



save energy

keep track

anticipate

lower cost

save time

stay tuned

improve performance

feel secure



**Holst Centre**

Open Innovation by IMEC and TNO



# **Intro & Background**



# Open Innovation on the High Tech Campus Eindhoven

- **Site-sharing:** >100 companies, >10000 researchers
- **Facility-sharing:** >8000m<sup>2</sup> cleanrooms, analysis equipment
- **Program Sharing:** Holst Centre

## Holst Centre: Open Innovation in action

### Who we are

- Independent R&D institute founded in 2005 by imec (BE) and TNO (NL)
- Own staff 210 researchers
- Located at the High Tech Campus in Eindhoven, The Netherlands

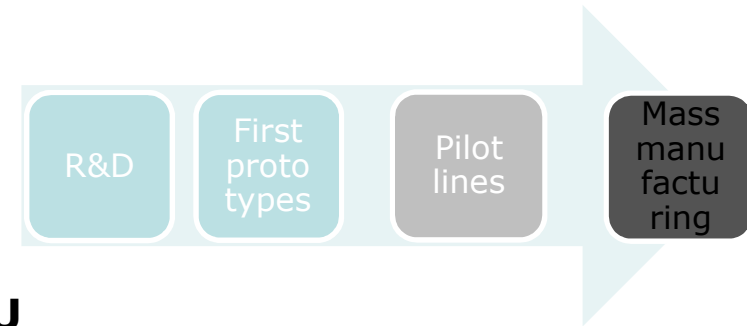


### What we do

- Enabling technologies for **flexible electronics** and **wireless autonomous microsystems**, based on long term roadmaps
- In close collaboration with **leading industrial partners** along the value chain



# Holst Centre: Bridging the gap from R&D to production



## Primary goals:

### 1) **Creating R&D ecosystems in NL and EU**

- Aligning roadmaps of key players
- Supported by NL and EU funding

### 2) **Designing & building up pilot scale facilities and process capabilities at Holst Centre**

- Increasing functionality, throughput, yield
- Approaching TRL7
- Offering pilot line services to Holst Centre partners

### 3) **Validating pilot lines with industrial cases at relevant volumes**

# Flexible Electronics Research areas in Holst Centre

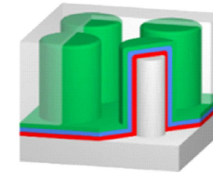
## Large area device technology



OLED Lighting



Flexible PV



Solid state batteries



Smart windows

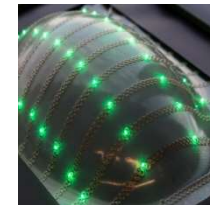
## Hybrid printed electronics



Wearables



Health patch



Conformable PCB

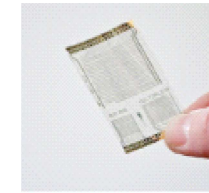
## Thin Film Transistor technology



Flexible displays



Flexible imager



Flexible circuits

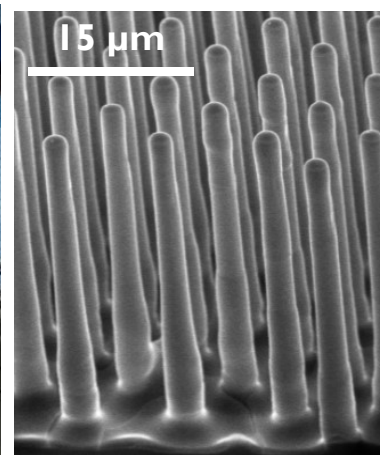
# Large area device technology

## Developing low cost and large area manufacturing processes

- S2S and R2R production (coating, printing, integrated front sheet, patterned slot-die, ALD)
- Create unique solutions for seamless integration in products

## Used for manufacturing and prototyping of:

- Thin Film Barrier Film
- Flexible OLED
- Flexible Perovskite solar cell
- Thin Film Battery



# e.g. Fully roll-to-roll evaporated OLEDs



**R2R moisture barrier**



**R2R OLED evaporation**



**R2R lamination of barrier film**



+

+



Barrier film
Adhesive
OLED
Anode
Flexible glass

30 cm wide



15 m length in one run

- Combining know how & infrastructure of European RTO's
- Combine best in class
- Performance & Features beyond current commercial offering



# Flexible Roll-to-Roll OLEDs from PI-SCALE



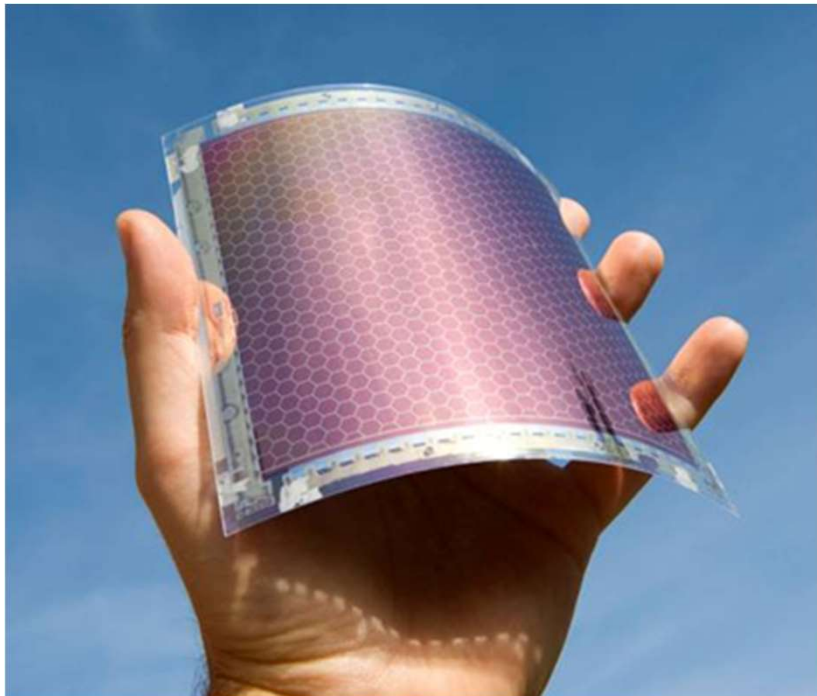
Sample length: 2 m  
Roll length: 15 m

## e.g. R2R Manufactured Flexible Photovoltaics

- Program by ECN, imec, Holst Centre and TU/e (in frame of Solliance)
- Focus on Roll-to-Roll technologies
- Flexible, can be semi-transparent



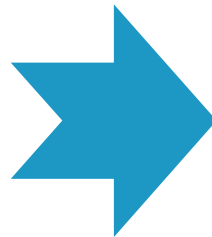
### PV-Sunscreen ?



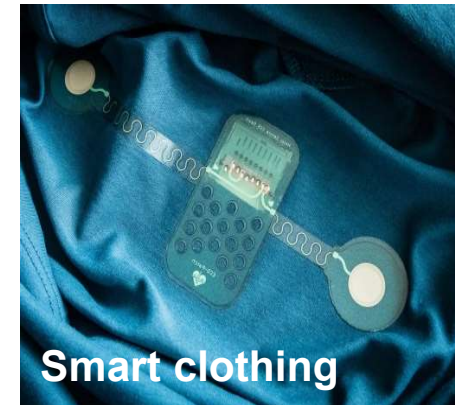
# Hybrid printed electronics

## Different applications and markets but common technology challenges:

- Printed electronics combined with integration of components
- Multilayer circuit printing
- Stretchable and conformable form factor



Smart clothing



Smart clothing



Health patch



Structural electronics

# Printed electronics platform

Use of additive manufacturing technologies for realizing conductive circuitry patterns...

