Printing Environmental Sensors On Polymeric Foil: Status and Perspectives for Air Quality Monitoring

Danick Briand

F. Molina-Lopez, A. Vasquez, G. Mattana, N.F. de Rooij

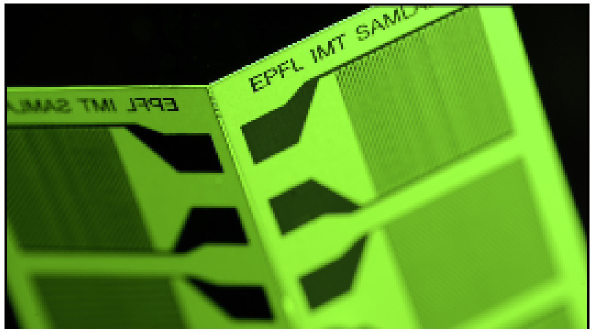
Team leader enviroMEMS

Sensors, Actuators and Microsystems Lab

Institute of Microengineering

EPFL STI IMT-NE

Neuchâtel, Switzerland



http://samlab.epfl.ch

danick.briand@epfl.ch

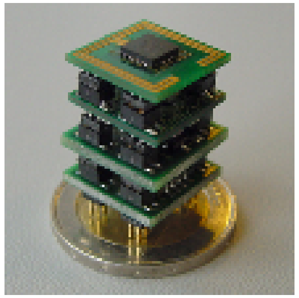
IMT - samlab

Why plastic and flexible ?

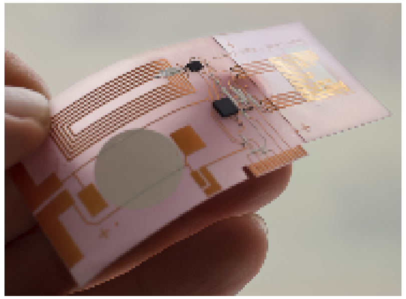
- **For some domains of application:**
  - Wearable, implantable solutions
  - Very low-cost RFID labels
  - Internet of Things
  - Smart textiles

➢ **Making smart systems on plastic foil can bring advantages and could bring sensors/MEMS where there is none at the moment:**

- Thin, planar, flat configuration
- Flexible, foldable, conformal
- Light weight, large area
- Lower-cost



3D Si sensor node



2D Flex

Collaboration with Holst Center (NL)

Why printing ?

Printing what is it ?

- Printing is a reproduction technique. It is used to apply information or functions to a printing substrate or directly on a product
- Two families:
  - **Conventional printing processe (permanent printing plate)**
  - **Digital printing process (inkjet as example)**

Benefits

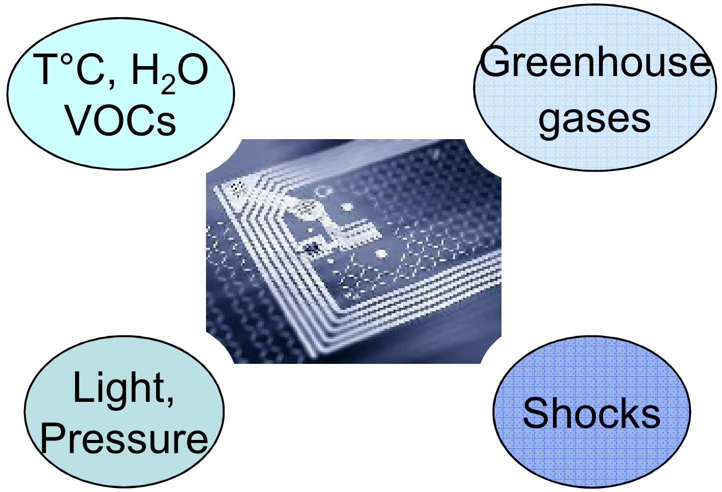
- Low cost manufacturing (additive)
- High speed fabrication (meters/sec)
- Low temperature process (< 100-200°C)
- Flexible substrates
- Localised material patterning
- Established technology

Source: PolyIC

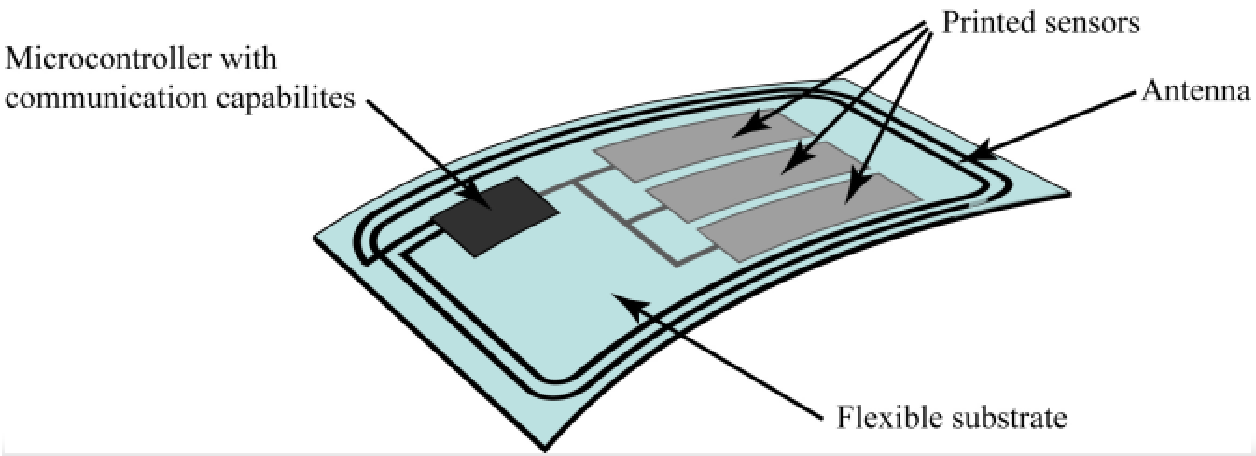
Motivations

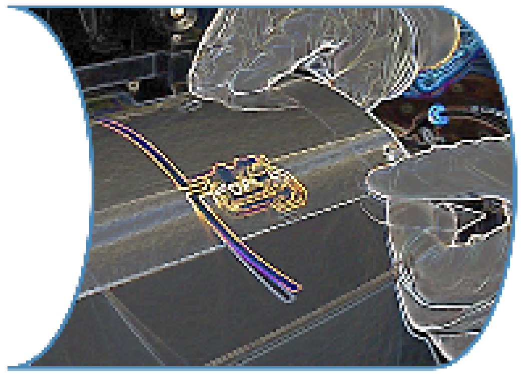
« Smart sensing systems on foil »

- Environmental monitoring
- Logistics / goods monitoring
- Body and health monitoring
- Internet of Things (IoT)
- Smart textiles…



➢ Our approach: hybrid processing and hybrid integration



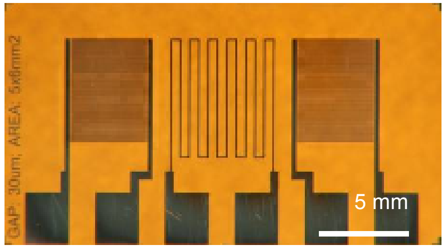


Sensors technologies on foil

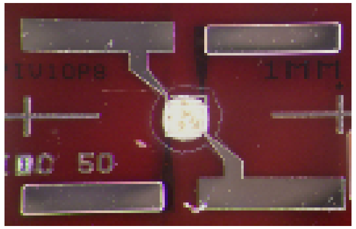
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

