Wearable Micro-Fluidic pH Sweat Sensing Device Based on Colorimetric Imaging Techniques

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10th October 2011

OUTLINE

- Sweat, Why is it Important?

- Introduction: Wearable Sensors

- Barcode and Micro-fluidic Device Fabrication

- Characterisation of the Device

- Results

- Development of Novel Wearable Systems

- Conclusions

INTRODUCTION

SWEAT, WHY IS IT IMPORTANT?

Sweat is naturally generated during exercise.

Monitoring its contents provides very rich information about the physiological condition of the individual.

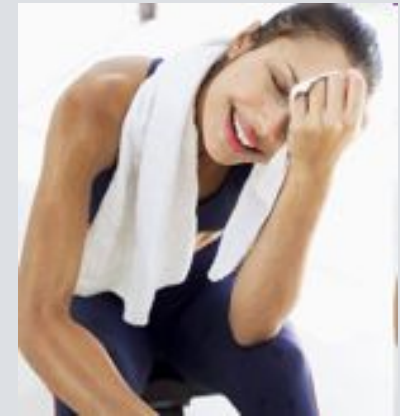## Rehydration and re-mineralisation

⬇

Improve performance and general health

Sweat analysis: identify pathological disorders
- ✧ Cystic fibrosis[*]
- ✧ Information on dehydration
- ✧ Changes in the concentration of biomolecules and ions
- ✧ Hyponatremia (low sodium concentration)

[*]Common hereditary disease which affects the entire body, causing progressive disability and often early death.

PHYSIOLOGICAL & CHEMICAL SENSORS CLARITY

clarity-centre.org

LIFESHIRT®

- ✓ Breath rate,
- ✓ Heart rate,
- ✓ Posture
- ✓ Skin temperature
- ✓ …

NIKE-APPLE iPOD Sports Kit®
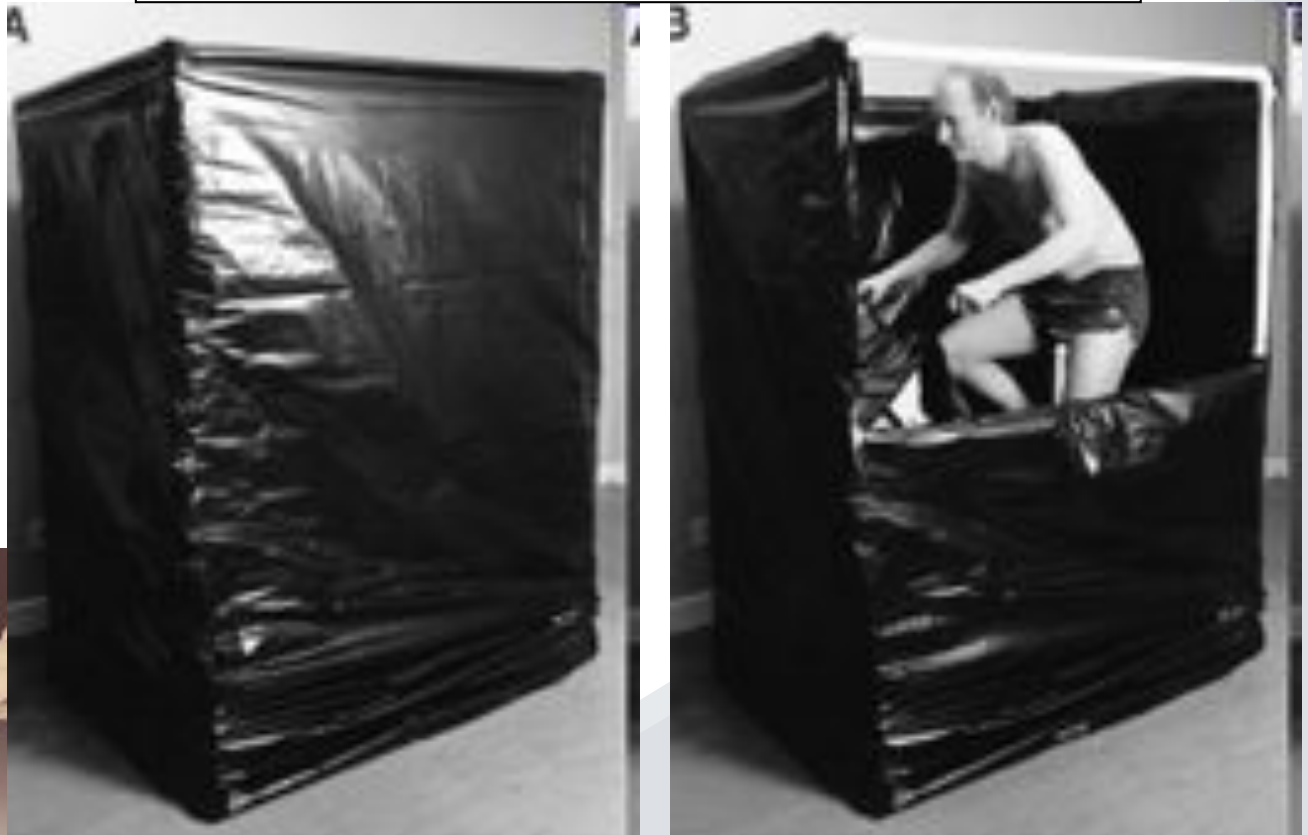
Medtronic Diabetes' Guardian®

Lactate Scout®

SWEAT ANALYSIS

Macroduct sweat collection system

Whole body sweat collection techniques

S. M. Shirreffs, *et al.*, **J Appl Physiol 82 (1997) 336-341**

PharmChek Sweat Patch

SWEAT ANALYSIS

PROBLEMS TO OVERCOME WITH CHEMICAL SENSORS?

SAMPLE GENERATION

COLLECTION

DELIVERY

WEARABILITY

SAFETY ISSUES

Sweat rate and fluid losses vary for individuals and are generally dependent on body size, gender, exercise intensity, environmental conditions and individual metabolism.

REAL-TIME ANALYSIS

REAL-TIME SWEAT ANALYSIS

CLARITY
clarity-centre.org

WHAT DO WE NEED????

DEVICE:

WEARABLE

ROBUST

FLEXIBLE / ADAPTABLE

REUSABLE/ DISPOSABLE (CHEAP)

IMMEDIATE FEEDBACK

MICRO-DEVICES!!

DETECTION:

NOT INVASIVE

WIRELESS

FREEDOM FROM ELECTRONIC NOISE

MINIATURIATION

FLEXIBILITY IN INTERROGATION APPROACHES
(human eyes, LED-sensors, cameras, spectrometers, …)
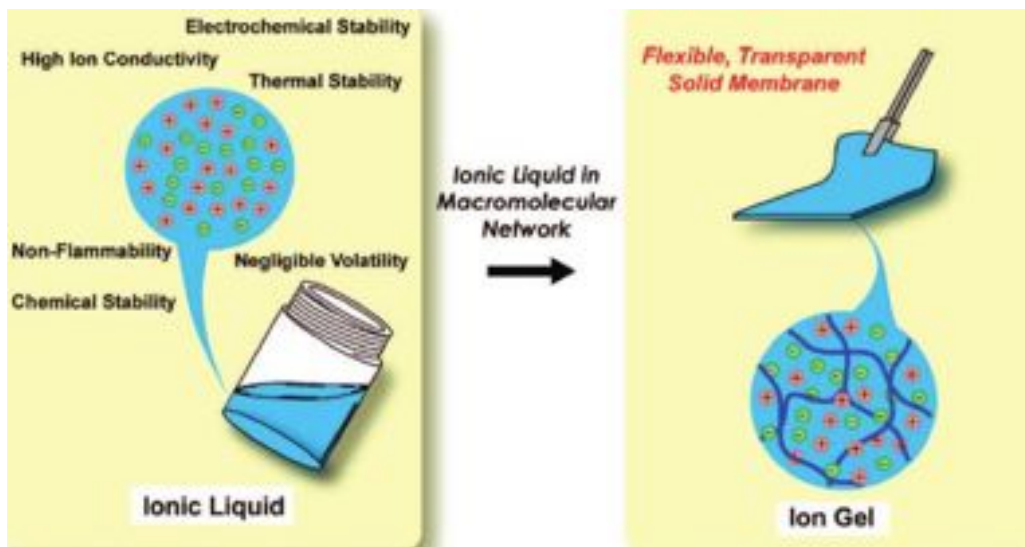
OPTICAL SENSORS!!

