Wearable Platforms for Biomarker Monitoring – Challenges and Opportunities

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Invited Plenary Lecture presented at
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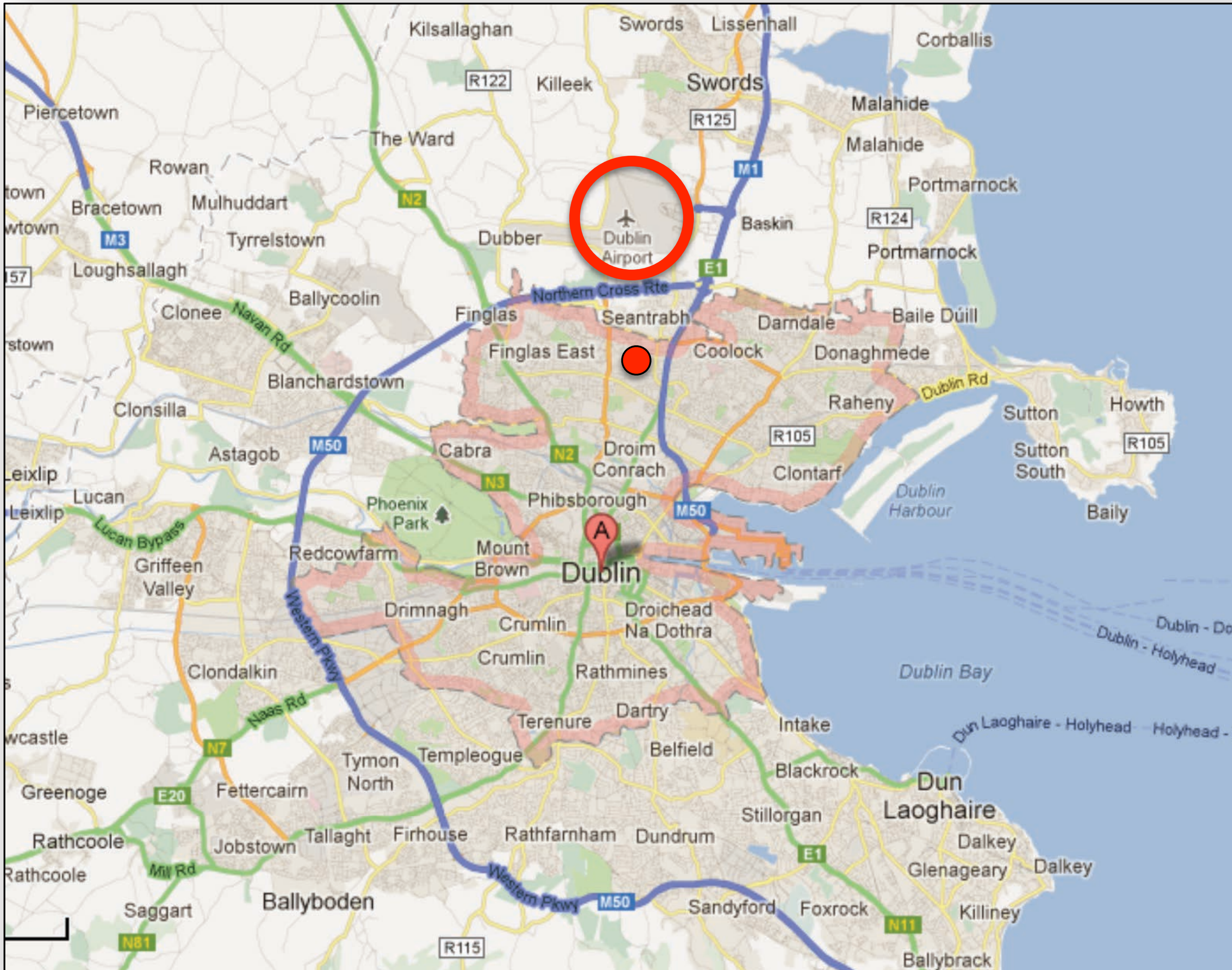
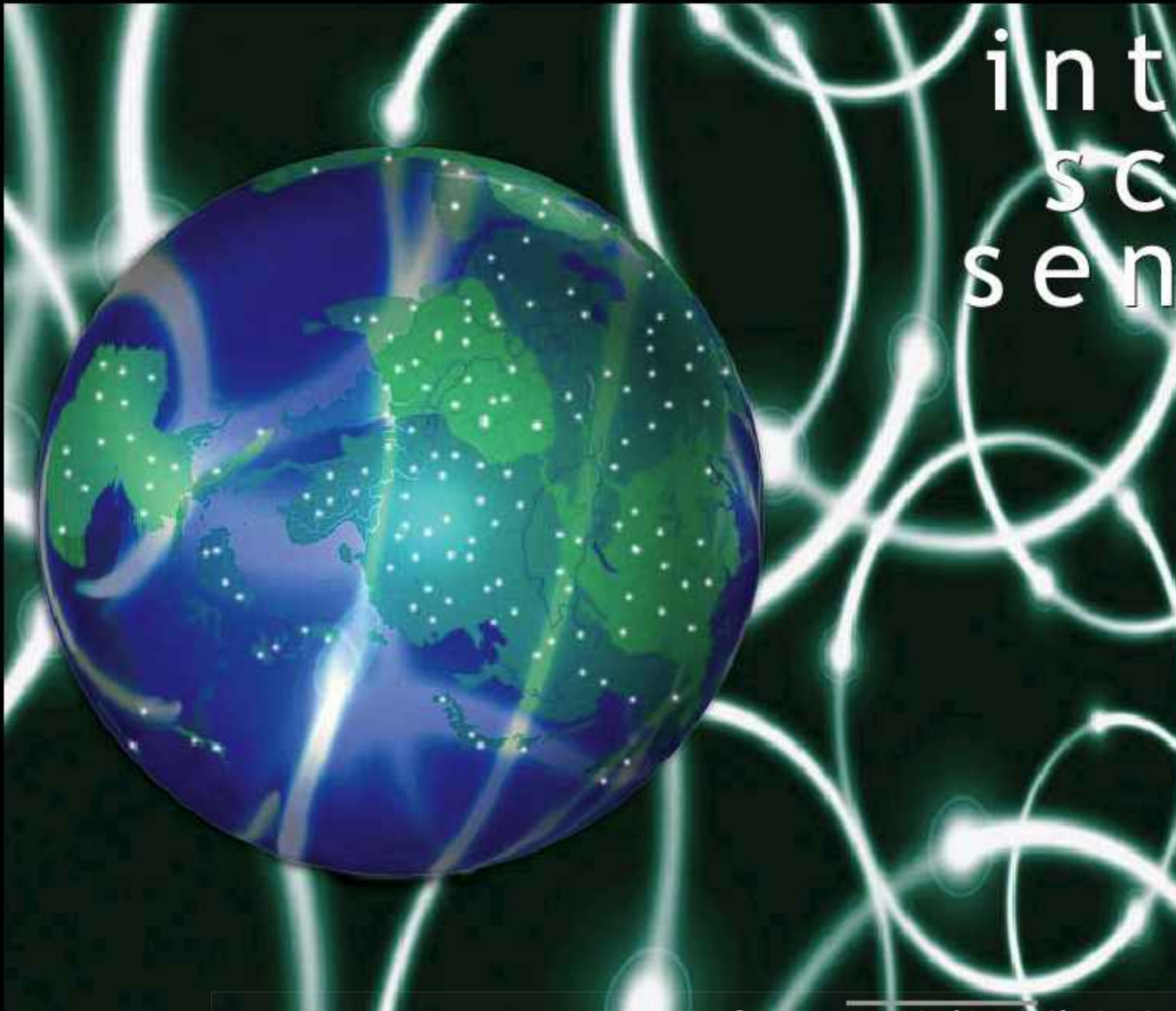
Monterey, California, 23-26 February 2015

Dublin & DCU Location



sfi DCU UCC OÉ Gaillimh NUI Galway UCD DUBLIN

Keynote Article: August 2004, Analytical Chemistry (ACS)



internet scale sensing

Dermot Diamond
Dublin City University
(Ireland)

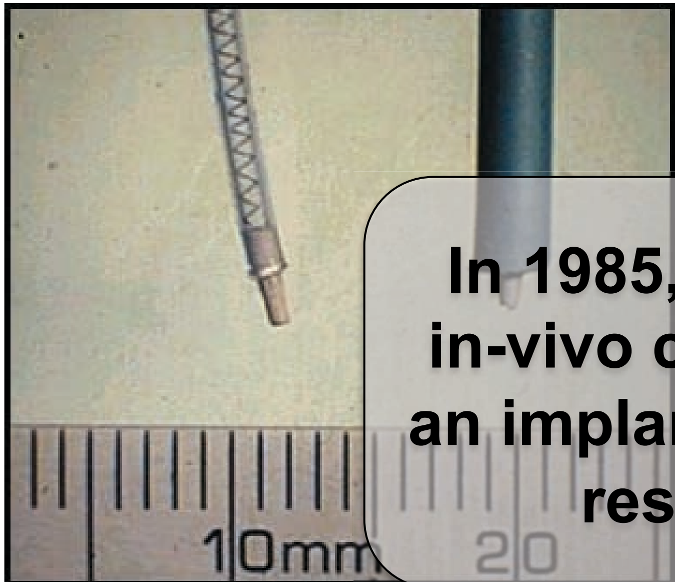
Incredible advances in digital communications and computer power have profoundly changed our lives. One chemist shares his vision of the role of analytical science in the next communications revolution.

Digital communications networks are at the heart of modern society. The digitization of communications, the development of the Internet, and the availability of relatively inexpensive but powerful mobile computing technologies have established a global communications network capable of linking billions of people, places, and objects. Email can instantly transmit complex documents to multiple remote locations, and websites provide a platform for instantaneous notification, dissemination, and exchange of information globally. This technology is now pervasive, and those in research and business have multiple interactions with this digital world every day. However, this technology might simply be the foundation for the next wave of development that will provide a seamless interface between the real and digital worlds.