## Screen printing: multilayer circuit patterns

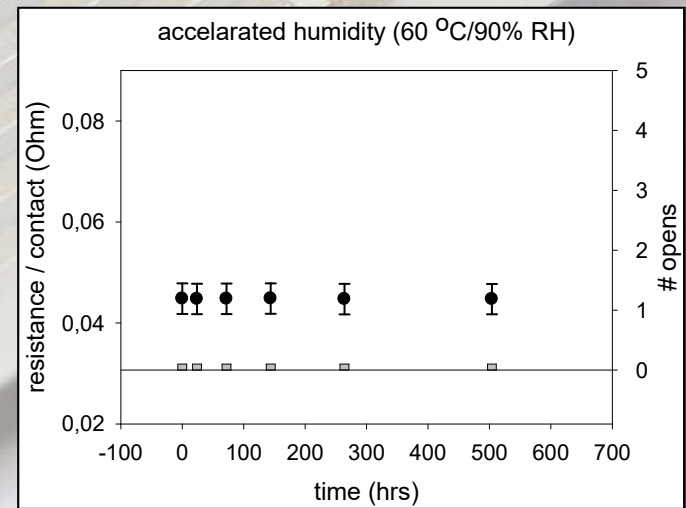
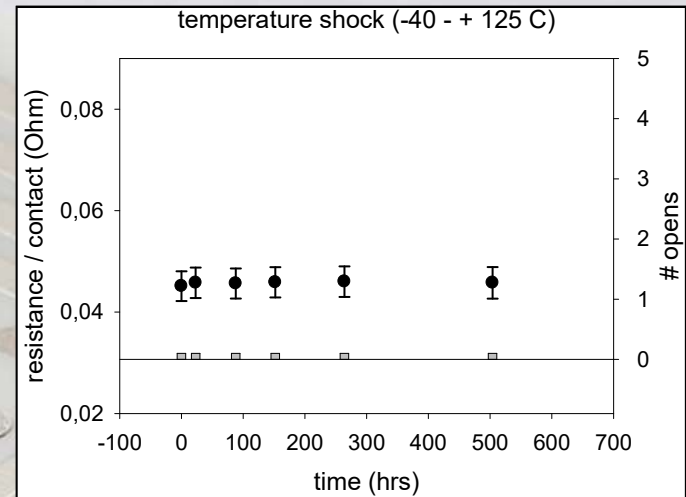
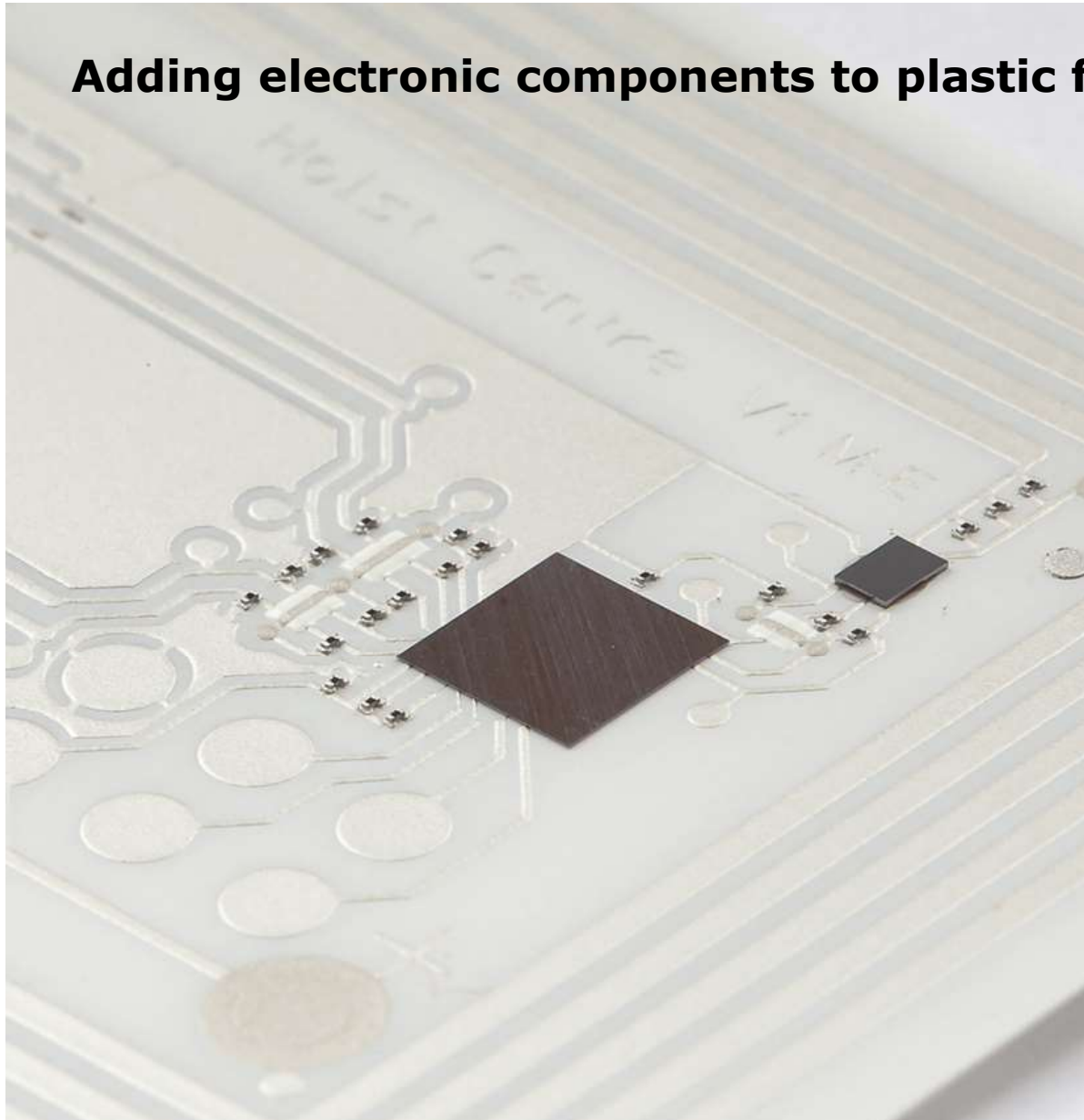
- done by printing alternating layers of conductive and isolating inks
- printed PCF's with 4 circuit layers possible, 6 layers in development



Wiring patterns for garments. Printed on 75 um thick TPU foil

- Printing on different substrates: rubbers, paper, (textiles)