BIOTEX – Biosensing Textile for

Emitter-detector LED's λ = 660 nm
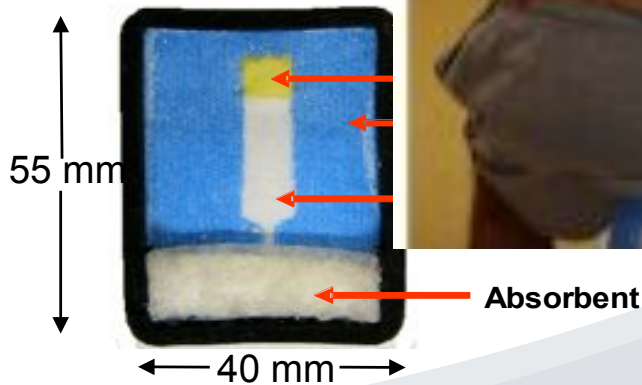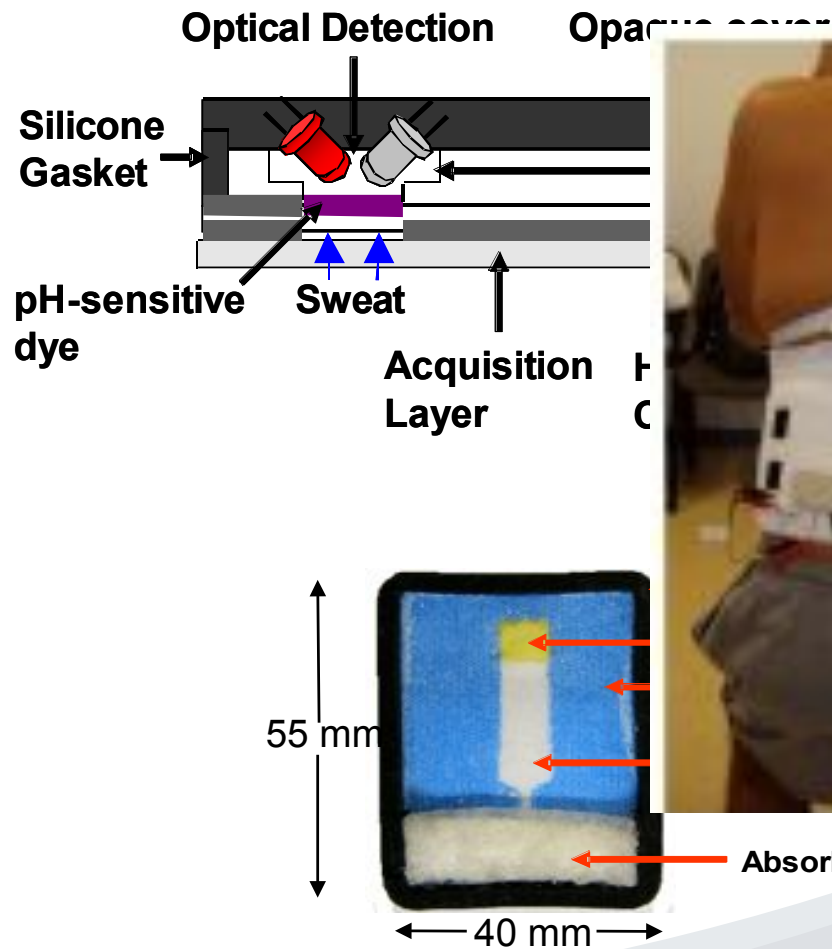
Optical Detection

Opaque cover

Silicone Gasket

pH-sensitive dye

Sweat

Acquisition Layer

55 mm

40 mm

Absorbent

**Cl...
p...hane**

NOVEL MATERIAL: Ionogel

T. Ueki, *et al.*, Macromolecules 41(11) 3739-3749.

(a)

(b)

FT-IR

— [P$_{6,6,6,14}$][dca] ionogel
— PNIPAm
— [P$_{6,6,6,14}$][dca]
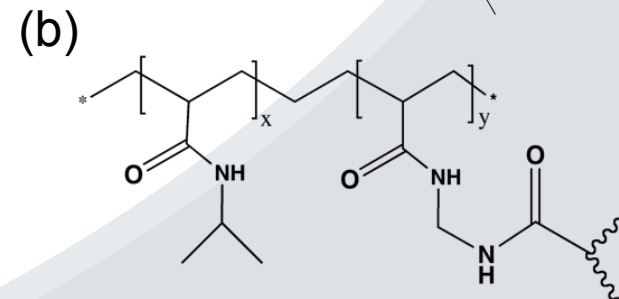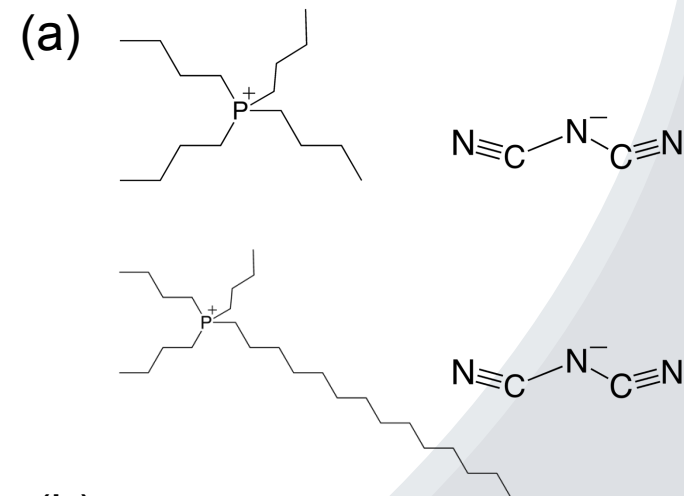
a) Ionic liquids: tetra-alkyl phosphonium dicyano-amide [P$_{4,4,4,4}$][dca] and [P$_{6,6,6,14}$][dca]