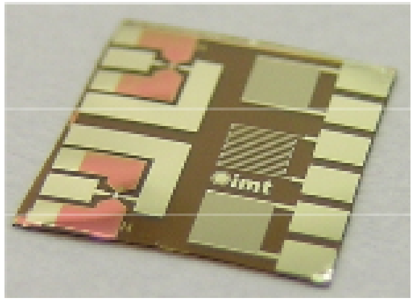
Chemical gas Sensors

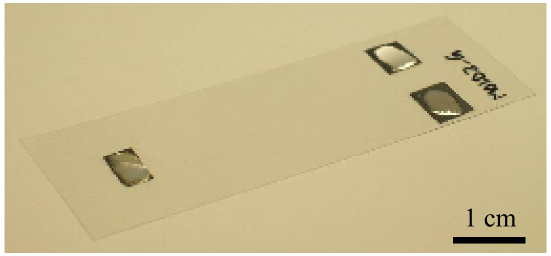
Lithography



PI

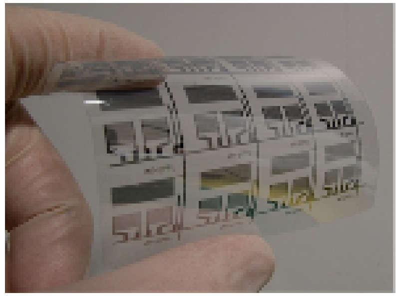


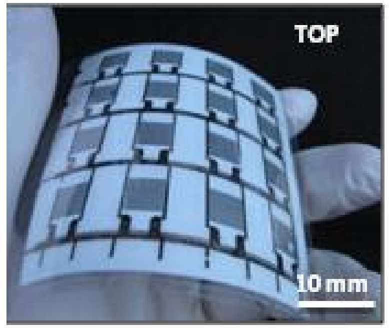




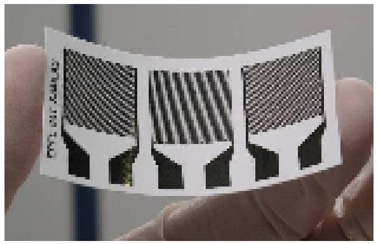
Chemical gas Sensors

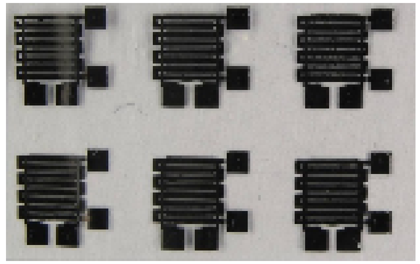
Printing



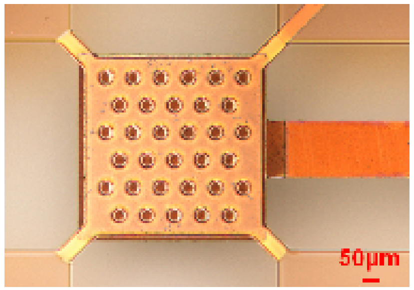


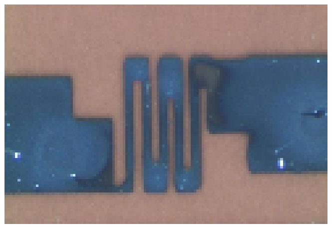
PET





Paper



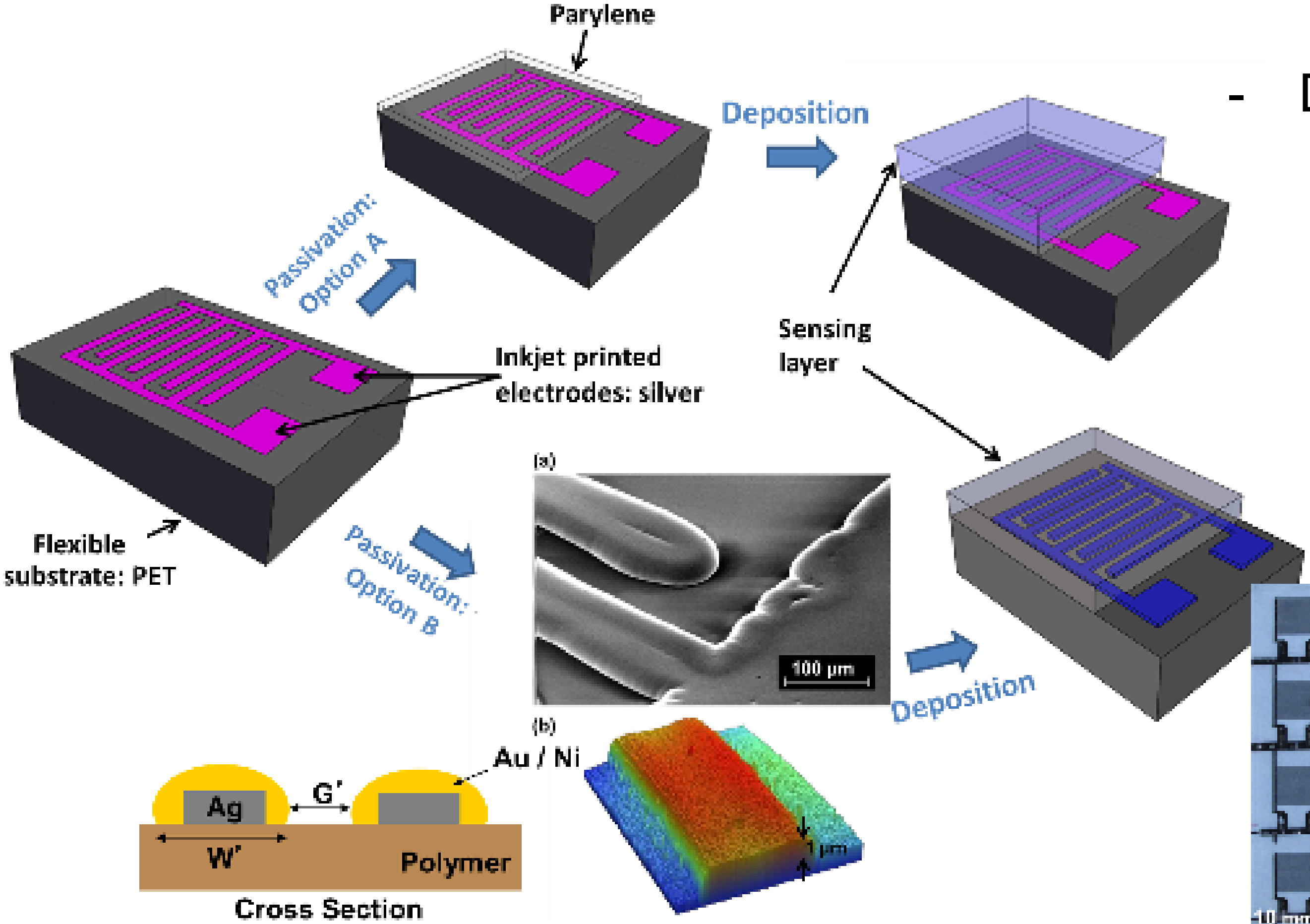


Physical sensors

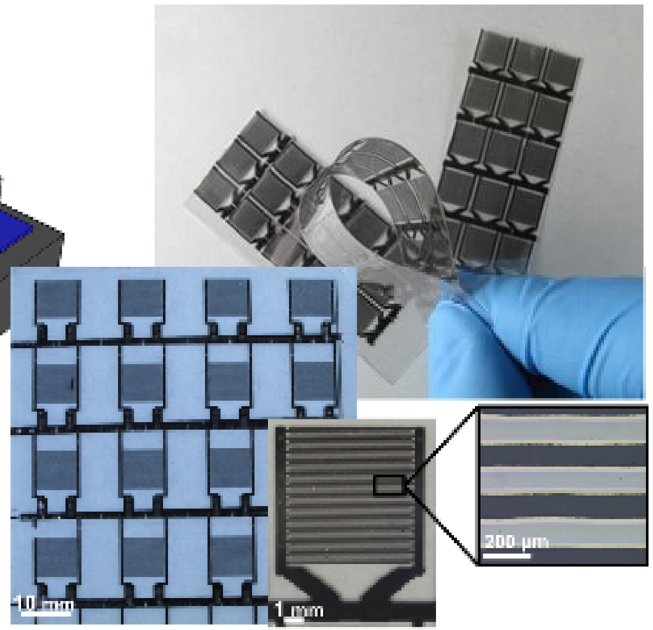
Lithography + printing

Printed sensors process flows

- Fabrication of IDE electrodes **+ passivation ➔** Improves sensing stability



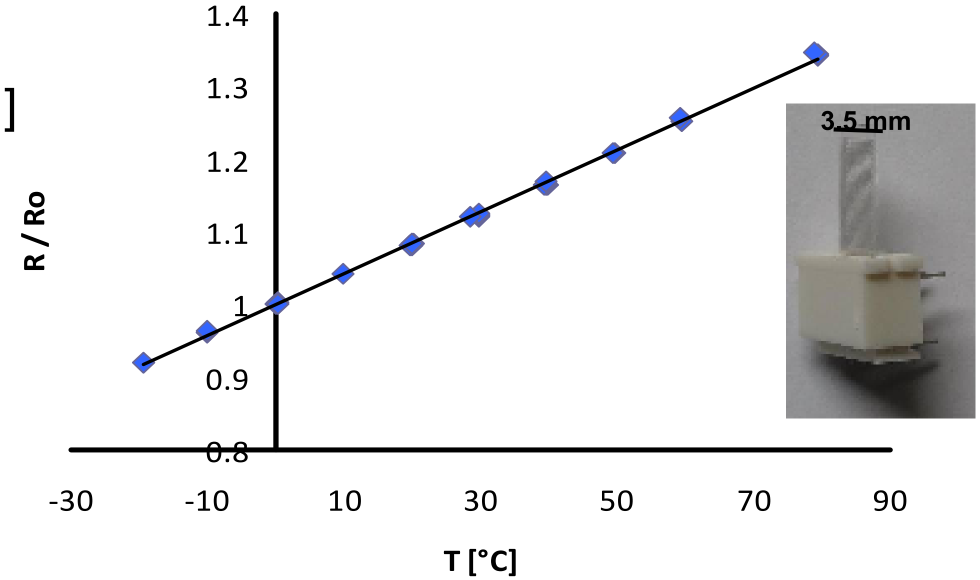
- Deposition:
  - CAB
  - PEUT



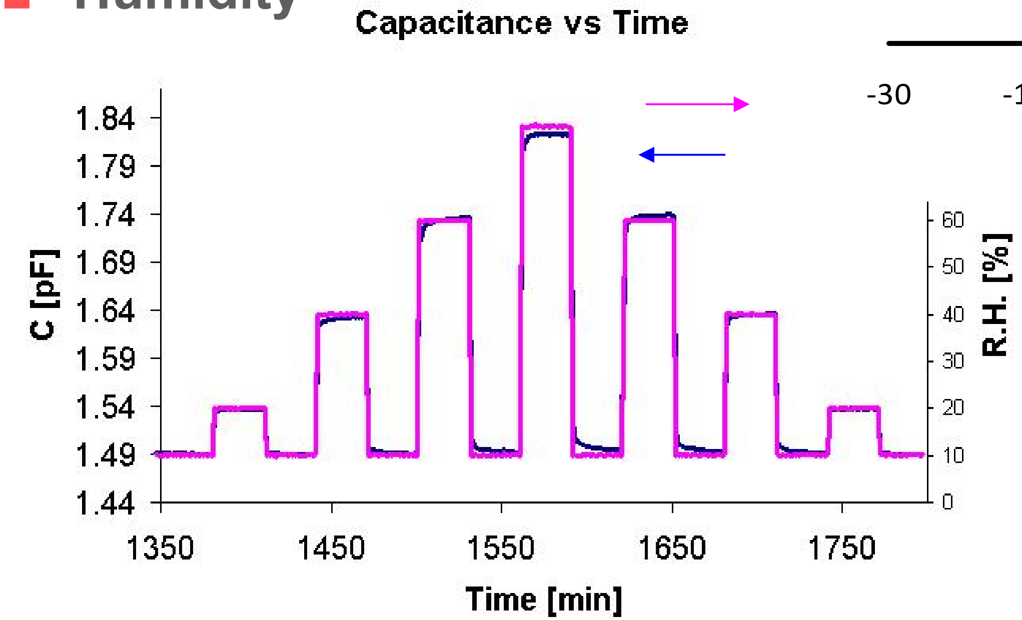