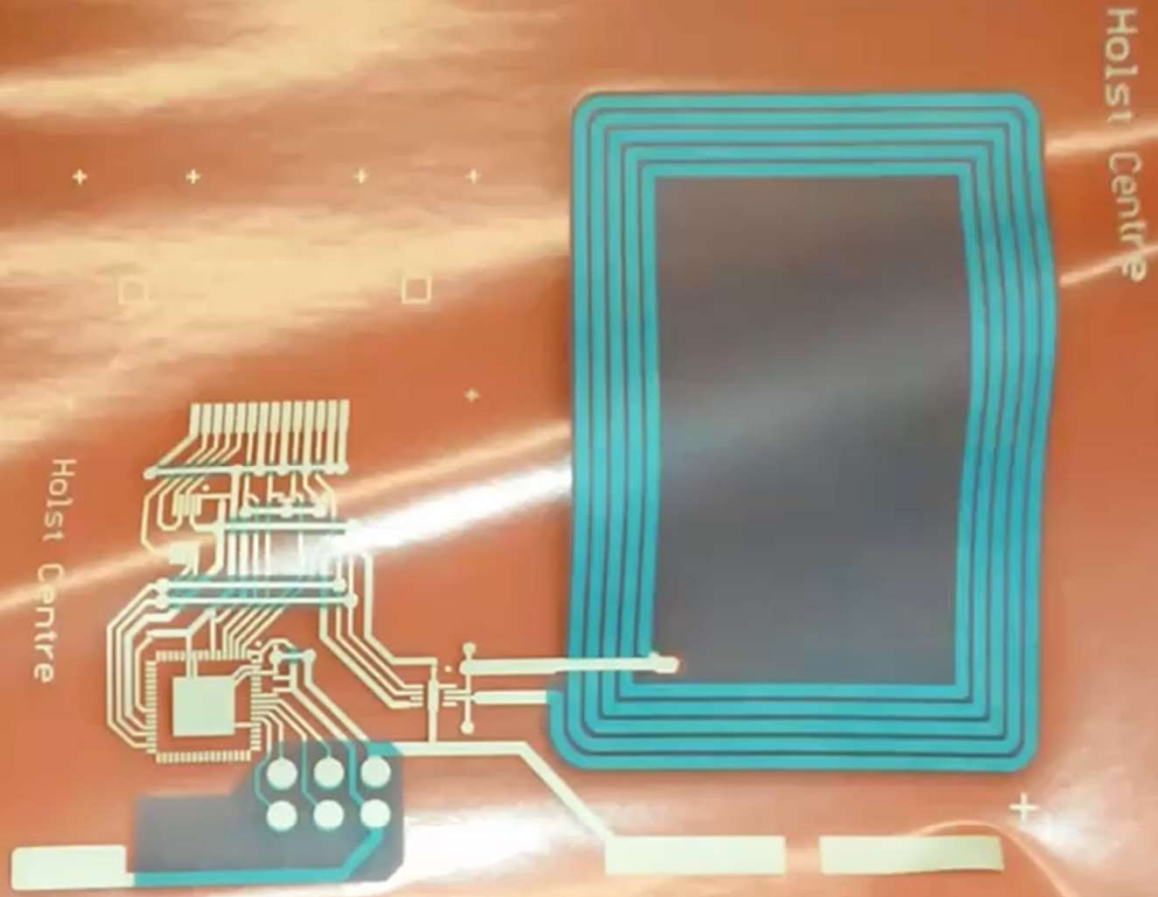
# Adding electronic components to plastic film



25  $\mu$ m thick, 90  $\mu$ m pitch microcontroller + 01005 components on PE foil

- several processes and technologies available for reliable heterogeneous integration of various types of components (passives, bare die chips, ...)

# Stretchable electronics



# Transferring Holst technology to agro-food applications



**iGrow demo**

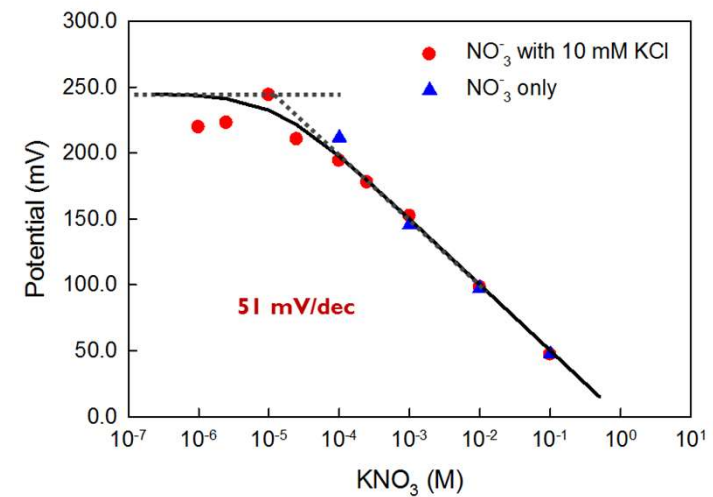


Light systems:



**Uniform lighting systems based on OLED**

Sensors:



**Nitrate & Conductivity of soil (internal)**





# **Interreg Grow! project**

## Interreg project Grow!

**Doelstelling: "Opbrengst en kwaliteit van glastuinbouwproducten te monitoren, optimaliseren en vergroten d.m.v. de ontwikkeling en toepassing van slimme draadloze sensor- en datanetwerken (Internet of Things, IoT)"**

- **Innovatieve sensorsystemen**
  - Beter, goedkoper, robuuster
  - Draadloos meten van gassen en voedingsstoffen in water
  - Monitoring van plantstress en pathogenen
- **Big-datanetwerken -> optimalisatie plantgroeimodellen**
- **Testen & valorisatie in fieldlabs en samenwerking met KMO/MKB glastuinbouwbedrijven**
- **Partners: TNO, Universiteit Antwerpen, LTO Glaskracht, Katholieke Universiteit Leuven, Stichting IMEC Nederland, HAS Hogeschool, Proefcentrum Hoogstraten, Vlaams Centrum voor Bewaring van Tuinbouwproducten**

**Start in januari 2018**

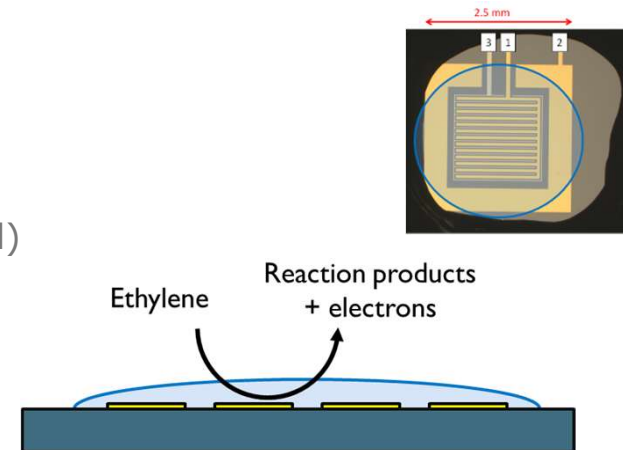
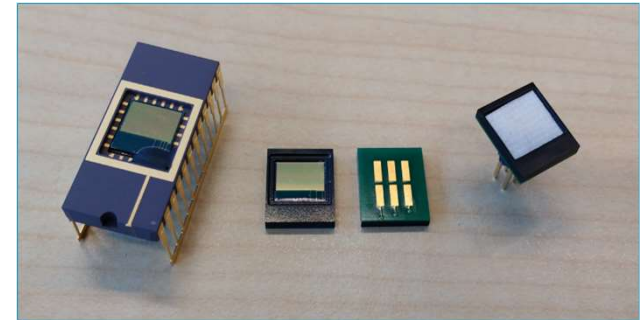




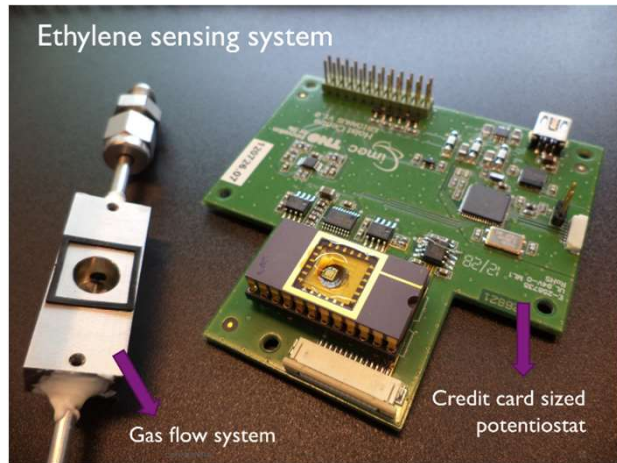
## **Examples of Connected Gas & Liquid sensors**

## e.g. Low cost ethylene sensor based on ionic liquids

- **Ionic liquids**
  - molten salts at room temperature
  - consisting solely of ions
  - application by ink-jet printing or dispense tool
  - liquid form or gel form mixed with polymer
- **Potentiometric based sensor:**
  - 2-electrode cell (CO<sub>2</sub> absorption)
- **Amperometric based sensor:**
  - 3-electrode electrochemical cell
    - Electrode 1: oxidation of ethylene (Gold)
    - Electrode 2: compensating reduction reaction (Gold)
    - Electrode 3: voltage reference (Platinum)
    - On top: ionic liquid