The crucial missing part in this scenario is the gateway through which these worlds will communicate: How can the digital world sense and respond to changes in the real world? Analytical scientists—particularly those working on chemical sensors, biosensors, and compact, autonomous instruments—are

Dermot Diamond, Anal. Chem., 76 (2004) 278A-286A
(Ron Ambrosio & Alex Morrow, IBM TJ Watson)

Blood Analysis; Implantible Sensors



In 1985, the use model for reliable in-vivo continuous monitoring with an implantable chemical sensor was restricted to a day or two

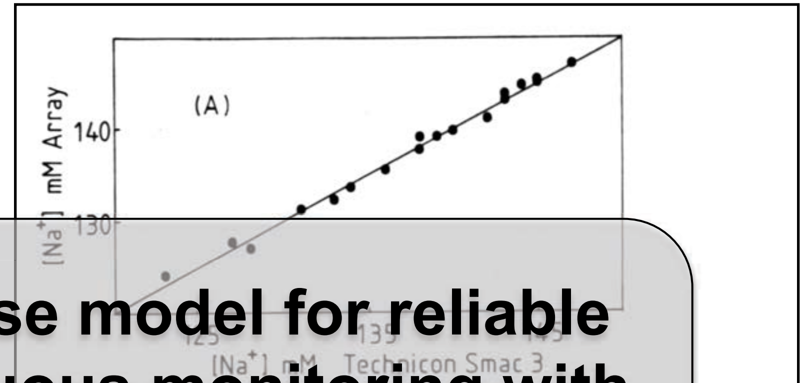
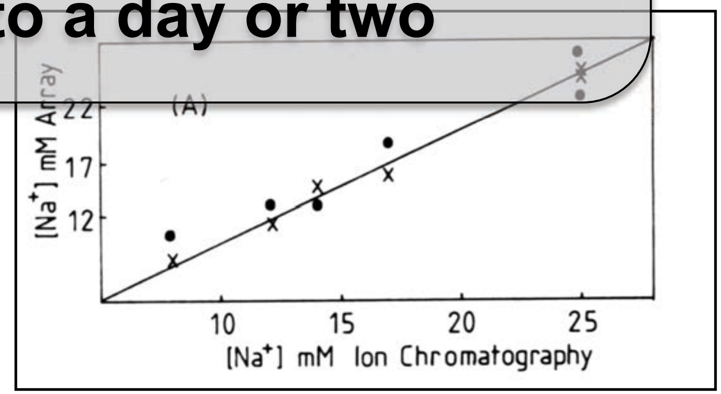


Fig. 3. Comparison of plasma sodium analysis using the array-FIA approach with a SMAC analyser. Good correlation without bias is obtained [5].



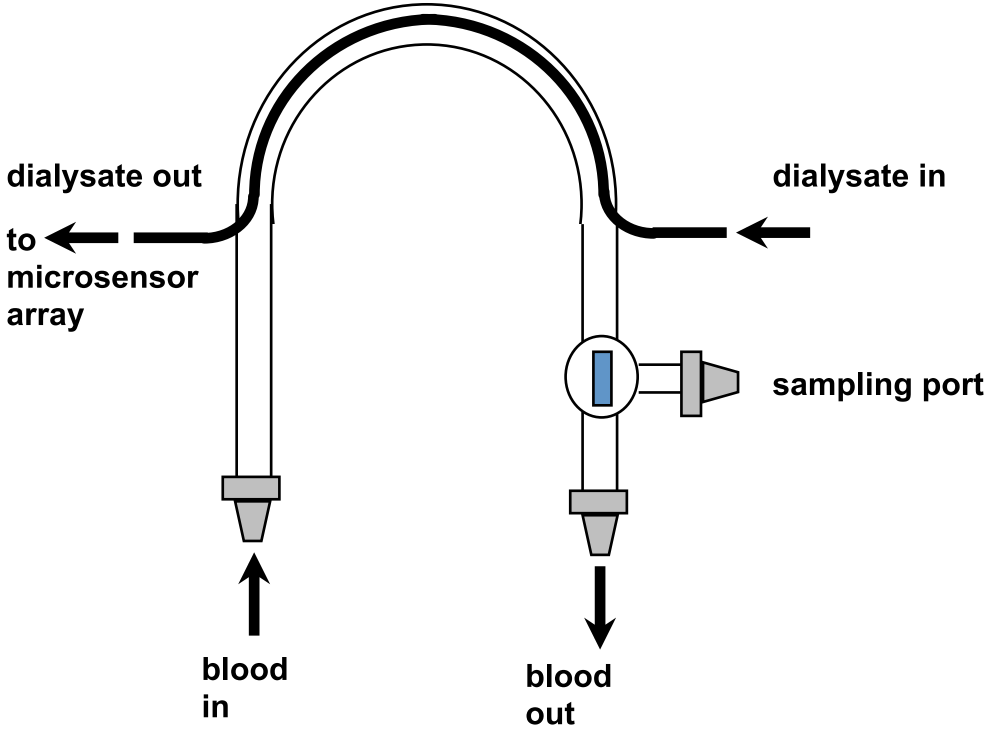
Anal. Chem., *64* (1992) 1721-1728.

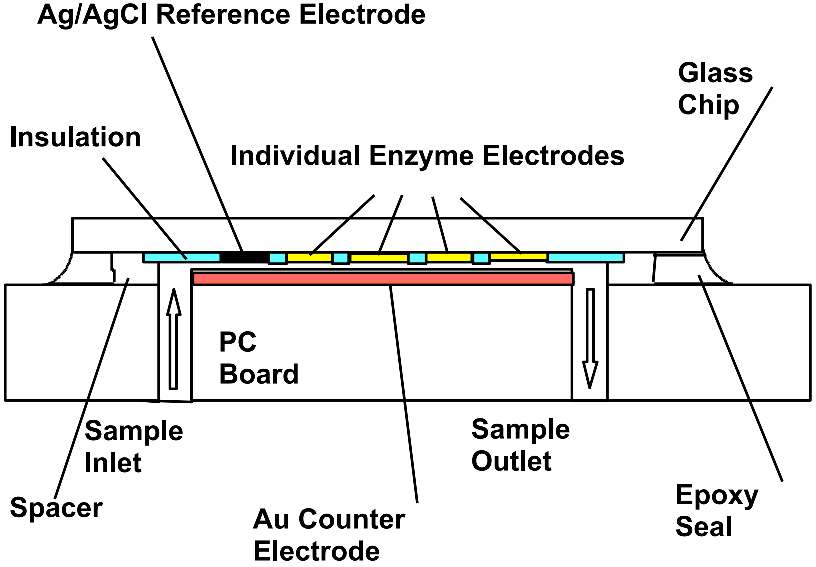
1985: Catheter Electrodes for intensive care – function for 24 hrs

Dr. David Band, St Thomas's Hospital London

Ligand (and variations of) used in many clinical analysers for blood Na^+ profiling

Microdialysis sampling via arterio-venus shunt



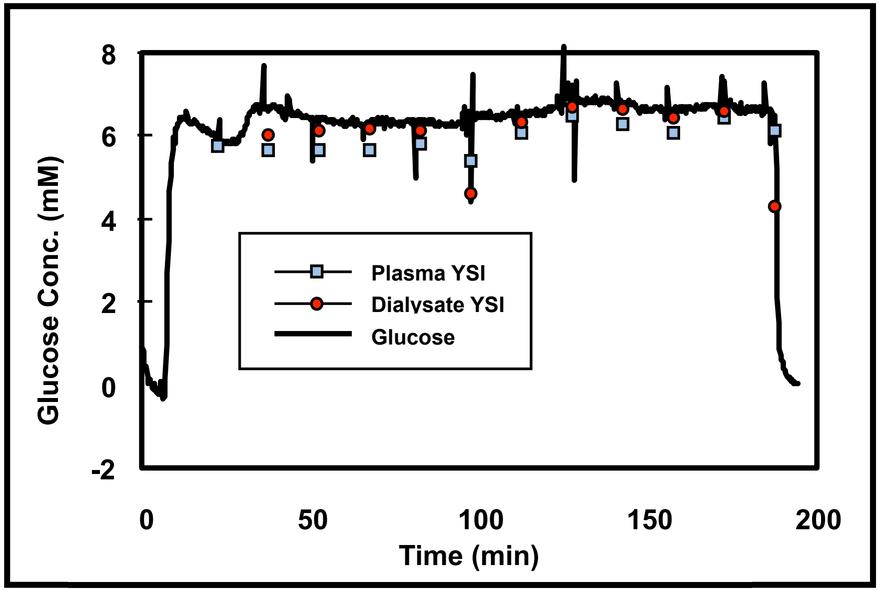


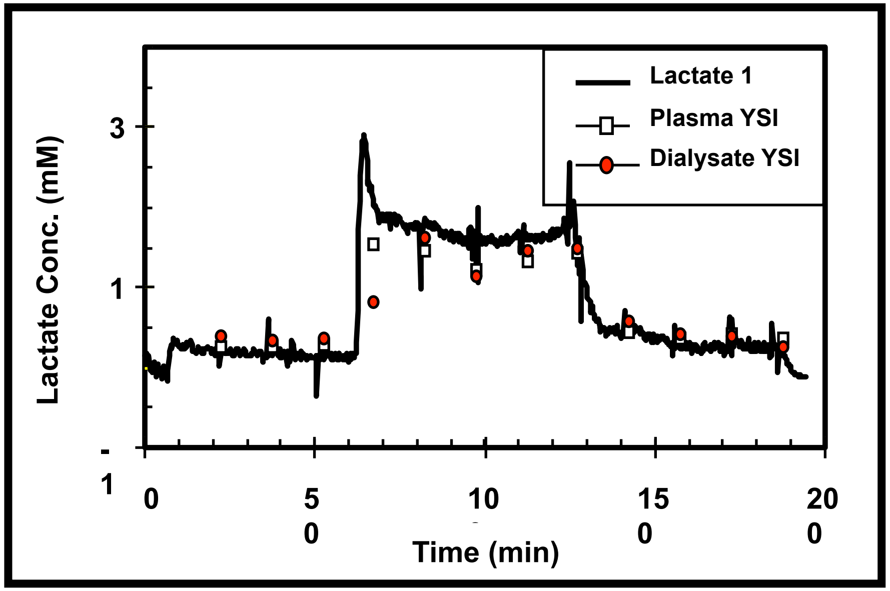
Novel Instrumentation for Real-Time Monitoring Using Miniaturised Flow Cells with Integrated Biosensors, R. Freaney, A. McShane, T.V. Keavney, M.McKenna, K. Rabenstein, F.W. Scheller, D. Pfeiffer, G. Urban, I. Moser, G. Jobst, A. Manz, E. Verpoorte, M.W. Widmer, D. Diamond, E. Dempsey, F.J. Saez de Viteri and M. Smyth, Annals of Clinical Biochemistry, 34 (1997) 291-302.

