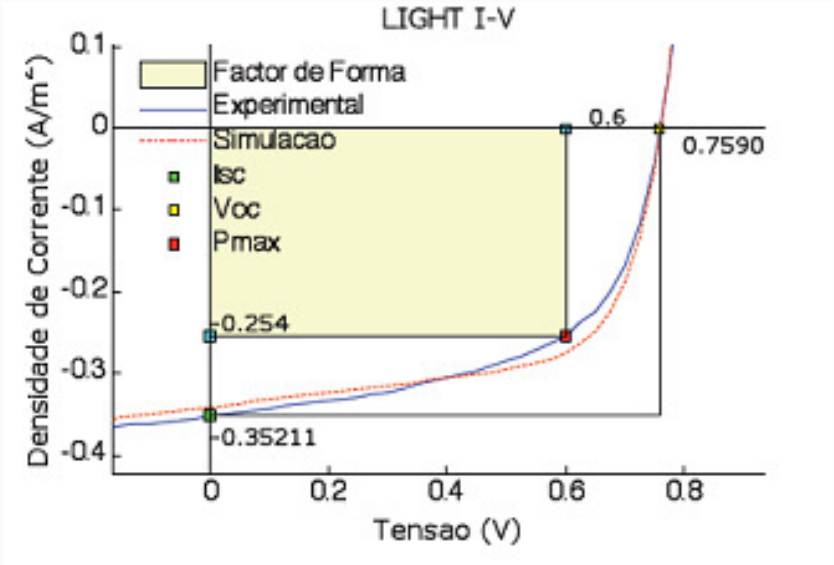






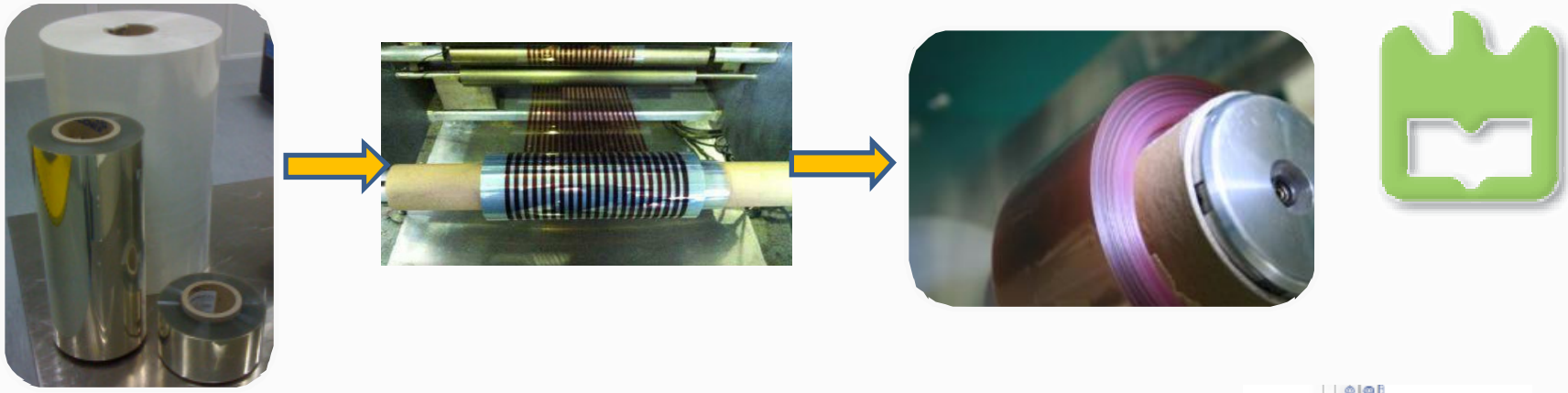
Organic Photovoltaic Devices



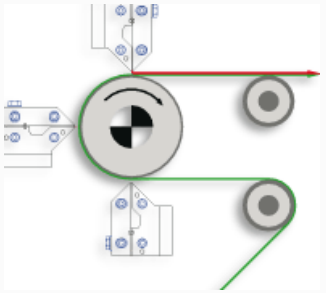


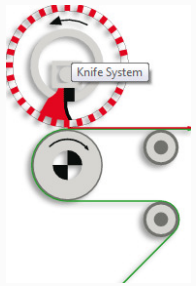
	Extrapolado	Light	Dark
Célula LargeArea	J_{SC} (A/m²)	0.35	-
	V_{OC} (V)	0.76	-
	J_{Max} (A/m²)	0.25	-
	V_{Max} (V)	0.43	-
	RS (Ω)	136	1.2k
	RP (Ω)	44k	538k
	FF (%)	57.01	
	P_{inc} (W)	1.5×10^{-3}	
	P_{Max} (W)	6.1×10^{-5}	
	η (%)	2.76	

Organic Photovoltaic Devices

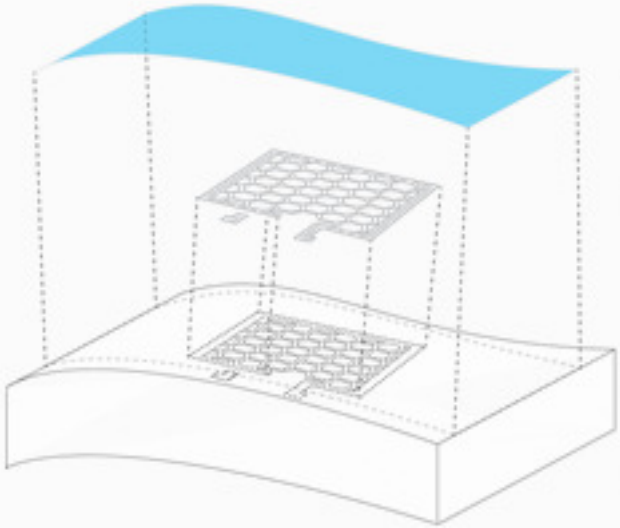


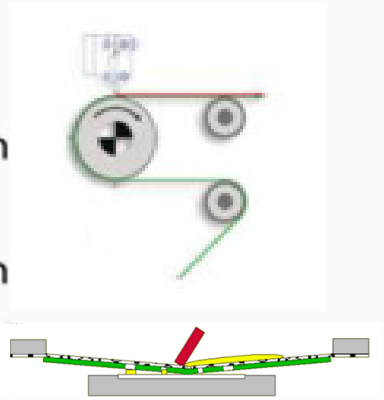
- Up scalling R&D processes to R2R processing methodologies;
- The process targets the optimization of R2R process conditions to achieve the same merit figures as attained in R&D trials
- Replacing ITO thin films – “All-printed concept”
- Modularity and mechanical and performance stability