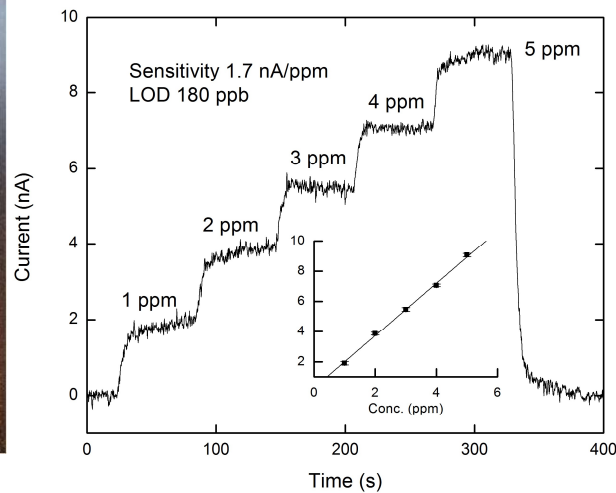


# Ethylene Sensor sensitivity and limit of detection



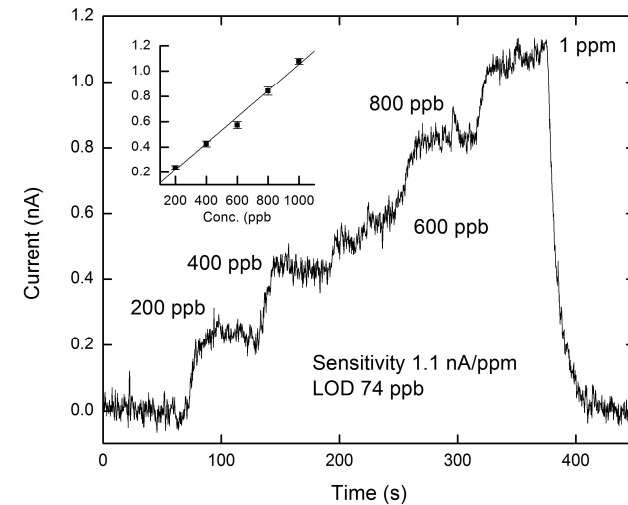
High concentration range

1 - 5 ppm



Low concentration range

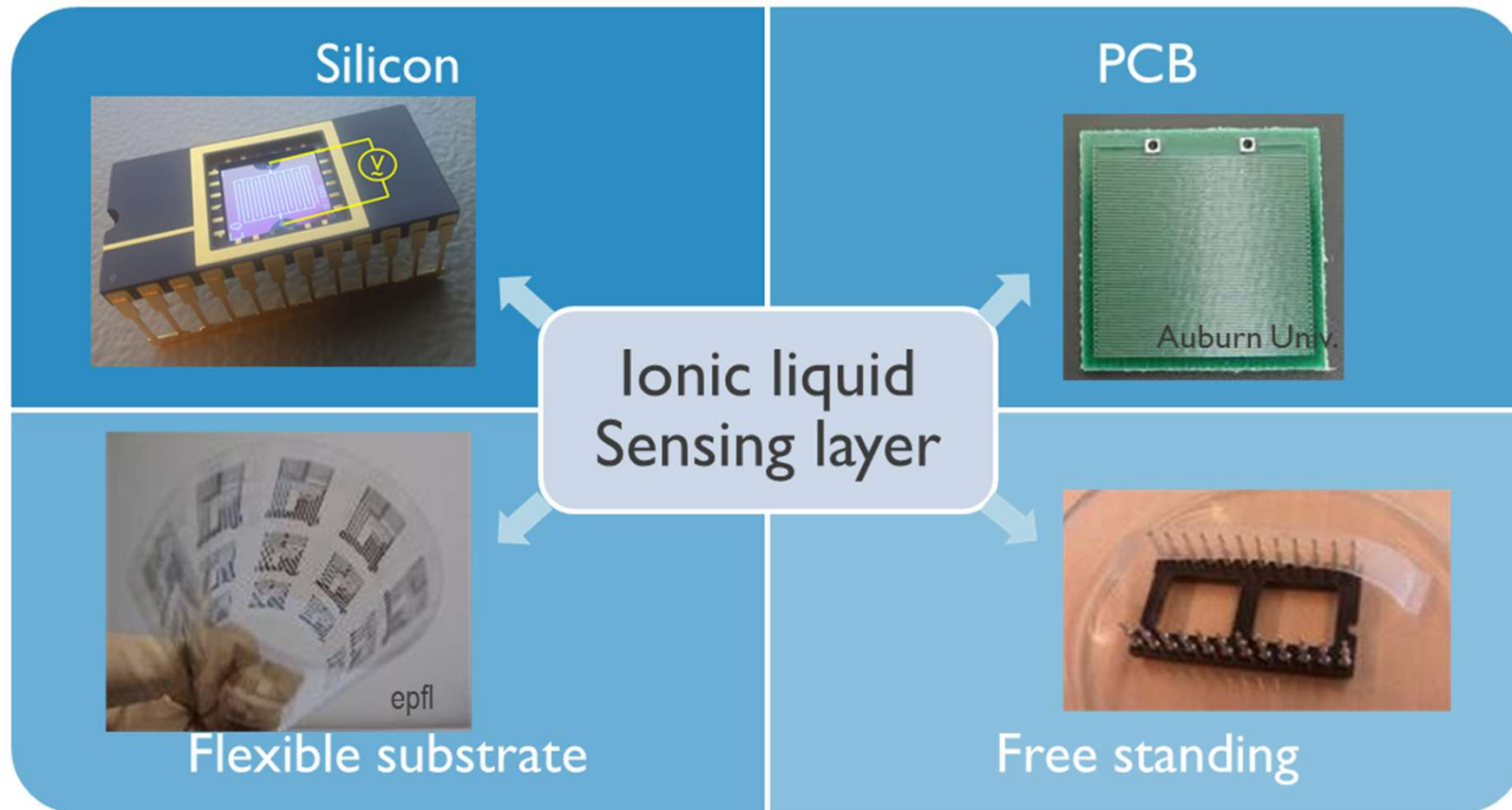
200 -1000 ppb



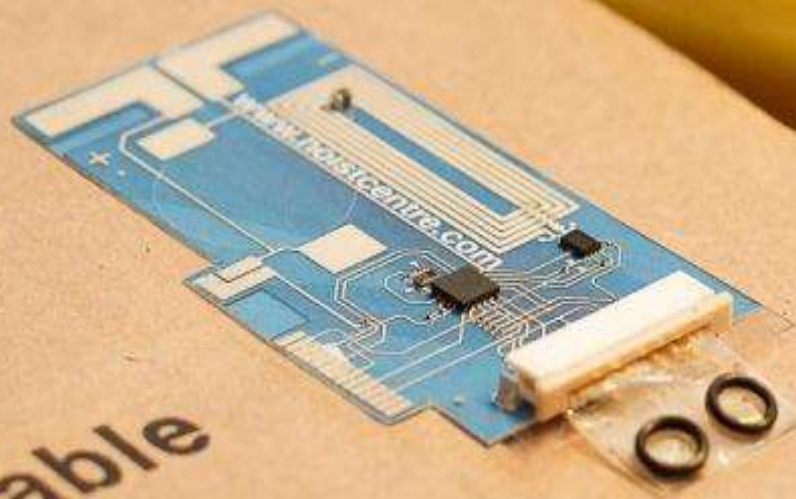
## Results

- Sensitivity: 1.7 nA/ppm
- LOD ~ 100 ppb

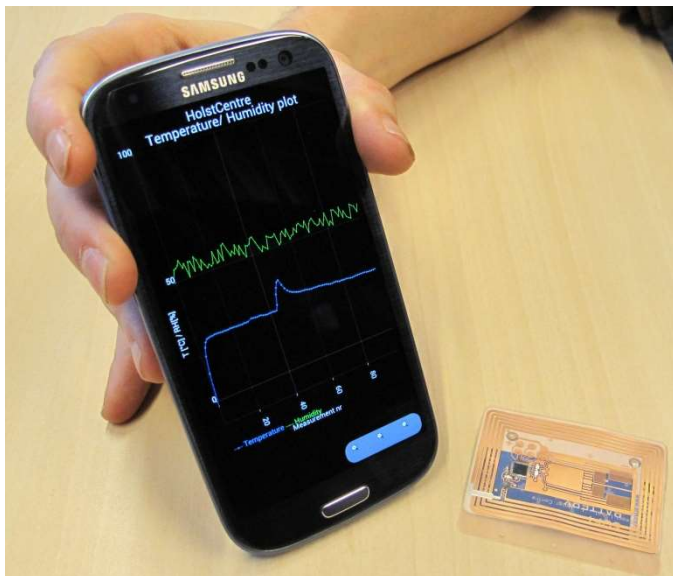
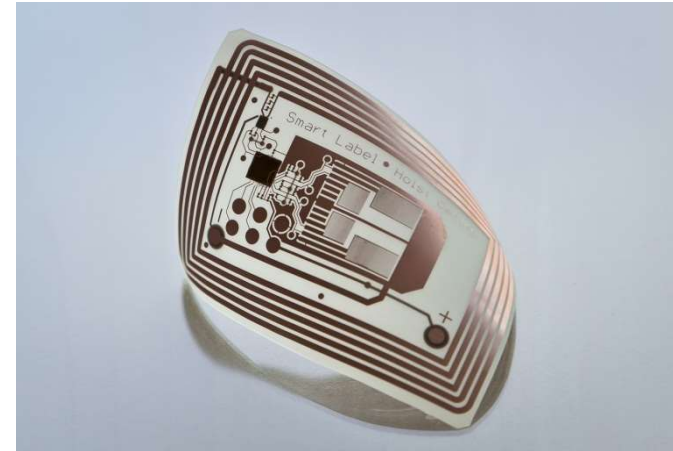
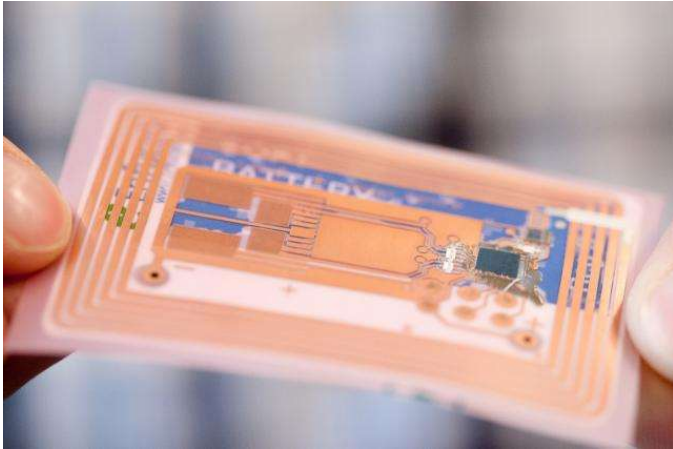
# Flexible implementation on different substrates



e.g. Fruit Ripening Sensor (Ethylene)



## Smart sensing label 4<sup>th</sup> generation



### Features:

- Fully integrated system in foil
- Ultra thin (0.5mm)
- Over 200 hours of measurements with 10 sec interval with paper battery
- Readout via NFC enabled mobile phones (Android)



# Water testing – state of the art



	Colorimetry tests	Hand-held spectroscopy	TDS	Multi-parameter probes
Time	~minutes per tests	~minutes/hr per test (depending on preparation of sample)	~seconds	~seconds to minutes, all parameters
Parameters	alkalinity, boron, bromide, chloride, chlorine, copper, chromium, DO, hardness, iron, nitrate, nitrite, pH, phosphate, sulfite, zinc	alkalinity, aluminum, ammonia, arsenic, boron, bromide, cadmium, chloride, chlorine, copper, chromium, cyanide, DO, hardness, fluoride, iron, lead, manganese, mercury, nitrate, nitrite, pH, phosphate, sulfite, zinc, etc.	