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# Real-time Analysis of Sweat Using Integrated Chemical Sensors

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# Outline

- Introduction
  - ✓ Sweat Analysis
  - ✓ Wearable sensors
- Sodium Sensors
- pH Sensors
- Lactate Sensor
- Conclusions

# Sweat measurement: State-of-the-art

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## The sweat test is routinely used for the diagnosis of cystic fibrosis

## Other conditions reported to cause a high salt level in sweat:

- Adrenal glands malfunction (adrenal insufficiency or Addison's disease)
- Hypothyroidism
- Diabetes Insipidus (caused by inability of the body to retain water)
- Kidney failure

## Sweat as a removal pathway for drugs

- Legal (salicylic acid, antipyrine, phenol) and illegal (cocaine, heroine, amphetamines) drugs
- Forensic medicine is trying to exploit this to detect drug abuse

# Sweat analysis – Potential Fields of Application

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## *Clinical Medicine:*

*Chronic disease management (heart, renal failure)*

*Peripheral vascular disease (therapy efficacy)*

*Post-surgery management (hydration protocols)*

## *Physical Training:*

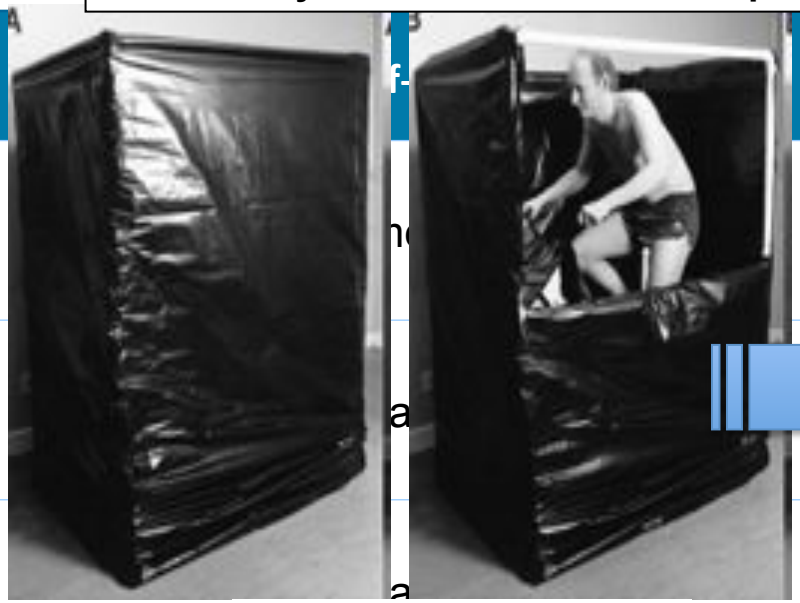
*Personalised training protocols and reintegration*

*Down's syndrome children training program*

*People with thermoregulatory impairment*

# Technology comparison

**Whole body sweat collection techniques**



S. M. Shirreffs, *et al.*, J Appl Physiol 82 (1997) 336-34

Minimum discomfort

**PharmChek Sweat Patch**

# BIOTEX – Biosensing Textile for Health Management

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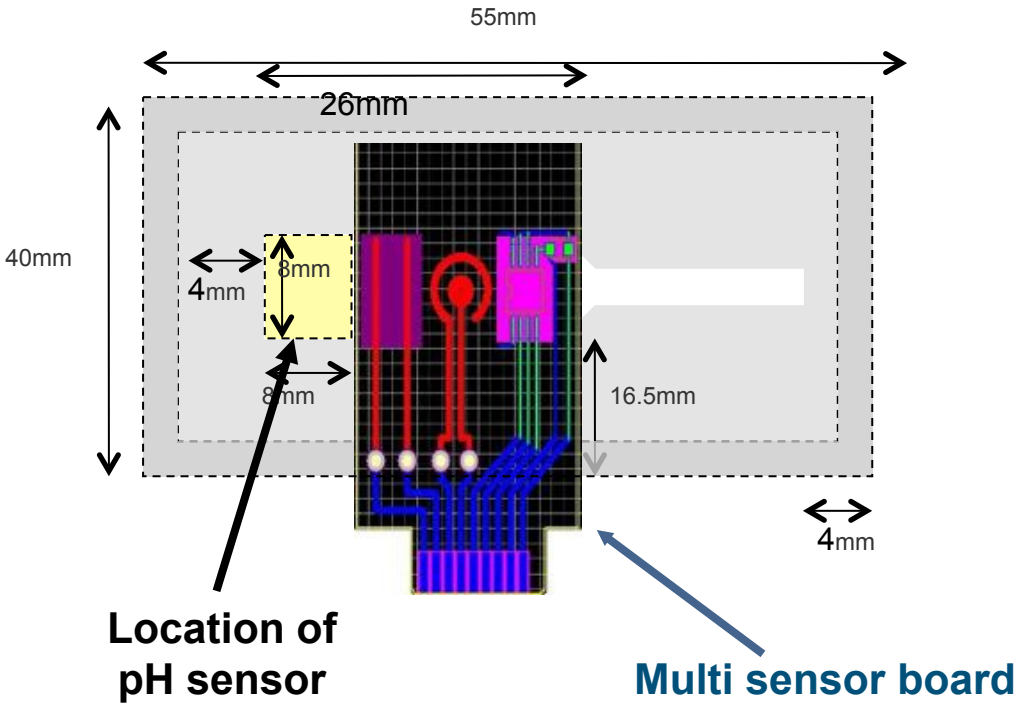
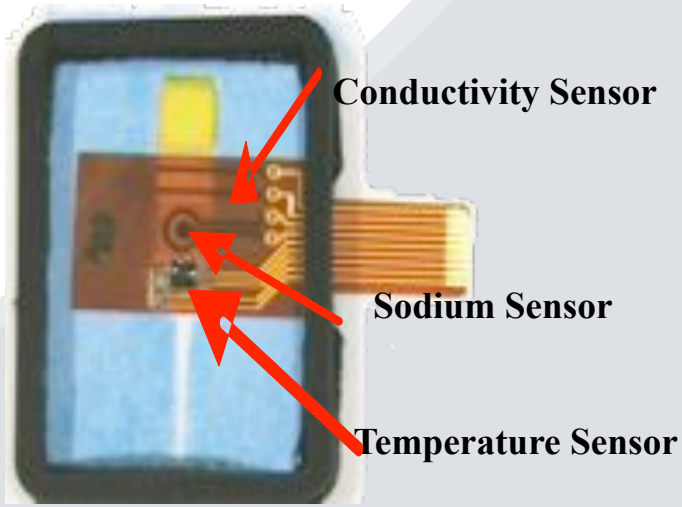


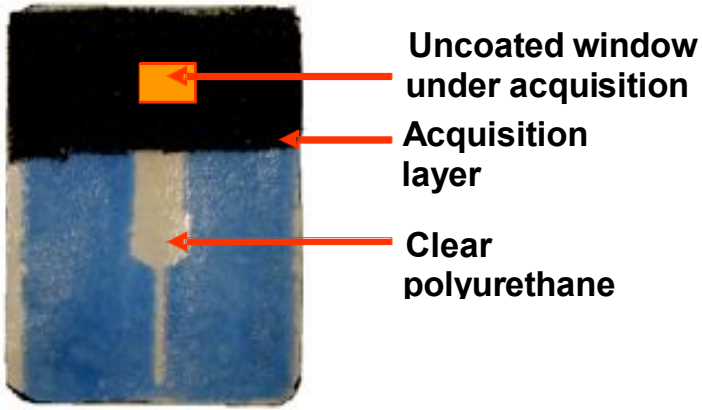

- pH
- Conductivity
- $Na^+$ ions concentration
- Temperature

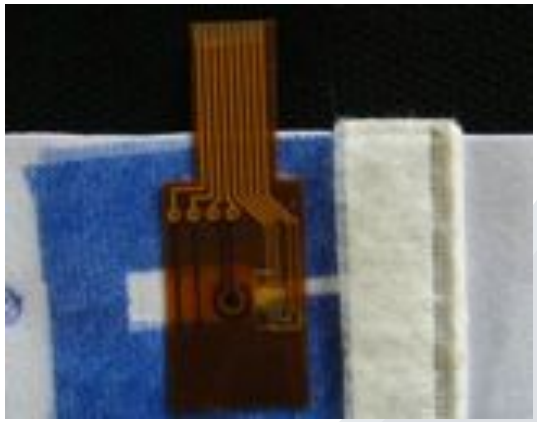



S. Coyle, *et al.*, IEEE Transactions on Information Technology In Biomedicine, 2 (2010) Vol.14

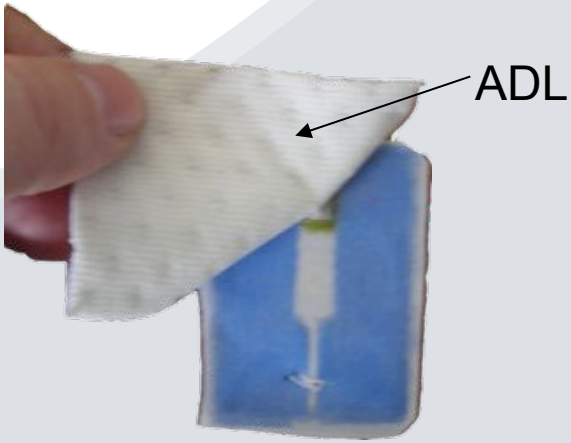
# BIOTEX – Biosensing Textile for Health Management