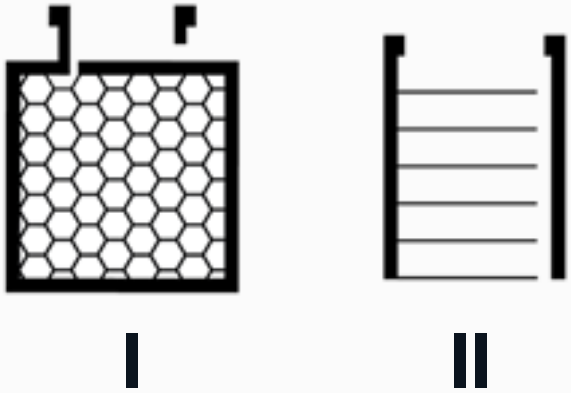




Processing thin hybrid films

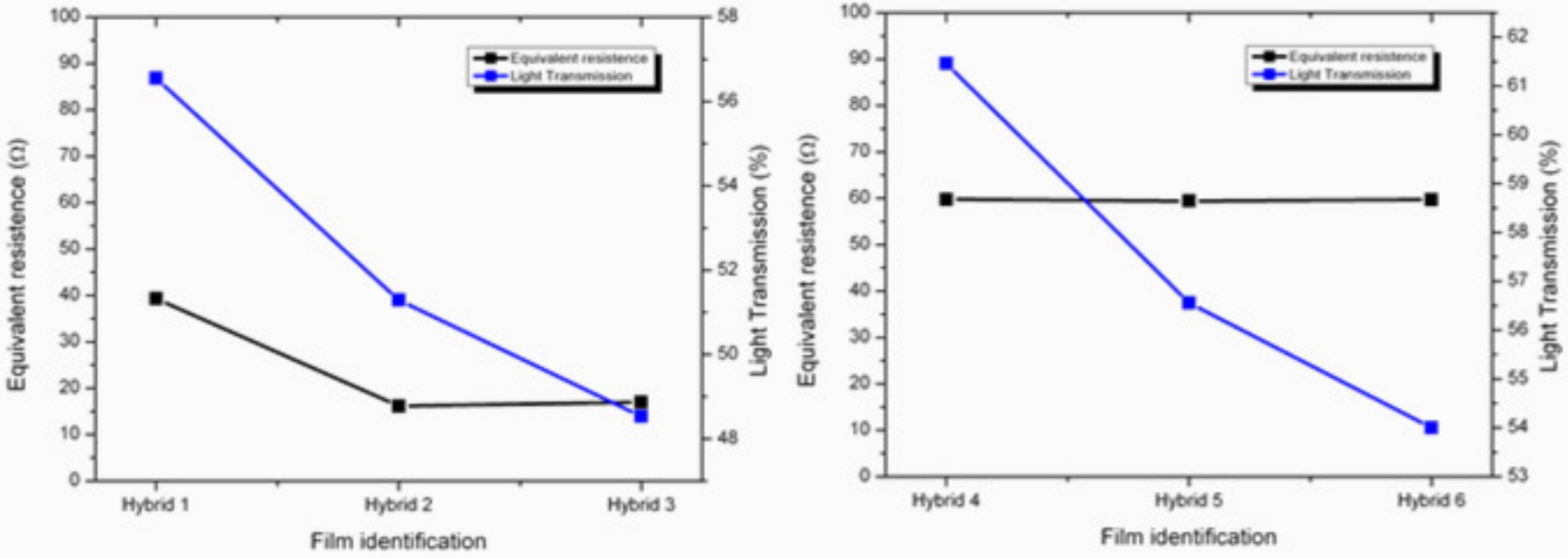






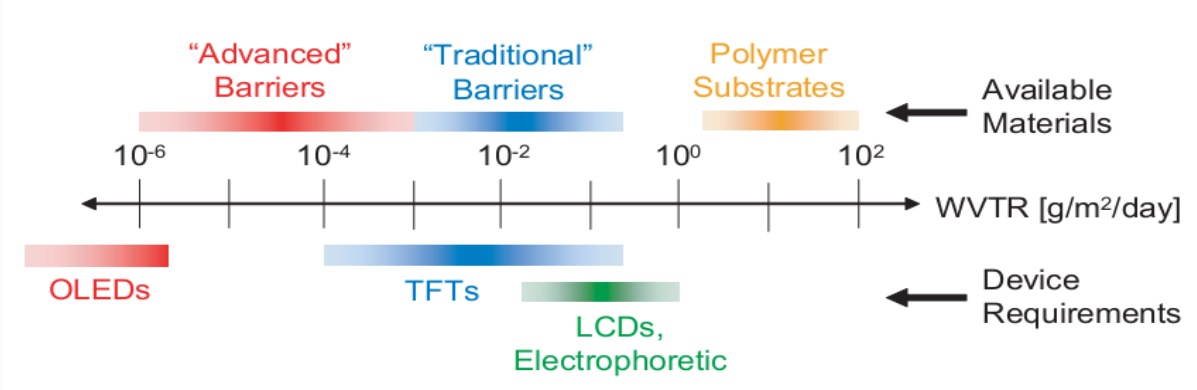
Pattern	Identification (Hybrid)	Line Width (µm)
I	1	350
	2	700
	3	1000
II	4	350
	5	700
	6	1000

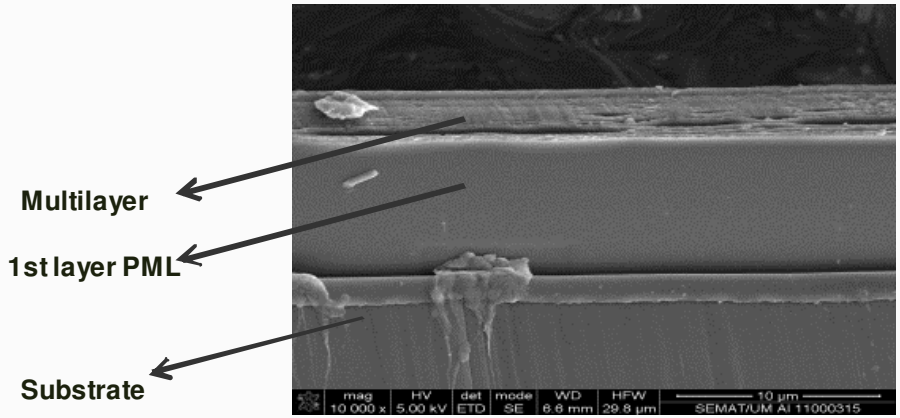
Processing thin hybrid films

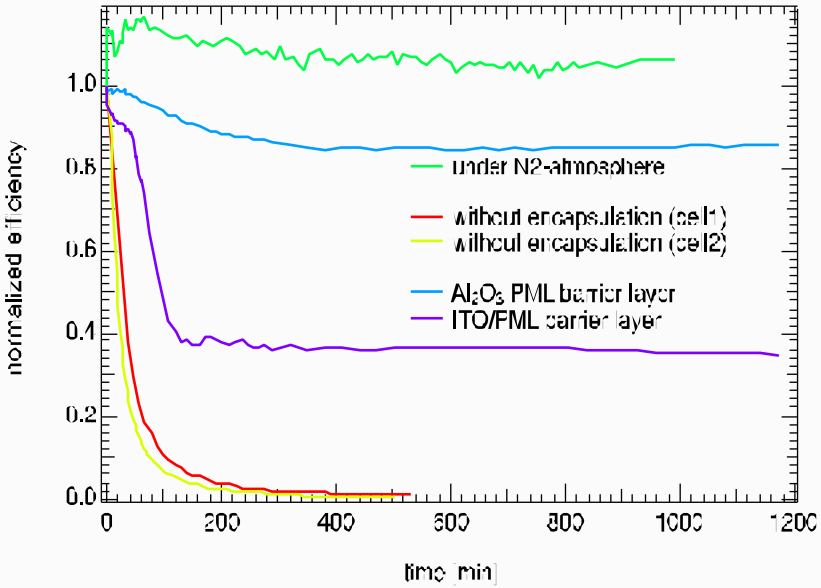


- Comparing the value of light transmission and resistance for all hybrid films, it is visible that hybrid film 1 has the best results.

Organic Photovoltaic Devices







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PRODUCT DEVELOPMENT

From R&D to Prototyping and Pre-Series

Sensor Tile

- Ceramic tile with an embedded light piezoelectric switch –*light switch* embedded on the tile structure
- Results: International patent held by Dominó.
- CE certified product

TP LEDs and PV Curtain

- Integrated flexible PV modules and LED lighting;
- CeNTI: Control electronics for PV, battery, light-sensor and textile integrated LED (3mm)
- Results: Product to be commercialized

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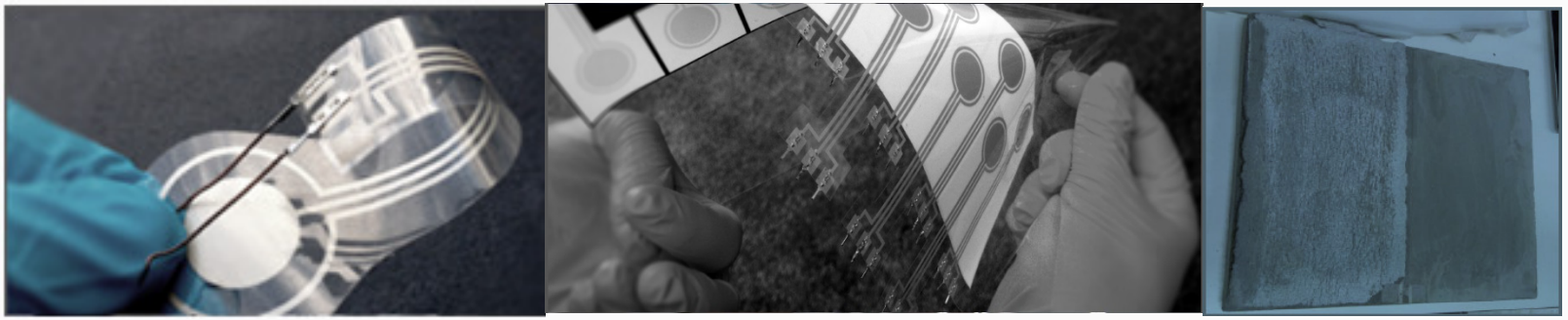
INVISIBLE NETWORK
project