-total dissolved solids	-ammonium, pressure, algae, chloride, copper, conductivity, DO, fluoride, iodide, nitrate, pH, ORP, sodium, potassium, turbidity, temperature, TDS
Selectivity by	Chemical reaction causes color change	Chemical reaction causes color change	None, based on conductivity sensor	Ion-selective electrodes
Advantages	-easy to use	-easy to use -quantitative (better than colorimetry)	-easy to use	-quantitative, continuous monitoring
Disadvantages	-semi-quantitative, comparison to colored chart, -labor intensive, time consuming for multiple parameters -different reagents per test required	-labor intensive, time consuming for multiple parameters -different reagents per test required	-often sold as inexpensive water quality tester, only a single parameter is measured	-electrodes need maintenance, cleaning, recalibration
Cost	kit with 6 parameter \$250 for 100 tests per parameter, additional parameter \$20-\$60	\$200-\$1000 for the spectrometer \$20 reagents for 100 tests	\$20-\$50	\$5000-\$10000 per probe

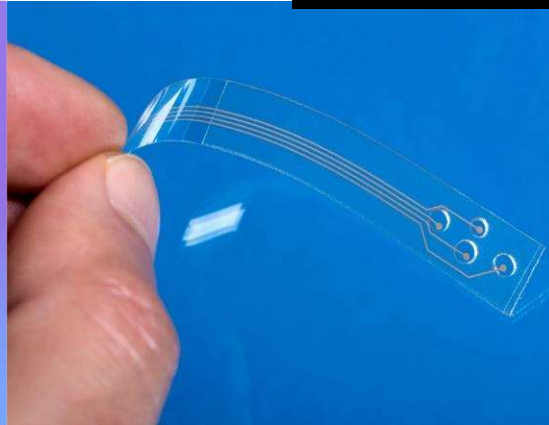
← **Enormous gap between continuous probes and labor intensive quick tests** →

