



1<sup>th</sup>  
year

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# Towards disposable sensors for gas detection and development of smart sensing systems on foil

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# Trends in gas sensor development

## 1. Food quality control (maturity, decomposition)

Harvesting, processing, transport, storage

## 2. Microorganisms

Identification by their volatile metabolism products



Source: [en.wikipedia.org/wiki/Food](https://en.wikipedia.org/wiki/Food)

## 3. Air quality

Identification of pollutants

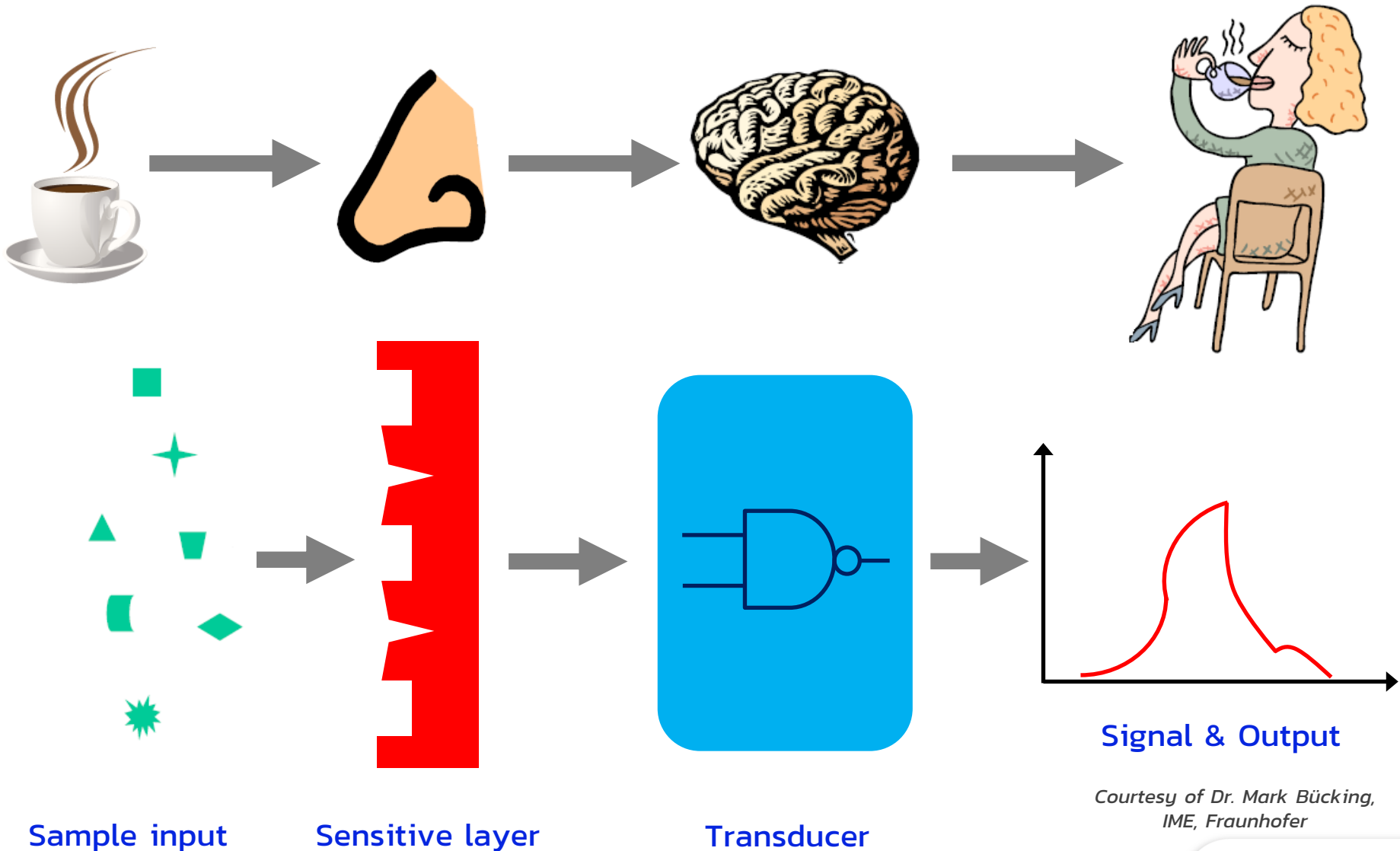


Source: IME, Fraunhofer & Freshplaza



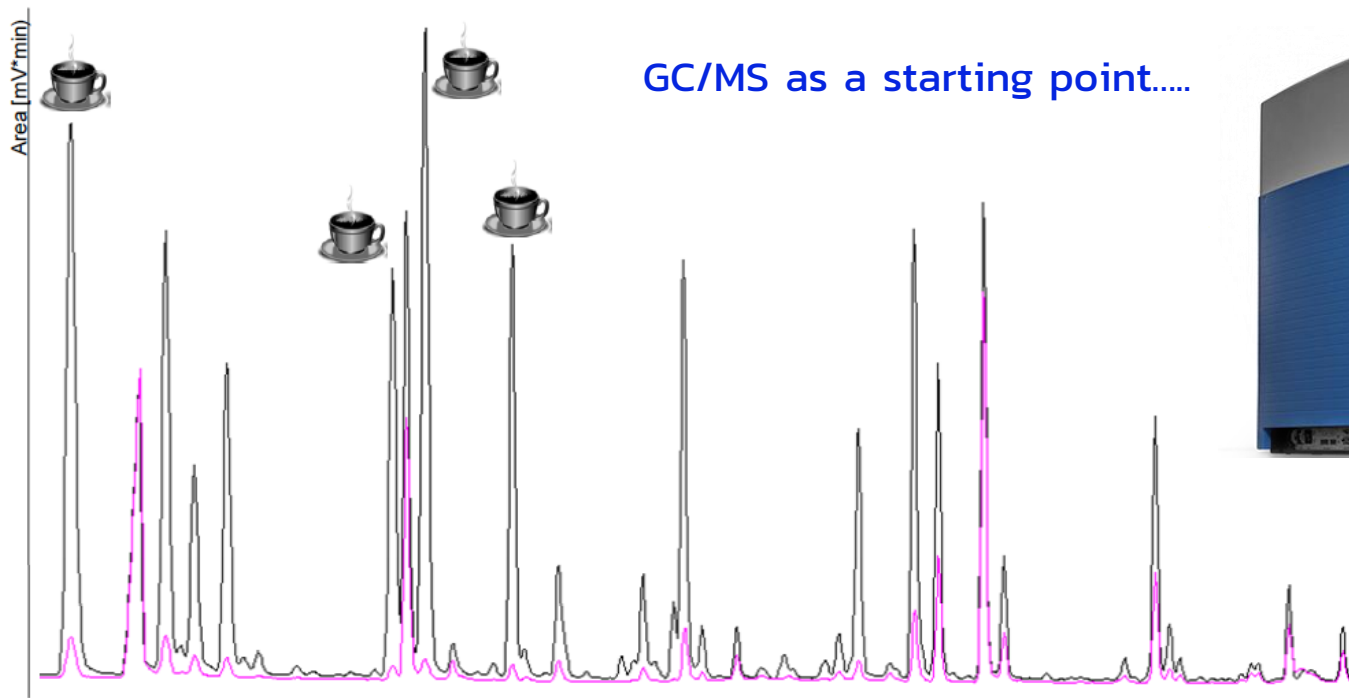
Source: Ecolink & Prachachat

# Principle of gas detection



*Courtesy of Dr. Mark Bücking,  
IME, Fraunhofer*

# Analytical instruments



Courtesy of Dr. Mark Bücking,  
IME, Fraunhofer

- ✓ Complex reference analysis of organic residues
- ✓ High accuracy & good sensitivity
- ✓ Fast detection
- ✗ Expensive