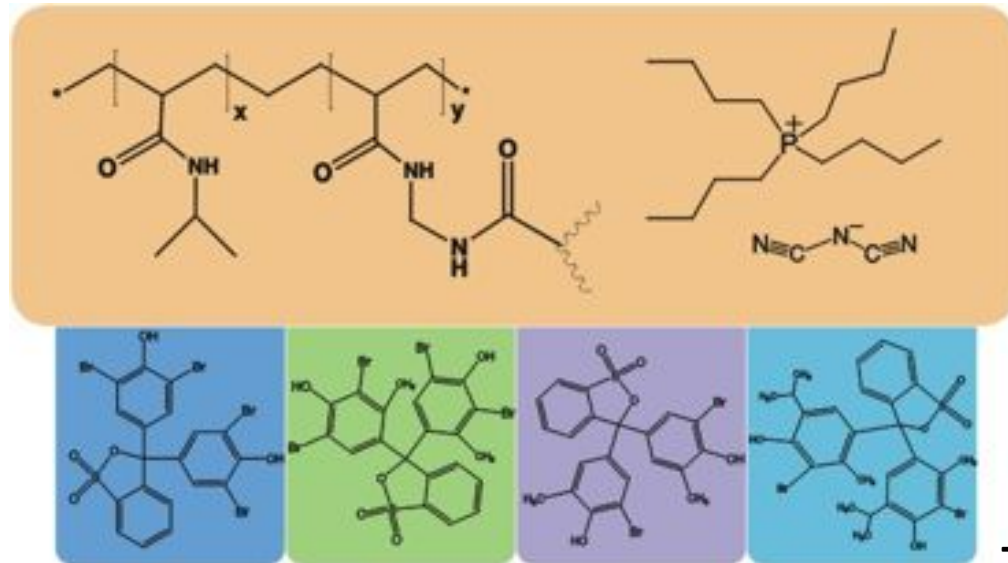b) Poly(*N*-isopropylacrylamide-co-*N*,*N*´-methylenebisacrylamide)
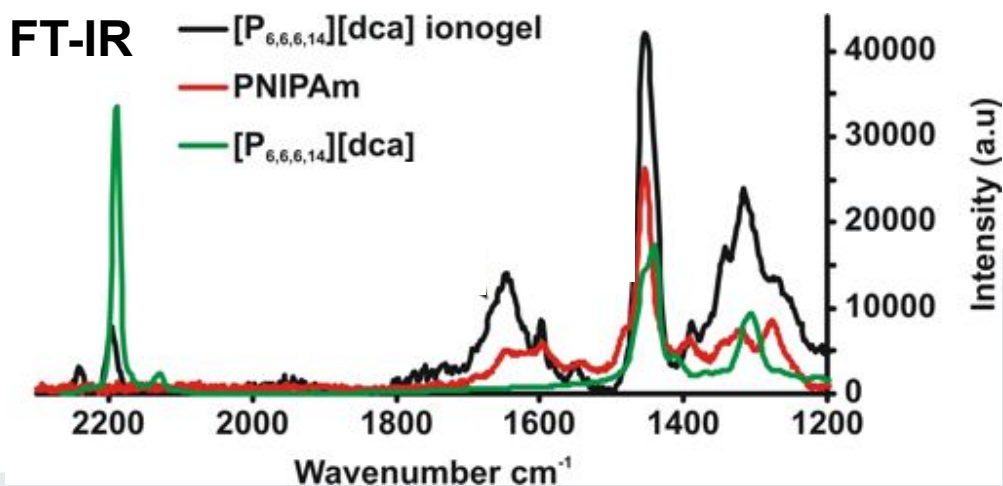
F. Benito-Lopez, *et al.*, Dublin City University, 2009, Patent Application No: GB 0904627-7.
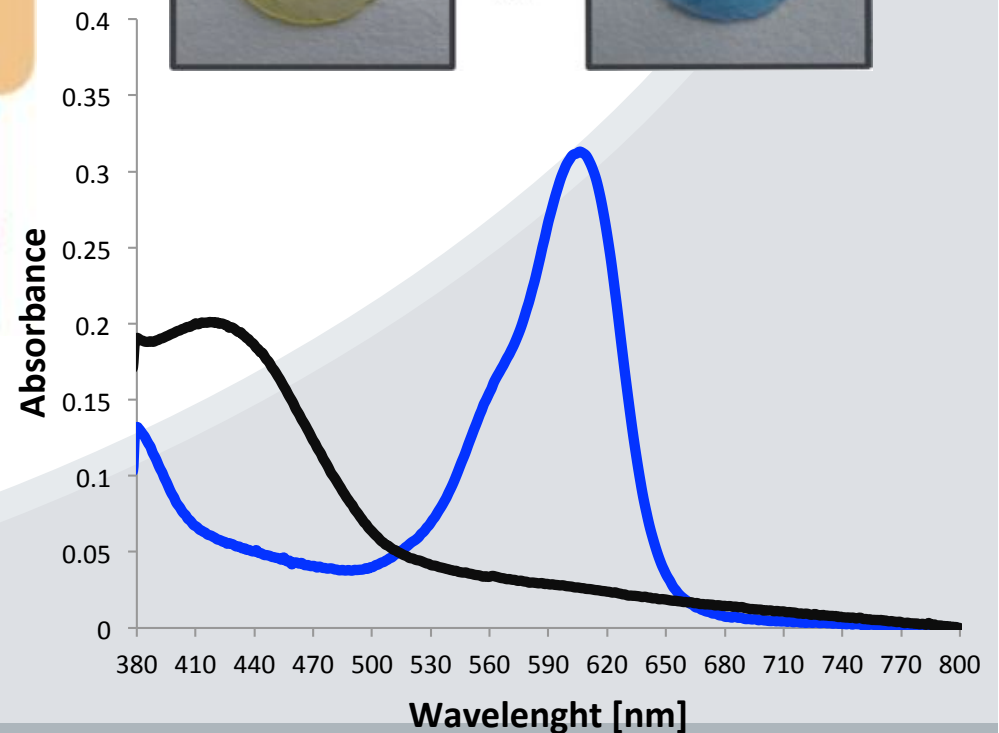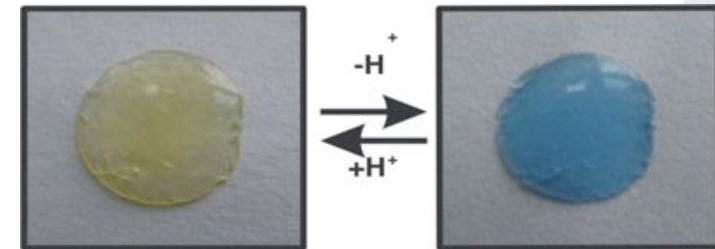
ADAPTIVE MATERIAL: Ionogel/dye
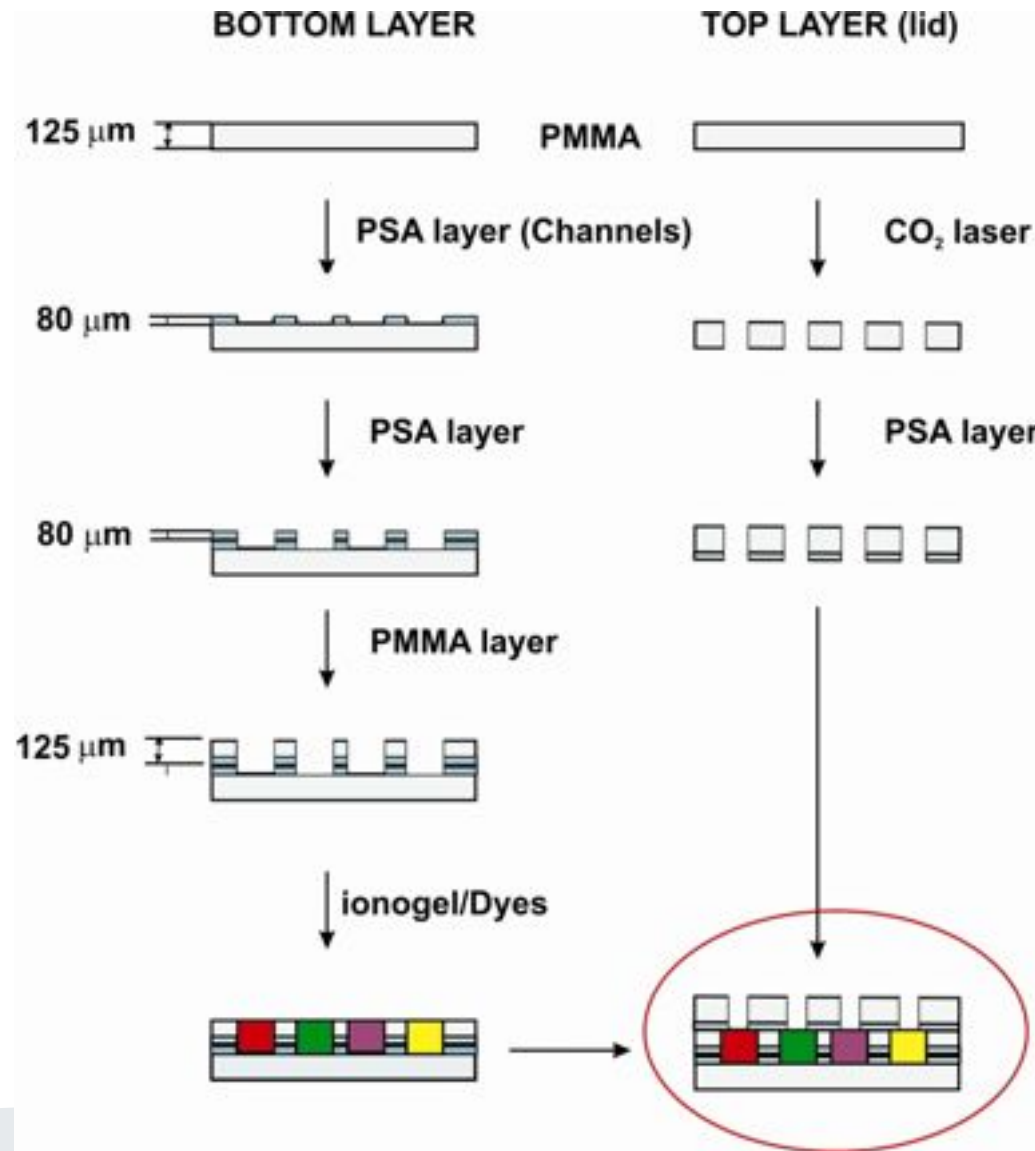
DOPED IONOGEL WITH A pH-DYE