A passive pump transports sweat to the multisensing patch



Acquisition and distribution layer (ADL) to collect sweat from a larger surface

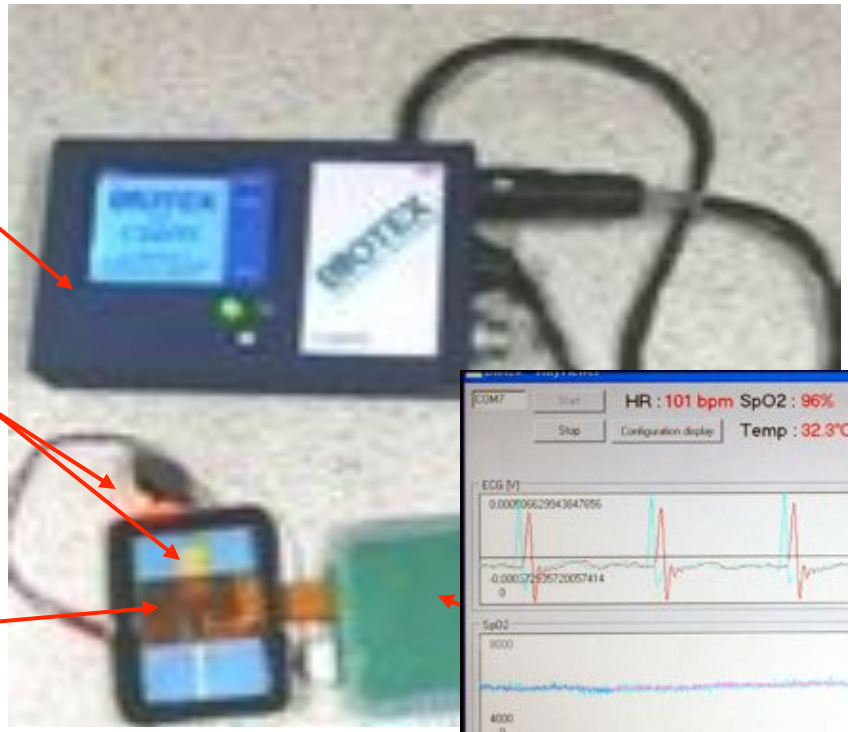


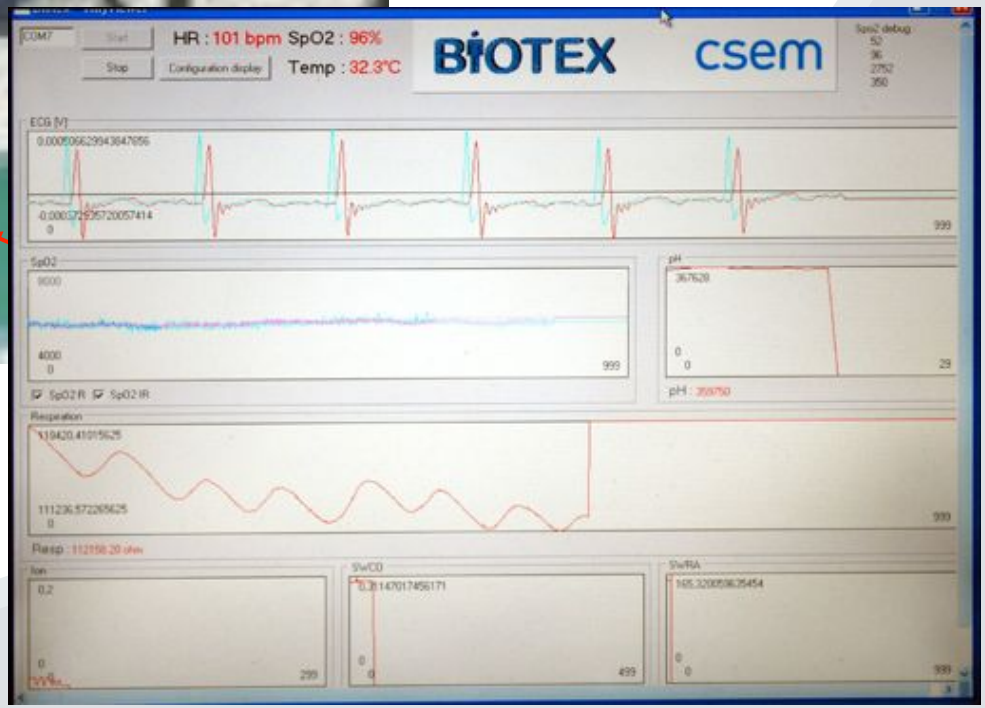
# Integrated patch and electronics

Control Unit

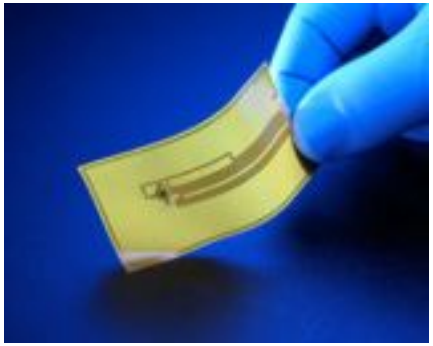
pH Sensor

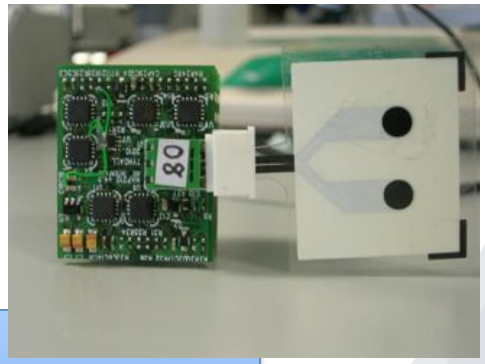
Patch Containing Sodium and Conductivity Sensor




**Jean Luprano, CSEM**





# Sodium Sensor


# $Na^+$ sensor: Ion Selective Electrode

**Measurement of Open Circuit Potential (OCP) between Reference Gold Electrode and SC-ISE** (Solid Contact- Ion Selective electrode)

**Gold electrode**

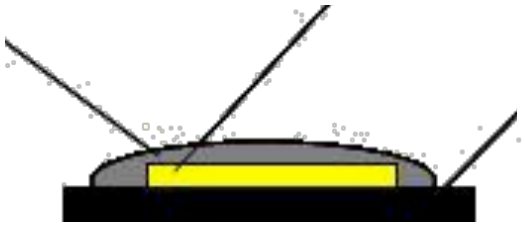
**SC-ISE**

**Picture of ISE on the patch**

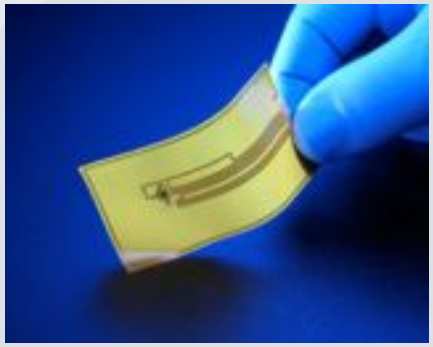
**Membrane**
- Ionophore
- Plasticizer
- PVC

**Au(+ Ppy layer)**

**Patch**



**Schematic representation of the (ISE)**



**With Dr. Isabelle Chartier CEA-LETI Grenoble**

# $Na^+$ sensors (SC-ISE): patch testing

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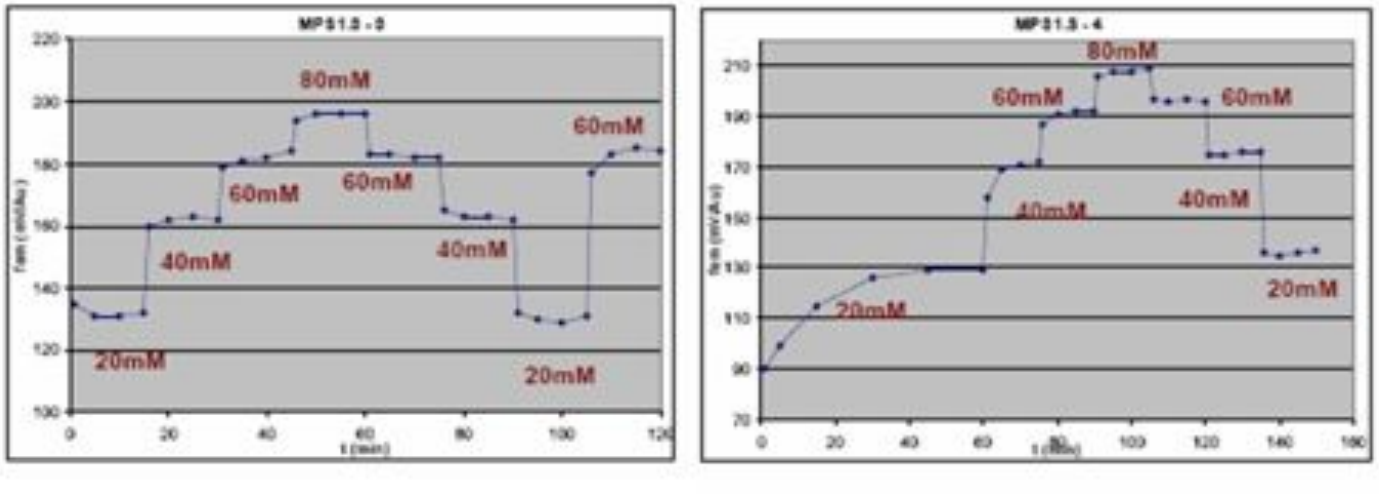
## Calibration curves