# Holst Centre Multi-ion sensor

**Solid State**



**Screen printed**



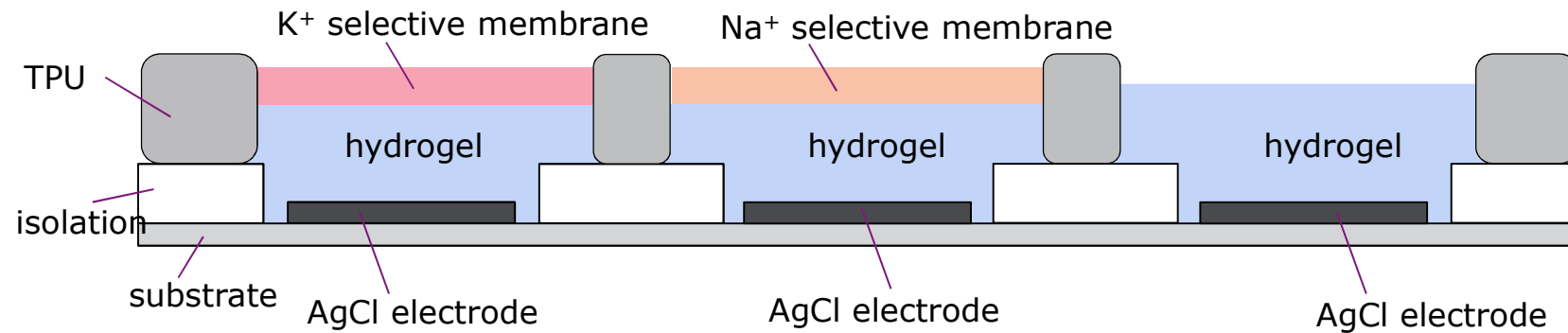
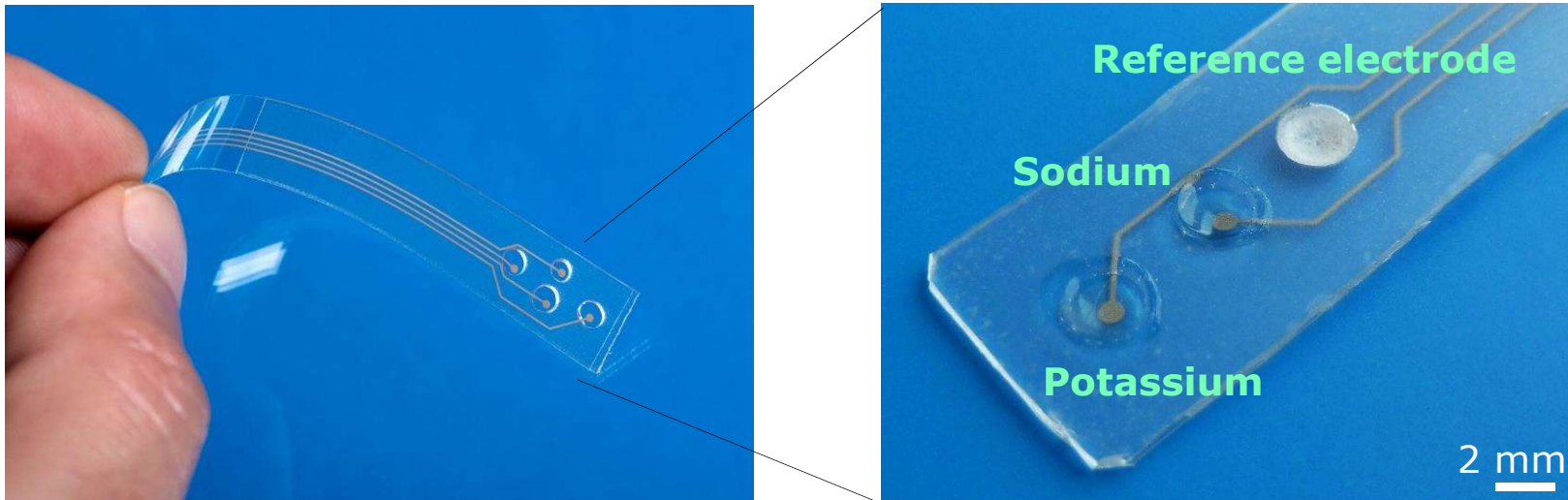
## Fluids monitoring

- Solid & flexible sensor
- Hand-held sensor demo kits available
- Trial tests and benchmarks performed
- Multiple ions: pH, ORP,  $\text{Cl}^-$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{NO}_3^-$ , extension to other ions possible  $\rightarrow$   $\text{Mg}^{2+}$ ,  $\text{NH}_4^+$
- pH: 2-10 pH range, 0.1 accuracy
- ions:  $10^{-4}$  M – 1 M range, 10% accuracy
- Conductivity: 5 – 100000  $\mu\text{S}/\text{cm}$  (variable cell constant)

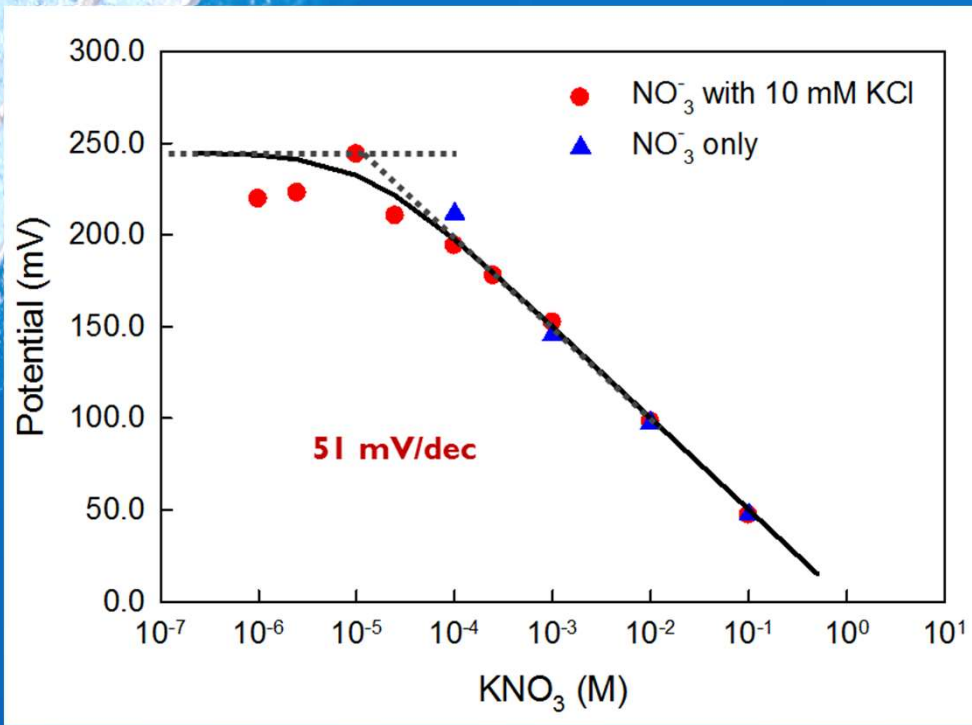
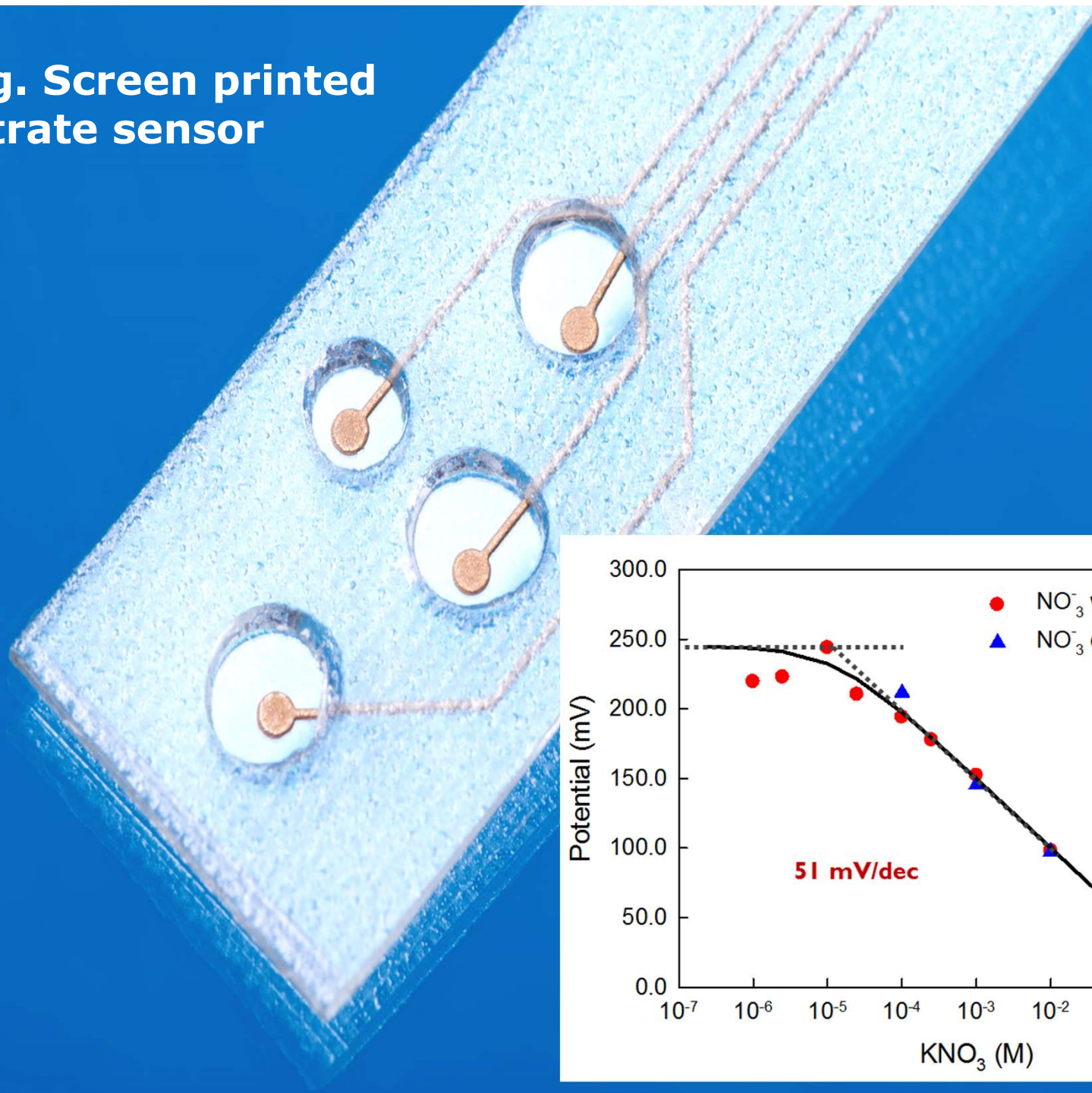