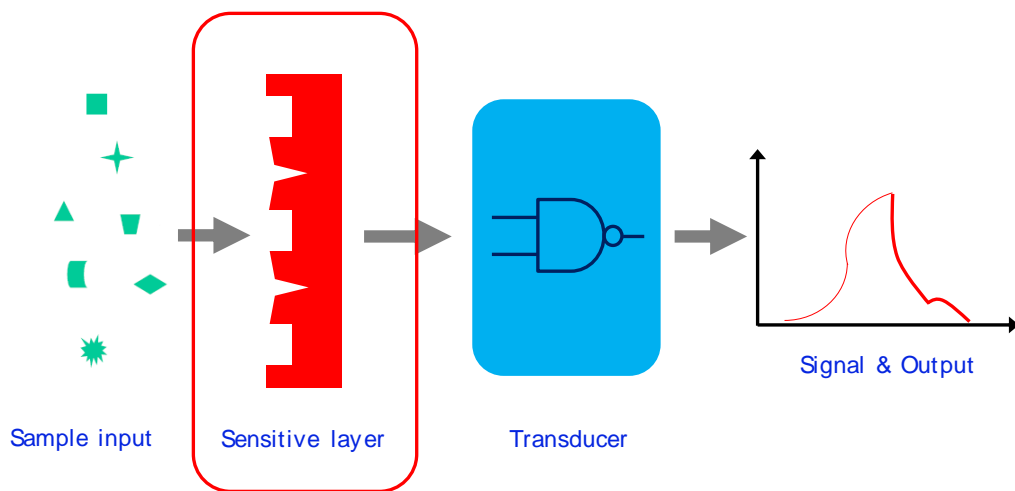
## Requirements: (further development)

- Smaller (portable and/or wearable)
- Faster & easier (integration to system)
- Reproducible
- Cost effective

# Metal oxide based gas sensors

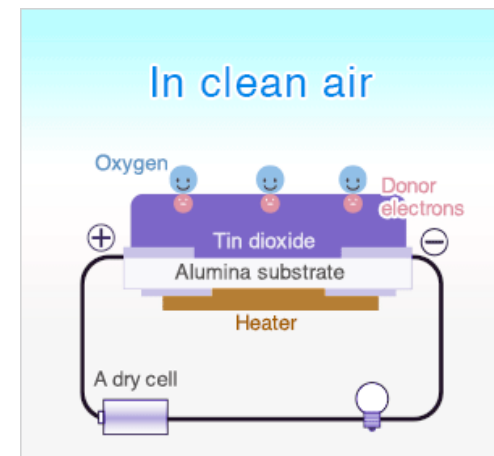
**Gas sensor (electronic nose)** – An instrument comprises of (an array) **an electronic chemical sensor(s)** with an appropriate pattern recognition system **capable of recognizing simple or complex odours**

*(Gardner, J.; Bartlett, P.; Sens. Actuators 18, 211-220)*



CO gas sensor module (arduitronics)

**Metal oxide (Mox) sensing layer** – **adsorbed volatile compounds on the surface of the semiconductors** generates **change in the electrical resistance** varying with the type of volatile compound and its concentration



Source: figaro.co.jp

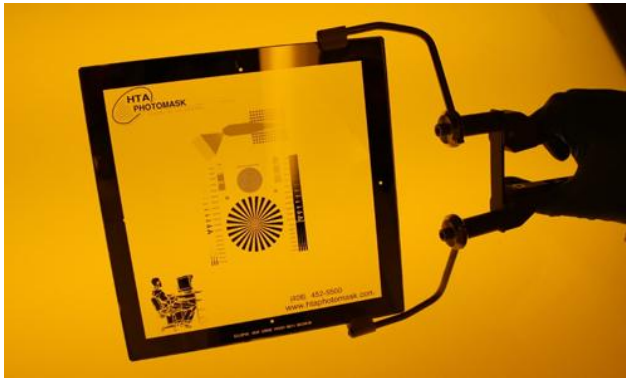


# Microfabrication of gas sensors

## Light source used for production

Light source	Wavelength	Feature size
I line Hg lamp (UV)	365 nm	0.25 $\mu\text{m}$

**Mask:** Chrome mask (Cr on Quartz substrate)

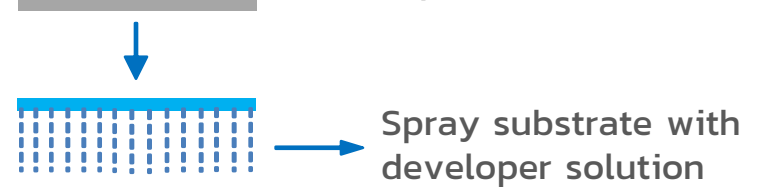
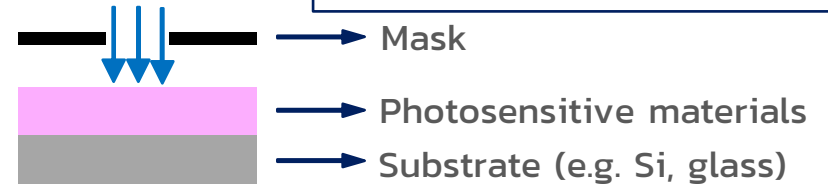


Source:htaphotomasks.com

- ✓ Good resolution
- ✓ Good chemical resistance
- ✗ Poor adhesion
- ✗ Low sensitivity

## Photolithography (cleanroom processing)

Radiation (UV)



✓ Good sensitivity

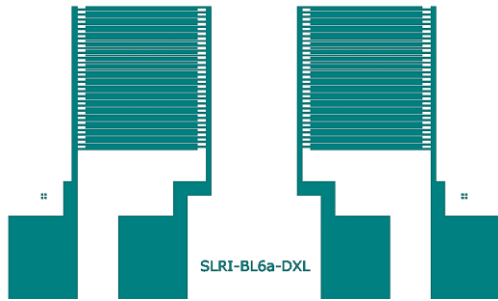
✗ Exposed area absorb developer (distortion)

a) Positive resist, developer-solution removes exposed area

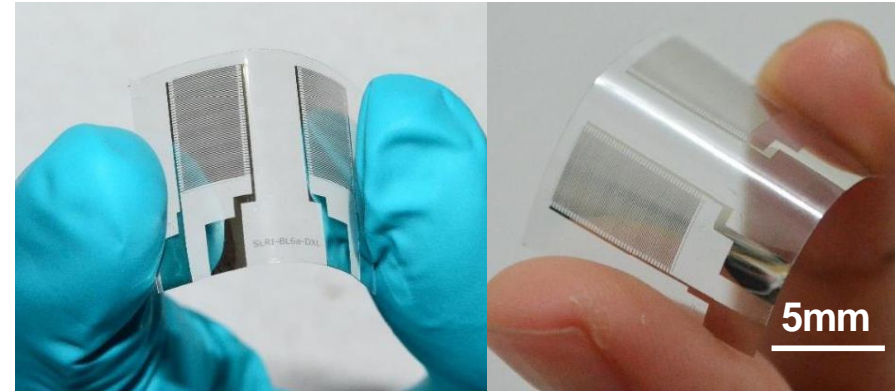
b) Negative resist, developer-solution removes unexposed area