NaCl model solutions 10 < [NaCl] < 100mM

Linear variation OCP vs Log [$Na^+$]
Good sensitivity 130-150mV/ log unit

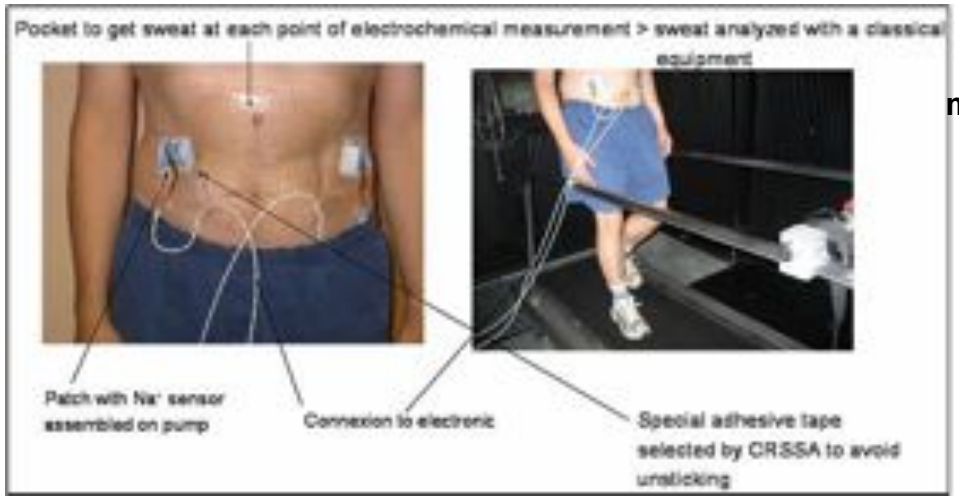
## Reversibility of $Na^+$ ISE with model solutions




| Ions | [ion] Hitachi 912 (mM) | [ion] ISE sensors (mM) | Typical concentration (literature, mM) |
|---|---|---|---|
| $Na^+$ | 53. 8 | 50 | 54. 5 ± 8.4 |

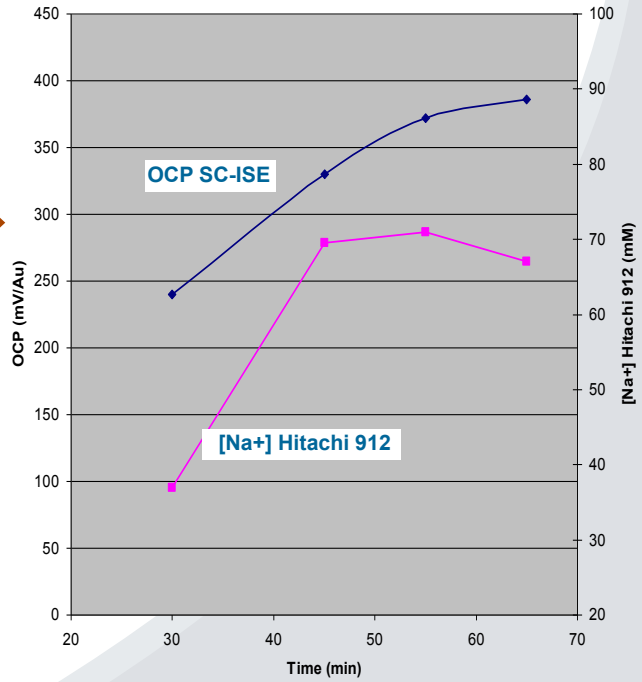
Measurements of sodium ions in **natural sweat** with two techniques (deviation 10%)

# $Na^+$ sensor: patch performance




**Pictures of the experiment with a volunteer**
(Experimental conditions : T = 45°C, hydrometry = 36%, speed 4km/h, slope 6% )

**Real-time measurements**




**At the beginning, correlated measurements of OCP**

***BUT***

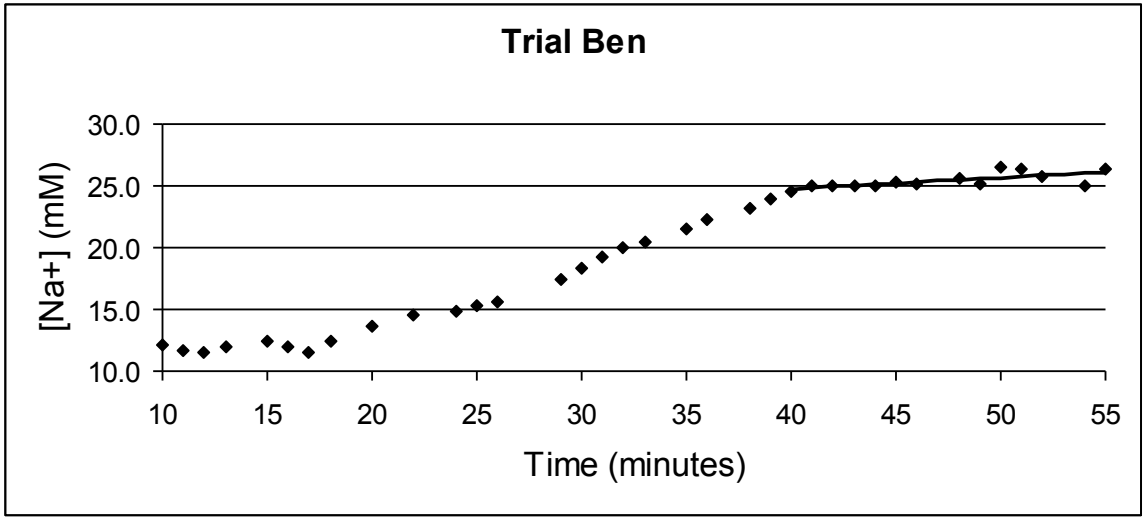
**Measured [$Na^+$] ↗ when real [$Na^+$] (Hitachi 912) ↘**

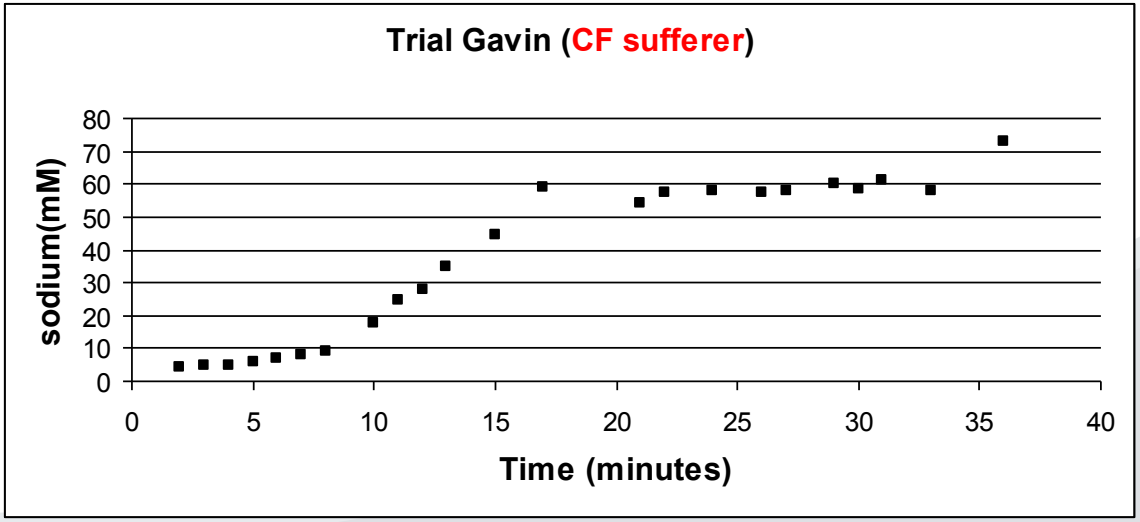
- ⇨ Contamination of the pump ? Concentration effect in the pump ?
- ⇨ Evaporation or saturation of the pump ?

# $Na^+$ sensor: Sodium Sensor Belt (SSB)


Schazmann, B., et al., Analytical Methods, 2010, **2**(4): p. 342-348.

# SSB - CF trials



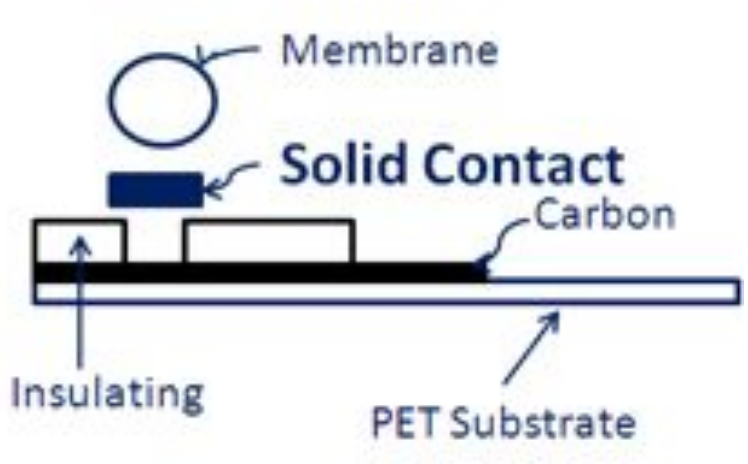



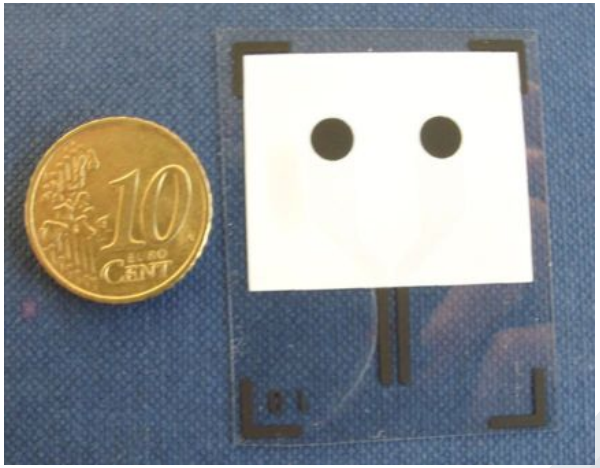

Literature

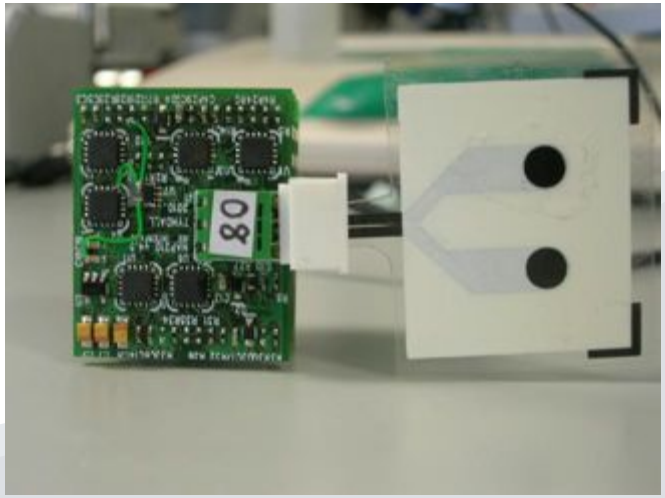
[Na⁺] Lower back range: 26±19mM

CF threshold > 60 mM [Na⁺]