Sweat pH: 4.5-7.5

— ionogel /acidic conditions
— ionogel /basic conditions

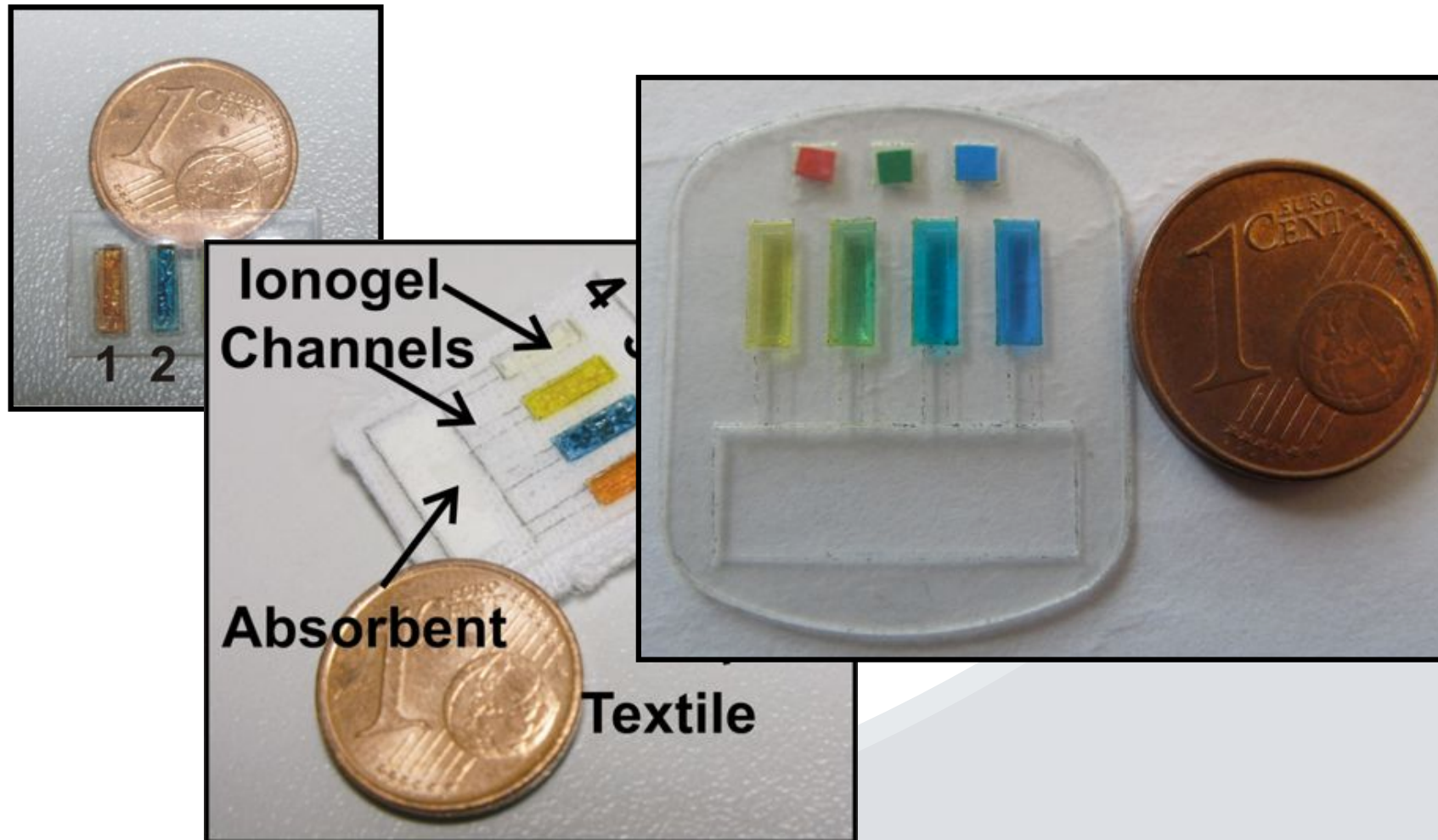|	pH	
1- BROMOPHENOL BLUE	3.0	4.6
2- BROMOCRESOL GREEN	3.8	5.4
3- BROMOCRESOL PURPLE	5.2	6.8
4- BROMOTHYMOL BLUE	6.0	7.6