# Fabrication of capacitive humidity sensors



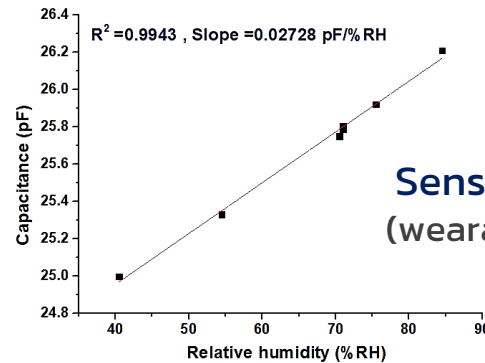
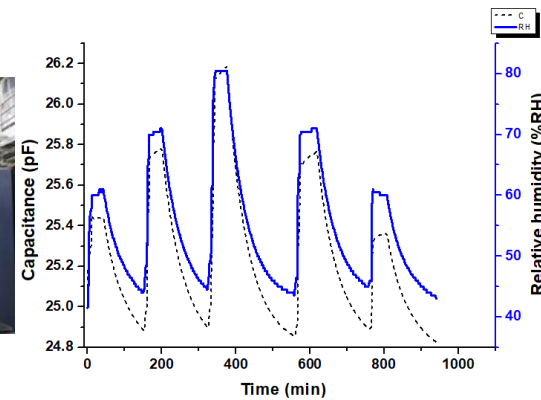
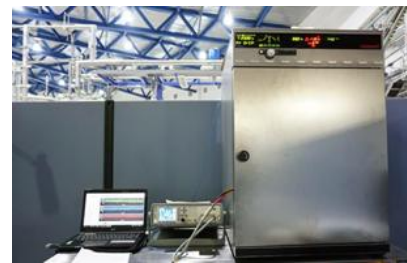
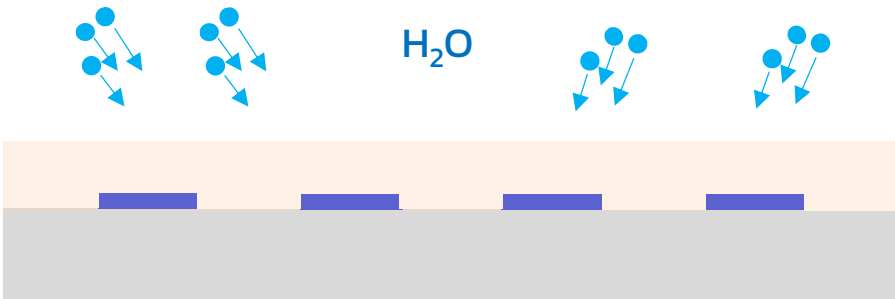
New device design  
(ClewIn, LayoutEditor)



Flexible humidity sensor on PET substrate

Absorbed water vapour in CAB  
cause change in dielectric property

$$C = \frac{\epsilon_0 \epsilon_r A}{d}$$



Sensitivity of **0.027 pF/%RH**  
(wearable device and packaging)

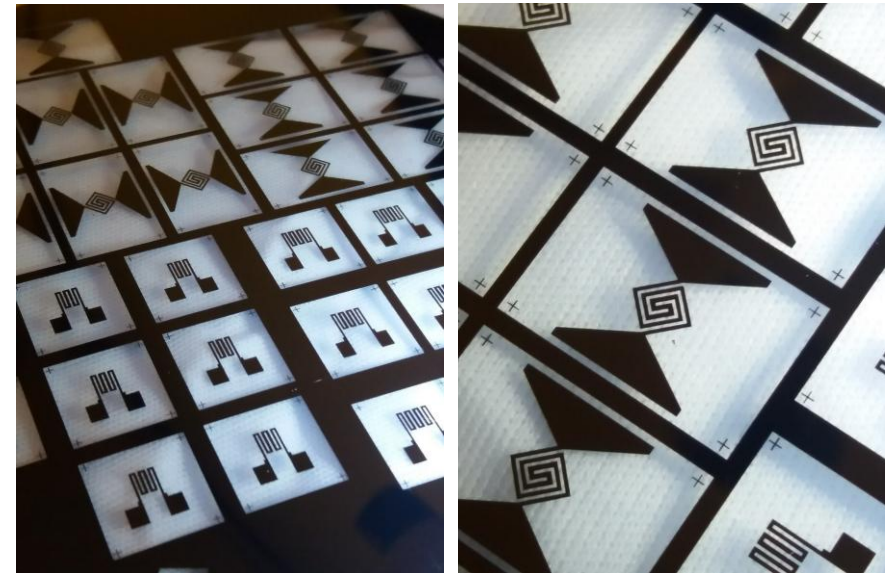
PET PR Cr/Ni CAB

# Flexible microhotplate for gas sensing application

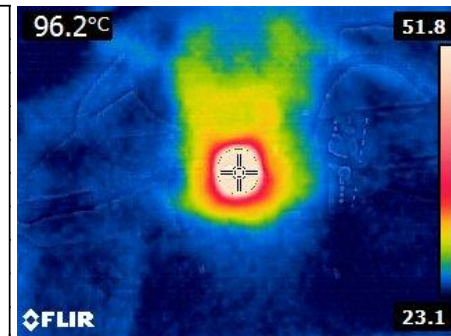
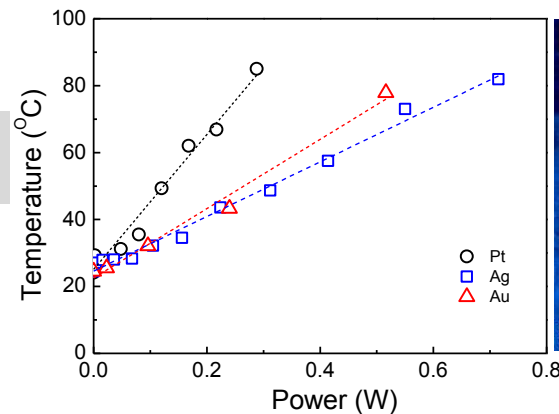
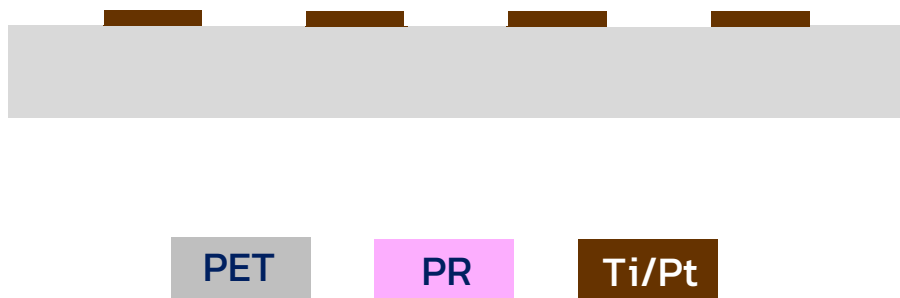


Design of  $\mu$ -hotplate (temperature sensor)