# $Na^+$ sensor: The Road Ahead



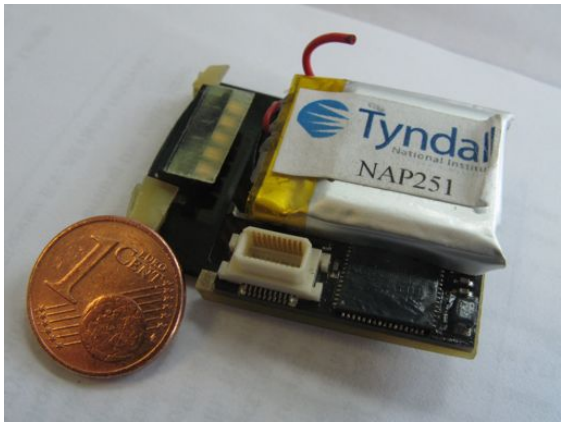



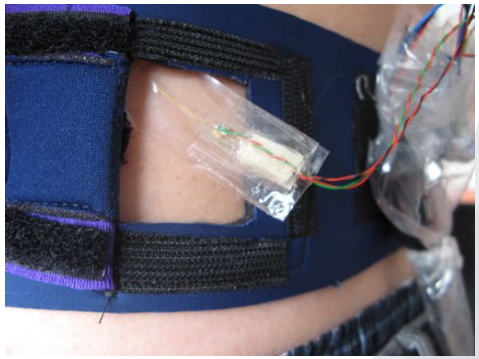



# $Na^+$ sensor: The Road Ahead

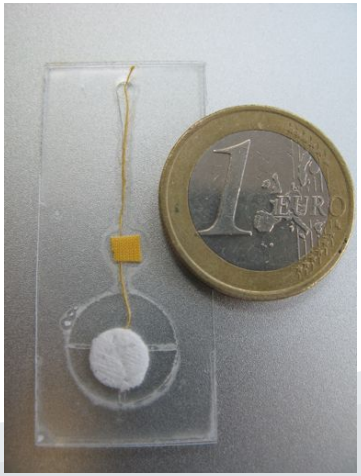
12.20 *A-2:L05* **Recent Progress in Flexible Screen-printed Ion-selective Sensors for Environmental and Wearable Applications**

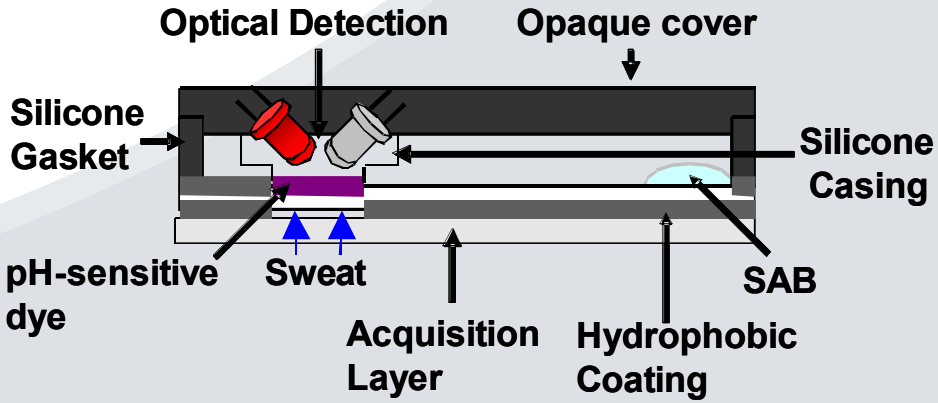
**G. MATZEU**, C. ZULIANI, D. DIAMOND, CLARITY Centre for Sensor Web Technologies, NCSR, Dublin City University, Dublin, Ireland


Tyndall
NAP251

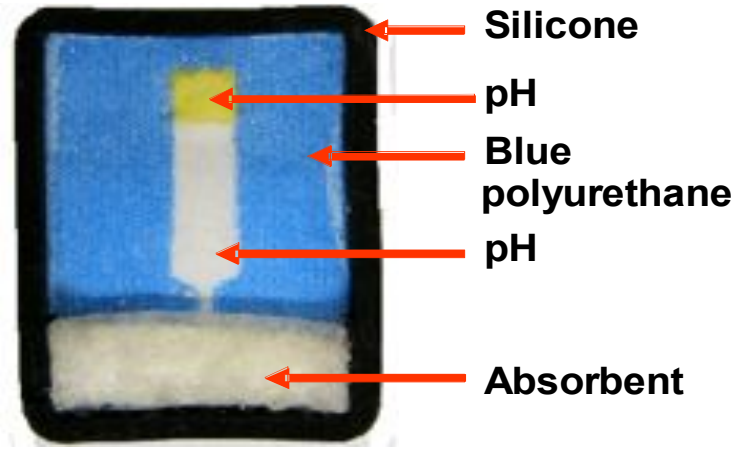


# pH Sensor



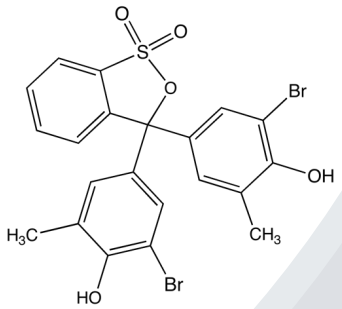

Optical Detection
Opaque cover
Silicone Gasket
Silicone Casing
pH-sensitive dye
Sweat
SAB
Acquisition Layer
Hydrophobic Coating

# BIOTEX – pH sensor



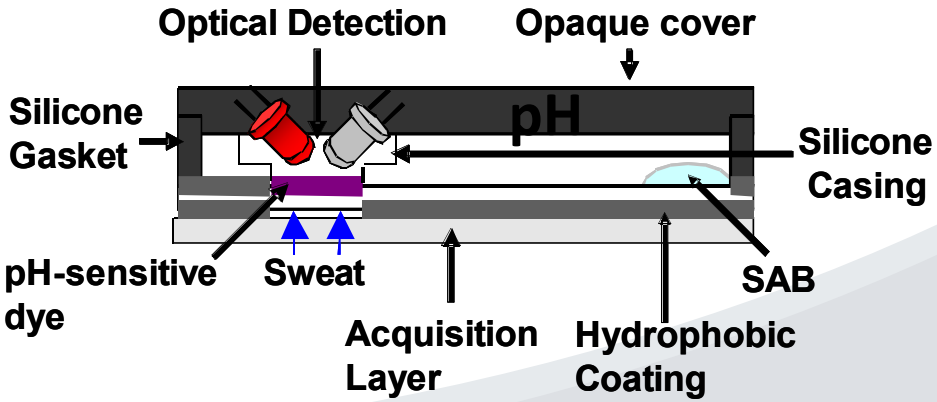

**Sweat pH: 5 - 7**

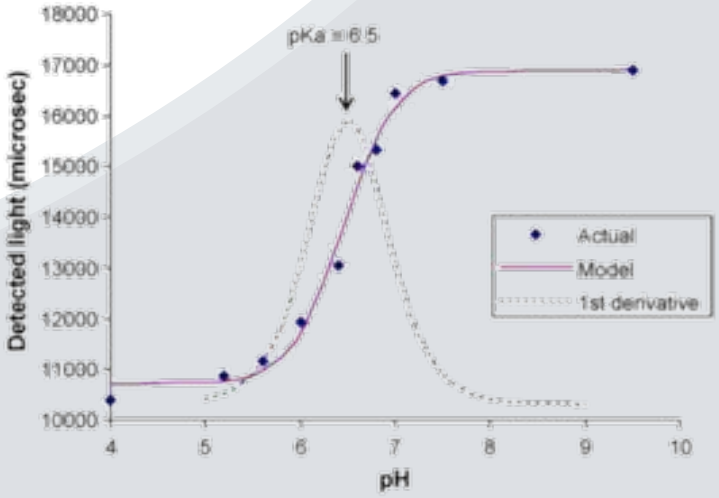
Bromocresol Purple ($pK_a$= 6.2)