MICROFLUIDIC FABRICATION

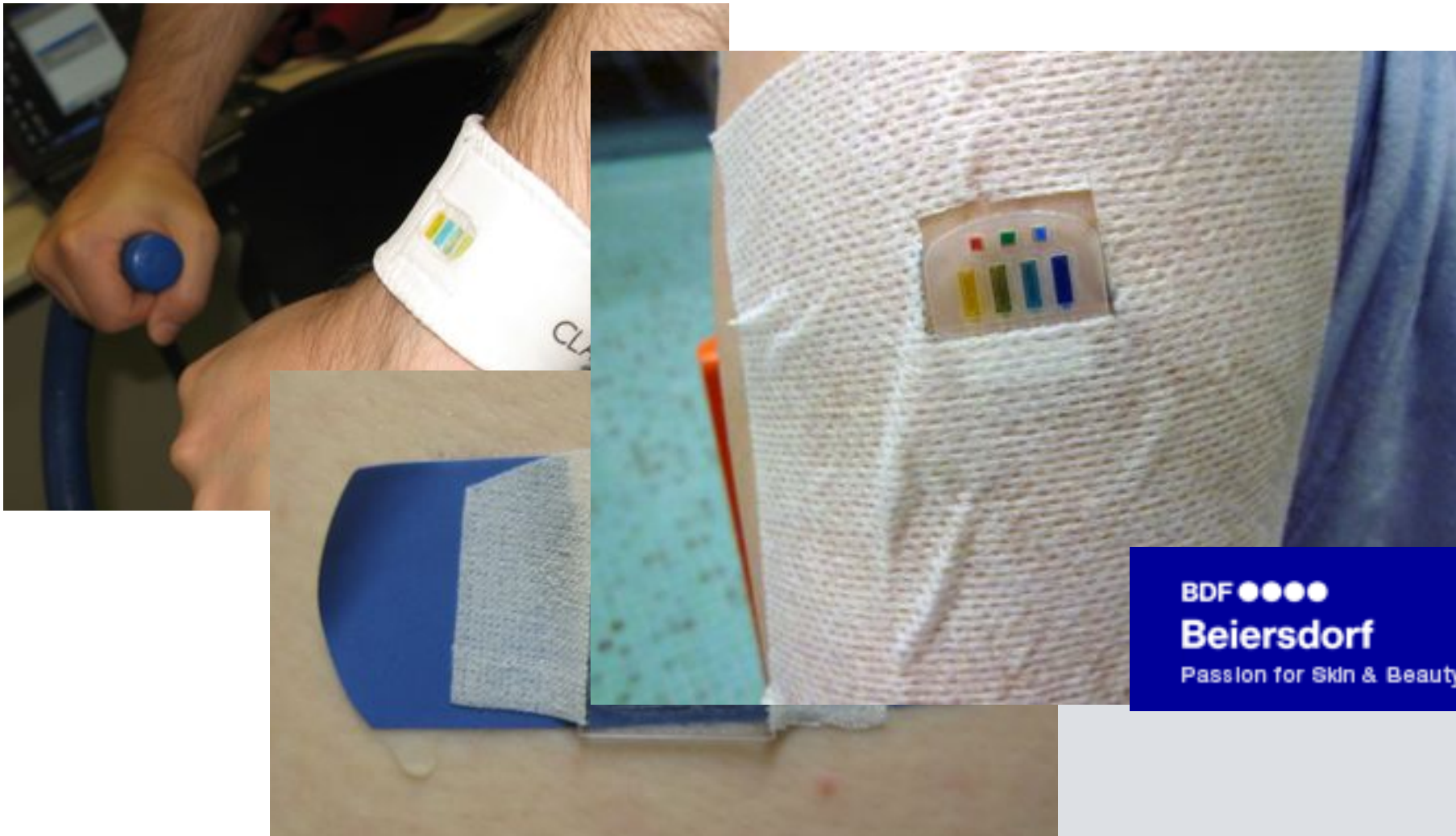

CO$_2$ laser
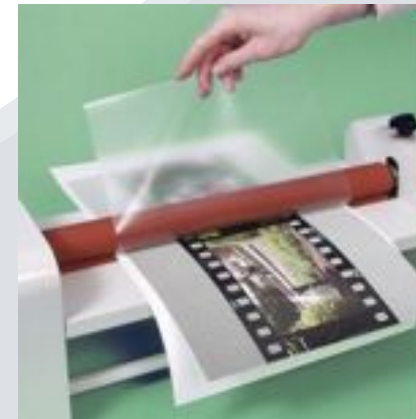
laminator

MICROFLUIDICS & BARCODE

V.F. Curto, *et al.*, Microfluid Nanofluid (Submitted)
F. Benito-Lopez, *et al.*, 7th International Workshop on Wearable and Implantable Body Sensor Networks-BSN (2010), 291-296
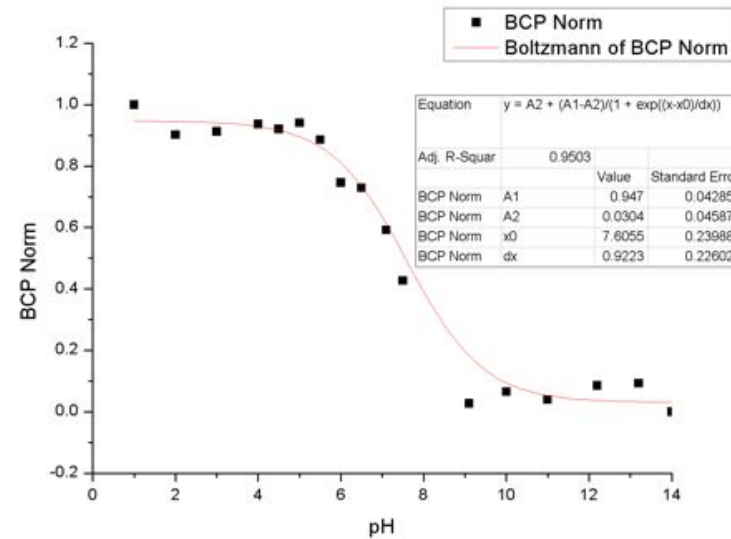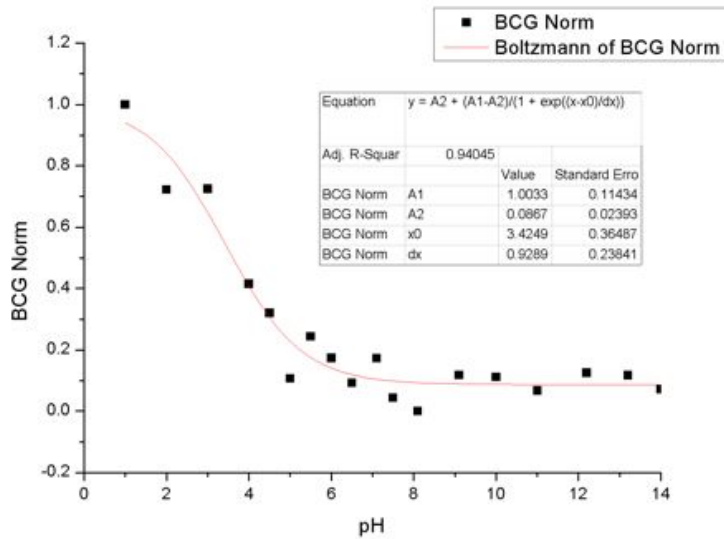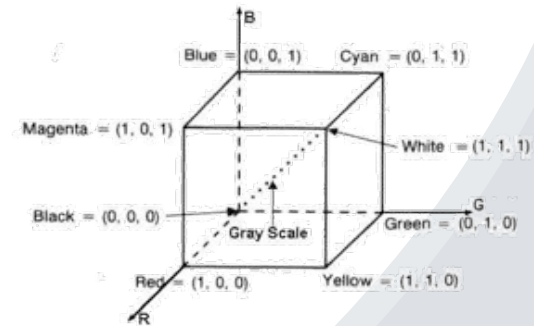
INTEGRATION

BDF ●●●●
Beiersdorf
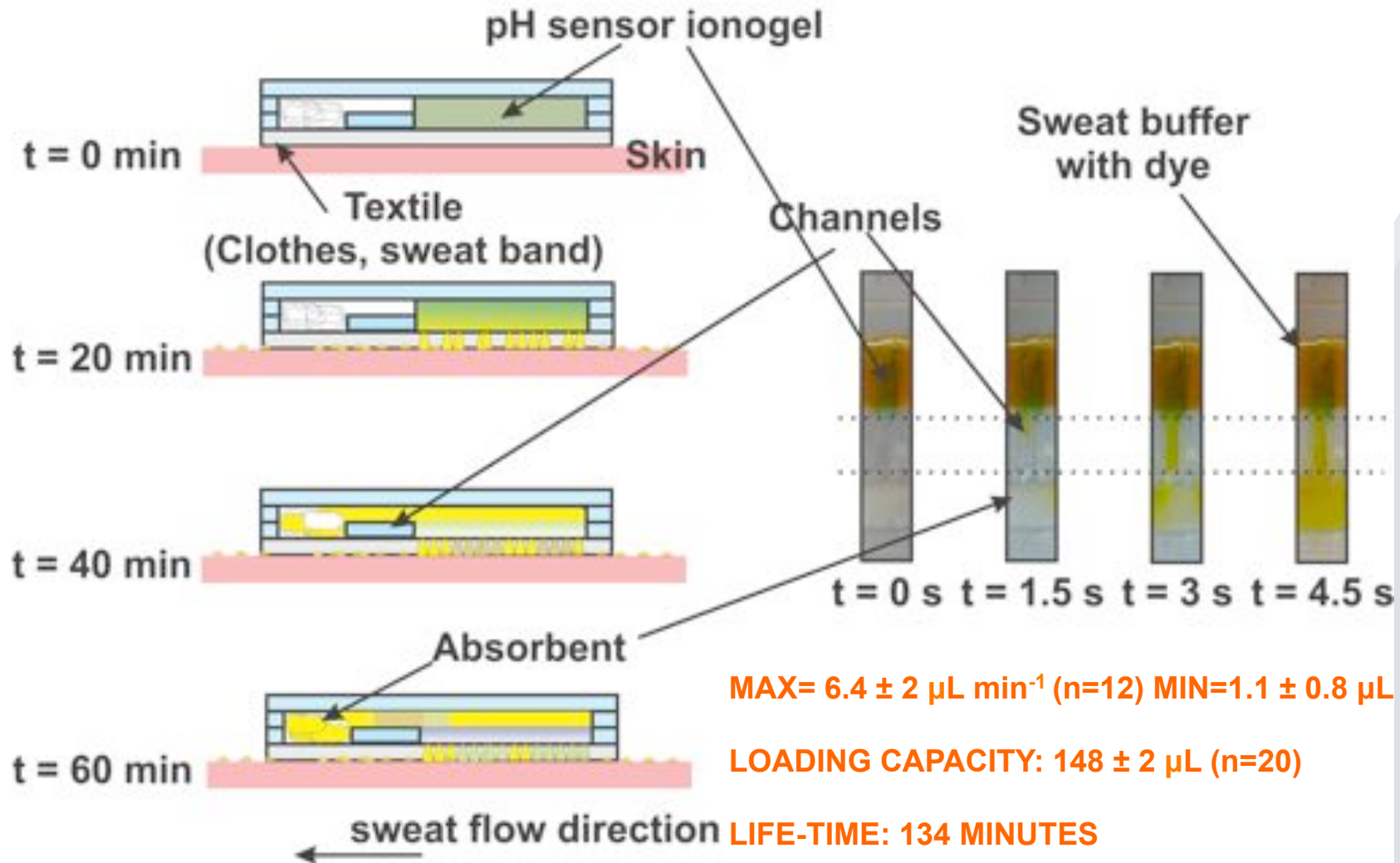Passion for Skin & Beauty Care