Heat generated when an electric current flows through a resistant path



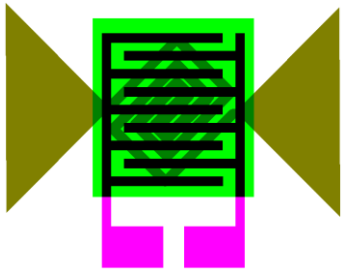
Flexible microhotplate on PET substrate





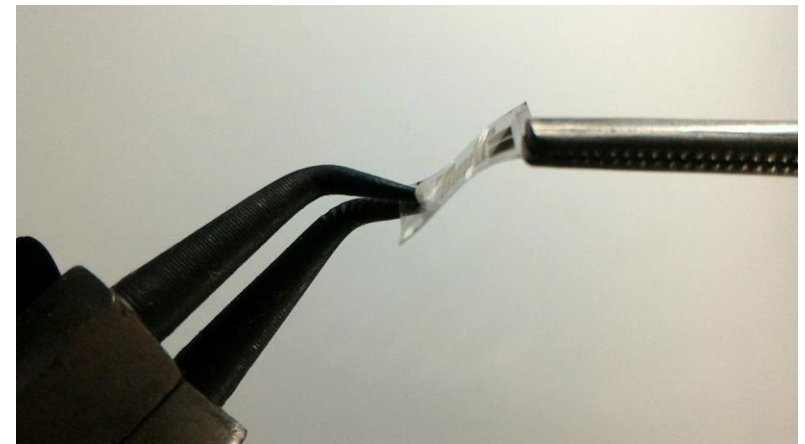
# Gas sensors based on metal oxide films

Metal oxide gas sensors on plastic foil platform

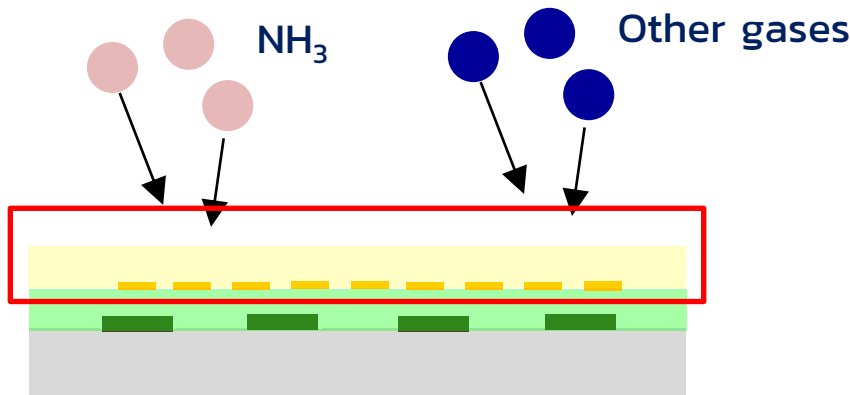


Multilayer devices

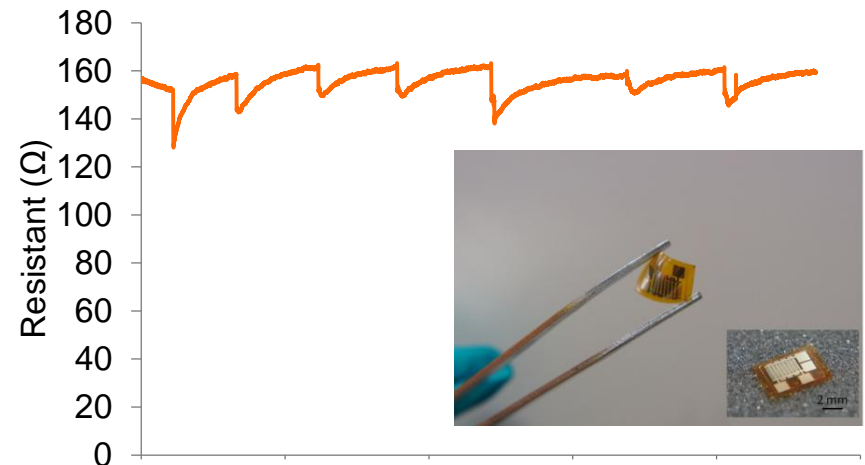
Change in electrical conductivity or resistivity of thin films on exposure to a target gas (reducing gas)



Flexible ammonia sensor on transparent sheet



PET    Ti/Pt    SU-8    Cr/Au    ITO



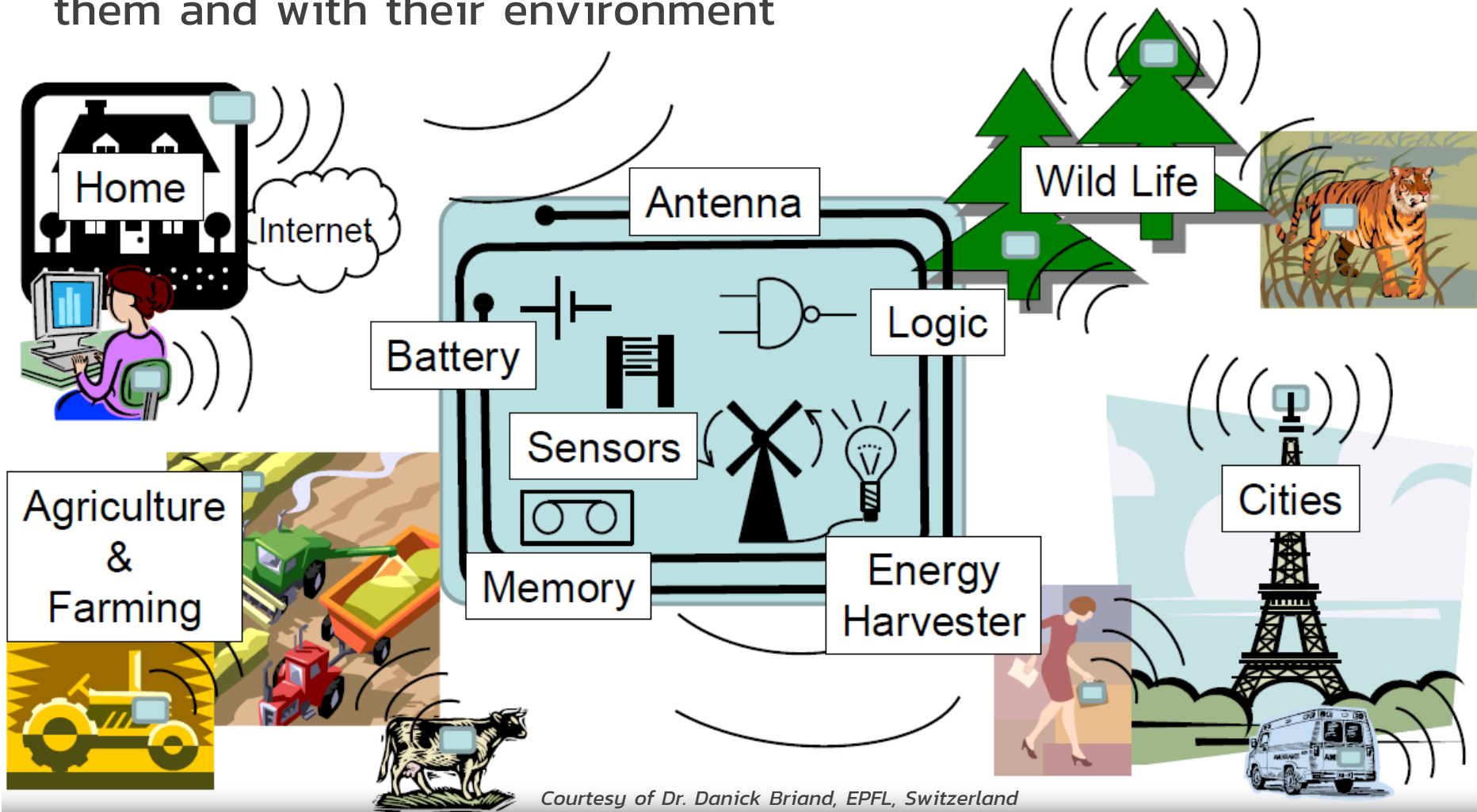
Ammonia cycle

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# ***New trends in smart sensors for industrial applications***