Emitter-detector LED's λ = 660 nm




Morris, D., et al., Sensors and Actuators B, 2009, **139,** p:231–236

# BIOTEX – pH Experimental setup

Sensing patch and electronics incorporated onto a waist band

Referenc

Fabric Patch

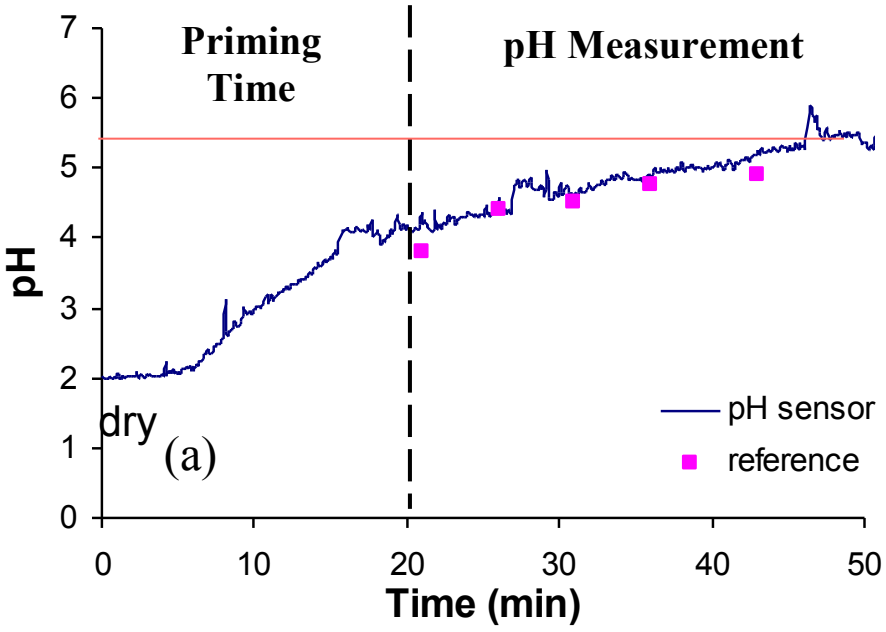
Hydrophobic surface

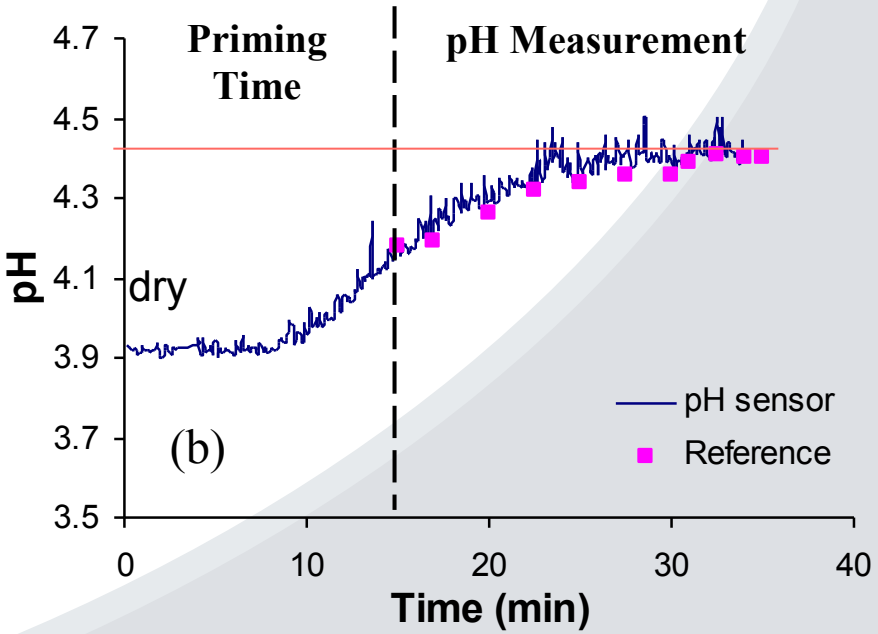
Waist band to secure sweat sensing system to reduce motion artefacts