- Development interactive surfaces based in printed electronics integration and substrate functionalization
  - Integrate sensors (ex: temperature, pressure, capacitive sensing, piezoelectric);
  - Miniaturized sensors;
  - Development of electronics for aquisition, treatment and signal transmission

COMPETE
PROGRAMA OPERACIONAL FACTORES DE COMPETITIVIDADE

QREN
QUADRO DE REFERÊNCIA ESTRATÉGICO NACIONAL
PORTUGAL 2007.2013

UNIÃO EUROPEIA
Fundo Europeu de Desenvolvimento Regional

YEXS – Your Extreme Experience

P&R - Textéis, S.A.

citeve

PT INOVAÇÃO

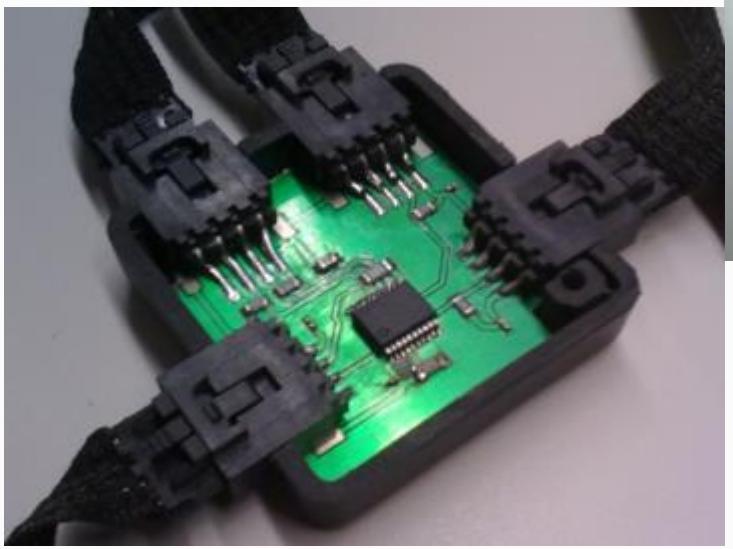
- Multifunctional climbing jacket with integrated electronics (biometric sensors and emergency heating systems)
- CeNTI: Integrated Electronics (Biometric sensors and heating systems) and high thermal insulation materials
- Results: Product to be commercialized

YEXS – Your Extreme Experiences

- Temperature sensors (internal and external)

Sensors

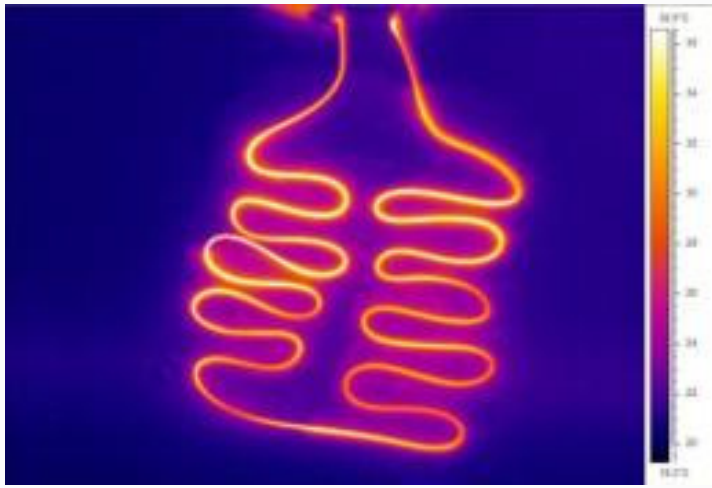
Control unit



Interconections

YEXS – Your Extreme Experiences

- Automomous and automated heating systems;
- Textile (weaved, knitted or embroidery) or printable heating systems;
- Integrated temperature management system;



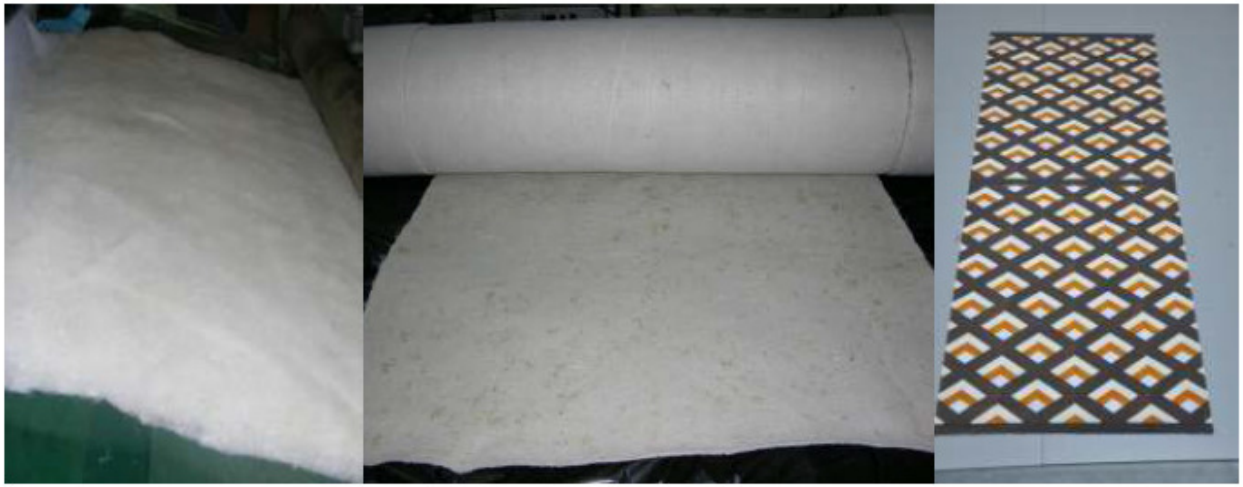
YEXS – Your Extreme Experiences

- Heart rate measurment

Control unit

Sensor PPG

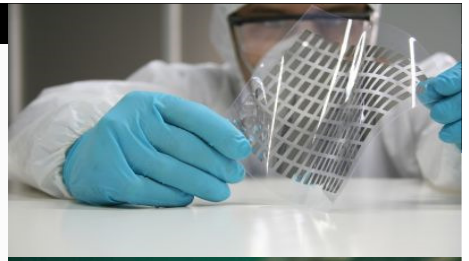
Wall-IT

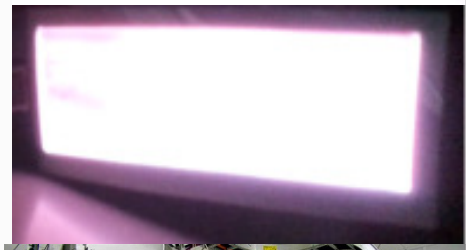


- Development of multilayer structures for interior walls
- Textile product for rehabilitation of interiors with no major interventions
- Product being industrialized by Termolan

Ongoing Projects

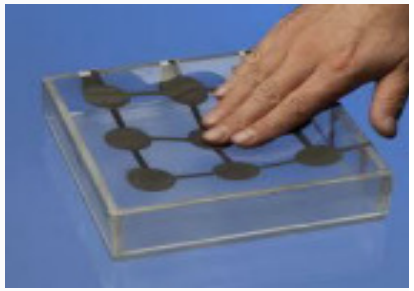
- Flexible PV applications and integration
- Conductive fibres and films
- Super-hydrophobic and super-oleophobic
- Low weight thermoplastic materials
- Organic solar cells and flexible EL
- Organic LEDs
- Electrochromic Devices
- Fully Printed Heating systems and devices
- Fully printed sensor-actuators and printed circuitry

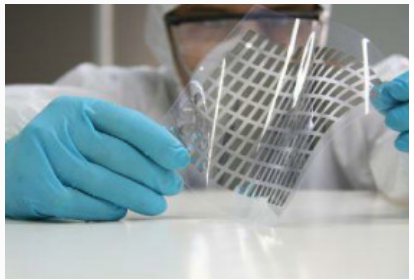



Opportunities

- Direct Integration automotive components
- Replacement of traditional switches
- Fully integrated/printed sensing;
- Fully integrated elements (ex. Heating);
- Decorative and ambient Lighting
- Interior lightning with higher areas, and lower power
- Static electricity dissipation
- Fibre-level devices
- Printed electronics
- Electronic devices printed in different materials