# Motivations

**Internet of Things:** Smart objects that can interact between them and with their environment

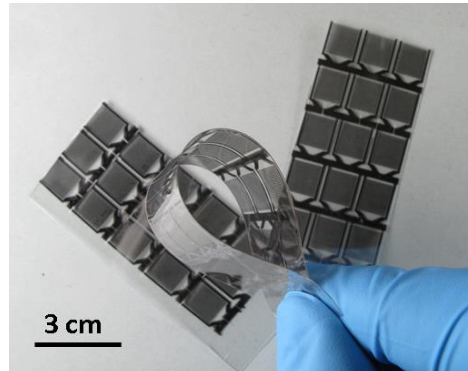


# Technology shift

## Flexible and printed sensors

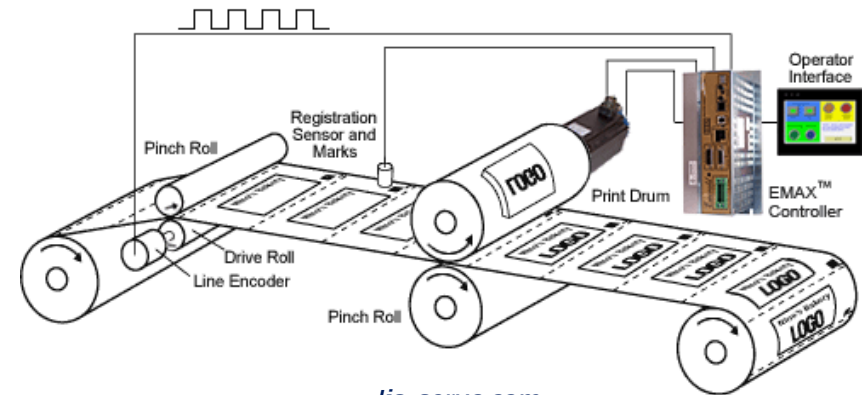


Fujifilmusa.com



Courtesy of IMT-EPFL, Switzerland

## Roll-to-Roll printer



lis-servo.com

## Inkjet printer

- ✓ Additive processes, i.e. printing
- ✓ Large area manufacturing (on foil)
- ✓ Good resolution ( $\geq 100 \mu\text{m}$ )
- ✓ Low cost production
- ✓ Environmentally friendly materials
  - Water based inks
  - Recyclable substrates (PET, paper...)



Courtesy of EPFL, Switzerland

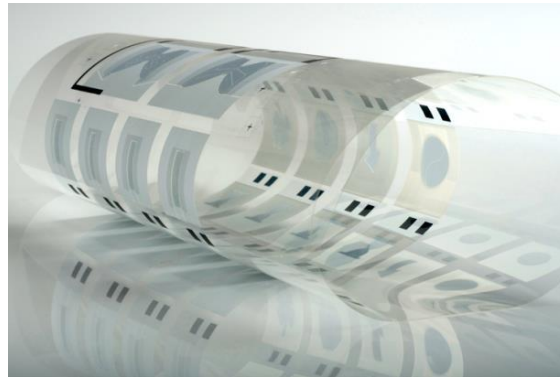
# Printing electronics devices

Why use plastic and/or paper substrate?



Source: Plasticlogic

Flexibility – good reliability



Source: Swedish ICT

Foldable



Source: SEMICONWEST 2012

Conformal

Large area  
(light weight)



Source: Princeton University, USA



Source: GSA

Lower costs

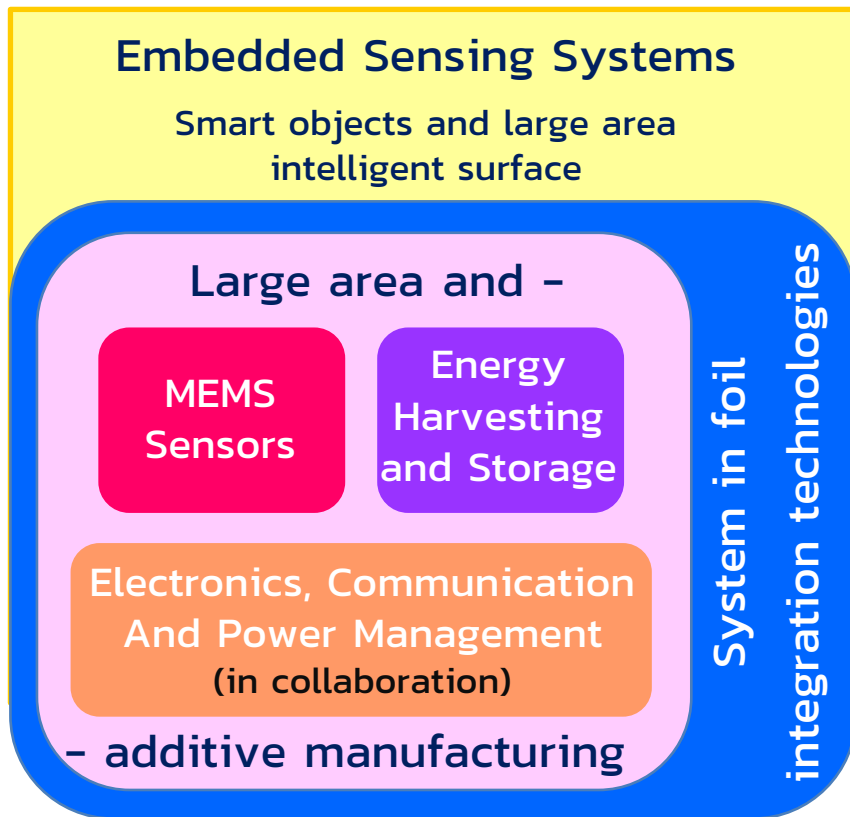
**REUSE**   
**REDUCE**  
**RECYCLE**

Courtesy of Dr. Danick Briand, EPFL, Switzerland



# Smart sensing systems on foil

## *Energy autonomous smart labels*



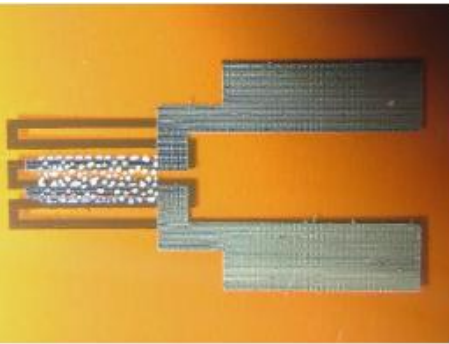
On foil using additive manufacturing  
➔ Integrating 'nano' and bio materials

Low environmental impact  
➔ Disposable / reusable electronics  
**GREEN electronics**