Skincheck 1™ pH meter

# BIOTEX – pH Trials Results

Subjects include healthy individuals and CF sufferers

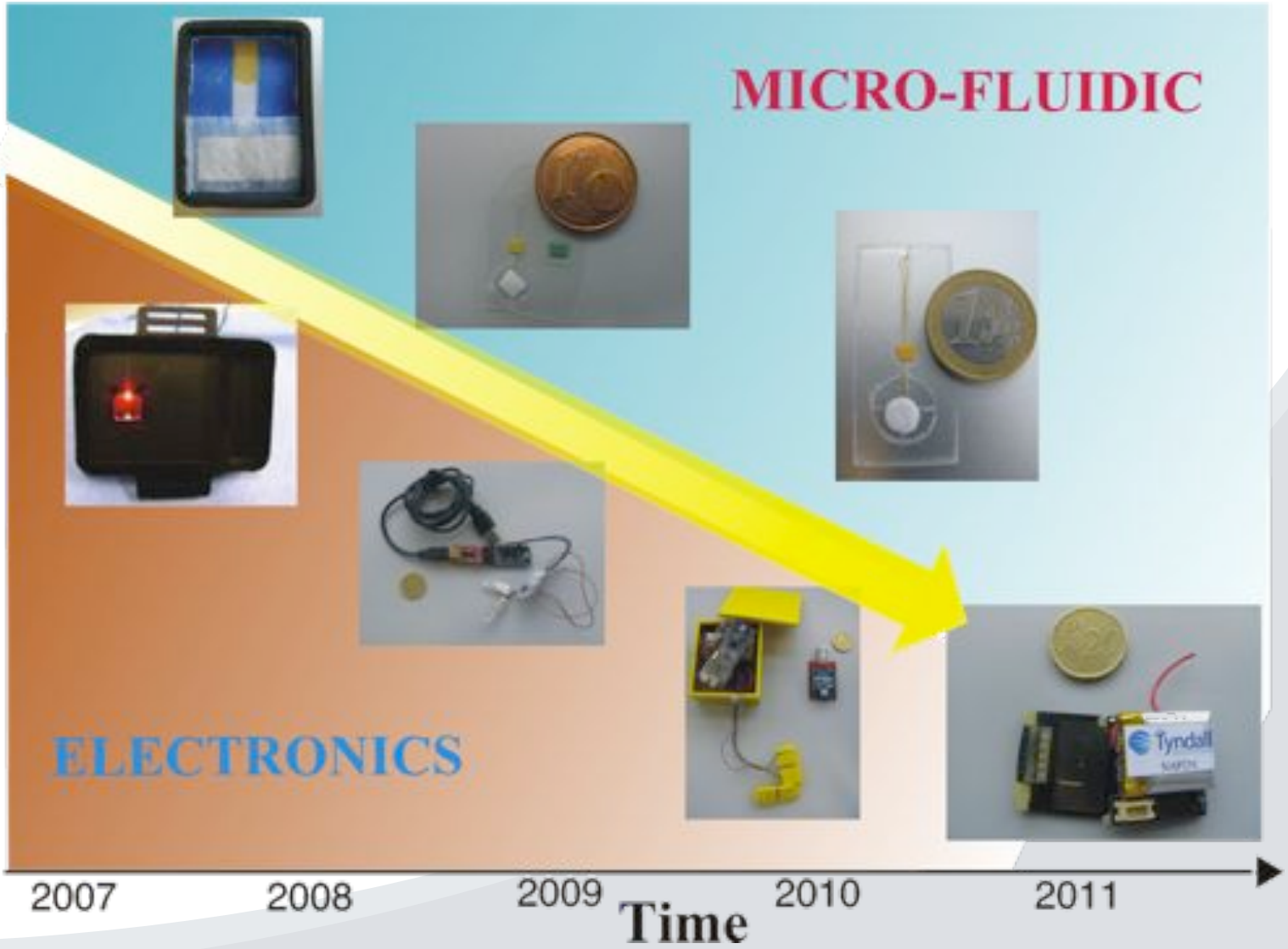



**(a) normal subject**

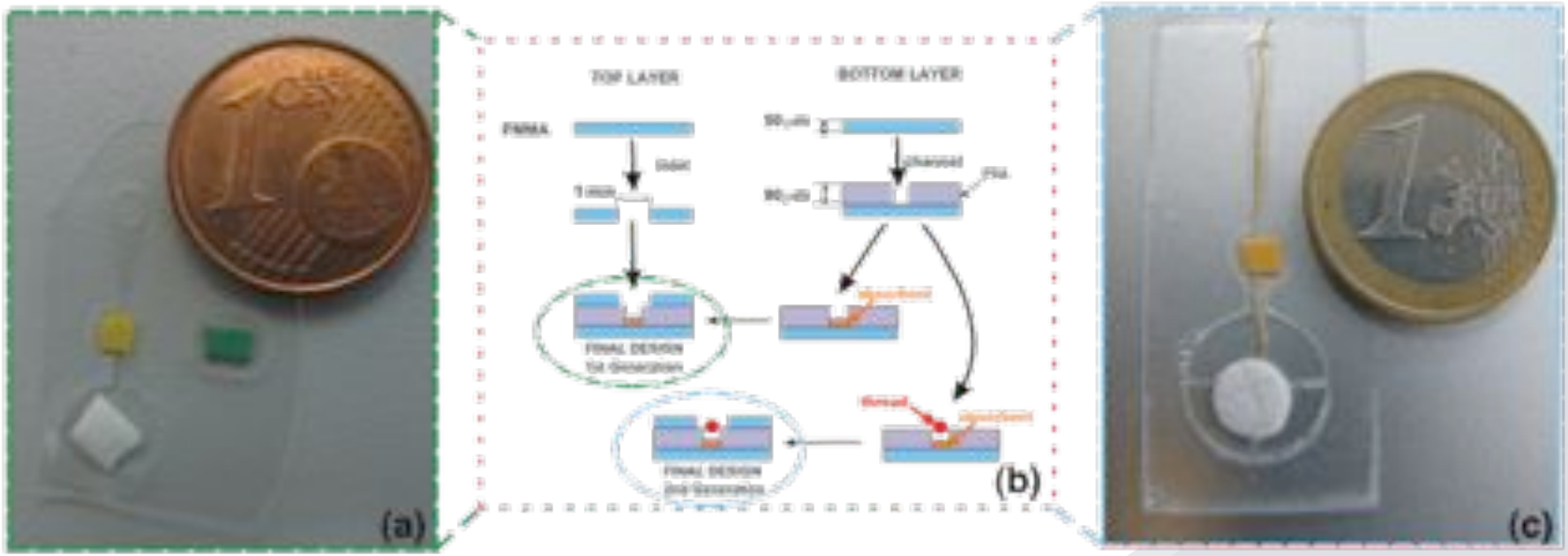
**(b) CF sufferer**

# Development of the Concept




Curto V., et al., Procedia Engineering, 2011, **25**, p:1561 – 1564

# Micro-fluidic: Fabrication




## Main Characteristics:

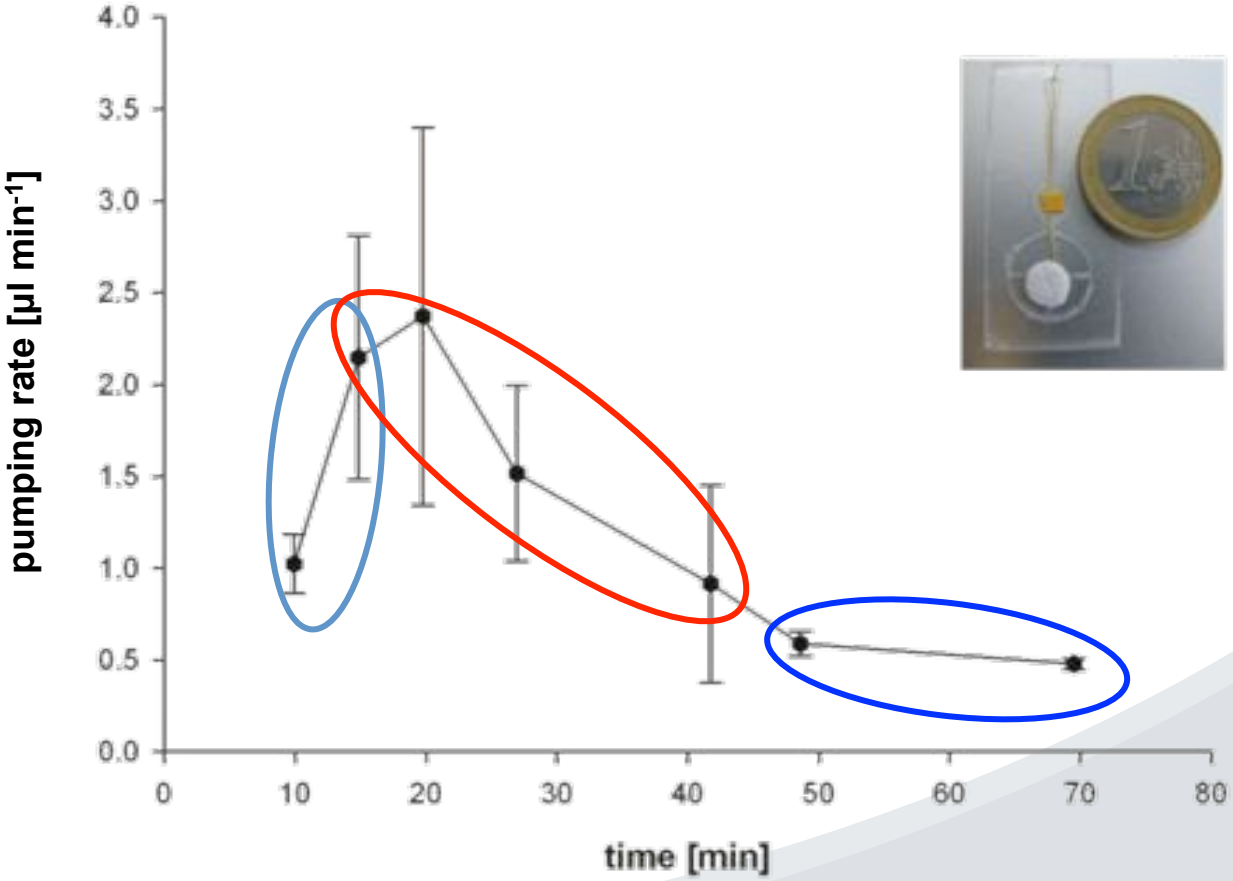
- pH dye bromocresol purple

- smLED-photodiode detection

-Absorbent = passive pump

Curto V., et al., Sensors and Actuators B, 2012, doi: 10.1016/j.snb.2012.02.010

# Micro-fluidic: Characterisation




n=4

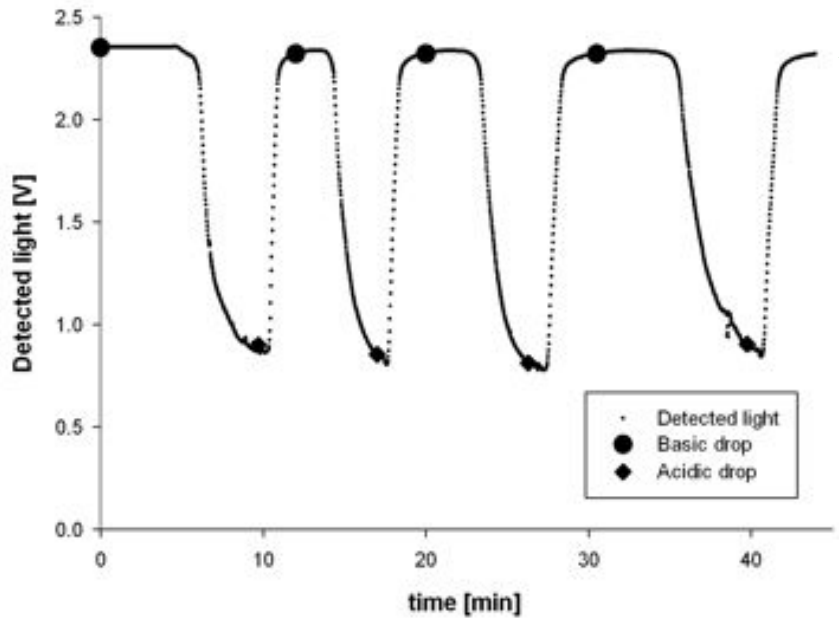


## Three operative regimes

- **Dry state**
  natural adsorption of the cotton thread
- **Capillarity**
  absorbing capacity of the absorbent material
- **Saturation**
  absorbent gets saturated