Molina-Lopez F, Briand D, de Rooij NF. Sensors and Actuators B: Chemical 2012;166-167:212–222.
Altenberend U, Molina-Lopez F, Oprea A, Briand D, Barsan N, De Rooij NF, Weimar U. Accepted in Sensors and Actuators B

Printed sensors: Results

- **RTDs**
  - TCR = $(4.27 \pm 0.02) \bullet 10^{-3}$ [°C^{-1}]
  - High linearity: R = 0.9990
  - Range: -20 to 80 °C



- **Humidity**

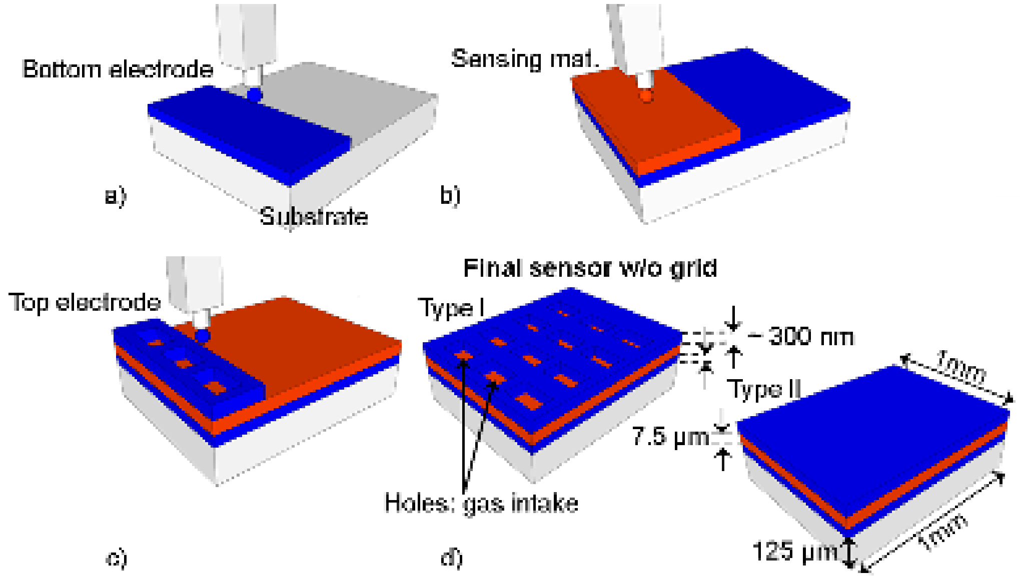


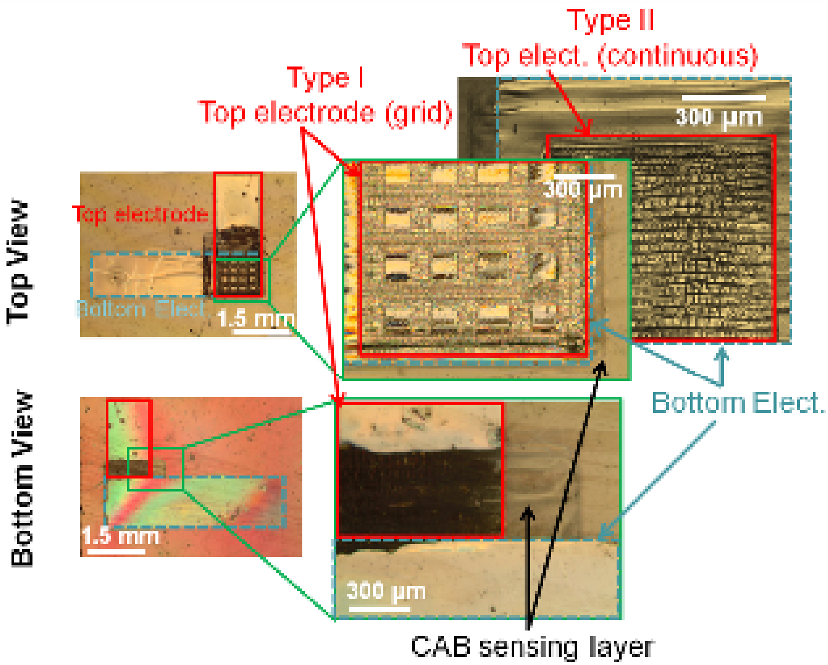
- Differential measurements
- 5 µm Ni layer. Improve stability
- Response time: ~ min
- Good linearity
- 3.75 fF / 1 % r.h.

F. Molina-Lopez et al., Sensors and Actuators B

Printed capacitive sensors: Optimisation

- Parallel plates configuration



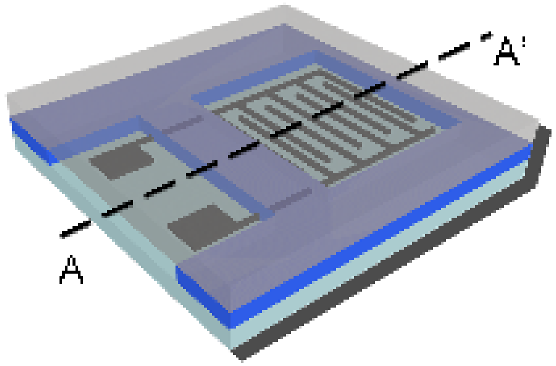


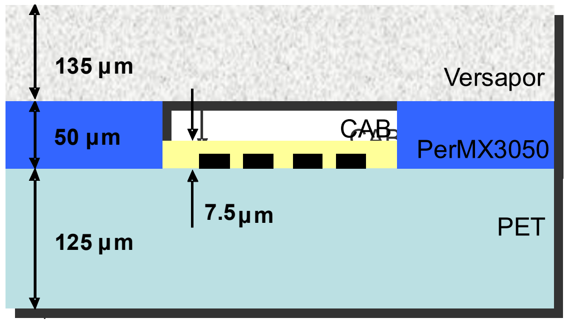
High printed silver porosity ➔
The top electrode does not need grid !