Ultimately ➔ Biodegradable

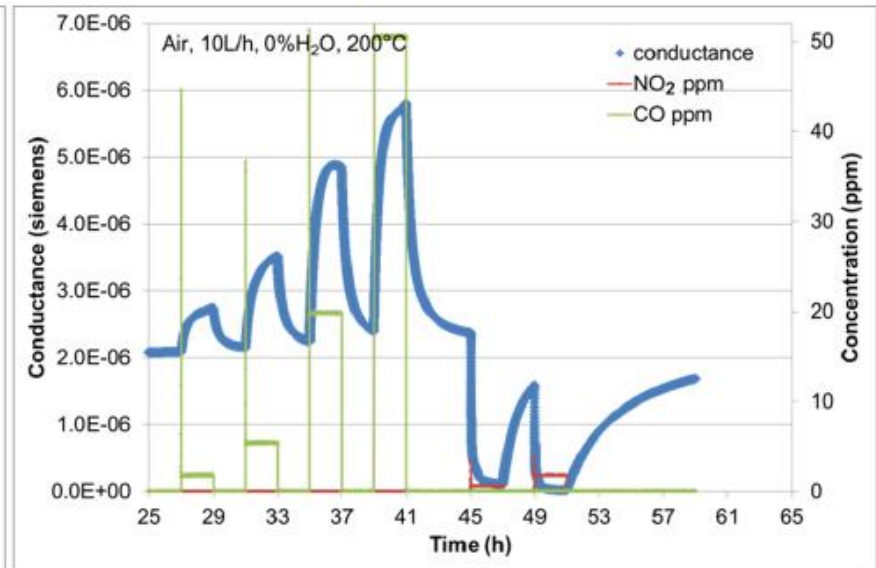
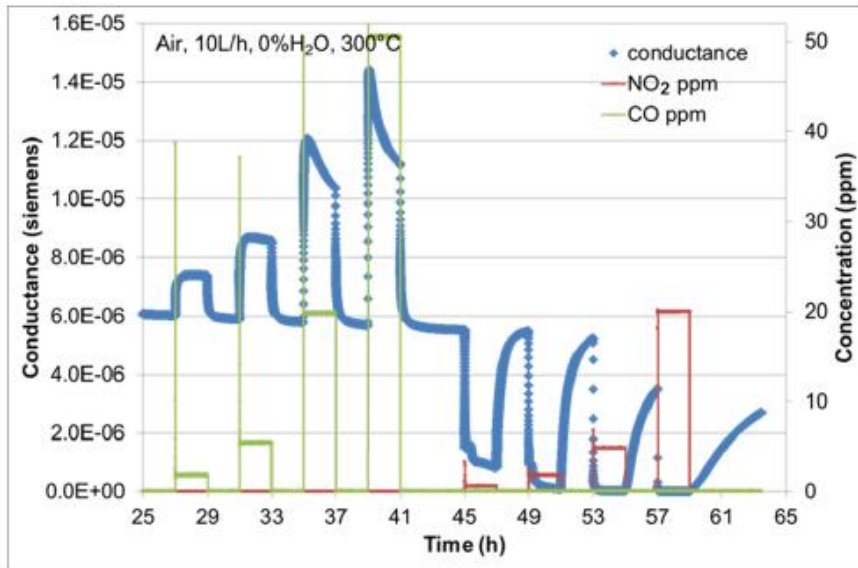
From imperceptible to Disappearing electronics

# Mox-based gas sensor on foil



Eurosensors 2015

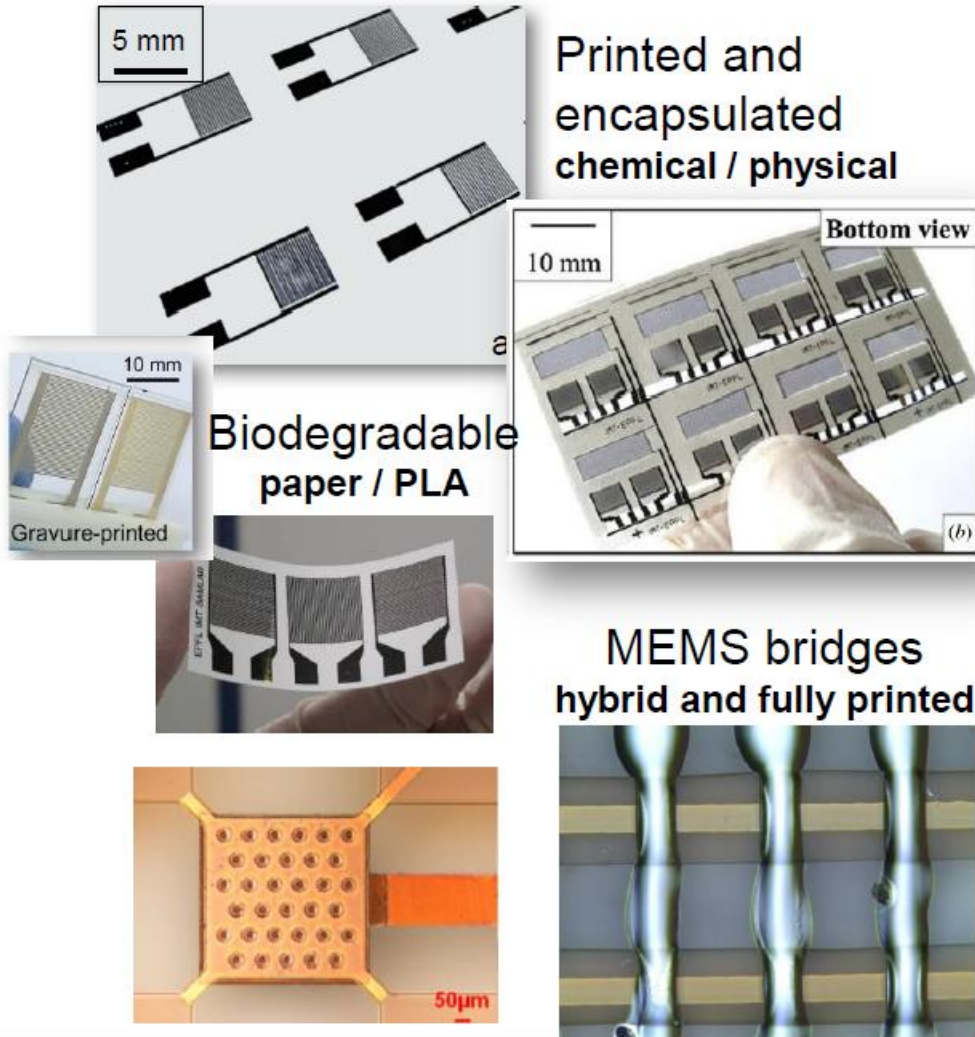
Inkjet printed  $\text{SnO}_2$  gas sensor on plastic substrate



Evolution of the sensor conductance in dry air with CO and NO<sub>2</sub> injections at 300°C (left) and 200°C (right)

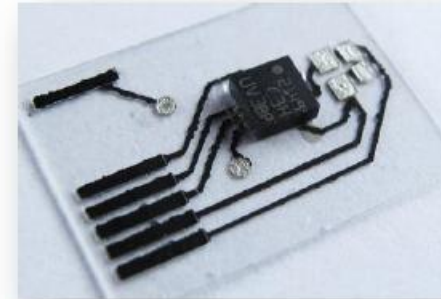
# Smart sensing systems on foil (II)

## Foil-based sensors (fully printed)

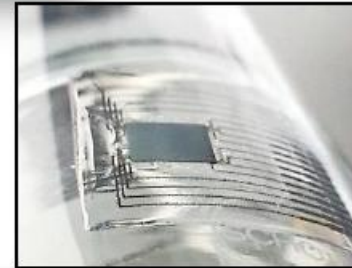


## Integration of components on foil

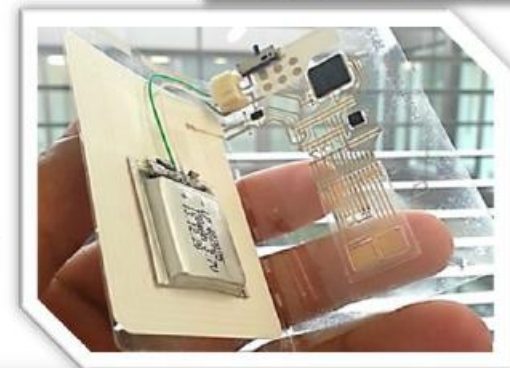
*Courtesy of Dr. Danick Briand, EPFL, Switzerland*