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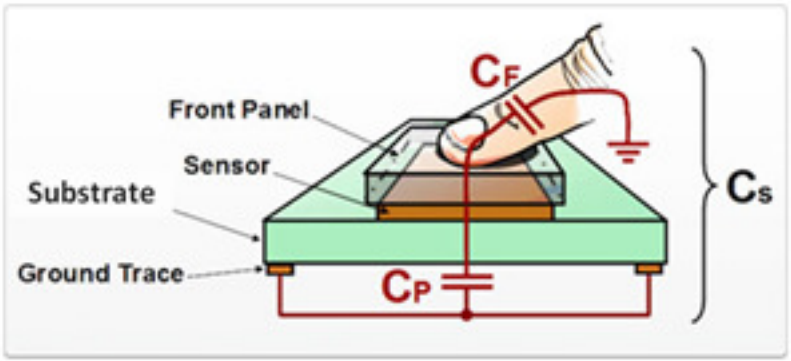
Printed capacitive sensors

A multidisciplinary approach

Capacitive printed sensors



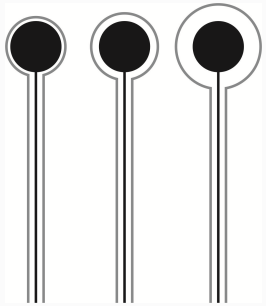
Main advantages:

- New design solutions and easy integration on conventional products;
- Flexible, lightweight and very thin;
- No moving parts and no direct contact with the sensor → long lifetime;
- Simplified manufacturing R2R techniques;
- Economical and resource-saving process.

Interdigital sensors

liquid level detection; dielectric constant determination

Circle+ring sensors



touch/proximity sensors

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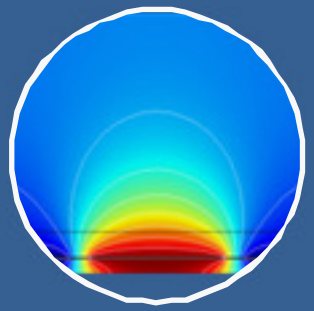
Capacitive printed sensors

An integrated and multi-disciplinary approach



Numerical simulation

Design optimization

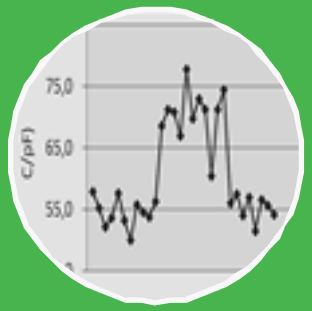
Processing

Printing

Lamination

Laser Cutting

etc.

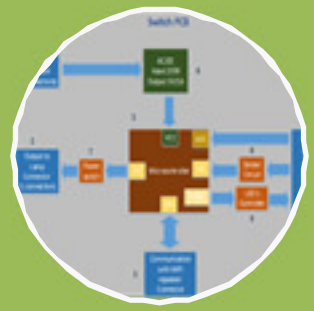


Caracterization

Electrical measurement

AFM,profilometry

Optical microscopy



Engineering

Development of systems for acquisition, treatment and transmission of data

Capacitive printed sensors

Numerical simulation | Processing | Characterization | Engineering

Defining physics of phenomena

Maxwell equation:

$$\nabla \mathbf{D} = \rho$$

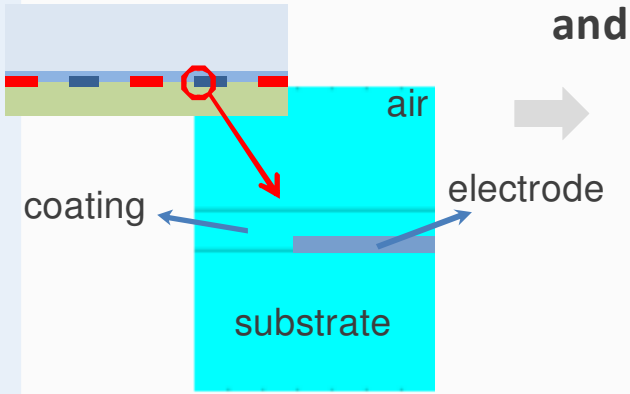
Constitutive relation:

$$\mathbf{D} = \varepsilon_0 \mathbf{E} + \mathbf{P}$$

Static conditions:

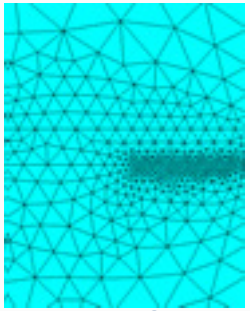
$$\mathbf{E} = -\nabla V$$

Defining geometry



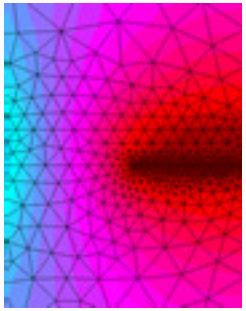
geometry

Defining discretization and solving method



mesh

Sensor performance evaluation



Electric Potential

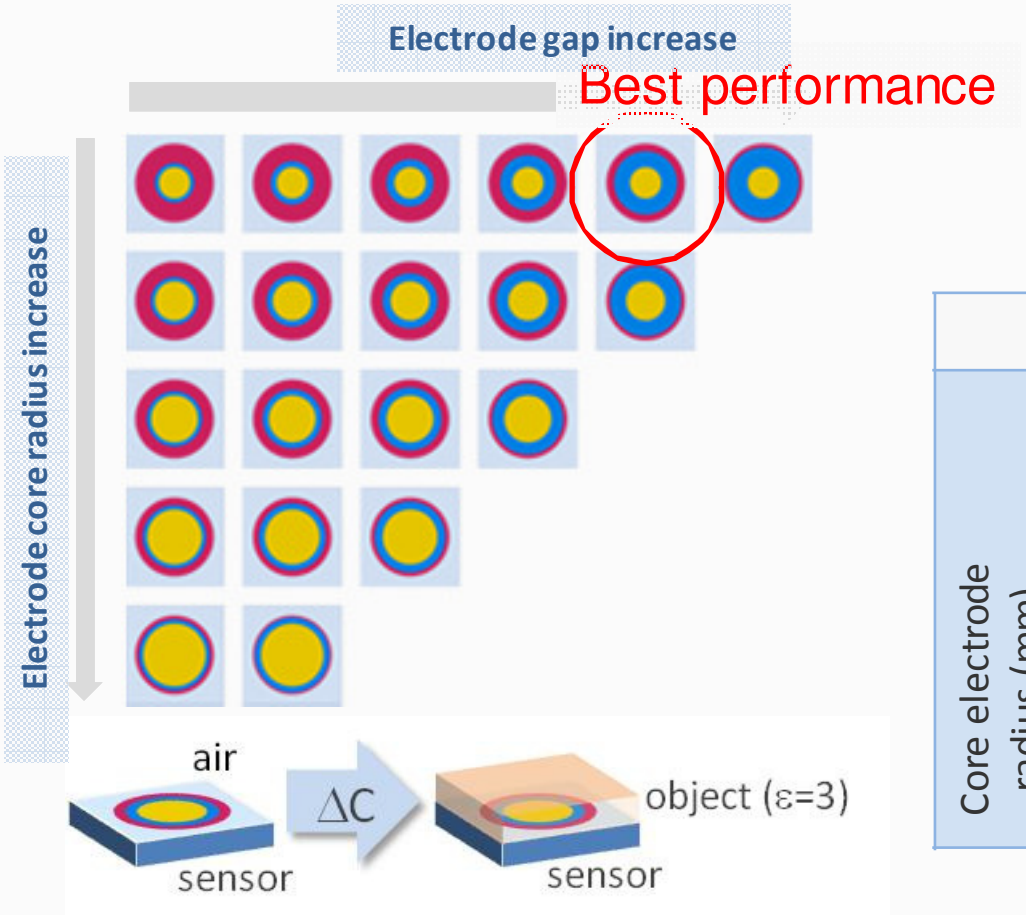
Capacitance

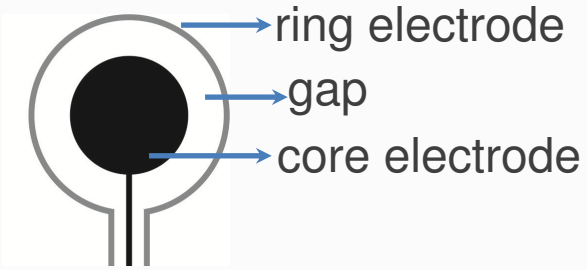
FEM provides rapid performance evaluation of electrode systems design