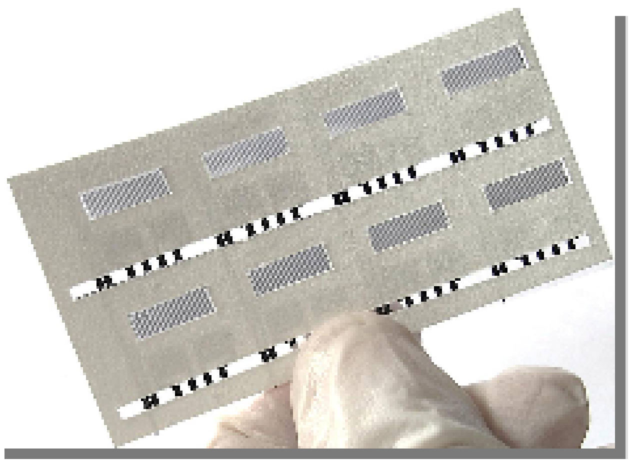
Molina-Lopez F, Briand D, de Rooij NF. Fully Inkjet-Printed Parallel-Plate Capacitive Gas Sensors on Flexible Substrate To be presented at the *IEEE SENSORS Conference*, Taipei (Taiwan), 28-31 Oct. 2012. *Patent submitted*

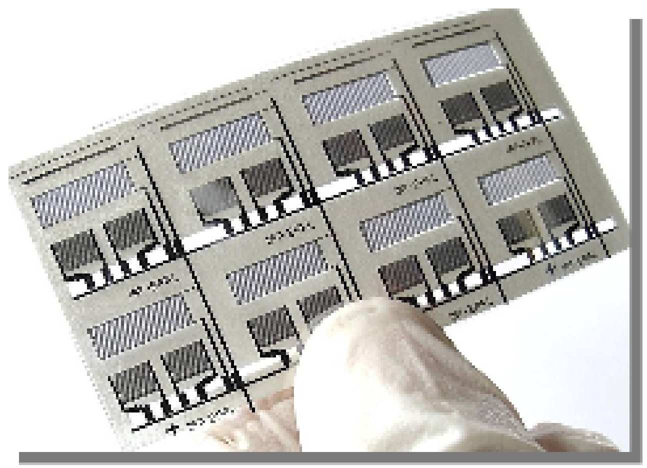
Foil level processing and encapsulation

- Printing and encapsulation of capacitive gas sensors with temperature compensation on PET substrate





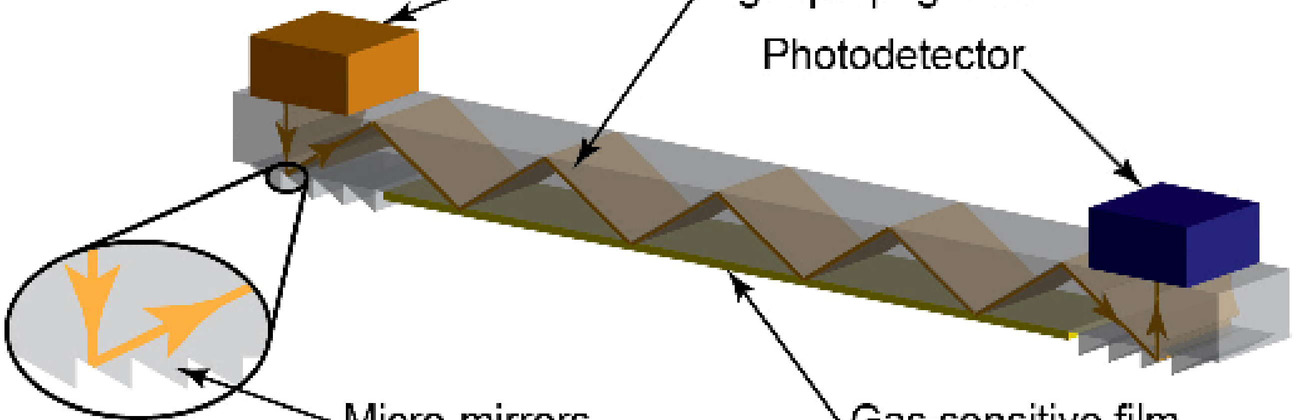




F. Molina-Lopez et al., Accepted in JMM

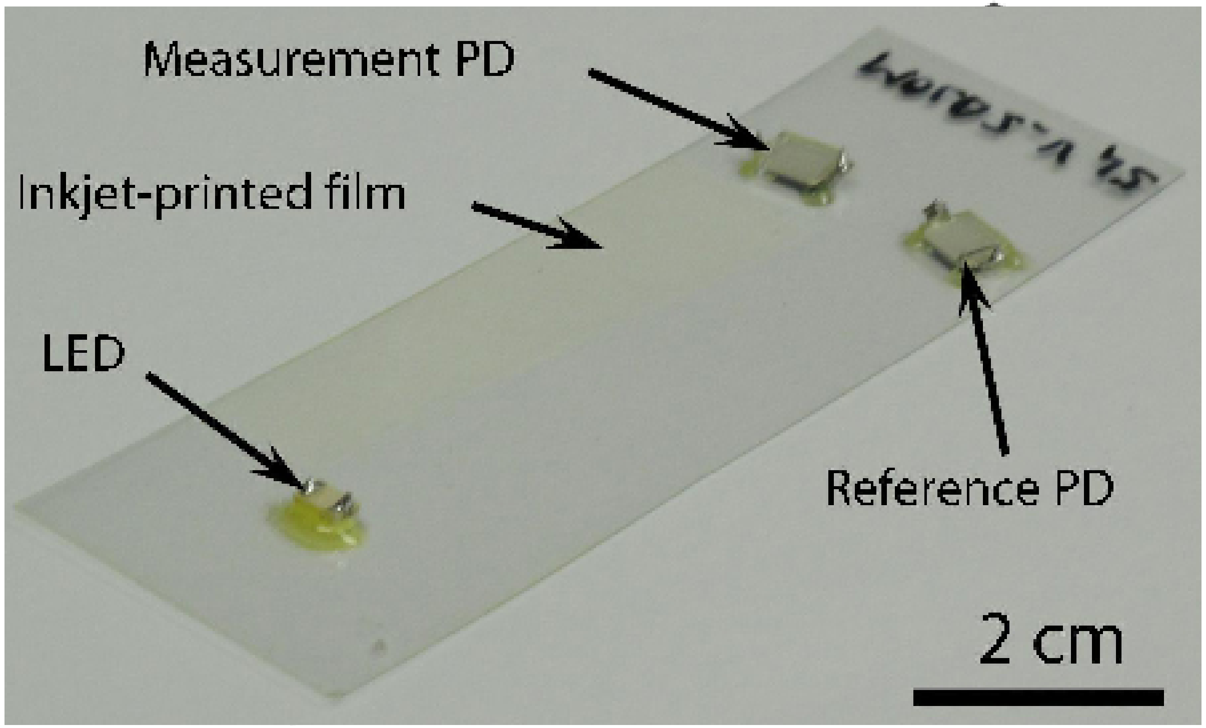
Colorimetric gas sensors on plastic

- **Integration on plastic foil**
  - Planar configuration ⇨ Large area manufacturing (R2R)
  - Simple fabrication ⇨ Low-cost
  - Additive techniques
- **Need for higher selectivity ⇨ Colorimetric detection**
  - Detection of NH_3, CO, NO_x



Realization of the colorimetric sensor

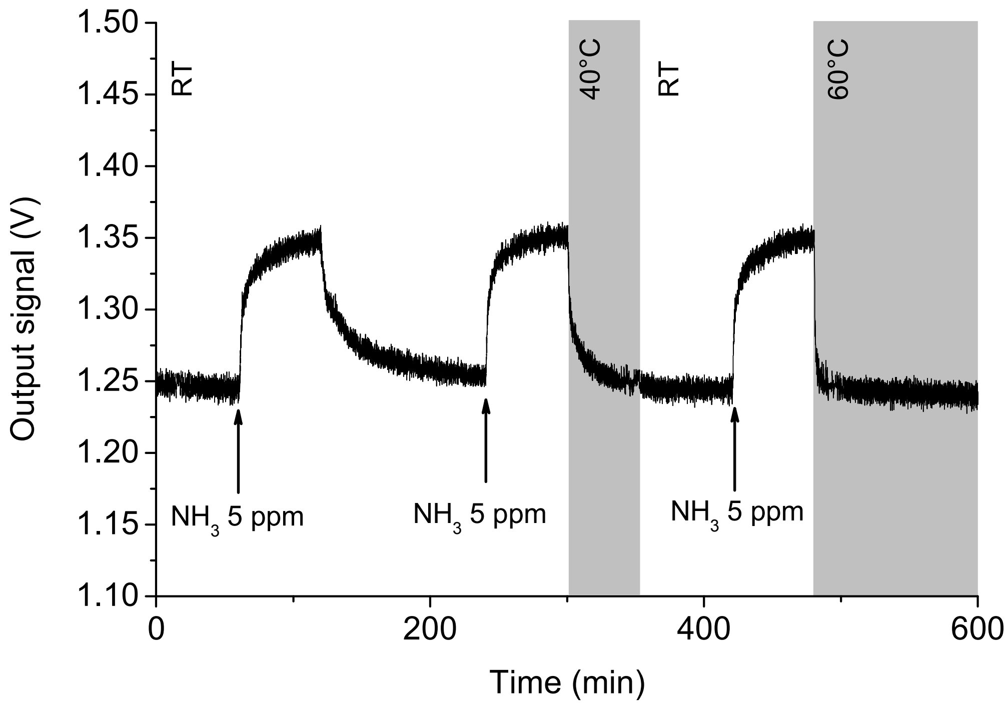
- Inkjet printing of the colorimetric film (~140 nm thick)
- Gluing of SMD LED and photodiodes