Adhesive Plaster

Athletes' Sweat Test Road to Glory. New Scientist, 27 April, 2010.
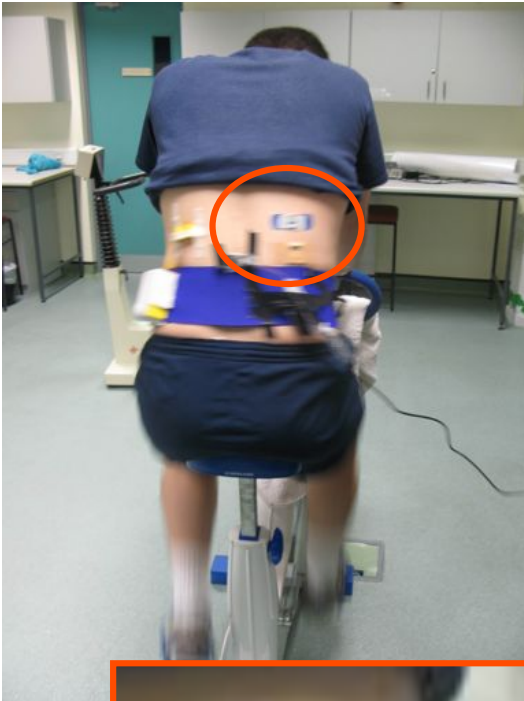
CHARACTERISATION: Calibration

RGB Color Space

CHARACTERISATION: Performance

pH sensor ionogel

Sweat buffer with dye

t = 0 min

Skin

Textile
(Clothes, sweat band)

Channels

t = 20 min

t = 40 min

Absorbent

t = 0 s t = 1.5 s t = 3 s t = 4.5 s

t = 60 min

MAX= 6.4 ± 2 µL min^{-1} (n=12) MIN=1.1 ± 0.8 µL

LOADING CAPACITY: 148 ± 2 µL (n=20)

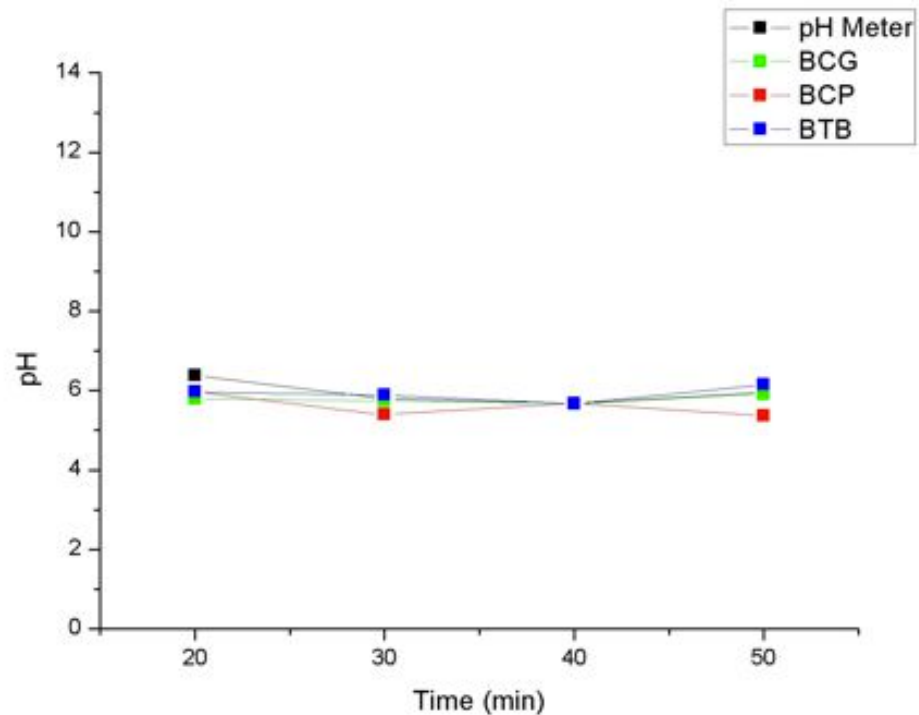sweat flow direction **LIFE-TIME: 134 MINUTES**

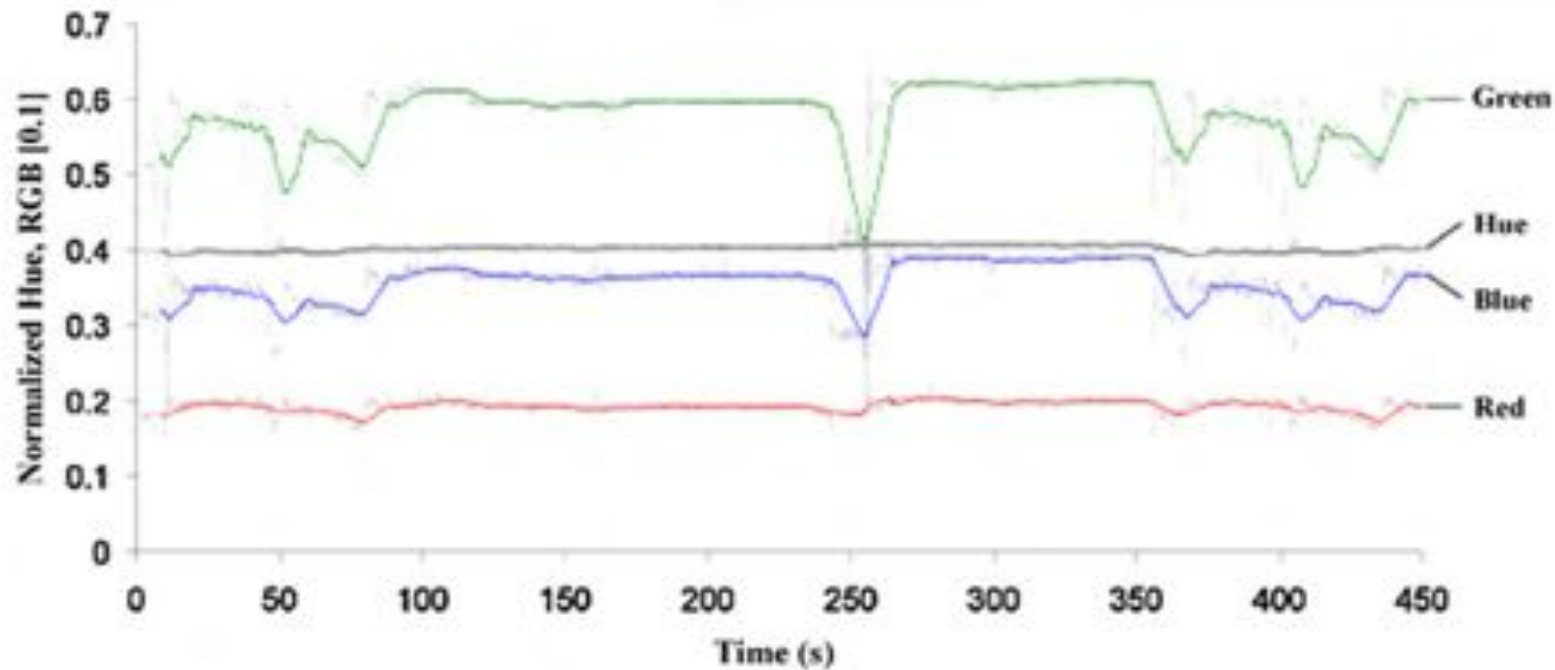**V.F. Curto, *et al.,* Microfluid Nanafluid (Submitted)**

PERFORMANCE On-Body TRIAL

Sweat pH determination using the barcode in an athlete during a 50 min training period

RGB *vs* HSV

- H value is stable, simple to calculate
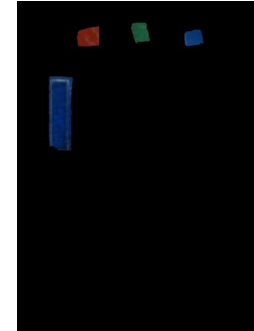- superior precision with variations in indicator concentration and illumination