**Average time to reach sensing area equal to 3 minutes**

# Micro-fluidic: Characterisation




Acidic pH = 1 $[H^+]$=0.1 M

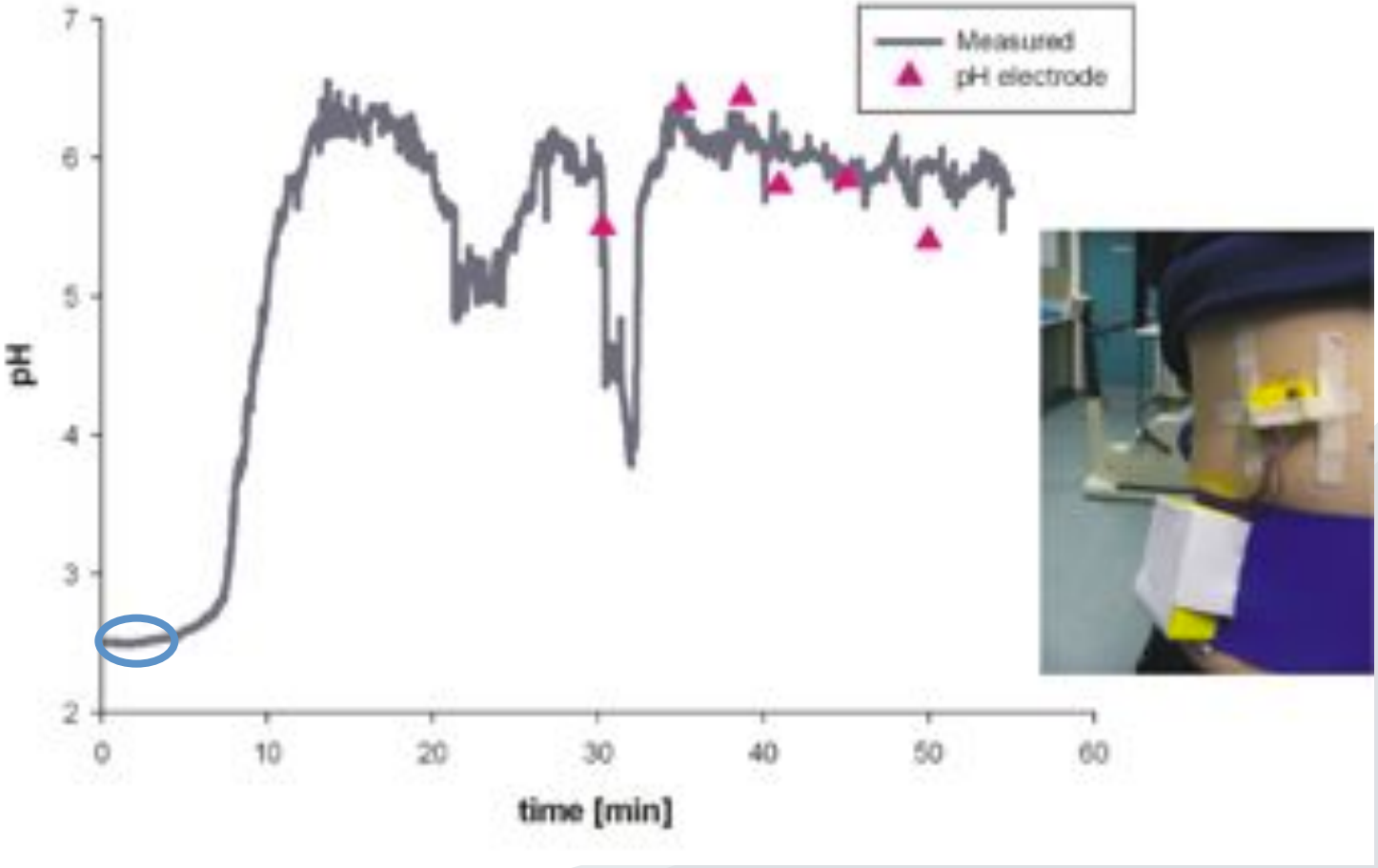
Basic pH = 12 $[OH^-]$=0.01M

| | Basic $t_d$ /min | Acidic $t_d$ /min | Basic $t_r$ /min | Acidic $t_r$ /min |
|---|---|---|---|---|
| *Cycle 1* | 4.74 | 0.60 | 4.96 | 1.7 |
| *Cycle 2* | 1.77 | 0.69 | 3.21 | 2.28 |
| *Cycle 3* | 2.37 | 1.13 | 3.97 | 3.06 |
| *Cycle 4* | 3.70 | 1.29 | 5.30 | 3.17 |

*$t_d$ – delay time*

*$t_r$ – response time*

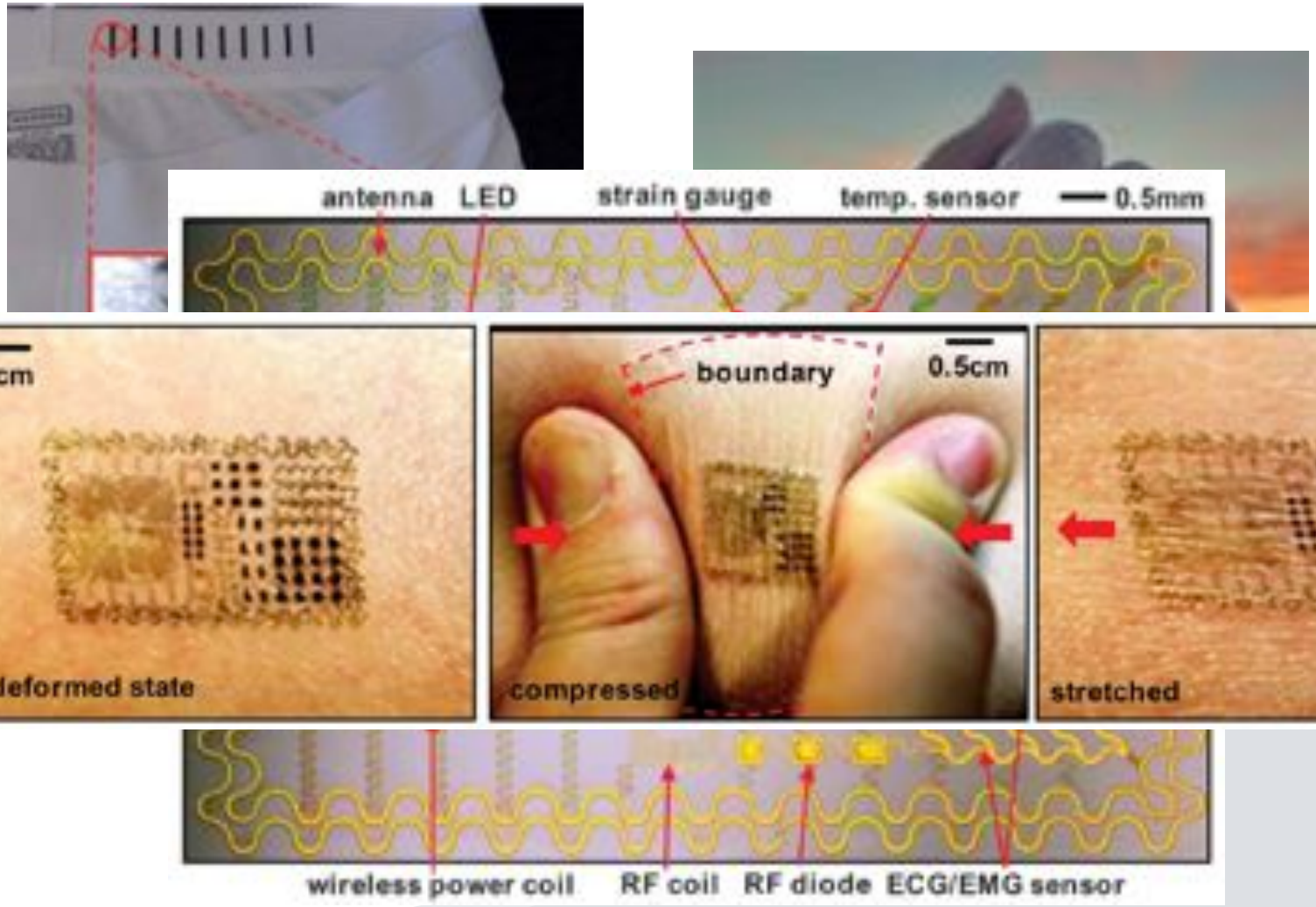
# Micro-fluidic: Performance




**0 – 5 minutes warm-up**

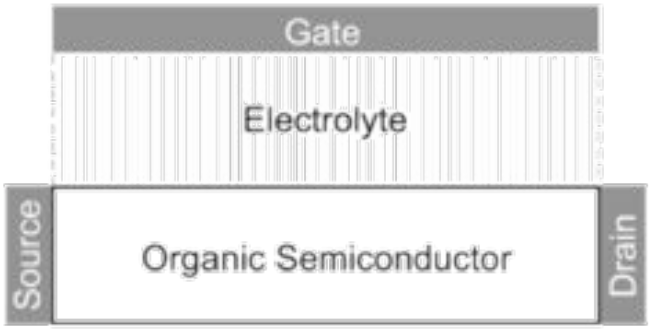
# Lactate Sensor

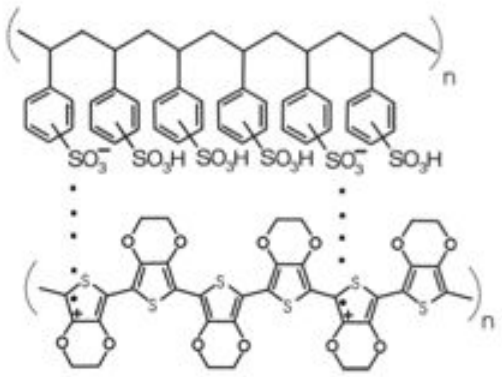
# Wearable Biosensing: New Trends




Prof. John Rogers @ University of Illinois

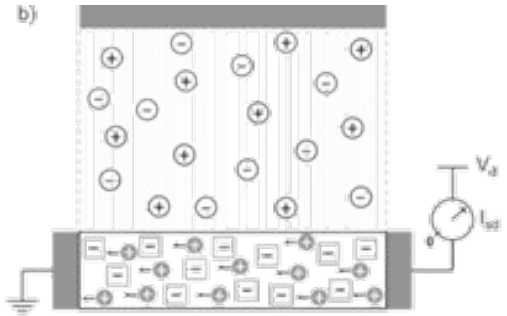
# Organic ElectroChemical Transistors (OECTs)



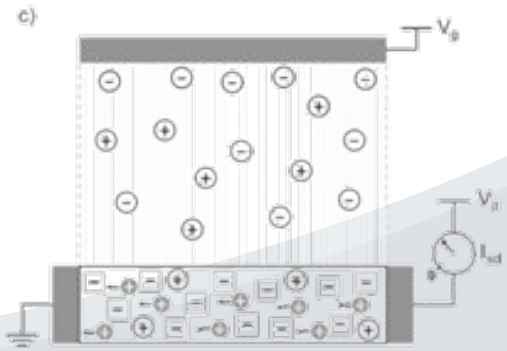



PSS

PEDOT



$V_g = 0$



$V_g \neq 0$

# OECTs and Wearable sensors

## Advantages

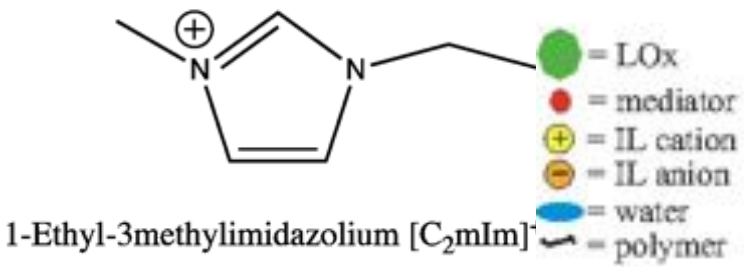
- ✓ Simple electrical readout
- ✓ Inherent signal amplification
- ✓ Easy incorporation into arrays and circuits
- ✓ Printing technologies make their fabrication particularly cost-effective for future industrialisation

## Disadvantages

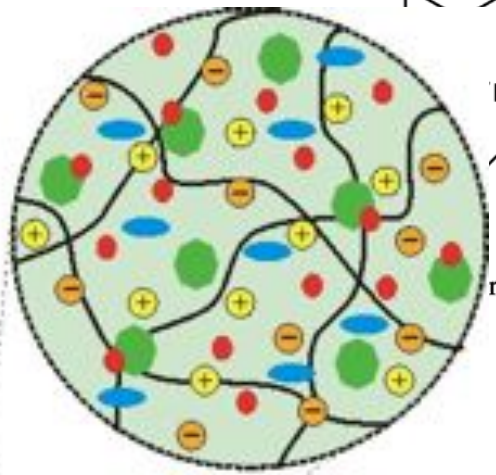
**Need of an electrolyte to put in contact gate and channel**