J. Courbat et al., Sensors and Actuators B

Response to ammonia

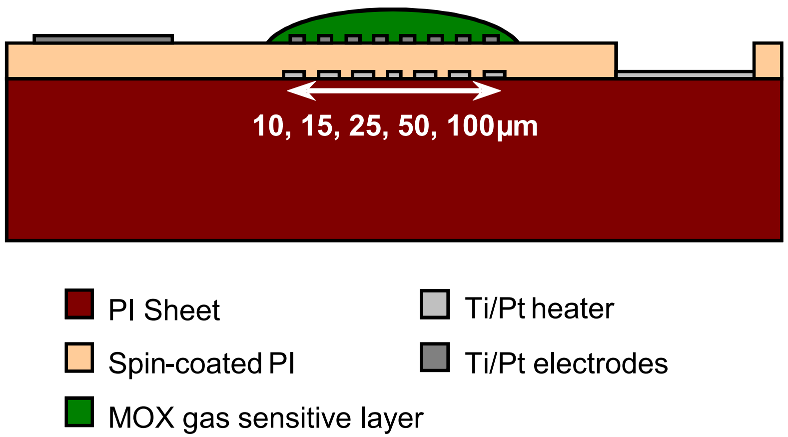
- **Waveguide: PEN 125 µm**
- **Recovery time ($t_{90\%}$) decreased with temperature increase:**
  - RT: 43 min
  - 40°C: 20 min
  - 60°C: 4 min
- **Operation:**
  - Pulsed mode
  - Power consumption: 974 µW
  - Limit of detection: 800 ppb



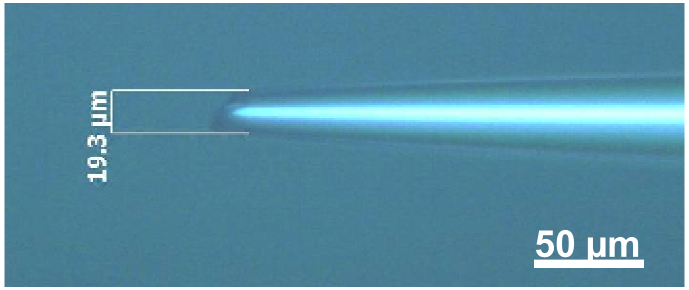
J. Courbat et al., Sensors and Actuators B

MOX gas sensors on PI

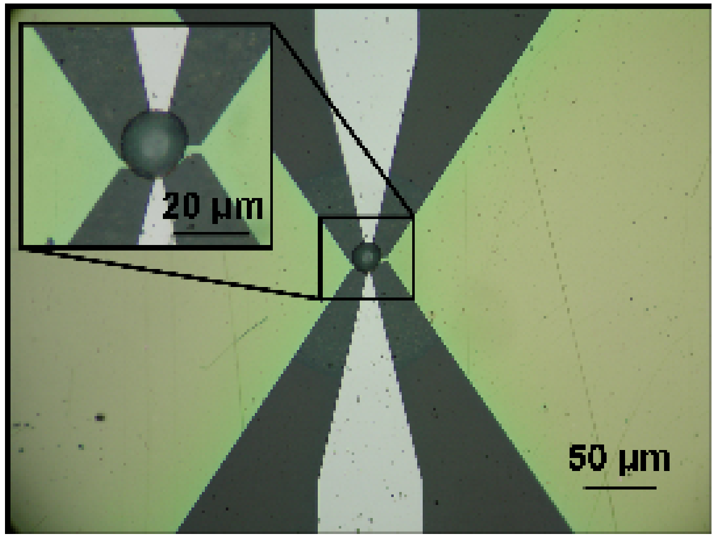
- **Drop-coating of the MOX layer**
  - Large scale fabrication
  - Used for commercial devices
  - No pollution of the MOX layer
  - Annealing at 450°C



Micro glass capillary



Drop coated MOX device on PI

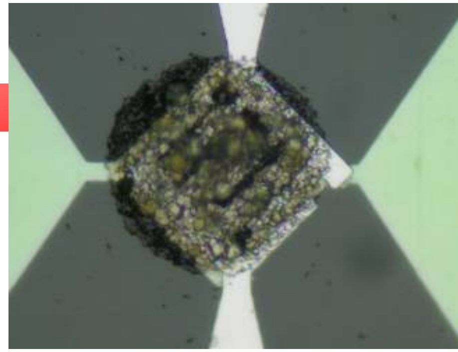


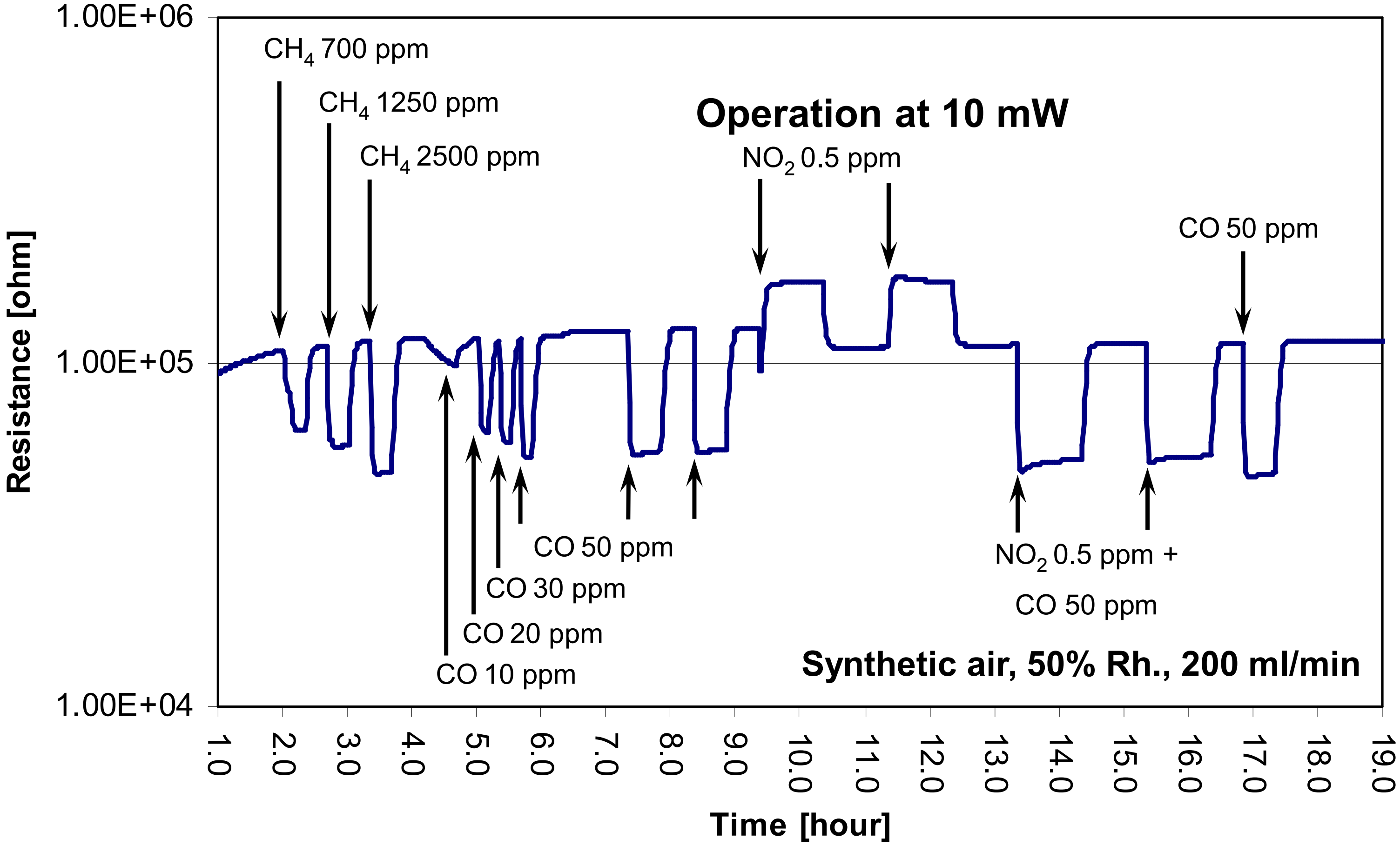
J. Courbat et al., Sensors and Actuators B

➢ **Towards ink-jet of MOX layers**

MOX gas sensors on PI

- Ultra low-power MOX sensors on PI
  - Results comparable to commercial Si devices