Capacitive printed sensors

Numerical simulation | Processing | Characterization | Environmental aging

Touch sensor





ΔC (%)

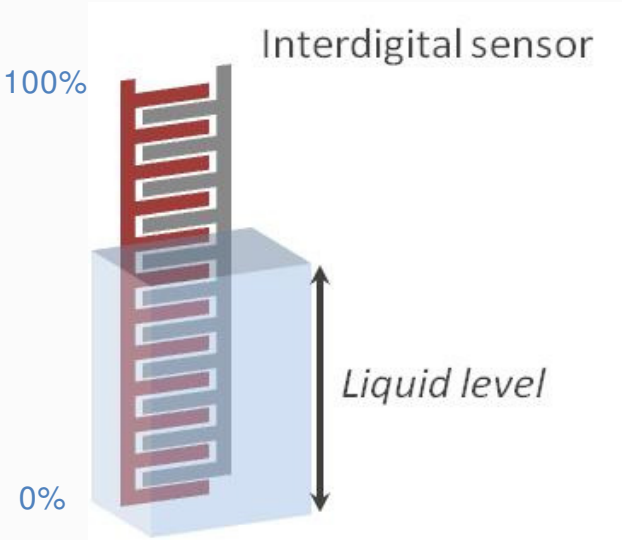
Core electrode radius (mm) \ Gap thickness (mm)	1	1.5	2	3	4	5
4	27.8	28.4	28.7	29	29.1	28.9
5	27.7	28.3	28.6	28.8	28.7	
6	27.5	28.1				
7	27.3	27.7	27.7			
8	26.5	26.0				

Best performance

Capacitive printed sensors

Numerical simulation | Processing | Characterization | Applications

Liquid level sensor

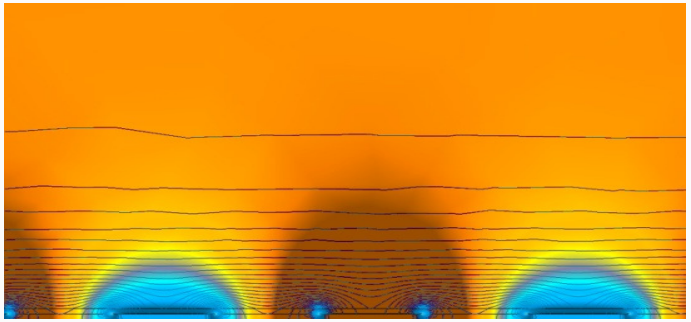


Substrate: PET (75µm)

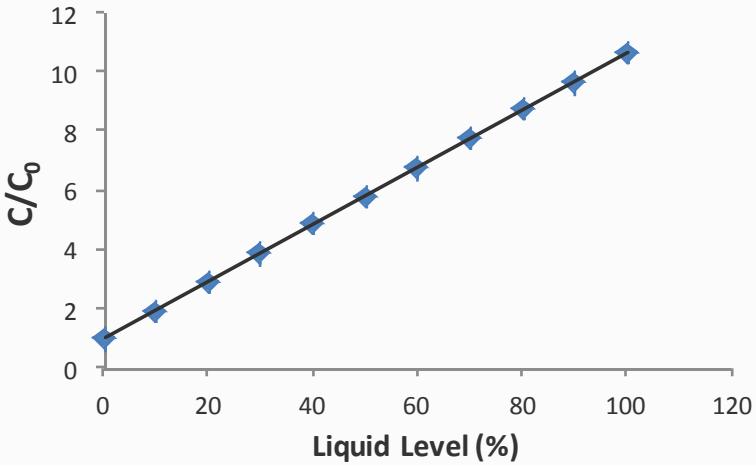
Encapsulator: PET (75µm)

Liquid: Water (ε=80)

Electric potential



Capacity *vs* Liquid Level

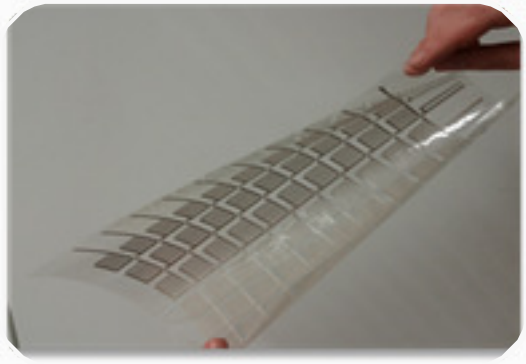


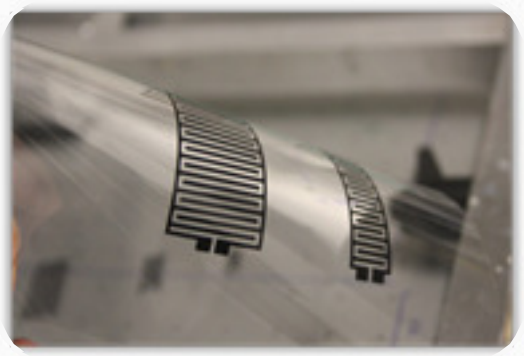
Capacitive printed sensors

Numerical simulation | Processing | Characterization | Engineering

Different kinds of substrates:

- Flexible polymeric substrates;
- Directly on company raw materials/final products (e.g. carbon composite, paper, cork, textiles, etc.).





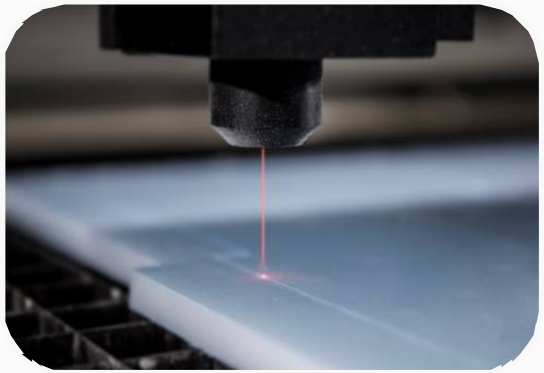
Capacitive printed sensors

Numerical simulation | **Processing** | Characterization | Engineering

Sheet/sample

Inkjet

Screen-printing

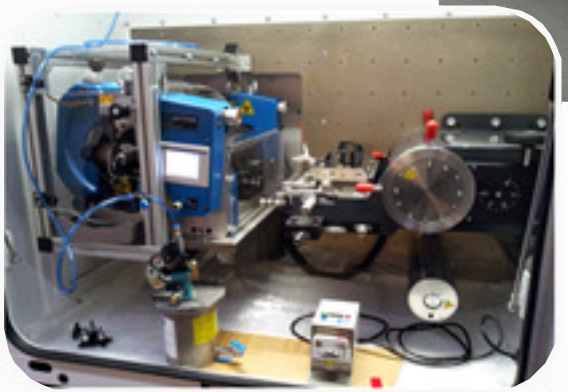


Laser cutting

Capacitive printed sensors

Numerical simulation | **Processing** | Characterization | Engineering

R2R unity



Rotaryscreen

Slot die

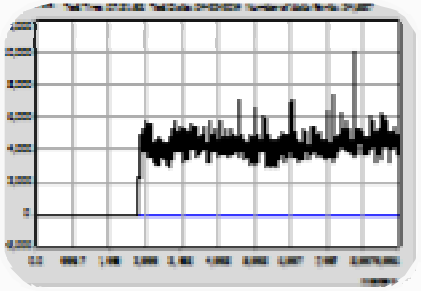
Lamination

Capacitive printed sensors

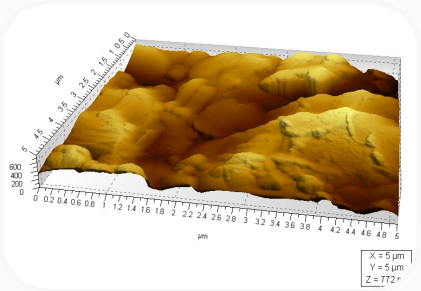
Numerical simulation | Processing | **Characterization** | Engineering