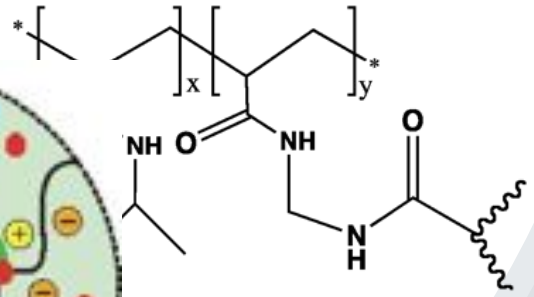
- ✓ complex liquid handling architecture
- ✓ leakage and contamination
- ✓ degradation of bio-receptor in solution (PBS)

# Ionogel & OECTs: Lactate Sensor



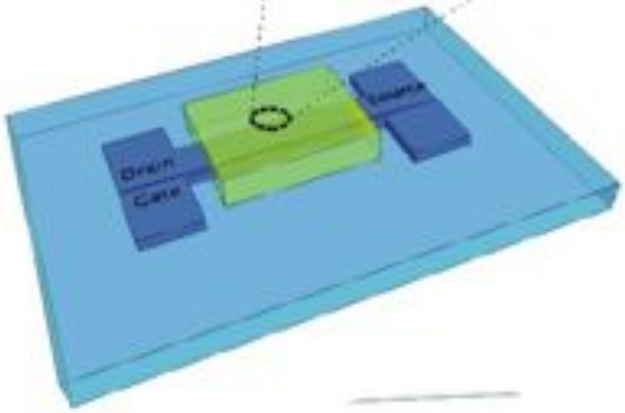

1-Ethyl-3methylimidazolium [$C_2$mIm]



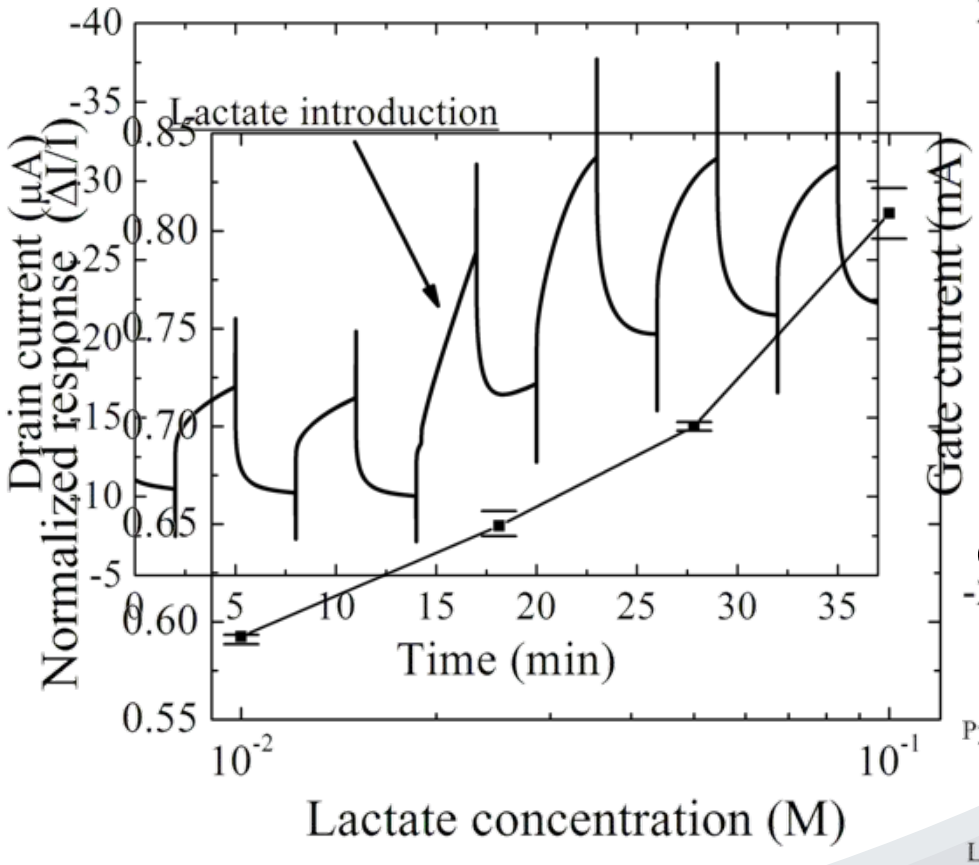


rylamide-co-*N*,*N*'-methylenebisacrylamide)

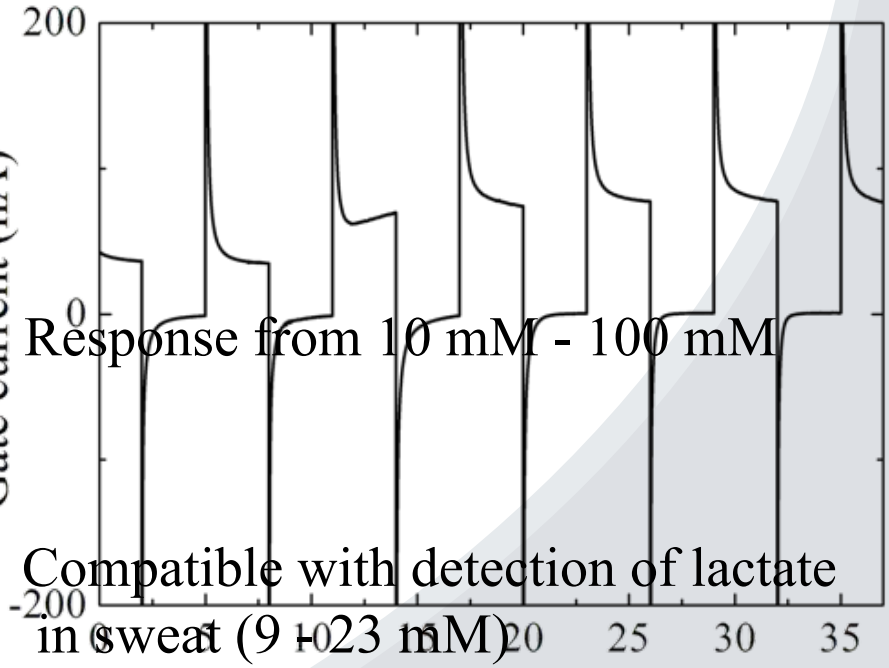
- Hydrophilic IL - avo ulyte solution.
- Hydrated IL complet itation observed
- 20 μL drop-casted ov
- UV polymerisation:



# Ionogel & OECTs: Lactate Sensor

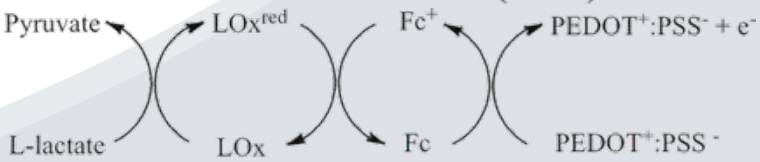



25 mM Lactate




Response from 10 mM - 100 mM

Compatible with detection of lactate in sweat (9 - 23 mM)

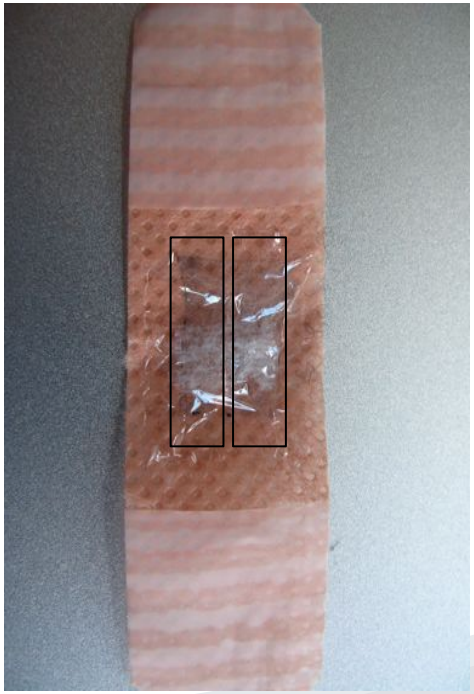



$PEDOT^+:PSS^- + M^+ + e^- \longrightarrow PEDOT + M^+:PSS^-$

V. F. Curto, et. al., J. Mater. Chem., 2012, **22**, p: 4440

# Lactate Sensor: toward wearability

- Novelty lies in the configuration of the sensor
- Solid State electrolyte on a flexible transistor based biosensor.
  - Implications for the wearability of the sensor



# Conclusions

- Sensors based on textile greatly simplify the sampling of sweat and allow real-time measurements.
- Developments of ISE $Na^+$ sensor technology in order to enhance its wearability
- Improvements of real-time pH sensor
- Detection of lactate within relevant physiological range.
- Solid State electrolyte overcomes problems related with the design of the future wearable sensor

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# Thank you for your attention

# Clinical trials with Cystic Fibrosis patients

- Cystic Fibrosis (CF) is the most common lethal genetic disease in Caucasians
- Exercise is also a useful method of increasing lung capacity and endurance in CF patients
- Low tolerance to climatic heat stress of sufferers might lead to increased morbidity and mortality
- pH has been reported to be more alkaline for subjects with CF; probably due to the increased sodium concentration
- pH/ $Na^+$ measurements might be useful for monitoring activity level to optimise physiotherapy / training regime