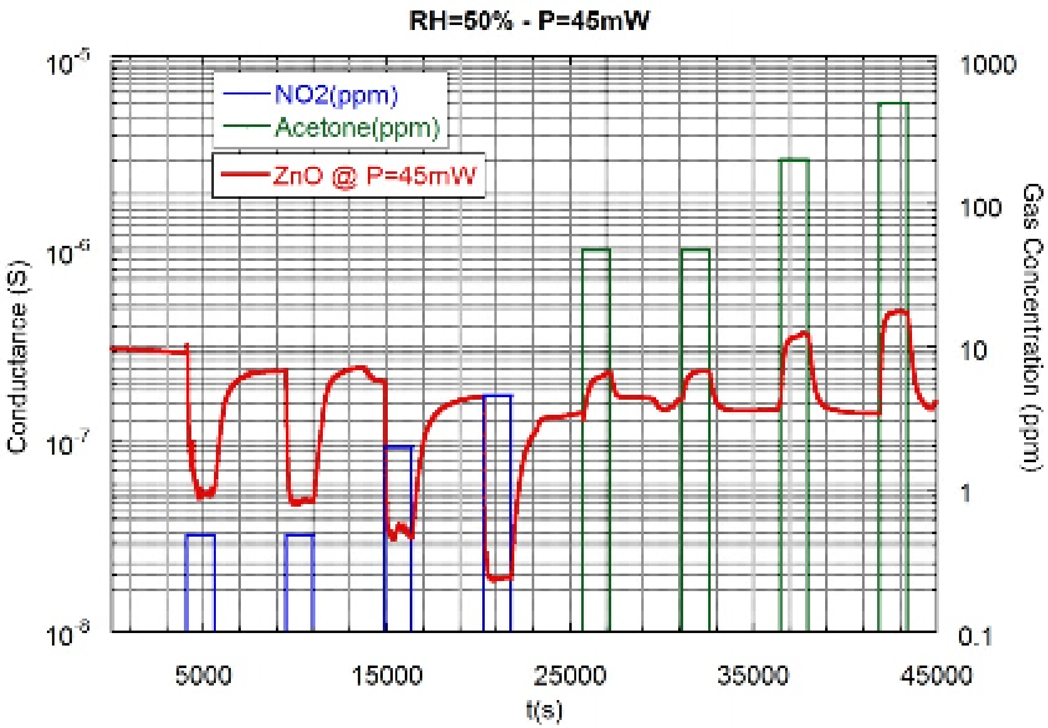


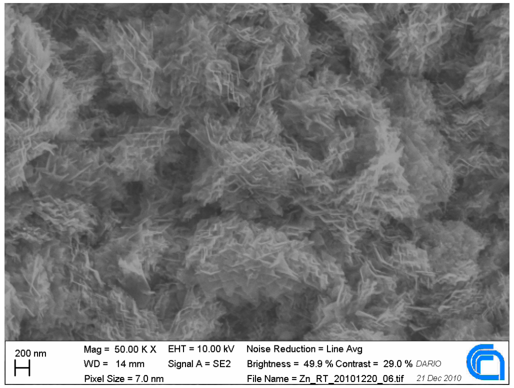


Nanowires on plastic foil

- ZnO nanowires on PI hotplates
  - Sputtered thin Zn – 800 nm
  - Thermal oxidation at 300°C, 12h, 80%O_2-20%Ar

D. Zappa et al., Eurosensors XXVI, Krakow, Poland, September 2012

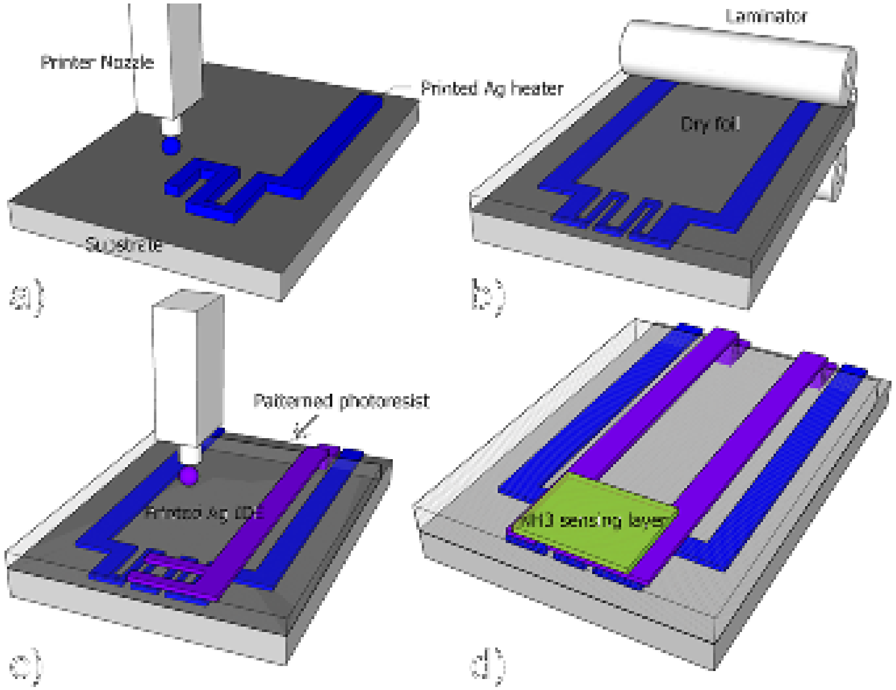




Collaboration with E. Comini, Univ. of Brescia, Italy

Printed micro-hotplates

■ Inkjet printing: Materials and methods



Schematic view of μ-hotplate inkjet printing

M. Camara et al., Transducers 2013

– Materials

- **Substrate:** PEN foil **125 μm thick** (*Dupont Teijin Films™)*
- **Heater and Electrodes:** silver nanoparticles-based ink (*Suntronic, SunChemical*) sintered at 180 C/3h
- **Dielectric interlayer:** dry foil 50 and 14 μm thick (*DuPont™*).
- **Sensing layer: Polyaniline (PANI)** with macromolecular polymeric acids doping for better thermal stability.

– Methods

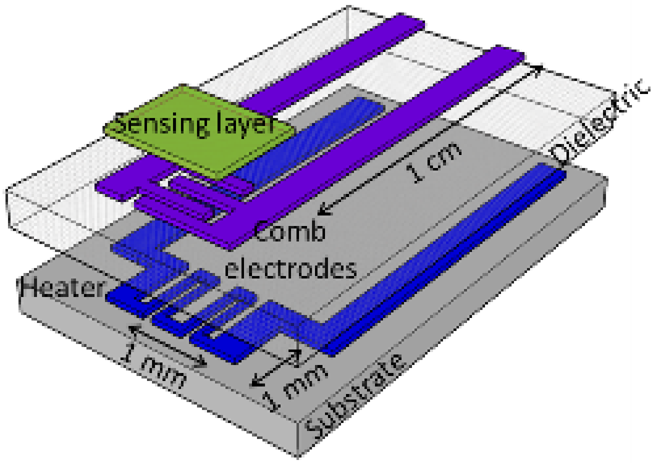
- **Inkjet printing :** heater and electrodes (*Dimatix, Fujifilm*).
- **Lamination:** interlayer at **low T C** (85 C) and 2 bars
- **Electrodeposition**: **Au** / **Ni** on the printed Ag (optional).
- **Vapor deposition polymerization (VDP)**: sensing layer

Printed micro-hotplates

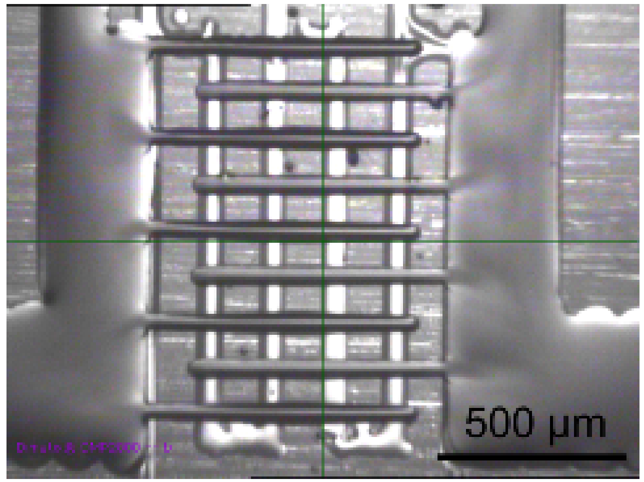
Design and fabrication

- Printed Ag + electroplated Ni heaters
- Laminated 14 µm dry foil resist as interdielectric
- Printed Ag + electroplated gold electrodes

  - Heater resistance: 36 3 Ω
  - Heater area: 1 x 1 mm^2
    - Thickness : 500 90 nm
    - Width : 60 µm
  - Electrodes area: 1 x 1 mm^2
    - Thickness : ~ 330 nm
    - Width / gap: 60 µm
  - Sensing layer area: 1 x 1 mm^2
    - Thickness : ~ 0.5 - 1 µm



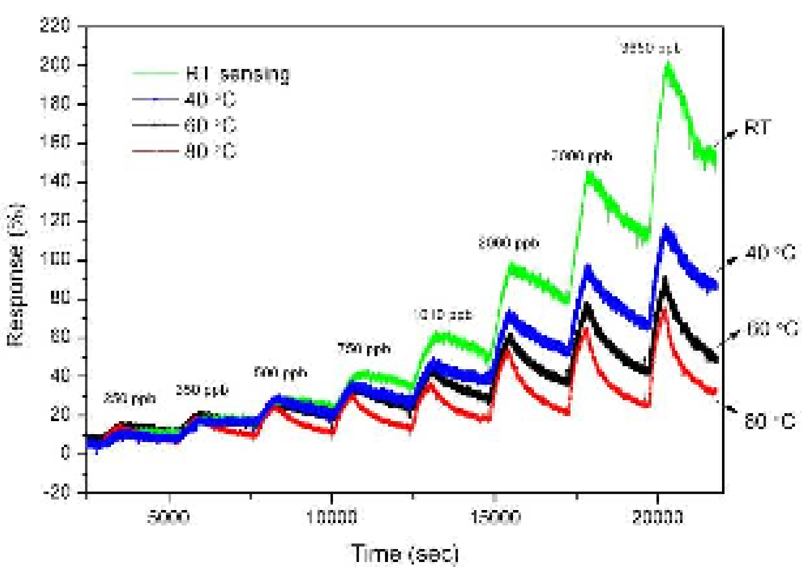
Schematic view of µ-hotplates.