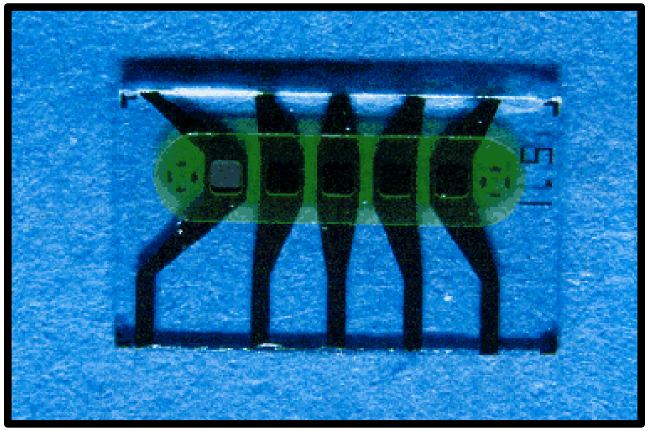
In Vitro Optimisation of a Microdialysis System with Potential for On-Line Monitoring of Lactate and Glucose in Biological Samples, E. Dempsey, D. Diamond, M.R. Smyth, M. Malone, K. Rabenstein, A. McShane, M.McKenna, T.V. Keavney and R Freaney, Analyst, 122 (1997) 185-189.

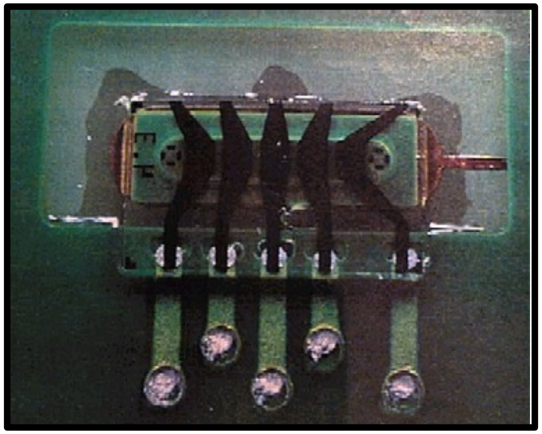
Design and Development of a Miniaturized Total Chemical-Analysis System for Online Lactate and Glucose Monitoring in Biological Samples, Ethna Dempsey, Dermot Diamond, Malcolm R. Smyth, Gerald Urban, Gerhart Jobst, I. Moser, Elizabeth MJ Verpoorte, Andreas Manz, HM Widmer, Kai Rabenstein and Rosemarie Freaney, Anal. Chim. Acta, 346 (1997) 341-349.

Real Time Blood Glucose and Lactate









System functioned continuously for up to three hours!

Artificial Pancreas

A. M. ALBISSER, M.A.SC., PH.D., AND ASSOCIA

Used a Technicon segmented flow colorimetric glucose analyser

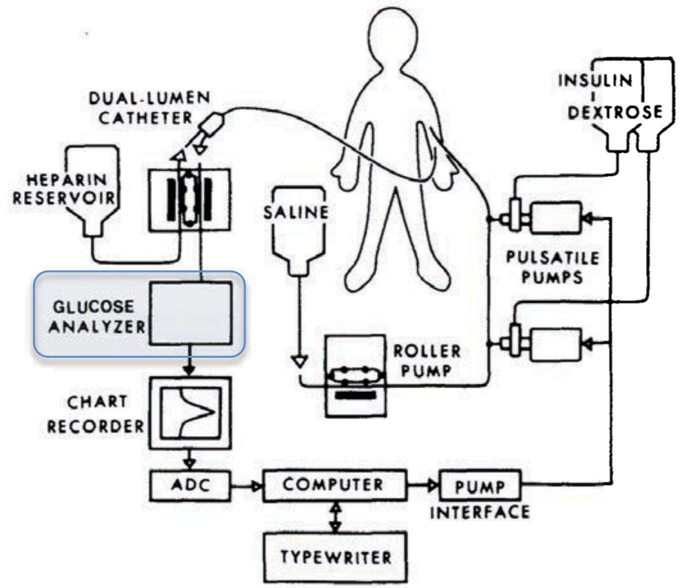
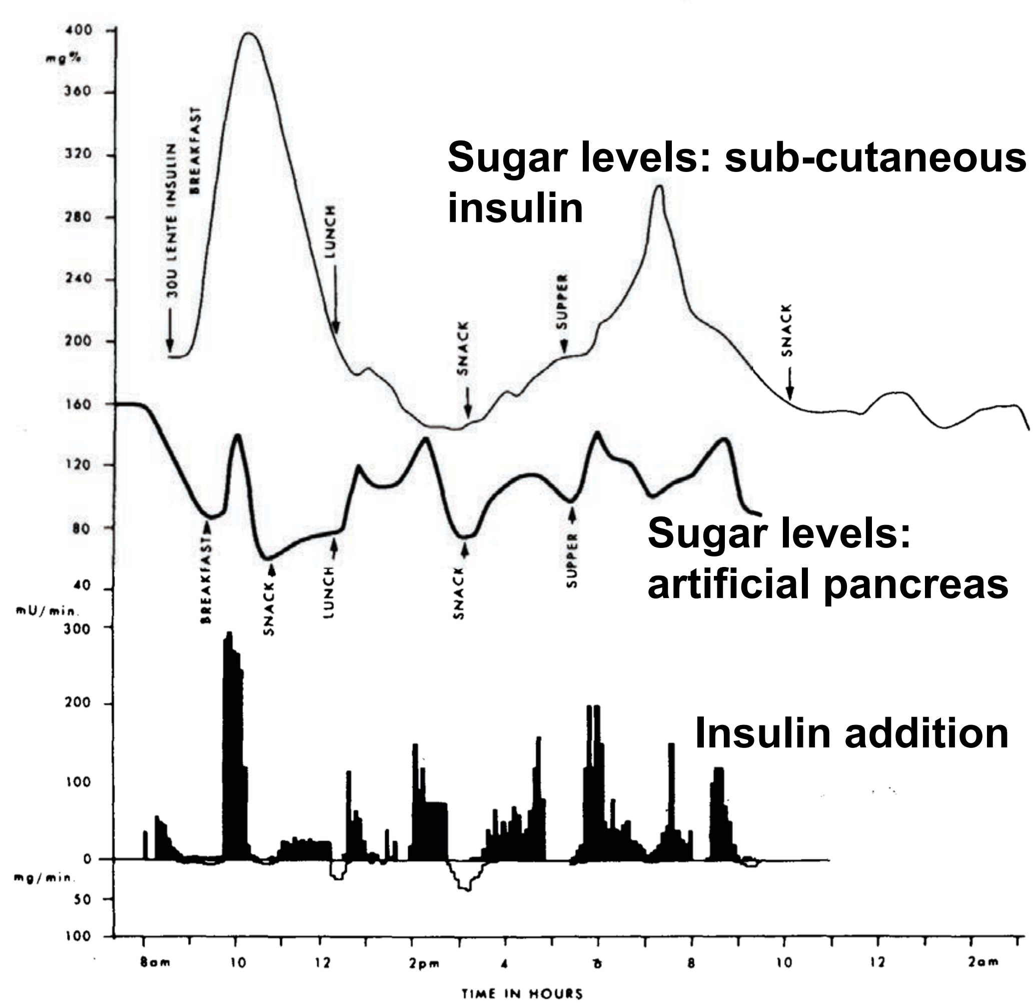


FIG. 1. Schematic diagram of apparatus used for monitoring and automatic regulation of blood sugar.



A M Albisser, B S Leibel, T G Ewart, Z Davidovac, C K Botz, W Zingg, H Schipper, and R Gander
Clinical Control of Diabetes by the Artificial Pancreas
Diabetes May 1974 23:5 397-404; doi:10.2337/diab.23.5.397 1939-327X (Toronto)

Impantable Artificial Pancreas

Up to now, implantable pumps for clinical application and suitable for the delivery of insulin have not been developed. However several groups are working on the development of both implantable dosing units and an implantable glucose sensor. Intravascular blood glucose sensing is difficult owing to the complex technology involved, and the foreign-body reaction of blood. The measurement of glucose in tissue would be easier to handle, but it has not been established whether the extravascular tissue concentration of glucose is sufficiently significant to serve as an input signal for a closed-loop system. Only when these questions have been answered and a suitable pumping and dosing unit have been developed, can the closed-loop system for the control of blood glucose be realised and miniaturised for implantation.

An implantable artificial pancreas, W. Schubert, P. Baurschmidt, J. Nagel, R. Thull, M. Schaldach;

Medical and Biological Engineering and Computing, July 1980, Volume 18, Issue 4, pp 527-537

‘Intravascular blood glucose sensing is difficult **owing to the complex technology involved** and **the foreign body reaction of blood**.’

‘The measurement of glucose **in tissue would be easier to handle**, but it has not been established whether the **extravascular tissue concentration of glucose is sufficiently significant to serve as an input signal for a closed-loop system**’

Adam Heller

Subcutaneous sampling of interstitial fluid using microneedles to access the fluid through the skin without causing bleeding

San Francisco Business Times; Tuesday, April 6, 2004

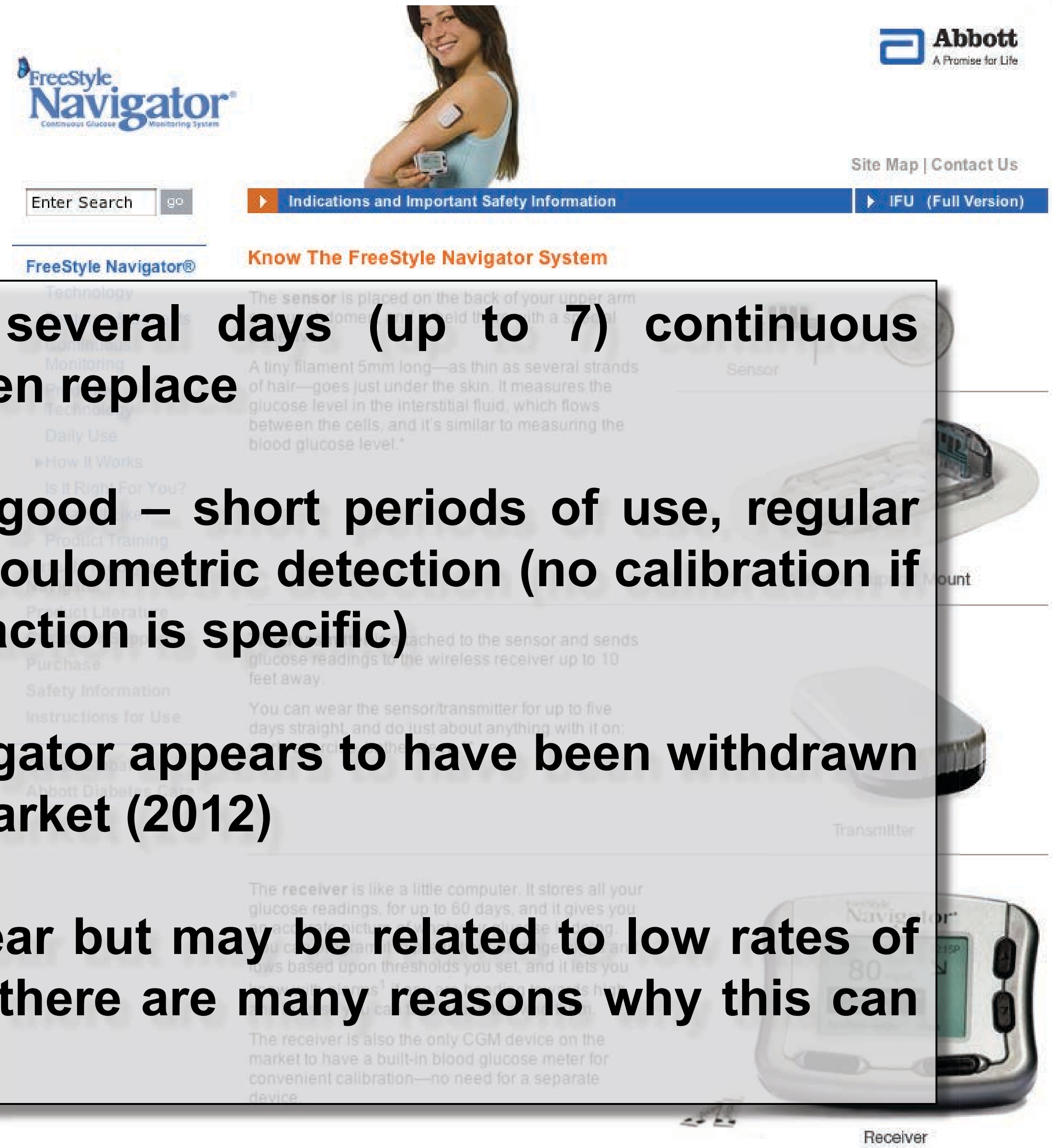
'Abbott completes TheraSense acquisition'