SMD and bare dies on PET



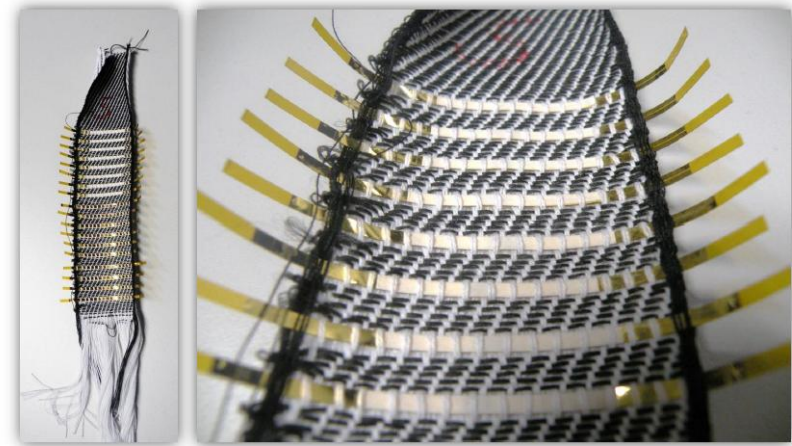
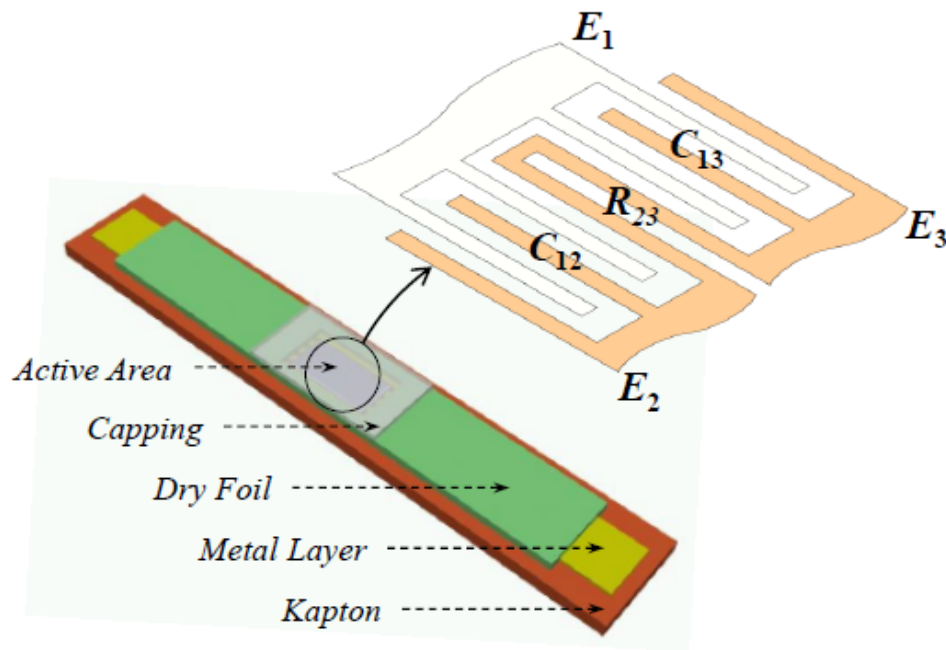
Foil to foil integration



# Smart textile

## Plastic stripes processed using printing technology

- *Capacitive humidity and VOCs sensors*
- *Resistive temperature detector (RTD)*



G. Mattana et al., Woven Temperature and Humidity Sensors on Flexible Plastic Substrates for E-textile Applications, IEEE Sensors Journal, vol. 13(10) (2013) 3001-3010.

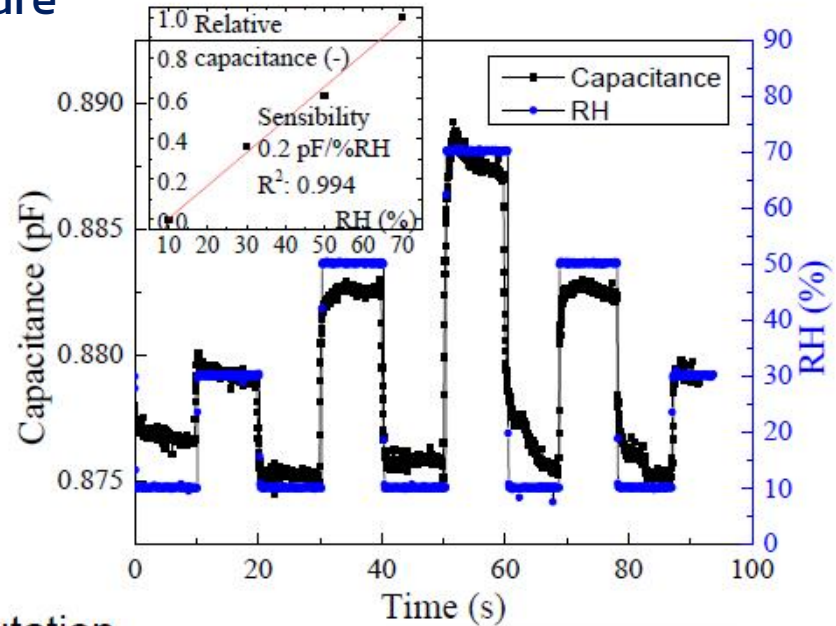
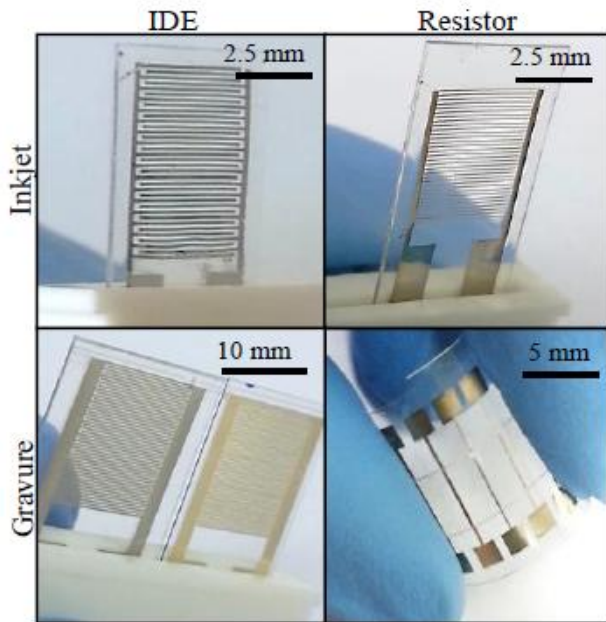


# Biodegradable sensors

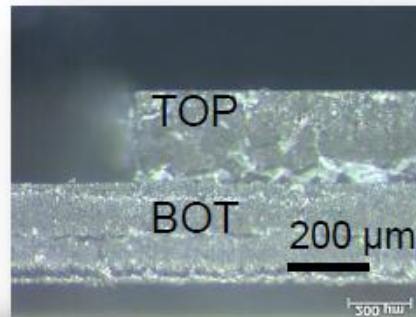
On biodegradable substrates low Tg (56°C) poly lactic acid (PLA)