Printing quality evaluation

Macrostructure analysis

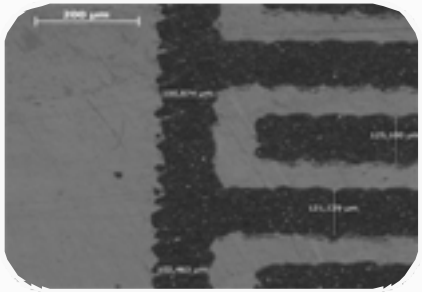


Profilometry



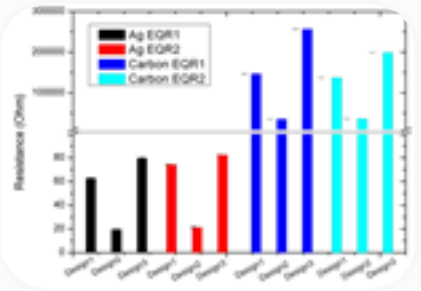
AFM

Lateral resolution



Optical Microscopy

Sheet resistance



4 probe measurement

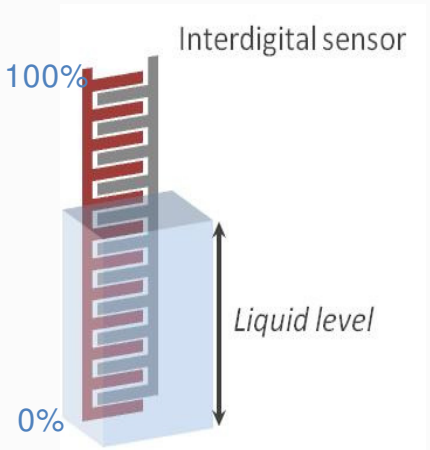
- Optimization of process parameters (screen properties, processes rates, curing conditions, etc.)
- Main goals: process reproducibility; low sheet resistance and smooth surfaces.

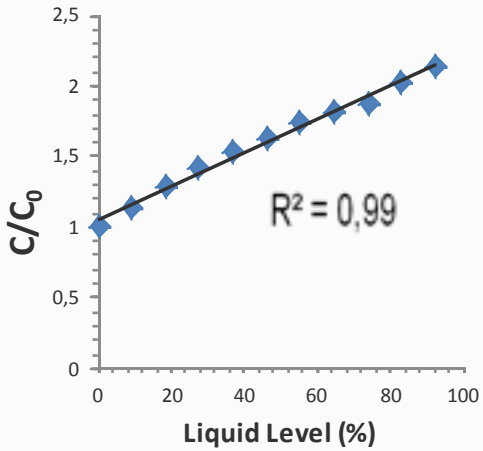
Capacitive printed sensors

Numerical simulation | Processing | **Characterization** | Engineering

Performance evaluation

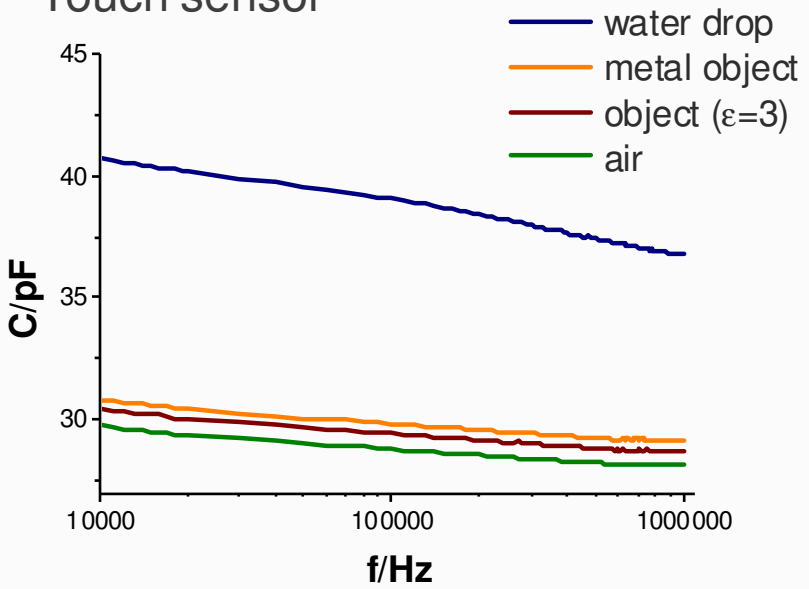
Liquid level detection





- Linear behavior.
- Good reproducibility.

Touch sensor



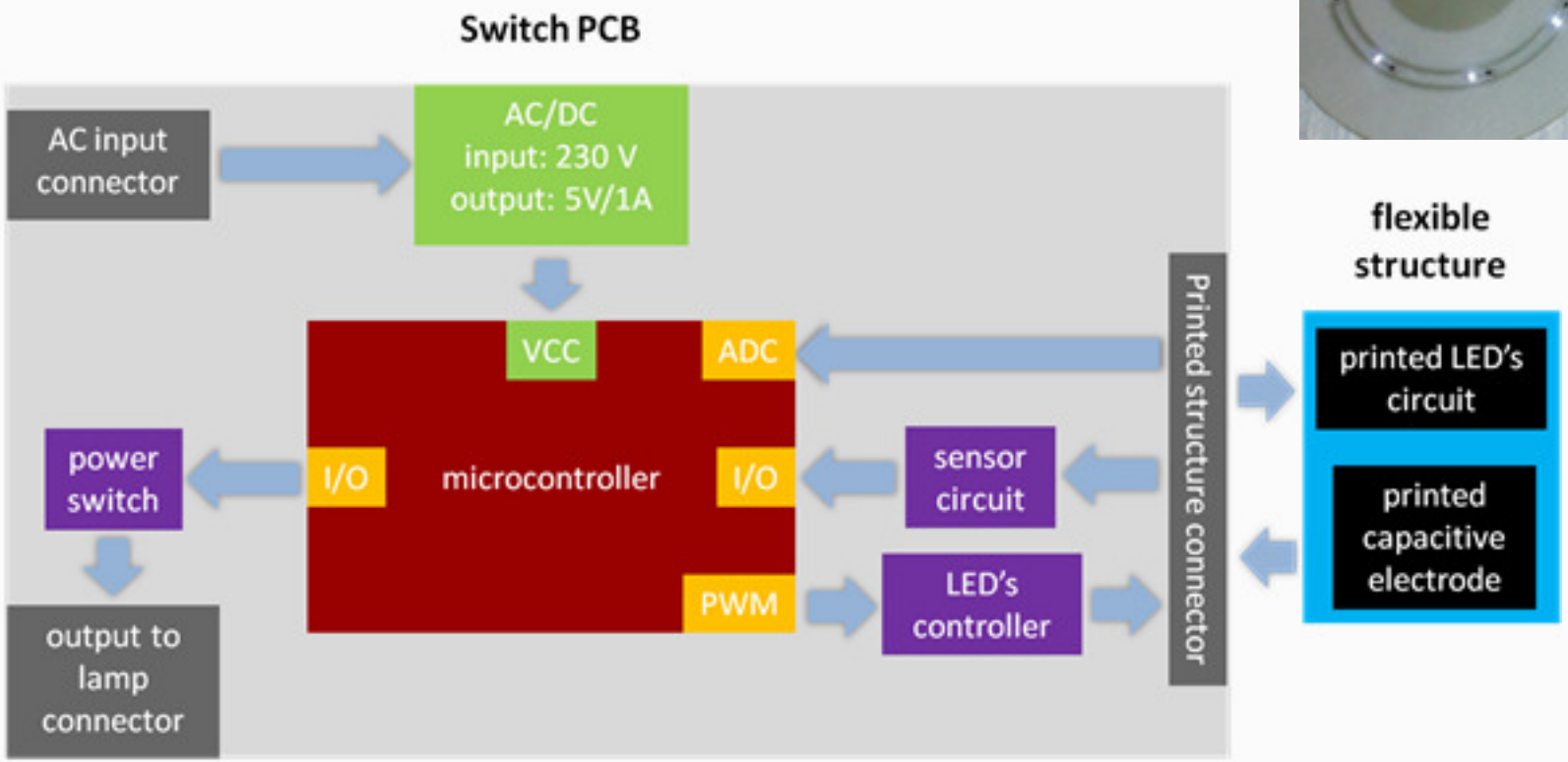
- Sensivity to different objects with low dielectric constant.
- Good reproducibility.