Abbott Laboratories said Tuesday it completed its $1.2 billion acquisition of Alameda-based TheraSense Inc. after a majority of shareholders approved the transaction a day earlier.

- **Abbott Press Release September 29, 2008**
- Abbott Park, Illinois — Adam Heller, Ph.D., a professor at the University of Texas in Austin who created the technology that led to the development of Abbott's FreeStyle Blood Glucose Monitoring Systems® and FreeStyle Navigator® Continuous Glucose Monitoring System, today received the 2007 National Medal of Technology and Innovation from President George W. Bush in an award ceremony at the White House.

Freestyle Navigator

- Combines microfluidics with a micro-dimensioned filament sampling unit which is designed to minimise the incidence of infection (therefore can be left in place for 5 days).
- Measures glucose in interstitial fluid (not blood). Diabetics have poor peripheral blood supply, therefore this is a major advance.
- Wireless communications used to harvest data continuously, and relay to carers and specialists. Enables trending, aggregation, warning….



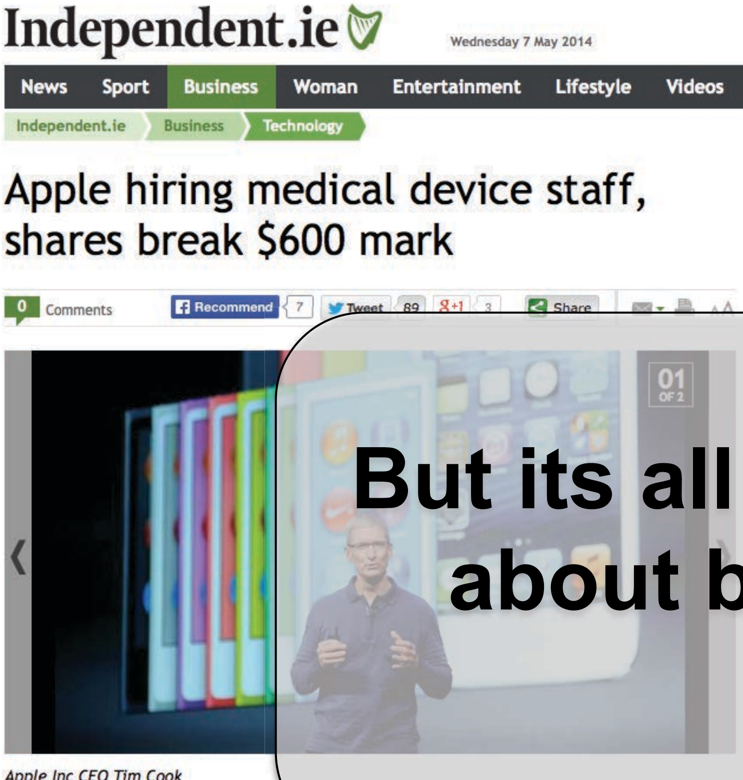
Target is for several days (up to 7) continuous monitoring; then replace

Use model is good – short periods of use, regular replacement, coulometric detection (no calibration if the enzyme reaction is specific)

Freestyle Navigator appears to have been withdrawn from the US market (2012)

Reasons unclear but may be related to low rates of user uptake – there are many reasons why this can happen

Apple, iWatch & Health Monitoring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Apple hiring medical device staff, shares break $600 mark

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Apple Inc CEO Tim Cook

May 7th 2014

'**Over the past year, Apple has snapped up at least half a dozen prominent experts in biomedicine**, according to LinkedIn profile changes.

Much of the hiring is in sensor technology, an area Chief Executive Tim Cook singled out last year as primed "to explode."

Industry insiders say the moves telegraph a vision of **monitoring everything from blood-sugar levels to nutrition, beyond the fitness-oriented devices now on the market.'**

"This is a very specific play in the bio-sensing space," said Malay Gandhi, chief strategy officer at Rock Health, a San Francisco venture capital firm that has backed prominent wearable-tech startups, such as Augmedix and Spire.

But its all gone very quiet about biosensors…..

Google Contact Lens

United States Patent Application ***20140107445***

Kind Code A1 Liu; Zenghe April 17, 2014

Microelectrodes in an Ophthalmic Electrochemical Sensor

Abstract

An eye-mountable device **includes an electrochemical sensor embedded in a polymeric material** configured for mounting to a surface of an eye. The electrochemical sensor includes a working electrode, a reference electrode, and a reagent that selectively reacts with an analyte to generate a sensor measurement related to a concentration of the analyte in a fluid to which the eye-mountable device is exposed.

Google Smart Contact Lenses Move Closer to Reality

- **Use model is 24 hours max, then replace;**
- **likely to leverage Google Glass* infrastructure;**
- **Novartis now working with Google.**

Fig. 2. Images of the sensor as it goes through surface functionalization and the related measured responses: (a) sequential images of sensor pre-treatment with GOD/titania/Nafion®; (b) measured amperometric response for the sensor just incubated with GOD; (c) measured amperometric response for the sensor prepared with GOD/titania/Nafion®; (d) measured amperometric response for the sensor prepared with GOD/titania sol–gel film; (e) three controls (signals for buffer) for the same pre-treatment of (b), (c), and (d); (f) the enlarged view of curve (b) and control of (b) for 120–360 s.

***Google Glass project has been abandoned! (Jan 15 2015) see https://plus.google.com/+GoogleGlass/posts/9uiwXY42tvc**

A contact lens with embedded sensor for monitoring tear glucose level, H. Yao, A. J. Shum, M. Cowan, I. Lähdesmäki and B. A. Parviz, ***Biosensors & Bioelectronics*, 2011, 26**, 3290-3296.

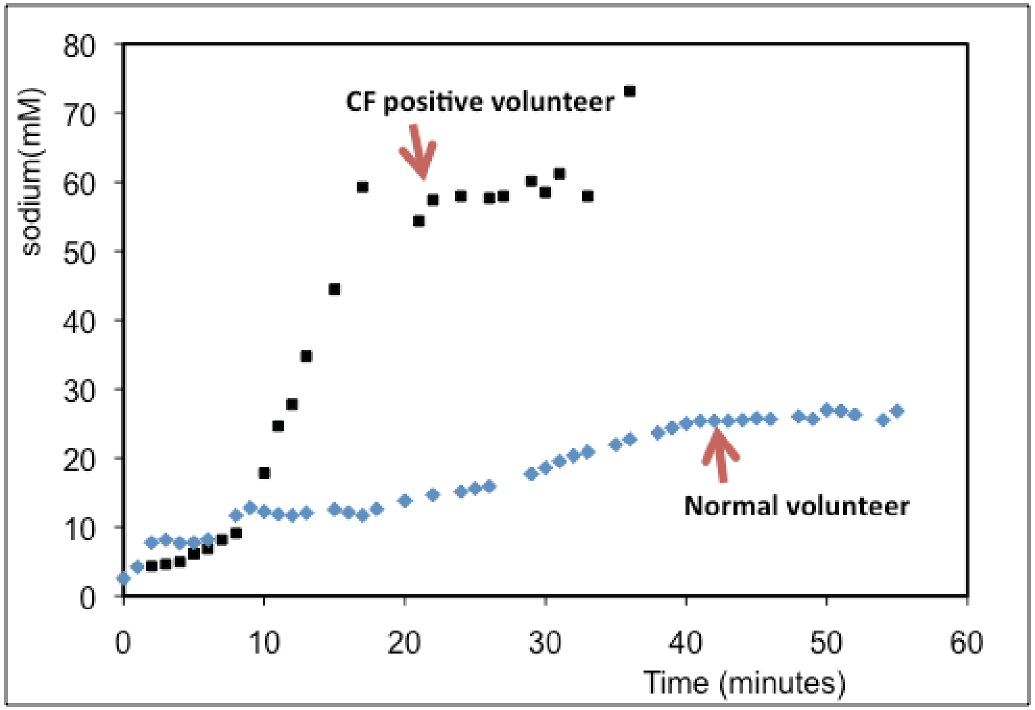
http://www.gmanetwork.com/news/story/360331/scitech/technology/google-s-smart-contact-lenses-may-arrive-sooner-than-you-think

After decades of intensive research, our capacity to deliver chemo/bio-sensors capable of long-term autonomous use of in remote locations is still very limited.