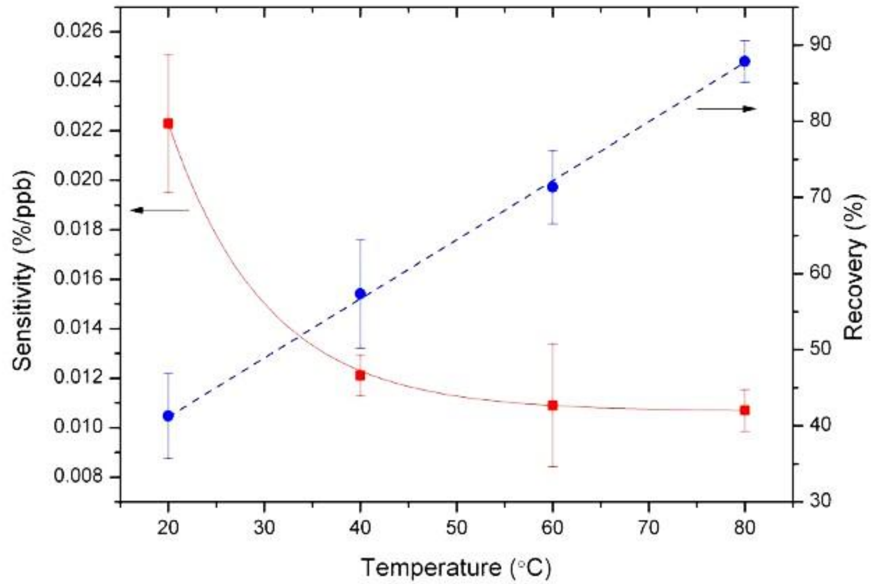
Optical top view of µ-hotplates.

Ammonia sensor

Results



Sensor response towards different concentrations of ammonia and temperatures (10min exposure + 30min purge clean air).

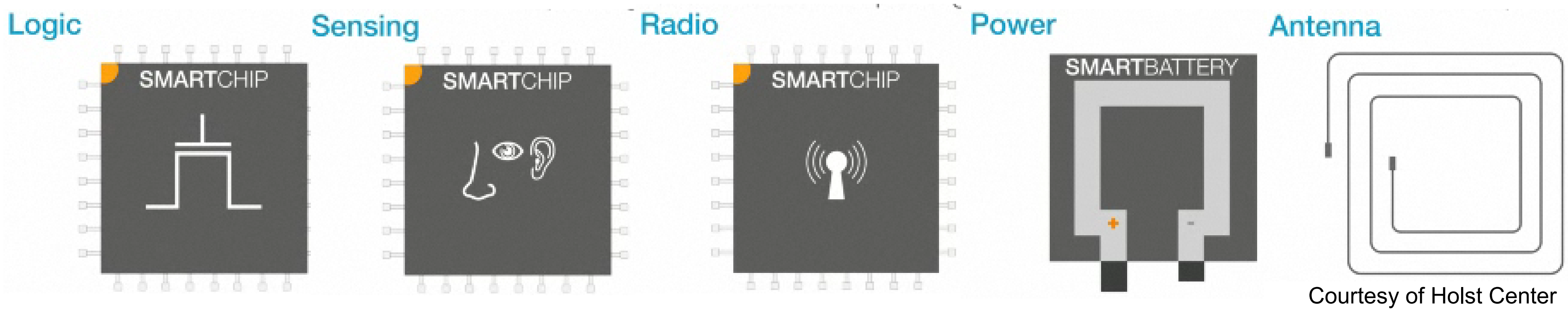


Effect of sensor temperature on sensitivity and recovery behavior of the sensor.

- High performance polyaniline-based sensor with fast response and recovery when operating at 80°C.
- Promising for real-time ammonia sensing applications.