Capacitive printed sensors

Numerical simulation | Processing | Characterization | **Engineering**

Example 1

Proximity sensor with LED indicator

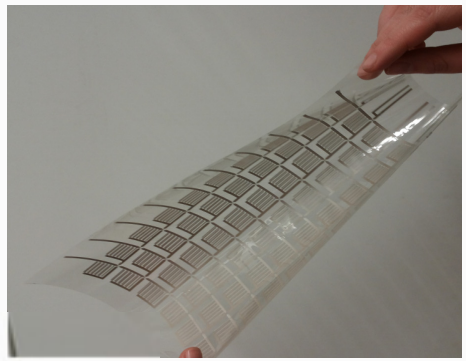


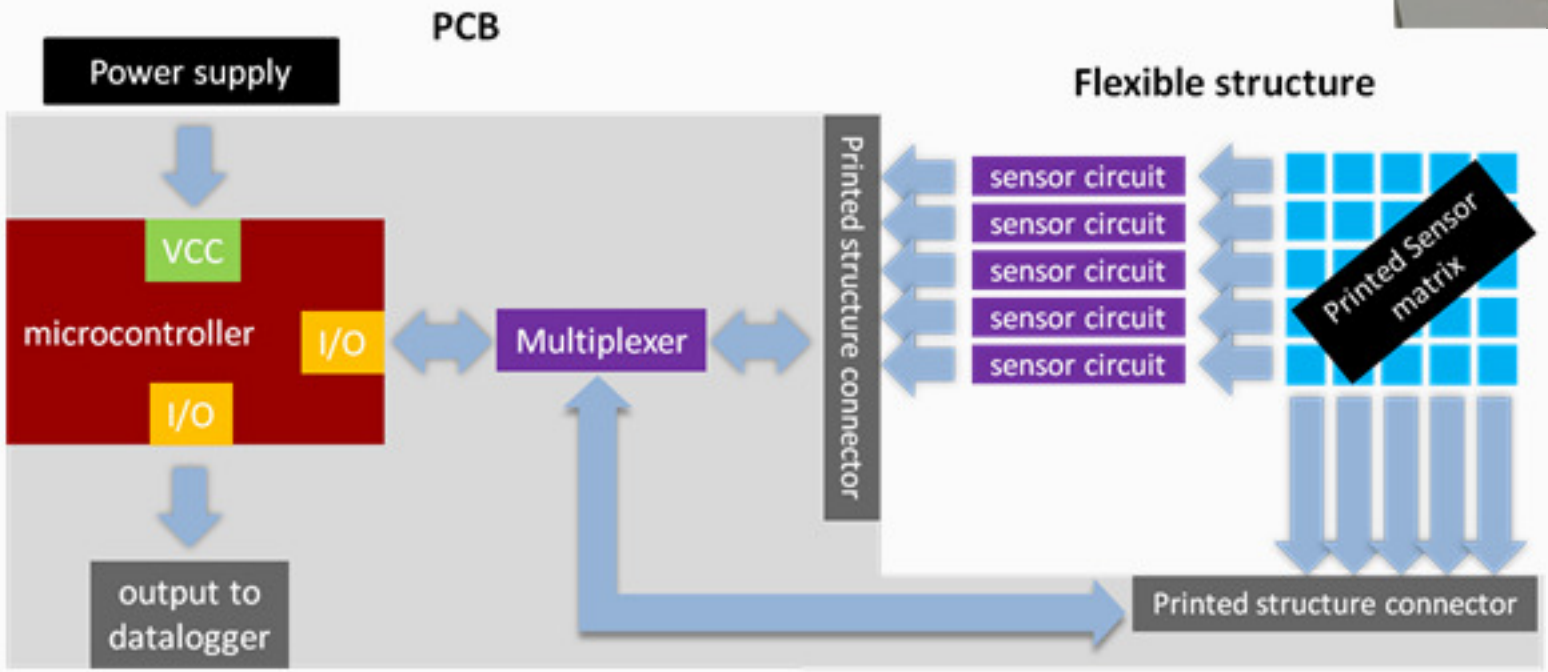
Capacitive printed sensors

Numerical simulation · Processing · Characterization · **Engineering**

Example 2

sensor matrix for dielectric object detection





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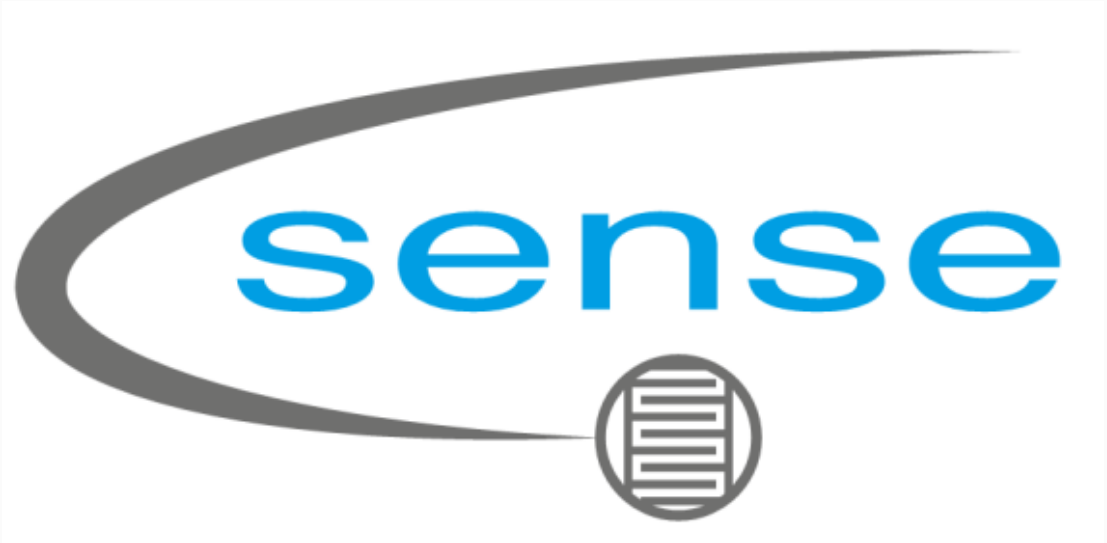
A case study



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sense

SENSE | Development of solution embedded sensing and/or printed electronics integrated on fuel tank.

GOALS | The objective of the work is to develop R&D activities that enhance innovation in sensorized structures.

OUTPUTS | Technologic demonstrator with integrated sensing multi-monitoring system: structure analysis system, fuel level and temperature sensors.

CEiiA

CRITICAL MATERIALS

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COMPETE
PROGRAMA OPERACIONAL FACTORES DE COMPETITIVIDADE

QREN QUADRO DE REFERÊNCIA ESTRATÉGICO NACIONAL

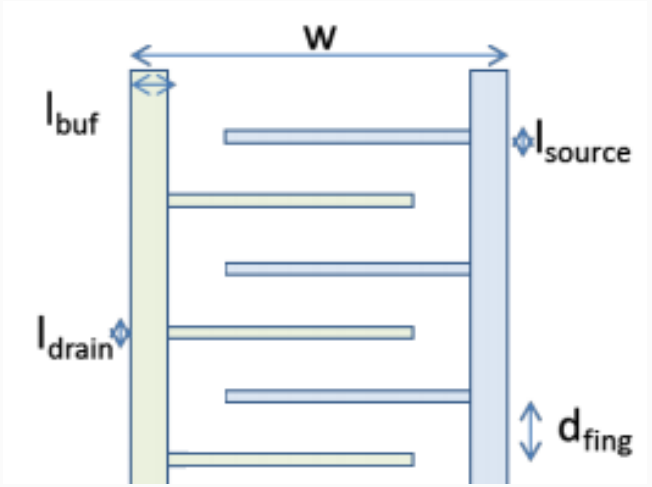
UNIÃO EUROPEIA
Fundo Europeu de Desenvolvimento Regional

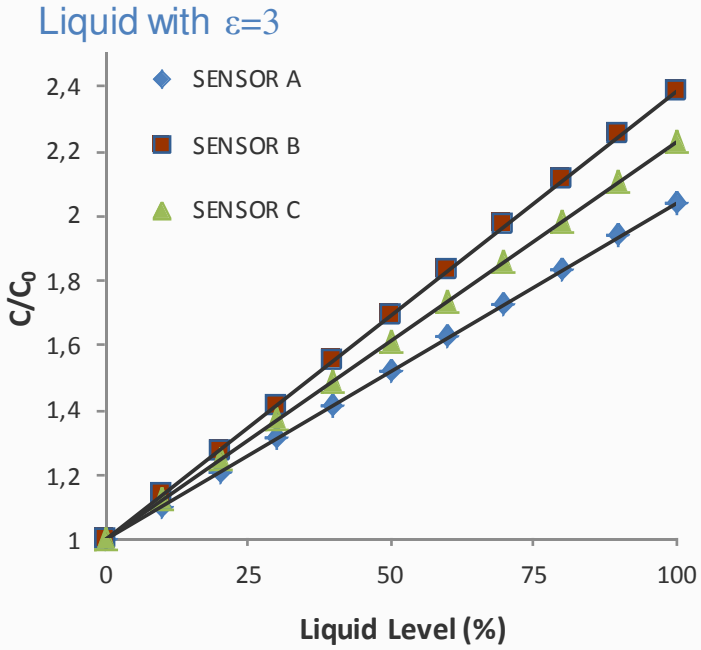
A case study: Sense Project

Numerical Simulation

Goals

- Increase fuel level sensibility;
- Decrease the sensibility to fuel drops.