➔ detection of humidity and temperature

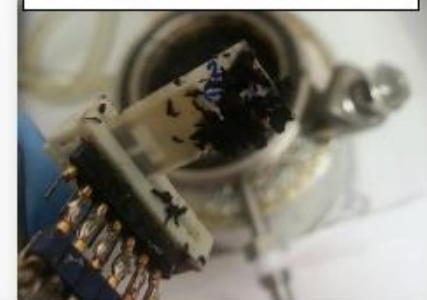
- *Printing of Au and Ag inks*
- *Photonic sintering*



Encapsulation by lamination



Compost chamber



A. Vásquez Quintero et al., Proc. of the MEMS 2014 conference, pp. 532-535.

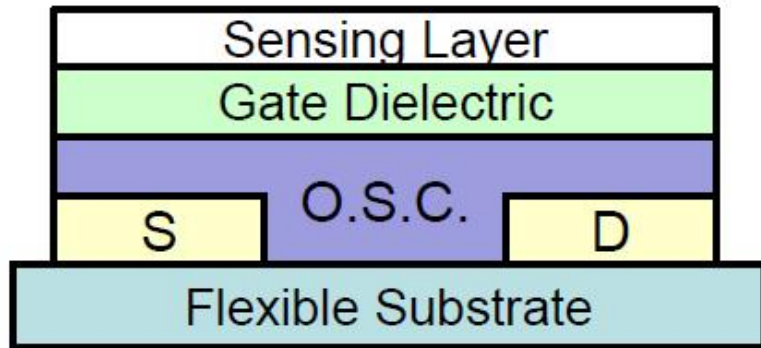


# Biodegradable sensors

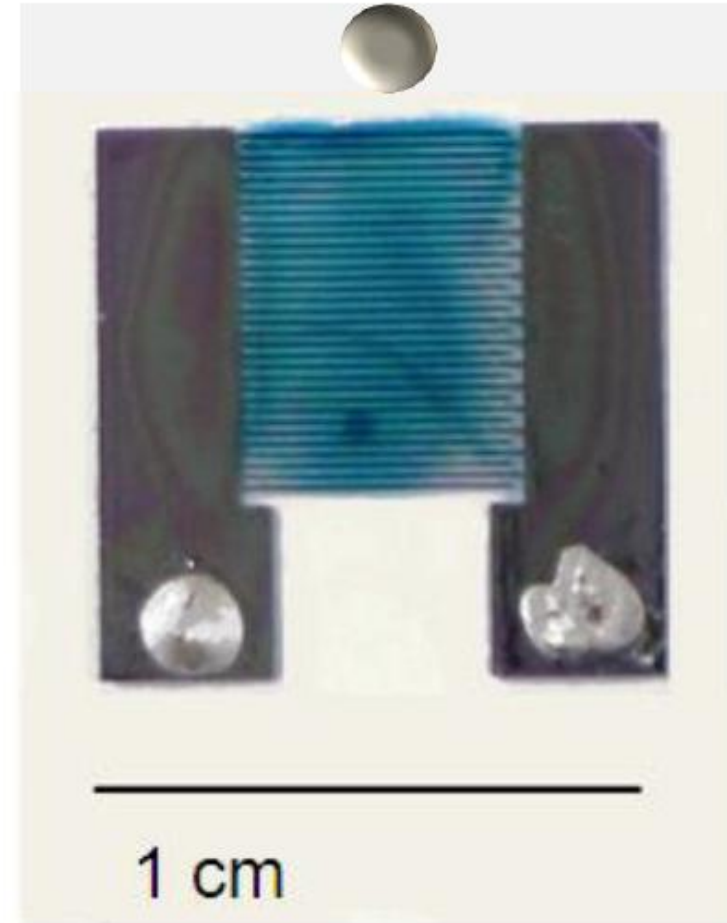
Printed organic field effect transistors (OFETs) on PLA



- *Thin films & electrochemical*
- *PLA as substrate & gate dielectric*

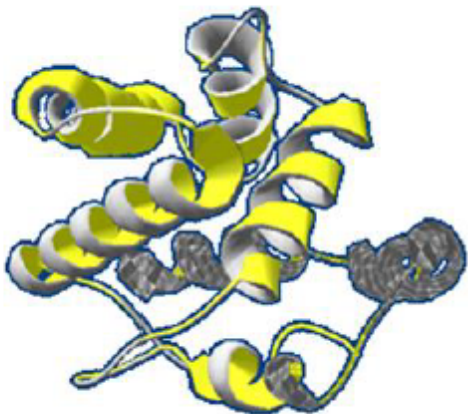


G. Mattana et al., *Org. Electronics* (2015)

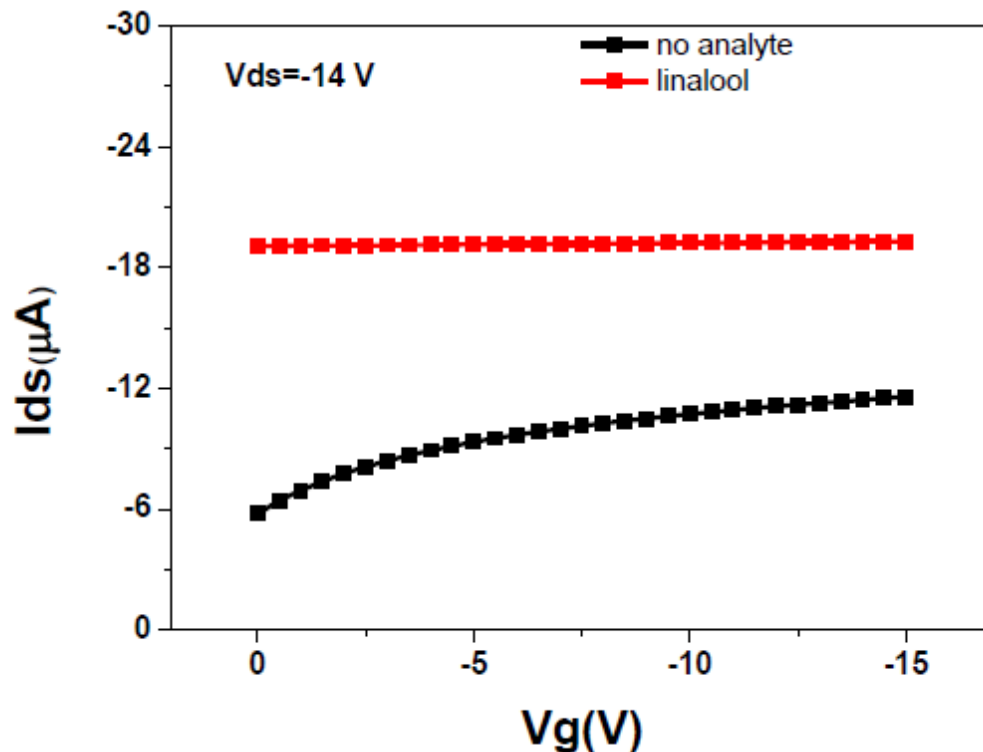


# Biodegradable sensors

## Gate functionalization with odorant binding proteins



*wasp OBPs ( $\beta$ -barrel shape)  
in PVA as sensing layer*



Ids-Vgs curves acquired before and after exposure to saturated vapours of analyte (ambient condition)

Courtesy of Dr. Danick Briand, EPFL, Switzerland

**None of us is as smart as all of us !!!**

***Thank you for your attention !***



***Looking forward to seeing you @ SLRI !!!***

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[pattanaphong@slri.or.th](mailto:pattanaphong@slri.or.th)