Blood is by far the best diagnostic medium, but no sensor will function acceptably for more than a few days continuous exposure to blood

Na$^+$ monitoring in sweat using wearable sensor

- **Measurements successfully made with CF-positive and normal volunteers**
  - clear difference between CF+ and normal levels
- **Elevated levels of Na$^+$ found in sweat of CF+ volunteers as expected**
- **Enables electrolyte loss to be estimated when combined with sweat rate/volume data**
- **Important for rehydration**
- **Interesting observations**
  - elevated viscosity of sweat of CF+ volunteers
  - sweat rate much lower – in some cases no sweating occurred
  - could not exercise as long as normal volunteers

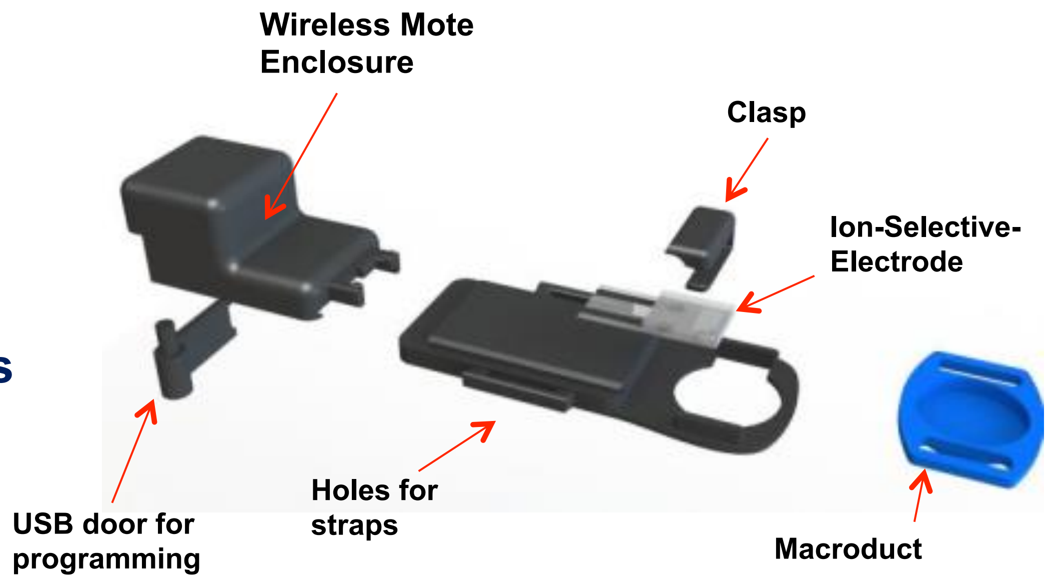


- **Diagnostic CF threshold >60mM [Na$^+$] reached**
- **Issue with initial delay**
  - arises from inherent delay in onset of sweating
  - contribution from device 'dead-volume'

Na$^+$ Monitoring in Sweat

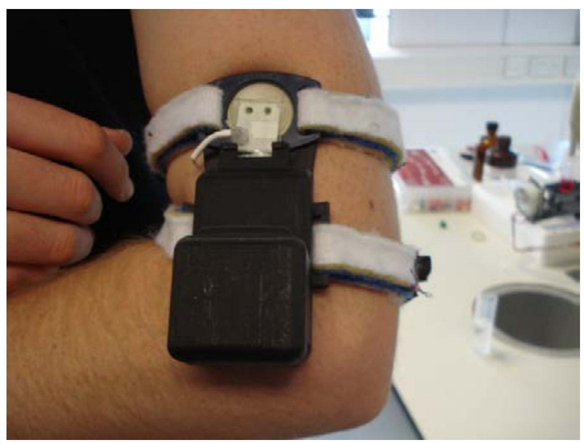
Real time monitoring of Sodium in Sweat through screen printed potentiometric strips:

- **Monitoring of athletes during exercise**
- **Monitoring clinical conditions e.g. Cystic Fibrosis patients**