State of the art pH sensor

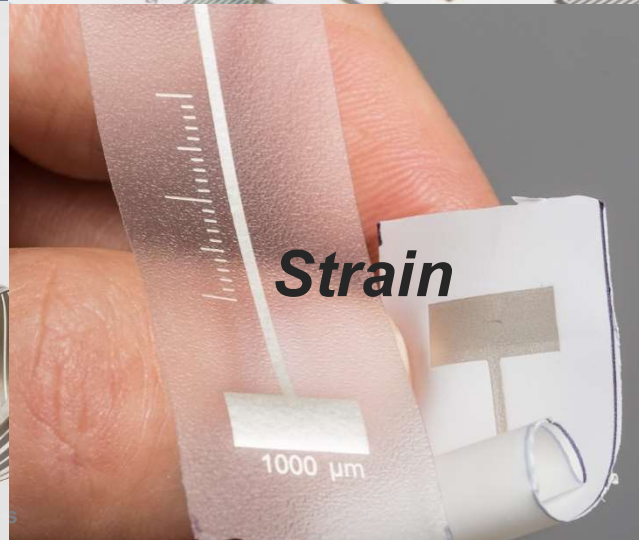
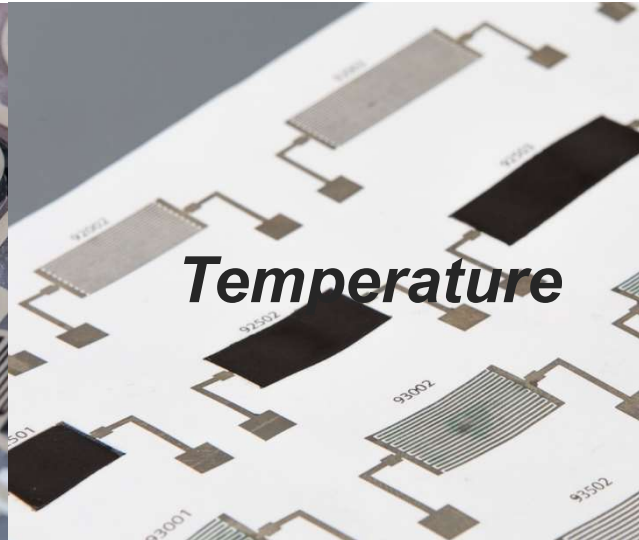
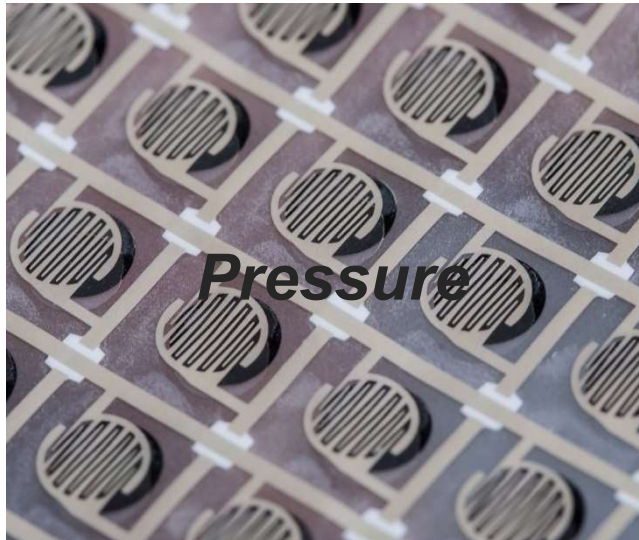
# Screen printed ion selective sensors *easy extension to other ions using selective membranes*