C. Fay *et al.*, Sensors and Actuators B 150 (2010) 425–435

HSV Detection

Original Image
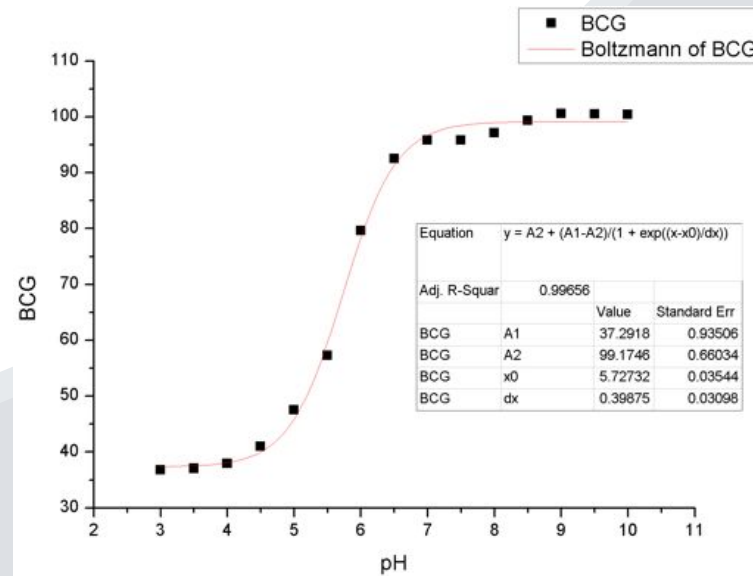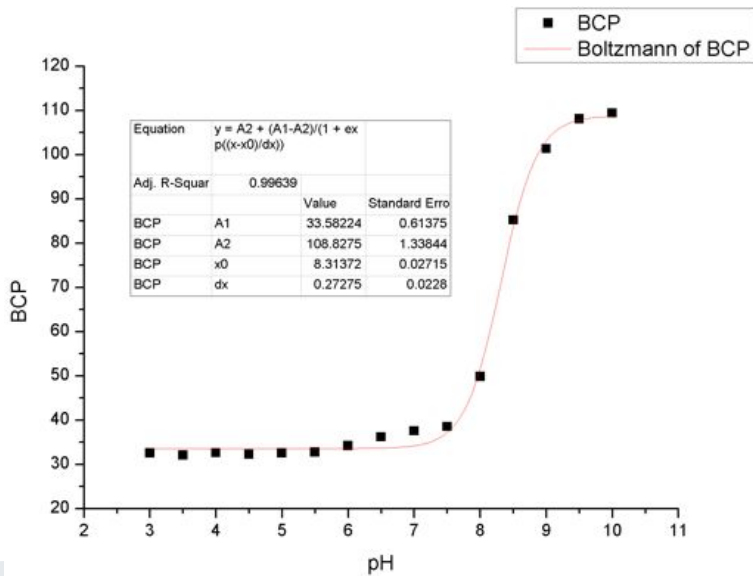

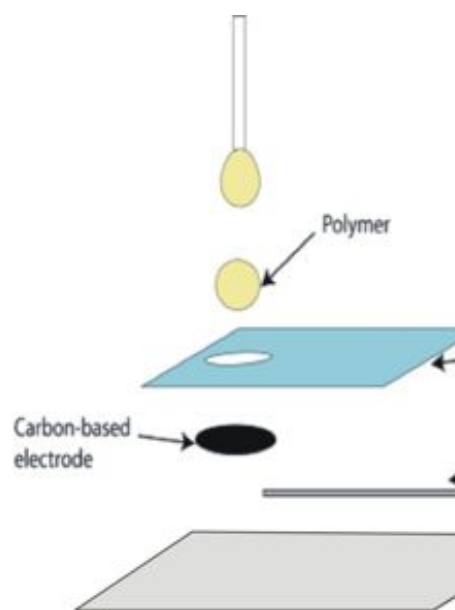**Mask Image**

**Mask Applied
to Original Image**

**Analyse Each Region in Turns
with Reference Patches**

FUTURE WORKS

Ion Selective Electrode (ISE): sodium

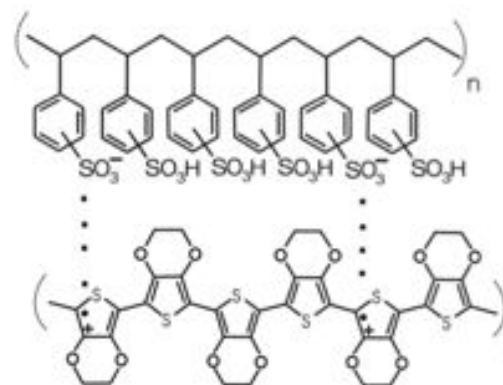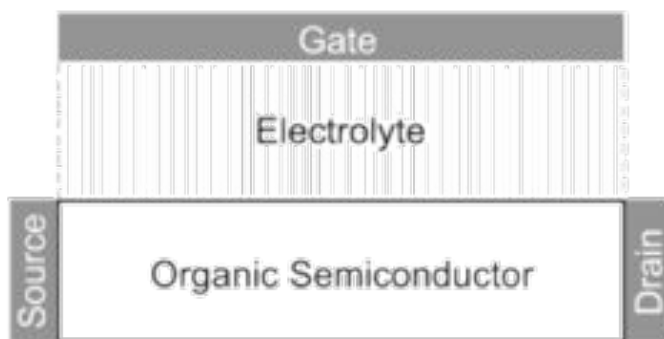**Screen Printed Electrodes**

Polymer
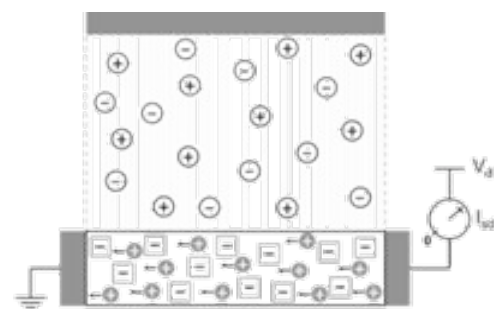
Carbon-based electrode

— Ag layer

Insulating layer

— Carbon layer

Great simpli
electronic/softwa
power consumption is
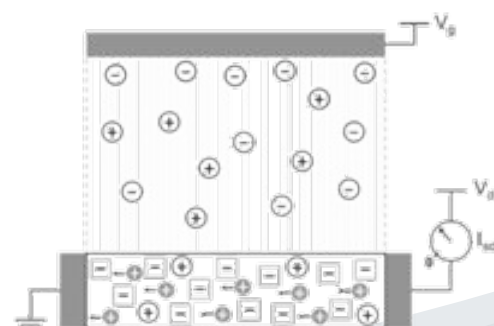reduced.

Organic Electrochemical Transistor (OECT)

PSS

PEDOT

$V_g = 0$
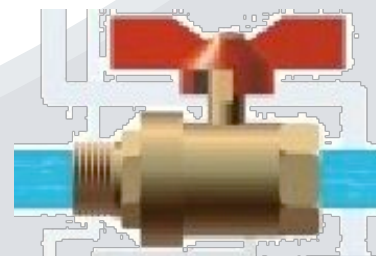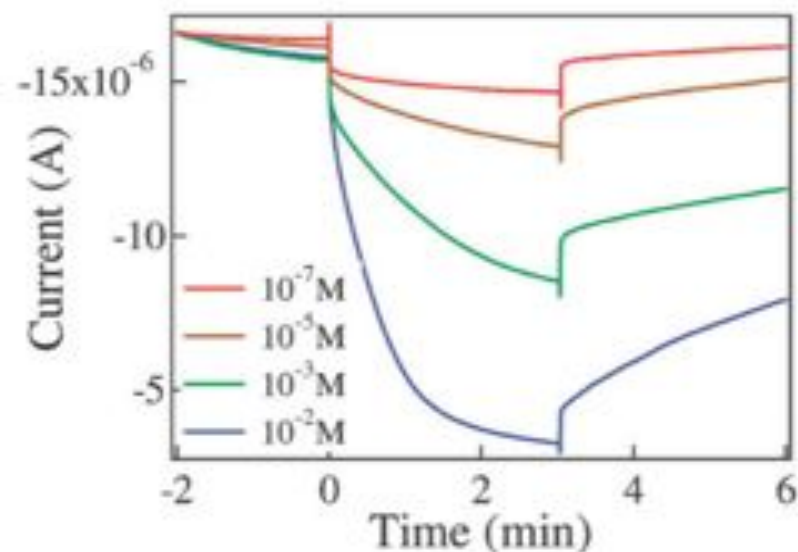
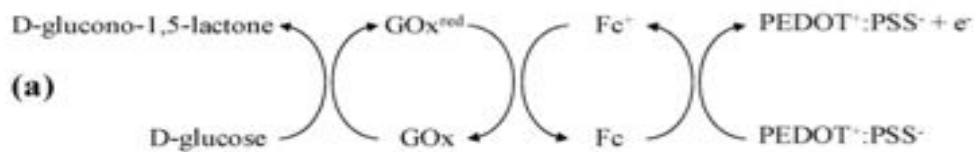$V_g \neq 0$