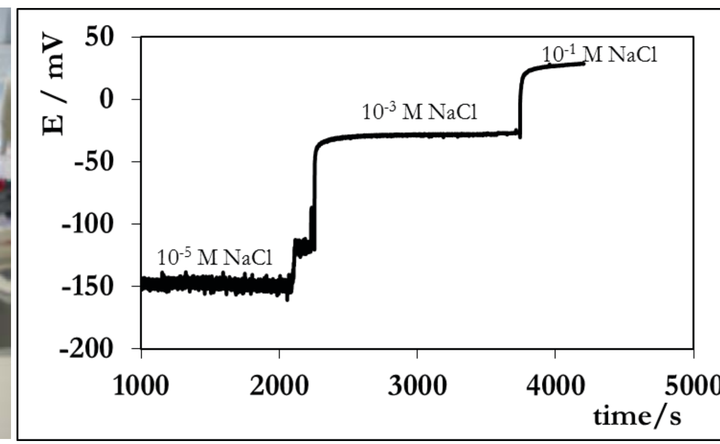


Macroduct sweat sampling unit (Wescor Corporation) Speed x4

Pilocarpine based sweat sampling

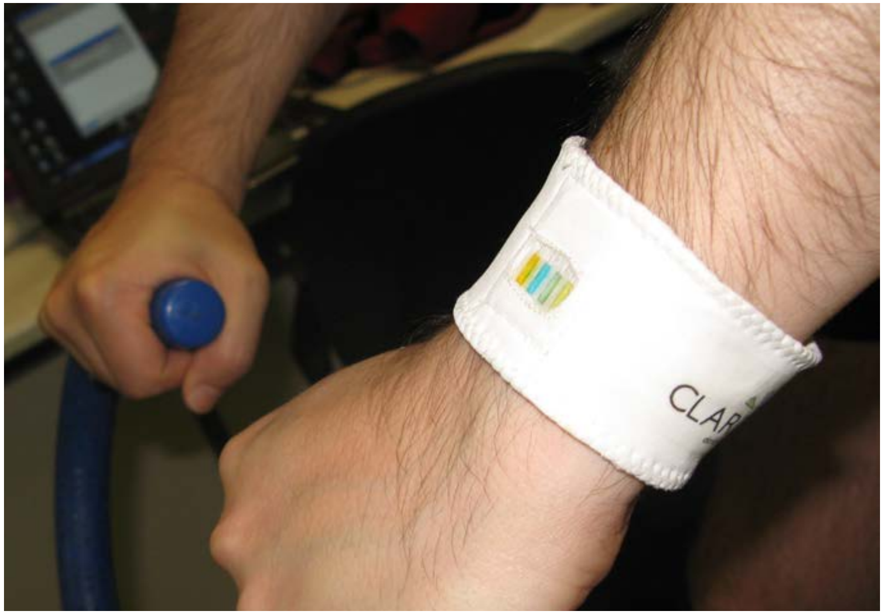


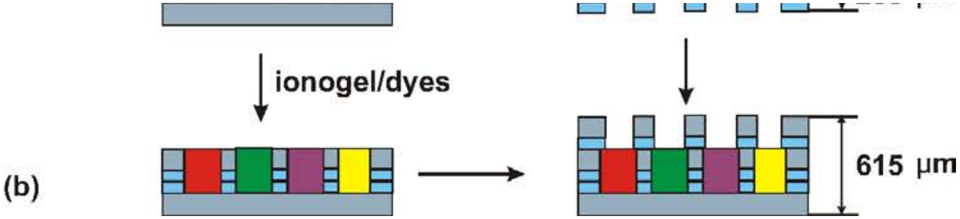
Exercise based sweat sampling



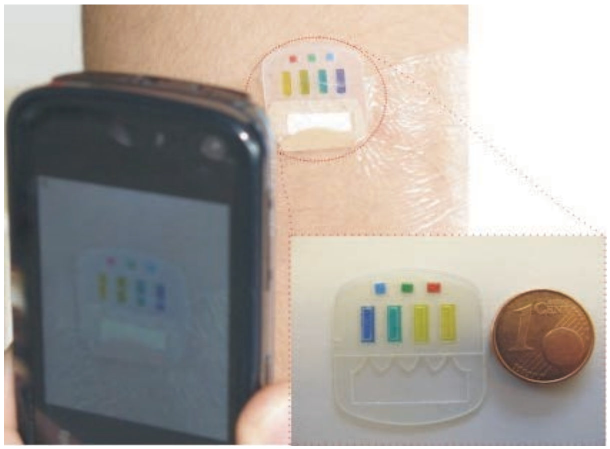
Sensor calibration

Microfluidic pH Sensor fabrication





pH Monitoring via Smart Phone App

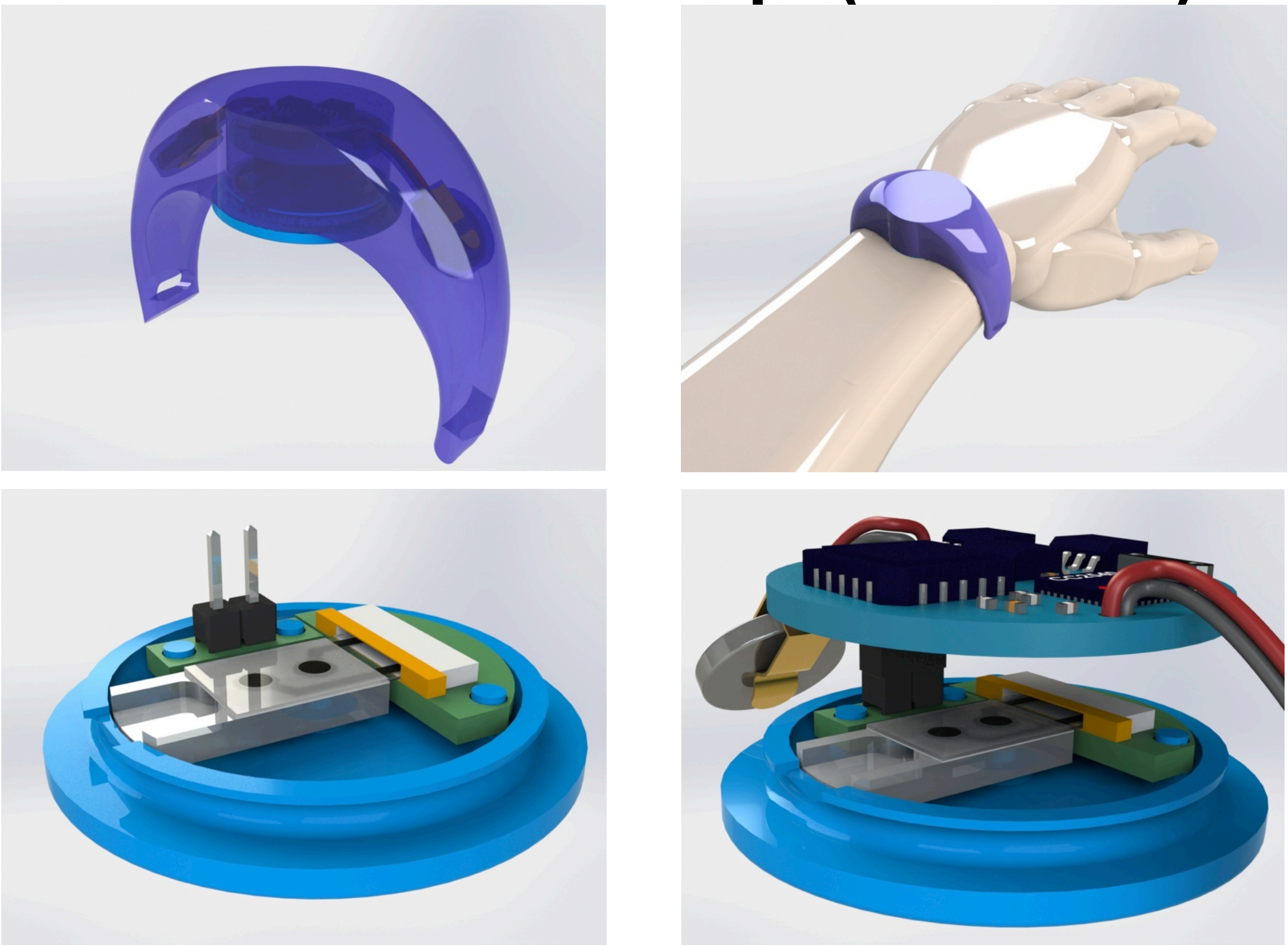


- COLOUR CHANGE VISIBLE BY EYE
- SMARTPHONE APP TO DETECT pH AUTOMATICALLY
- REAL TIME VIDEO ANALYSIS IS POSSIBLE

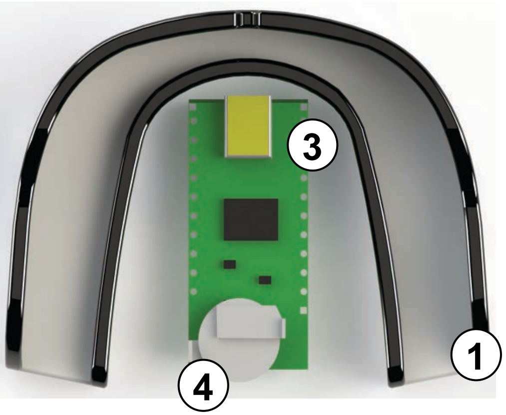
Time [min]	pH Meter	Dyes Prediction (pH)	% RE
20	6.38	5.89	7.68
30	5.8	5.56	4.14
40	5.67	5.67	0.00
50	5.95	5.63	5.38

SWEAT pH DETERMINATION USING THE BARCODE IN AN ATHLETE DURING A 50 MIN TRAINING PERIOD

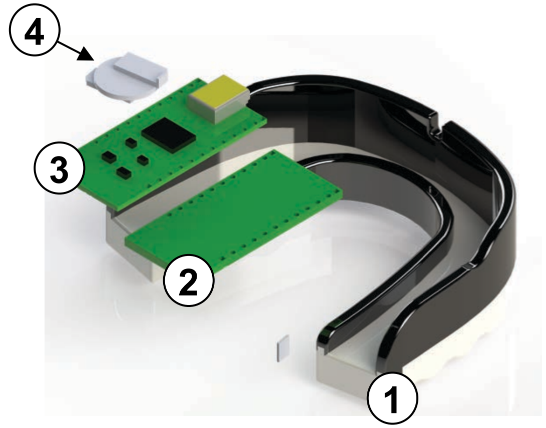
Next Generation: Watch Fluidic Sensor Concept (Shimmer)



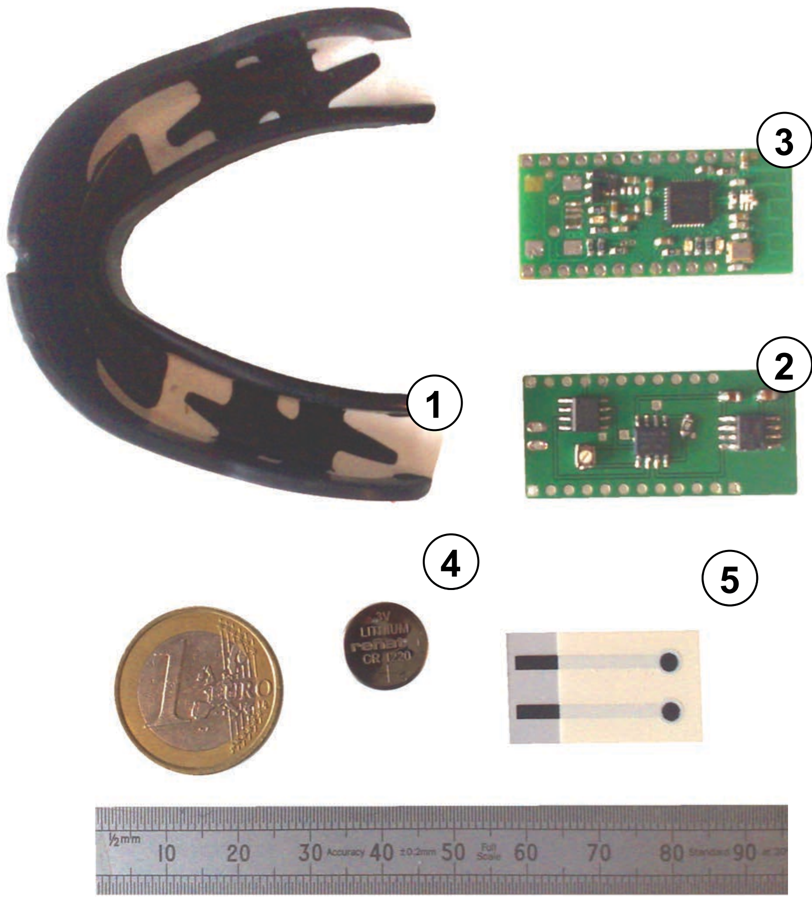
Smart Gumshield



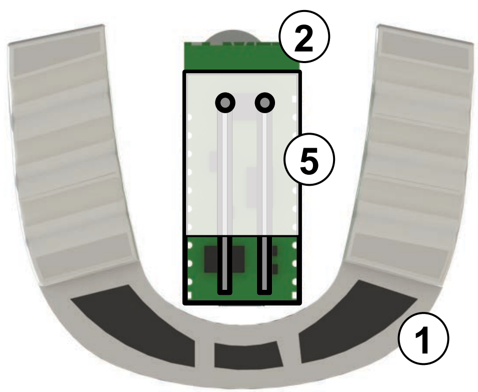
(a) Top View



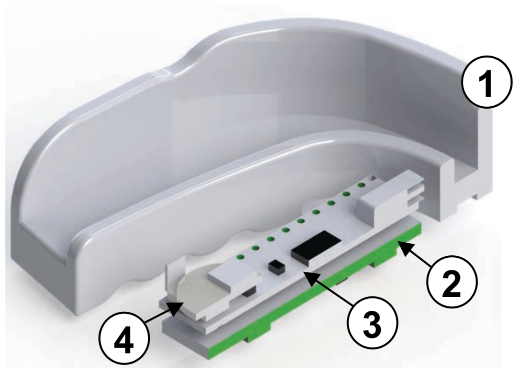
(b) Exploded View



(e) Photo of components laid out



(c) Bottom View



(d) Assembled Sectional View

Smart Splint – Preliminary In-Vivo Data

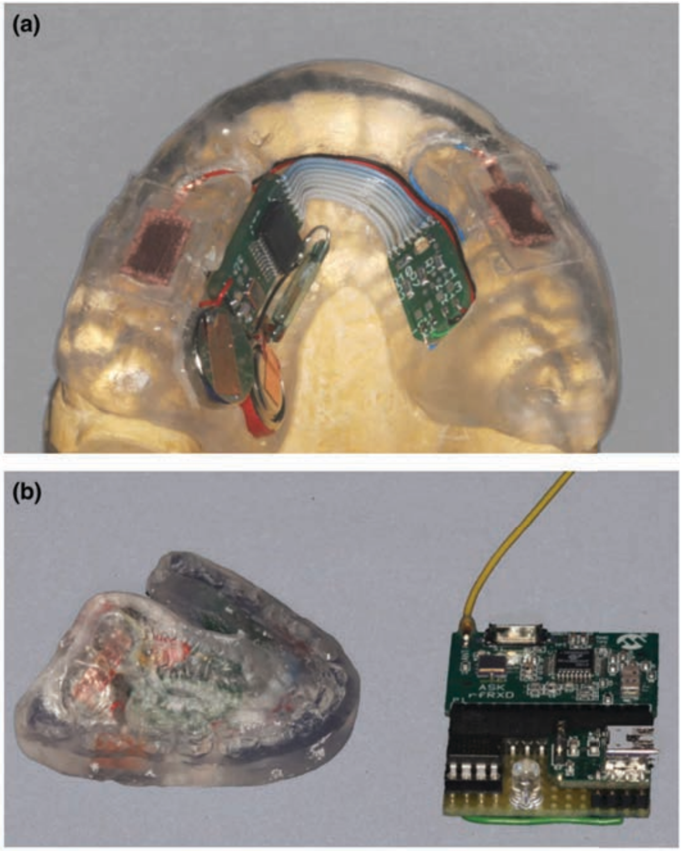


Fig. 1. (a) First prototype splint with electronics exposed before hermetic sealing (b) splint containing sensors and wireless receiver circuit.

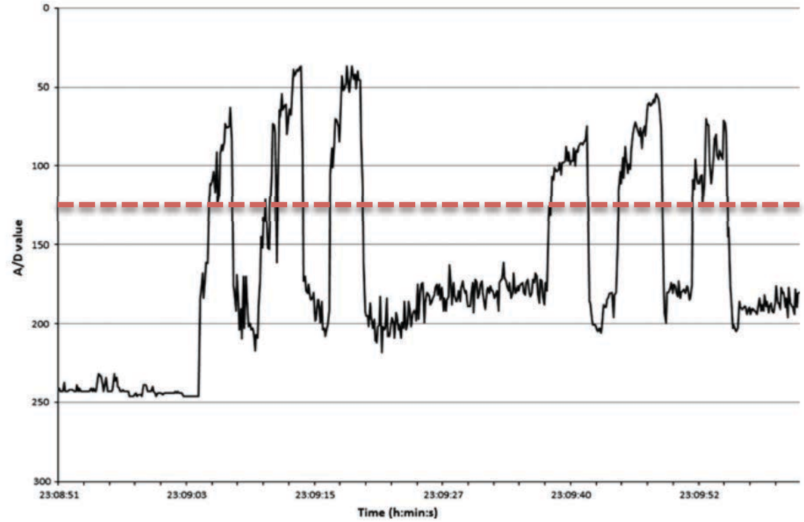
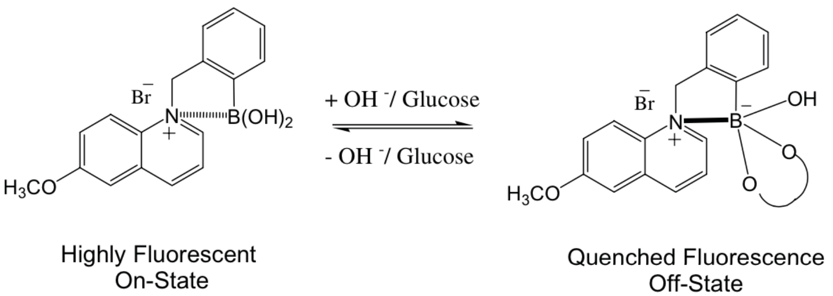