Sensor	l_{source} mm	l_{drain} mm	d_{fing} mm	Slope C/C_0	Drop 5% sensor size
A	1.00	1.00	1.00		
B	2.00	2.00	4.00	**2.39**	**1.92**
C	1	1	3	2.2	2.24

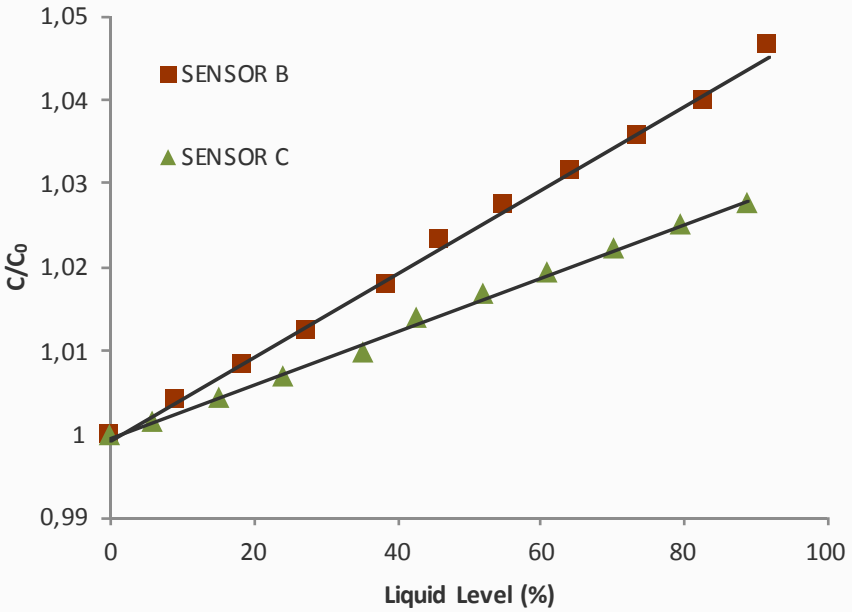
Best performance

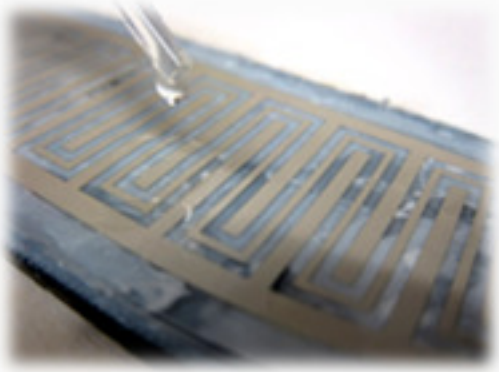
A case study: Sense Project

Performance evaluation

Sensor B and C

Sensitivity to liquid with low ε (~3)



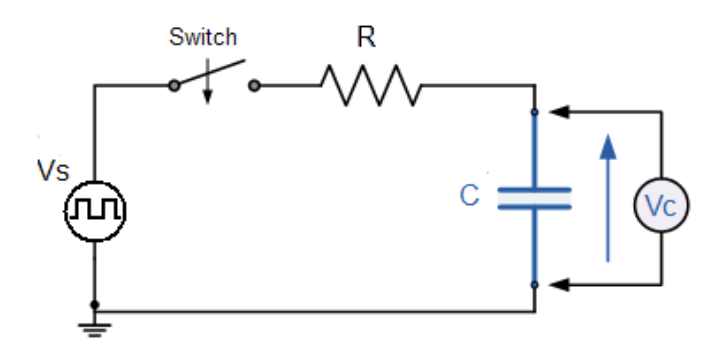


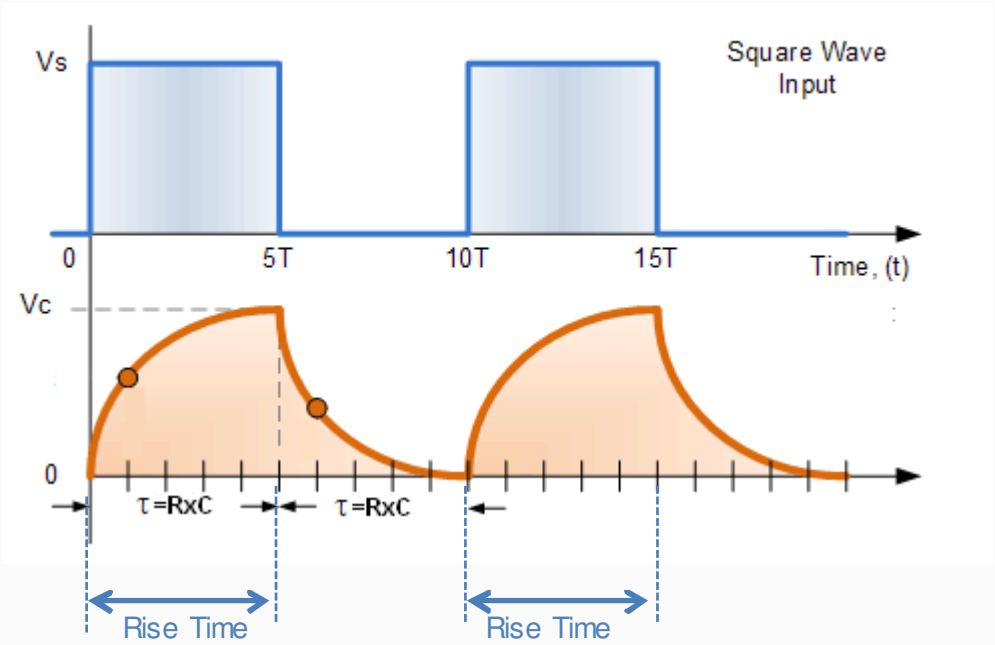
Insensitivity to liquid drops

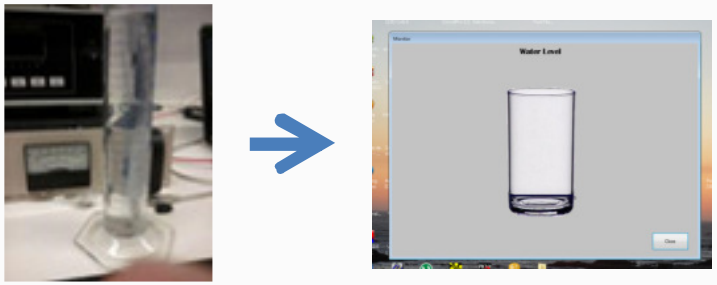
Number of drops	SENSOR B Output Signal
10	0.0%
20	0.1%
30	0.3%
50	0.7%

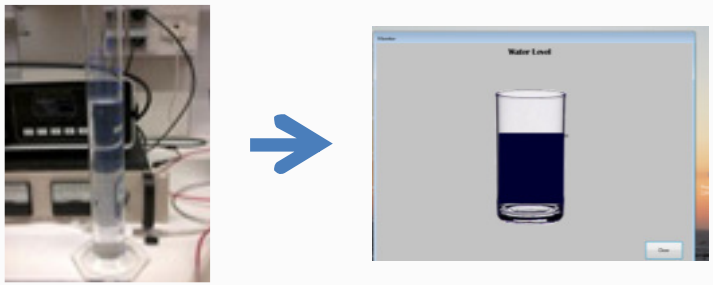
A case study: Sense Project

Engineering









Measuring rise time and fix the R value, the C is proportional to rise time.

Final Notes

- **An integrated strategy is necessary in order to successfully upscale R&D systems to pilot and production processes:**
  - Proof-of-concept;
  - In house" "market test" production (pre-series)
  - Bridge the gap between pre-series and full scale production - Valley of death;

Final Notes

Focus on integrated sensoring systems:

- Integrated/added functionality;
- Added-value;
- Interconnectivity and hardware integration;
- Interactivity and availability of information;

Final Notes

- Moving towards all printed and all-integrated flat film electronics – still a way to go… ;
- Certification and quality control processes need to be developed concurrently with engineering and Up-scaling processes;

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Thank you

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