Cations — Fixed Dopant Anions
Anions — Holes

D. Bernards, *et al.*, Adv. Funct. Mater., 17 (2007) 3538–3544

OECT: Glucose detection

GOx/Fc in $[P_{1,4,4,4}][Tos]$
PEDOT:PSS

$[P_{1,4,4,4}]$ cation

Tosylate ([Tos]) anion

(a) D-glucono-1,5-lactone ← GOx^{red} ← Fc$^+$ ← PEDOT$^+$:PSS$^-$ + e$^-$
D-glucose → GOx → Fc → PEDOT$^+$:PSS$^-$

(b) PEDOT$^+$:PSS$^-$ + M$^+$ + e$^-$ → PEDOT + M$^+$:PSS$^-$
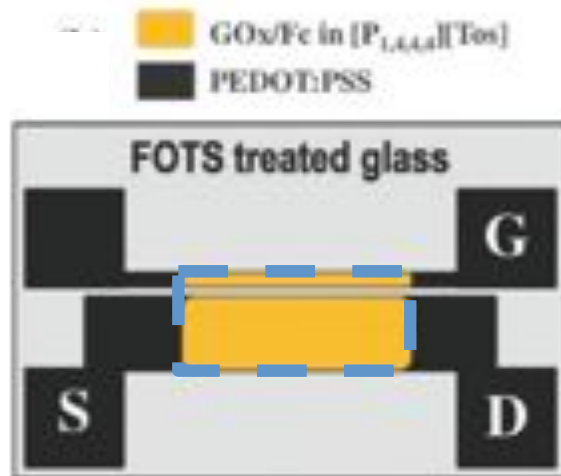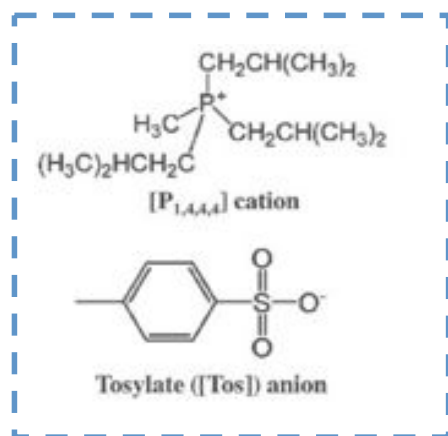
Reactions at the gate electrode (a)

and at the channel (b) of the OECT

S. Yang, *et al.*, *Chem. Commun.*, 46 (2010) 7972-7974

OECT: Lactate detection

~ 208 nl
2 mm
6 mm
~ 417 nl
~ 625 nl
~ 837 nl

V. F. Curto, *et al.*, Chem.Commun. (Submitted)

CONCLUSIONS

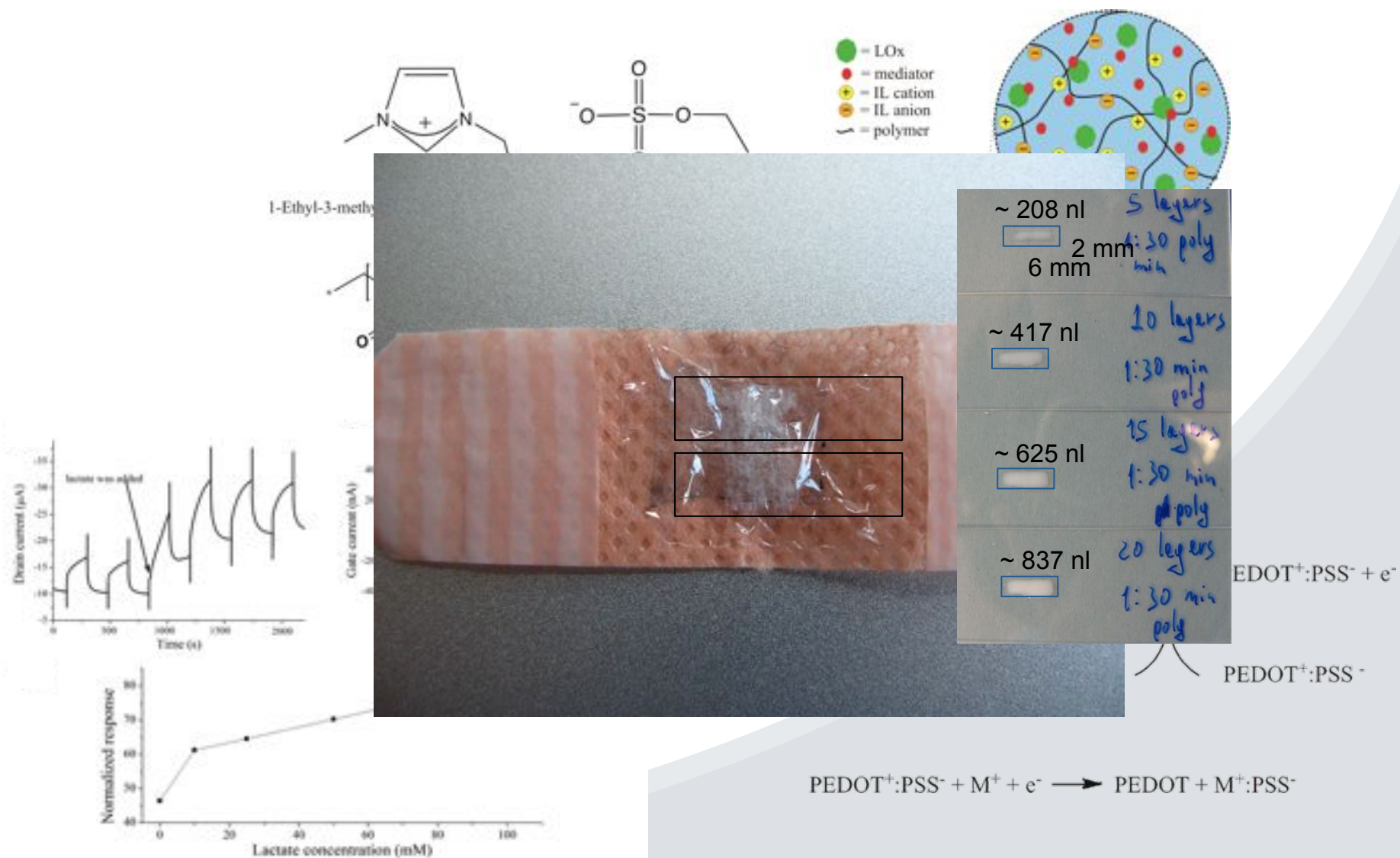- The fabrication, characterisation and performance of a wearable micro-fluidic system based on ionogels for monitoring, in real-time mode, the pH of sweat generated during exercise has been presented.

- The ionogel/dye interactions ensure no leaching of the dyes.

- Accuracy on the pH of sweat measurements over time.

- The redesign of the barcode improves its wearability and makes it reusable.

- Image analysis through Hue value gives better performance at different light ambient conditions.

FUTURE WORK:

- Establishment of a correlation between pH of sweat and other physiological parameters, such as pH and lactate in blood, and sweat electrolytes.

- Development of wearable micro-fluidics capable of measuring sodium, glucose and lactate concentration, in real time.

Acknowledgements

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Thank you for your attention