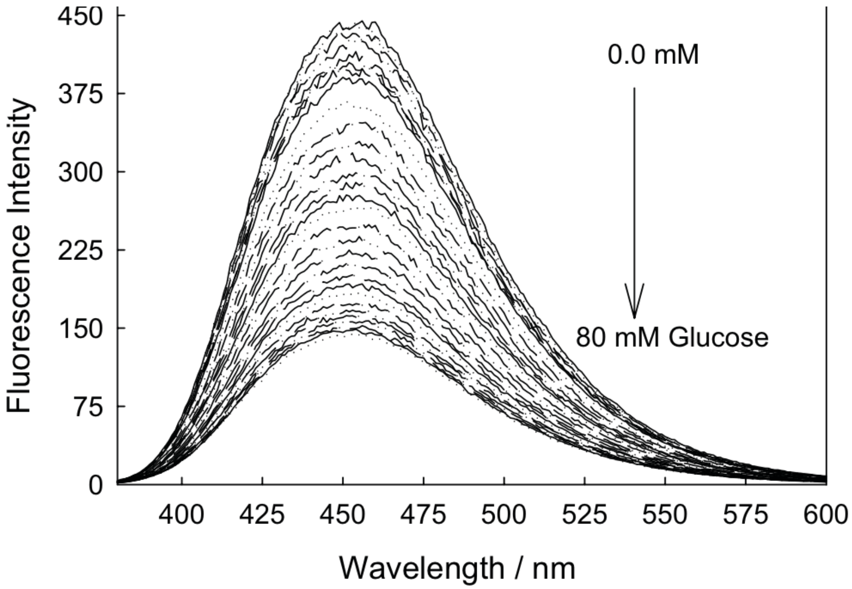
Fig. 2. *In vivo* response of wireless sensor-containing occlusal splint to forces simulating phasic bruxism, as described in Table 1. The *x*-axis shows the time line of the recording, and the *y*-axis is the analogue-to-digital value of the device output, which represents the resistance of the sensor.

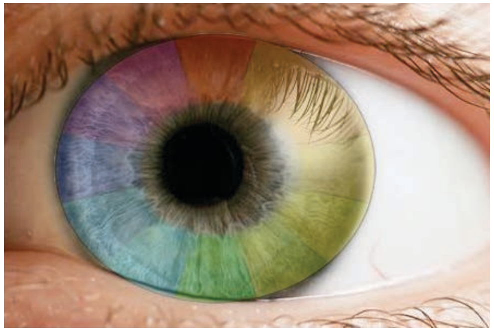
- **Event detection algorithm -> number of, severity, duration…**
- **Convert this to a score (where on scale the person is)**
- **Track effect of interventions on this score**

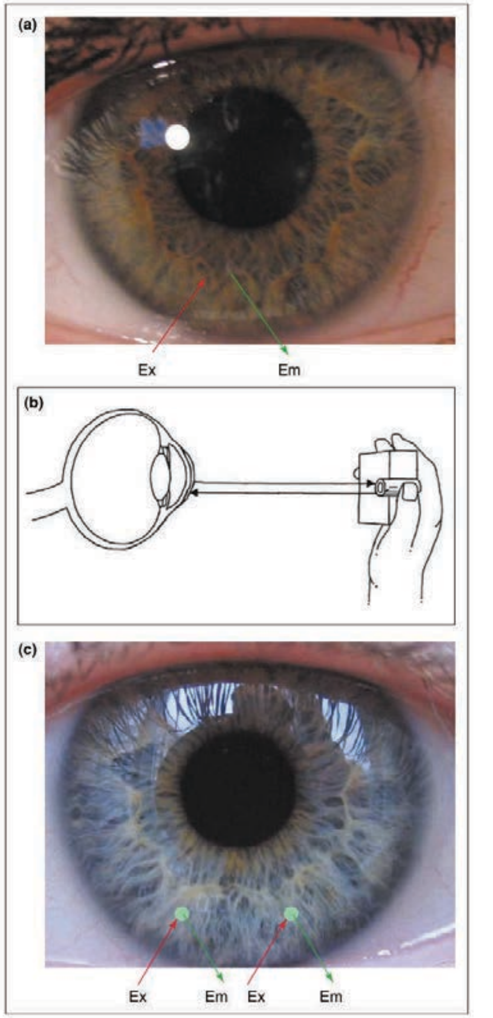
A sleep bruxism detection system based on sensors in a splint – pilot clinical data, Journal of Oral Rehabilitation 2015 42; 34--39
P. MCAULIFFE*, J. H. KIM†, D. DIAMOND†, K. T. LAU† & B. C. O'CONNELL* *Department of Restorative Dentistry & Periodontology, Dublin Dental University Hospital, Trinity College Dublin, and †National Centre For Sensor Research, Dublin City University

Optically Responsive Contact Lens for Diabetics









Potential methods for non-invasive continuous tear glucose monitoring. **(a)** Boronic acid doped contact lenses. **(b)** Schematic of a possible tear glucose-sensing device. The hand-held device works by flashing a light into the eye (Ex) and measuring the emission (Em) intensity. **(c)** Sensor spots on the surface of the lens can be included to monitor other analytes in addition to glucose, such as drugs, biological markers, Ca^{2+}, K^+, Na^+, O_2 and Cl^-. Sensor regions could also allow for ratiometric, lifetime or polarization based fluorescence glucose sensing.

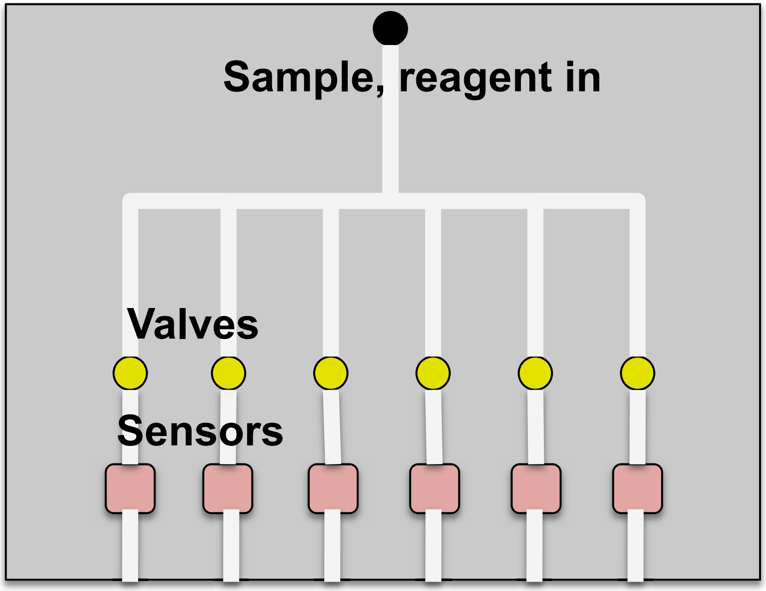
Series of papers by Ramachandram Badugu, Joseph R.Lakowicz, and Chris D. Geddes [1] & Jin Zhang of the University of Western Ontario [2] based on boronic acid quinolinium receptors: Under alkaline conditions (pH9) saccharide diols bind to form the B^- centre which interacts strongly with the N^+ centre, quenching the fluorescence emission.

[1] Noninvasive continuous monitoring of physiological glucose using a monosaccharide-sensing contact lens, R. Badugu, J.R. Lakowicz, C.D. Geddes, Analytical Chemistry, 76 (2004) 610-618.

[2] Jin Zhang*, William Hodge, Cindy Hutnick, and Xianbin Wang, "Non-invasive diagnostic technology for diabetes through monitoring ocular glucose", J. Diabetes Sci. Tech. 5,166, (2011)

Extend Period of Use via Arrays of Sensors….?

- If each sensor has an in-use lifetime of 1 week….
- And these sensors are very reproducible….
- And they are very stable in storage (up to several years)….

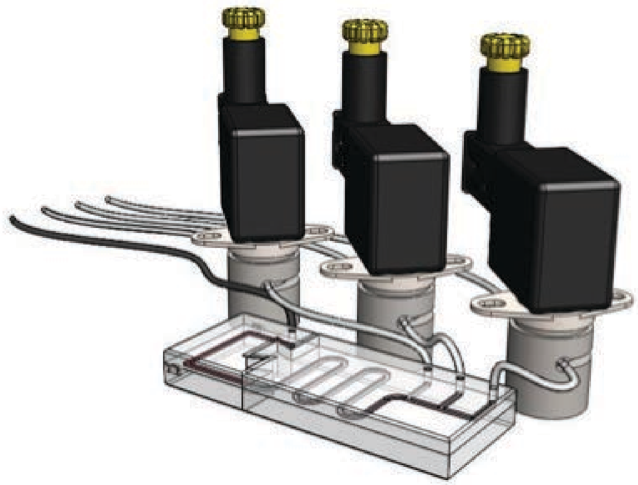


Then 50 sensors when used sequentially could provide an aggregated in-use lifetime of around 1 year

But now we need multiple valves integrated into a fluidic platform to select each sensor in turn

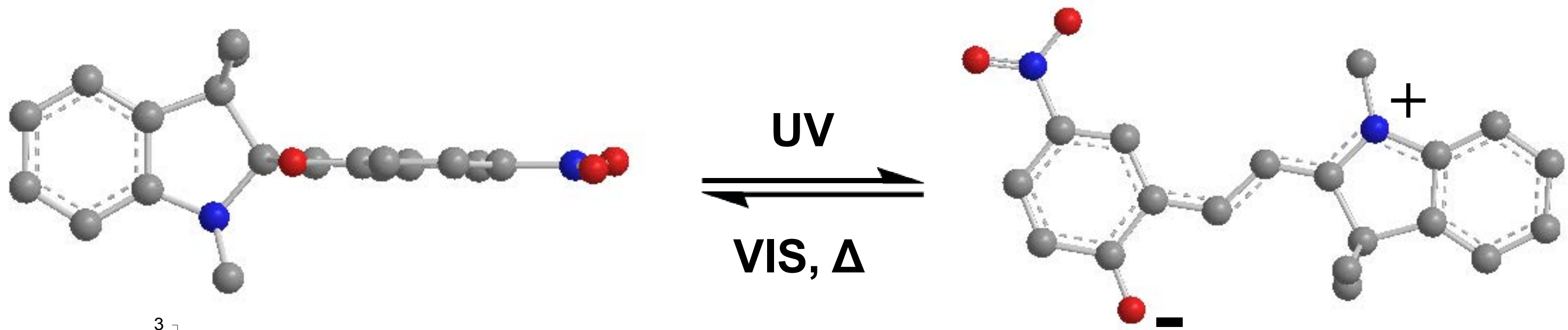
How to advance fluid handling in LOC platforms: re-invent valves (and pumps)!