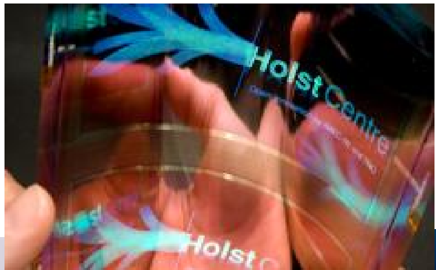
Wireless smart sensing labels

- Co-integration of silicon and printed components



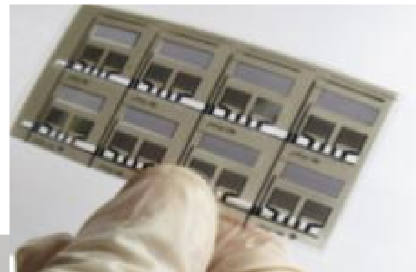
Courtesy of Holst Center

Holst Center



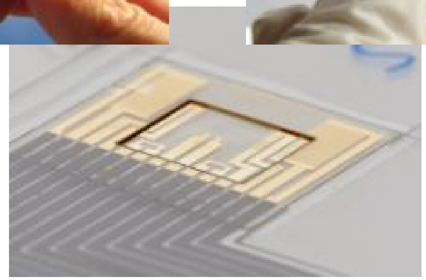
Fraunhofer ISE

SAMLAB



IMS-CHIPS

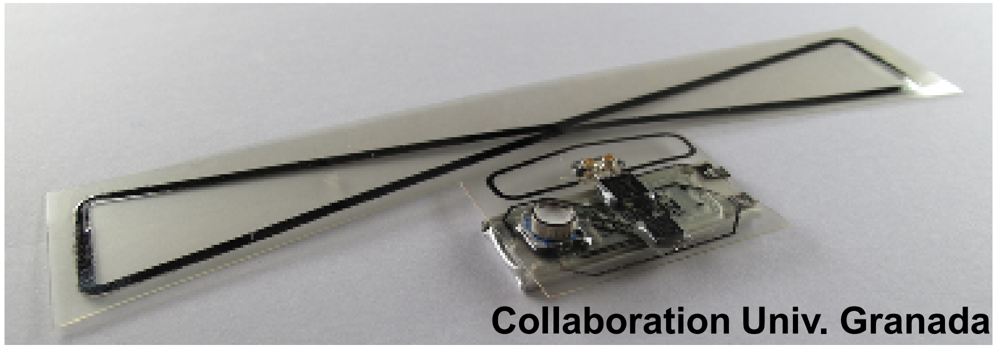
Thinergy



SAMLAB/Holst Centre

Wireless smart sensing systems

Inkjet printed UHF RFID label with pressure sensor

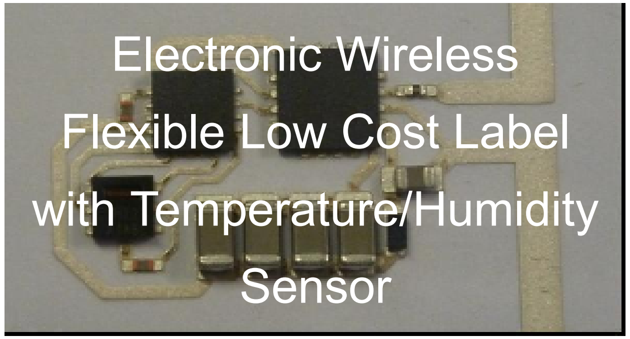


Collaboration Univ. Granada

FlexSmell HF Printed Tag

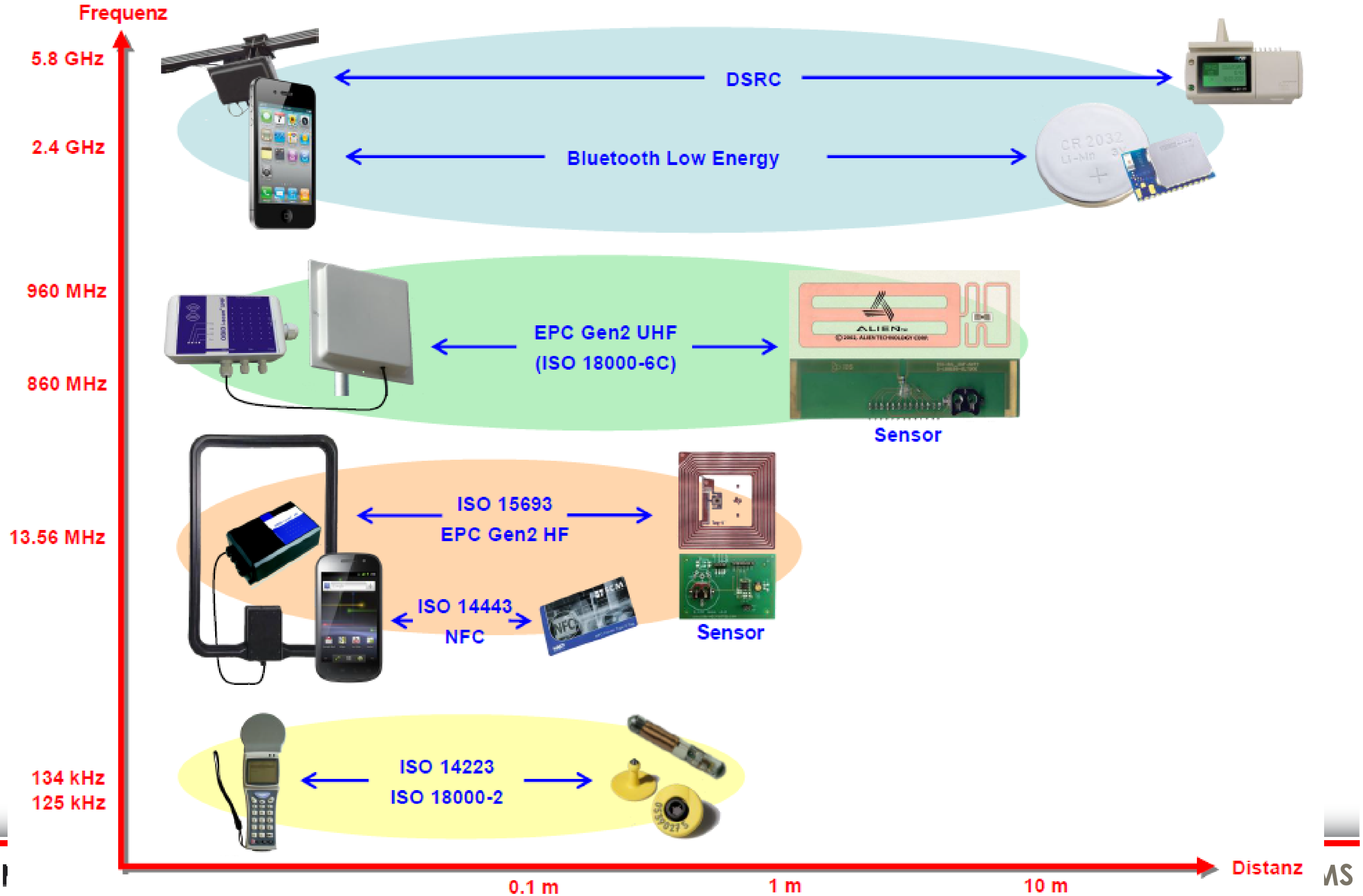
Collaboration
Holst Centre
EKUT, UMAN

Screen printed UHF RFID label with Sensirion sensor



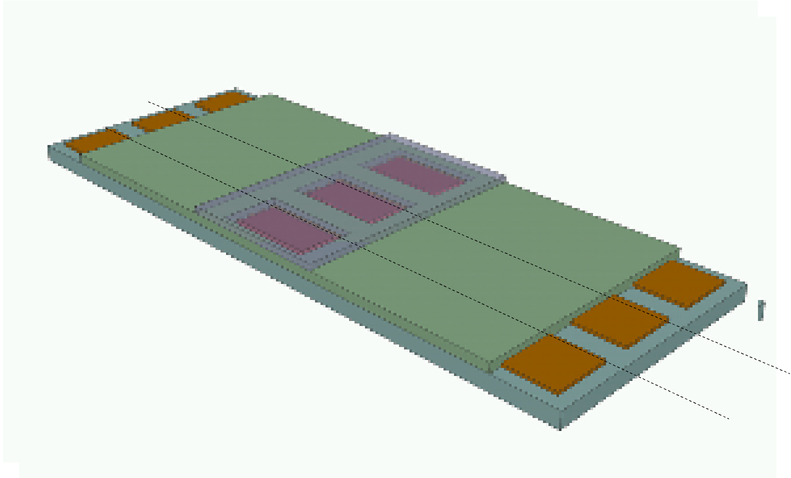
Collaboration ZHAW

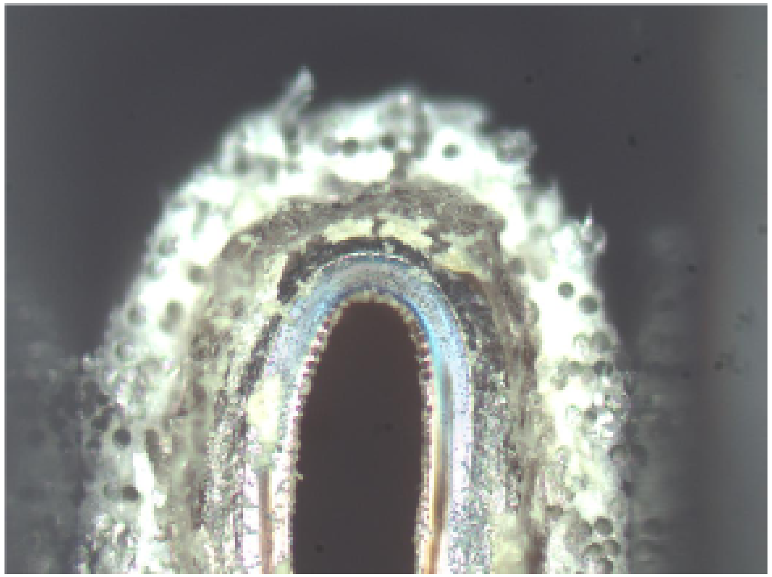
Wireless smart sensing labels

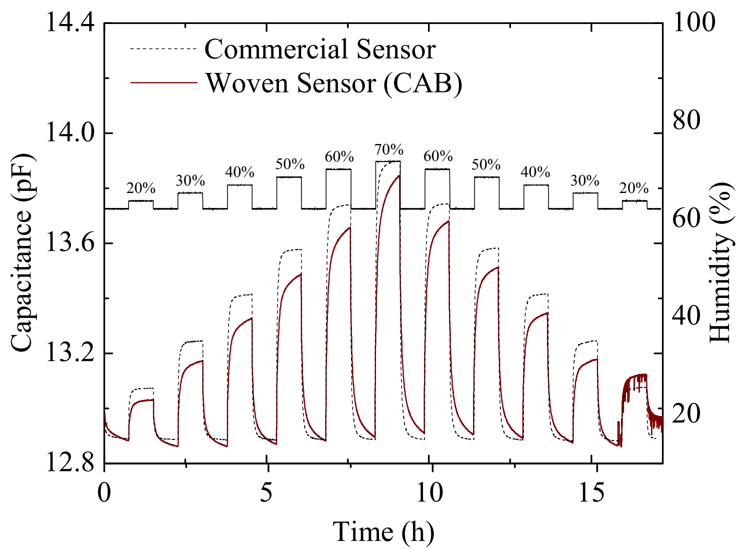


e/smart textile

- ❖ Flexible Kapton® or PET substrates
- ❖ Integrated temperature + gas sensing
- ❖ Teflon encapsulation of the active area
- ❖ Slender sensor design for thread integration







C. Ataman et al., Proceedings Eurosensors 2011 / T. Kindeldei et al. CIMTEC 2012 Symp. D

Conclusion

- Printing technologies represent the most promising fabrication techniques for the realisation of cost-effective low complexity electronic devices and systems
- Recently high interest to print gas sensors and integrated smart systems
- But:
  - Sensitivity, power consumption, reliability: sensing materials !
  - Sensor in itself is not a solution: wireless labels !

Question: Printed or Silicon sensors ?

Acknowledgements

- Dr Herman Schoo + Dr E. Smits + team, Holst Center NL
- Group of Prof. U. Weimar / Dr N. Barsan, University of Tübingen DE
- Group of Prof. G. Tröster, ETHZ Zurich CH
- Group of Prof. A Palma, University of Granada SP
  - CSEM Division C clean room facility
  - Center for Microfabrication: CMI-EPFL

Funding: GOSPEL EU Network of Excellence, FP6

FlexSmell, ITN, FP7

Nano-Tera.ch, Swiss Confederation Program evaluated by the SNSF


Thank you for your attention
EPFL
ECOLE POLYTECHNIQUE
FEDERALE DE LAUSANNE