# e.g. Screen printed nitrate sensor

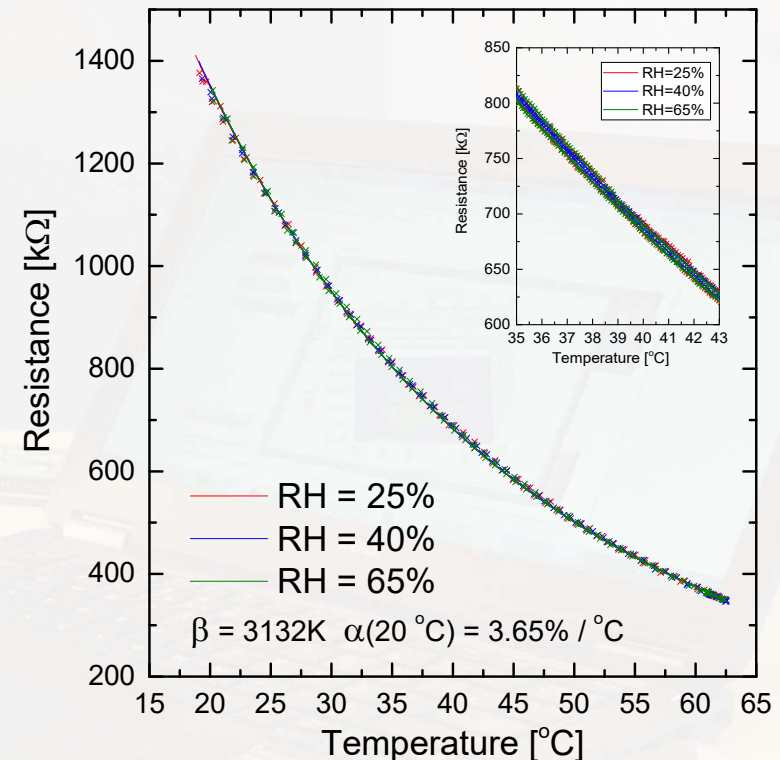


# Printed conformable sensing surfaces

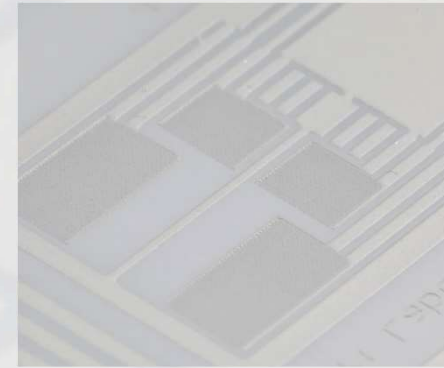


## e.g. Printed Temperature Sensor

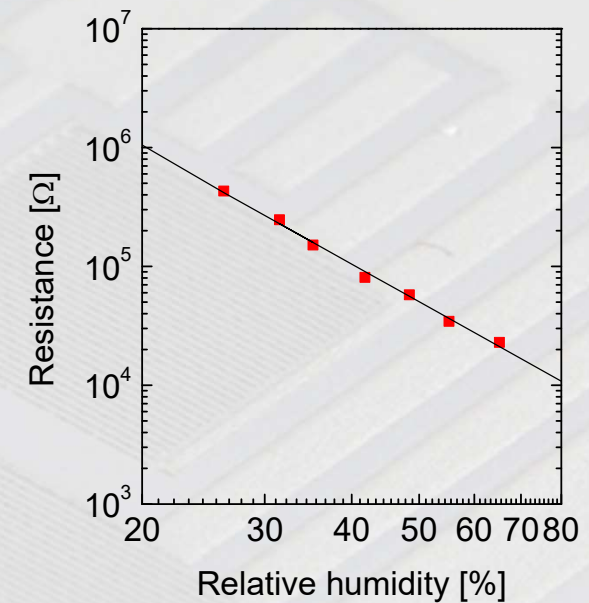
- **Easy processing**
  - screen printing
  - No thin-film or metal encapsulation
- **Low temperature process: <120 °C**
  - compatible with PEN/PET/TPU substrates
- **Excellent response to temperature**
  - 3 to 4% change per °C
- **Good Accuracy**
  - < 0.1 °C
- **Good stability versus humidity**



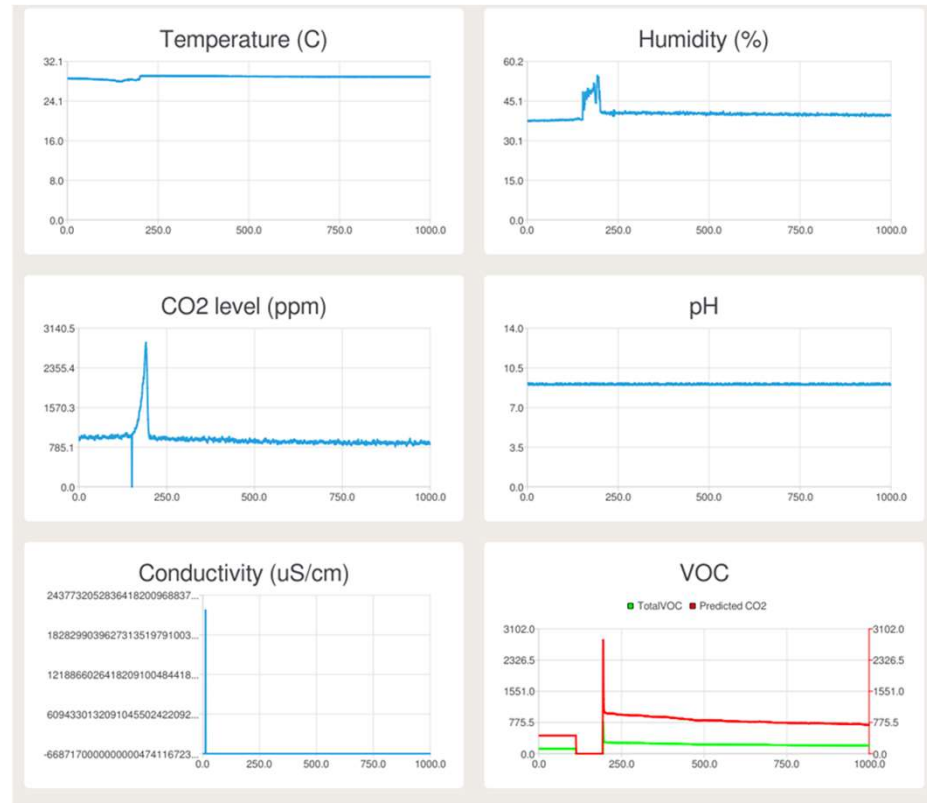
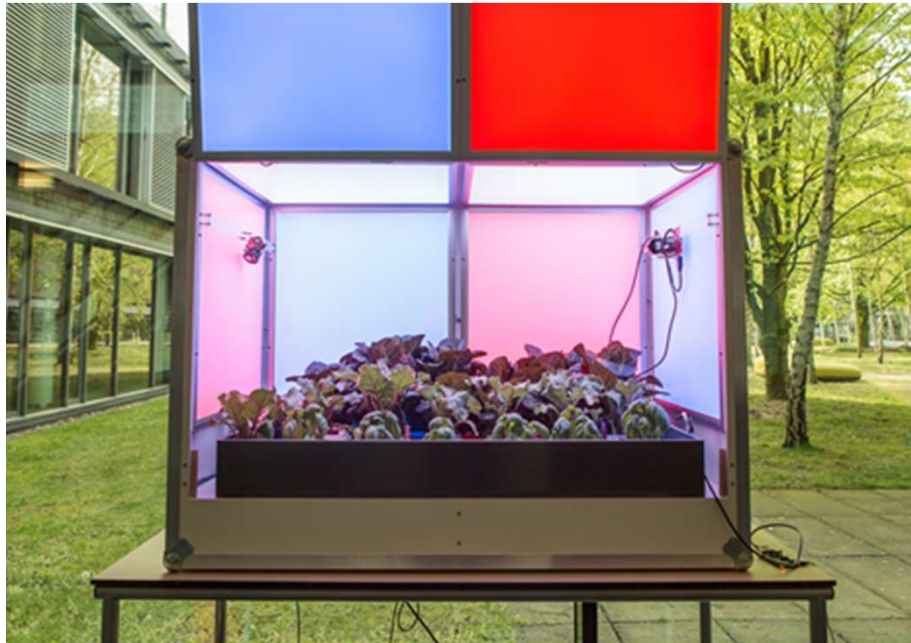
## e.g. Printed Humidity Sensor



- **Based on ion conduction in polymer electrolyte**
- **Medium accuracy and speed**
- **Simple readout and fully compatible with foil substrates**

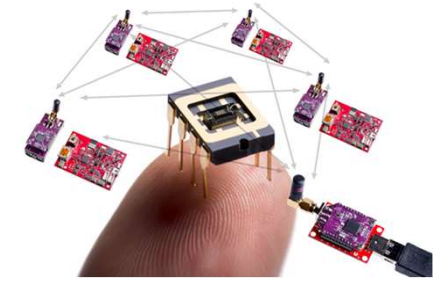


# Next step: Horticulture





## Focus Interreg project Grow!



- **Kunnen IoT oplossingen helpen bij het monitoren en optimaliseren van de groei condities van groente en fruit in de kas/serre. Het verbeteren van productie in zowel kas als ook 'vertical farming' oplossingen, met tegelijkertijd duurzaam watergebruik en bescherming van het milieu.**
- **Focus op technologie ontwikkeling:**
  - Draadloze sensor systemen → 'Internet of Things' (IoT)
    - Radio technologie (verschillende standards)
    - Network en 'cloud' platform
  - Gassen ( $\text{CO}_2$ ,  $\text{NO}_x$ ,  $\text{C}_2\text{H}_4$ ...), Temperatuur, luchtvochtigheid
    - Rigide (Si-substraat) en flexibel folie uitvoeringsvorm
  - Monitoring water kwaliteit
    - Meting van voedingsstoffen en verontreiniging in water
  - Geprinte sensoren
    - Goedkoper
    - Robuuster



The **future**  
**belongs** to those  
who **create** it



Open Innovation by imec and TNO