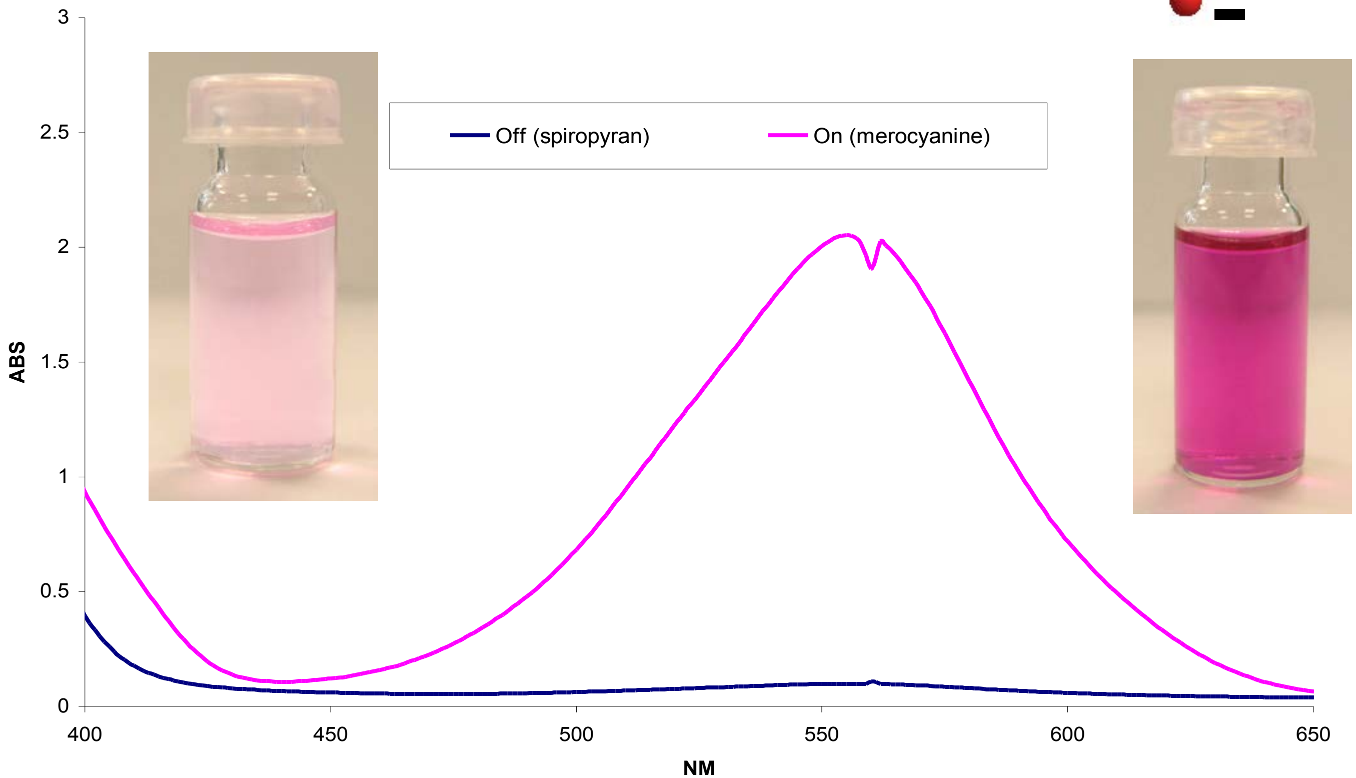
- **Conventional valves cannot be easily scaled down - Located off chip: fluidic interconnects required**
  - Complex fabrication
  - Increased dead volume
  - Mixing effects
- **Based on solenoid action**
  - Large power demand
  - Expensive



Solution: soft-polymer (biomimetic) valves fully integrated into the fluidic system

Photoswitchable Materials

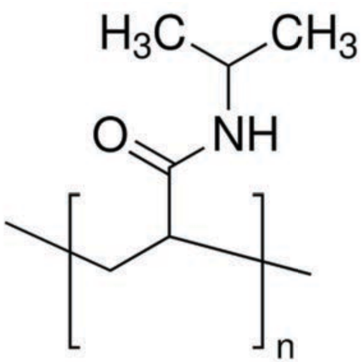




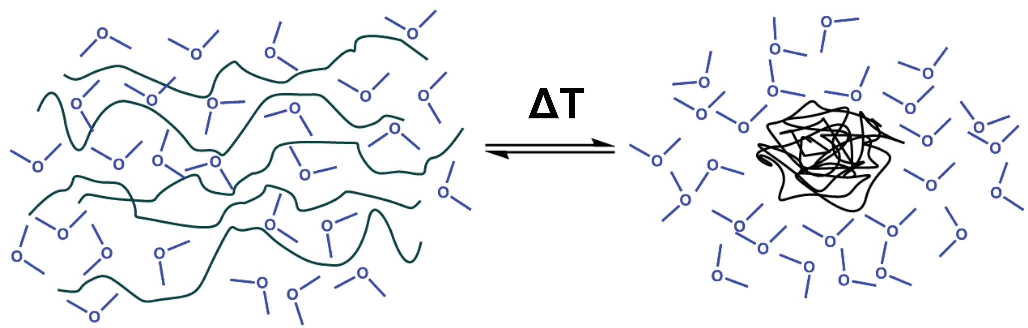
Poly(*N*-isopropylacrylamide)

- **pNIPAAM exhibits inverse solubility upon heating**
- **This is referred to as the LCST (Lower Critical Solution Temperature)**
- **Typically this temperature lies between 30-35^{o}C, but the exact temperature is a function of the (macro)molecular microstructure**
- **Upon reaching the LCST the polymer undergoes a dramatic volume change, as the hydrated polymer chains collapse to a globular structure, expelling the bound water in the process**

pNIPAAM



Hydrophilic **Hydrophobic**



Hydrated Polymer Chains

Loss of bound water -> polymer collapse

Polymer based photoactuators based on pNIPAAm

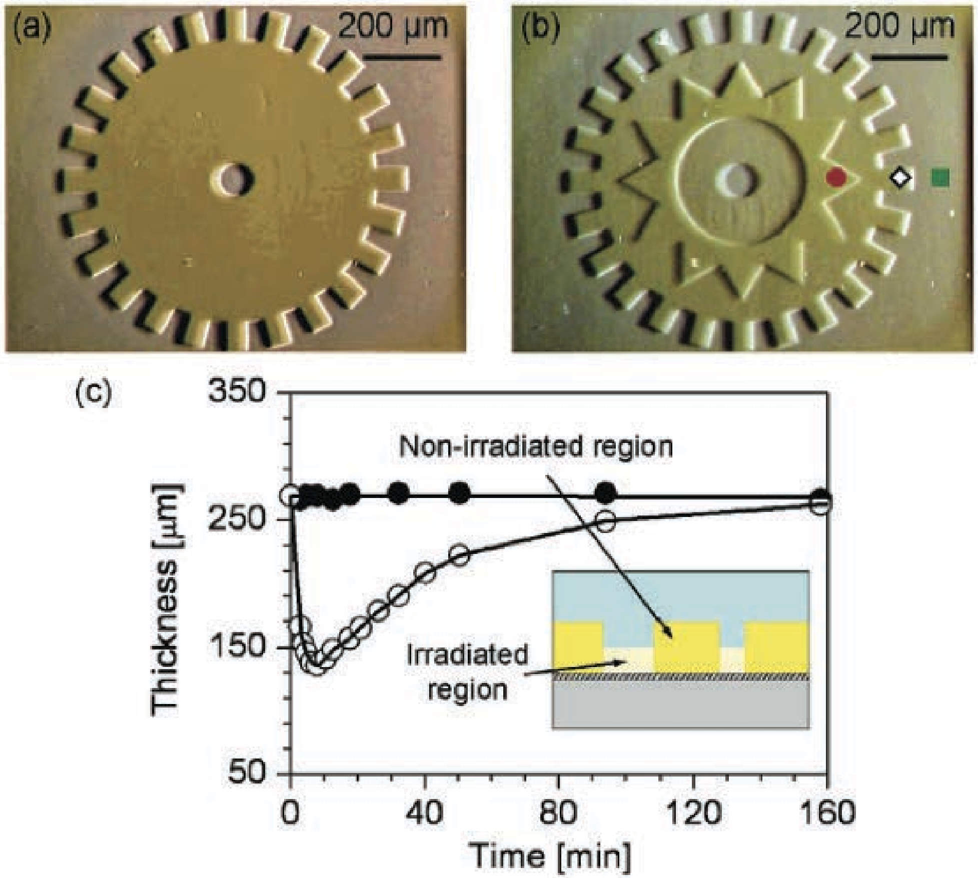
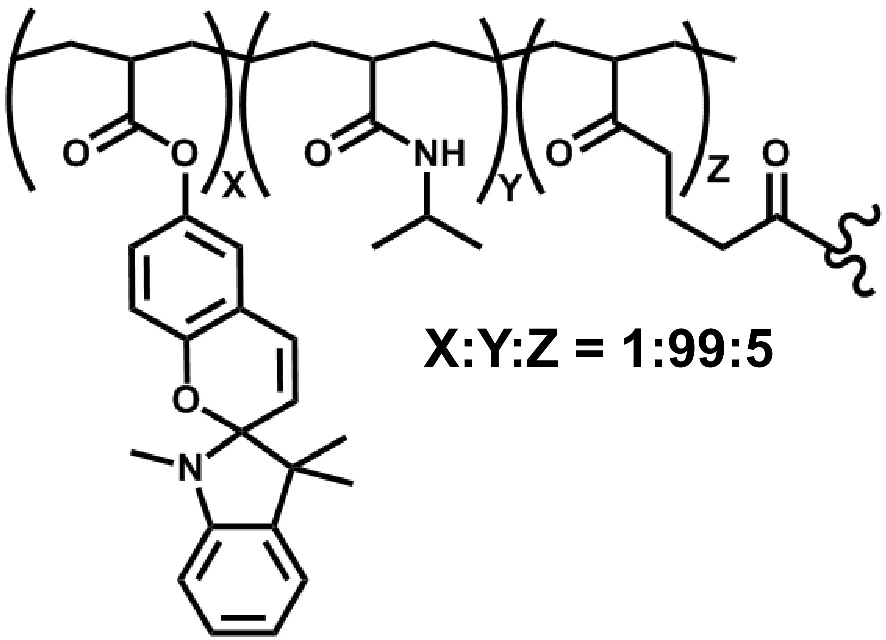


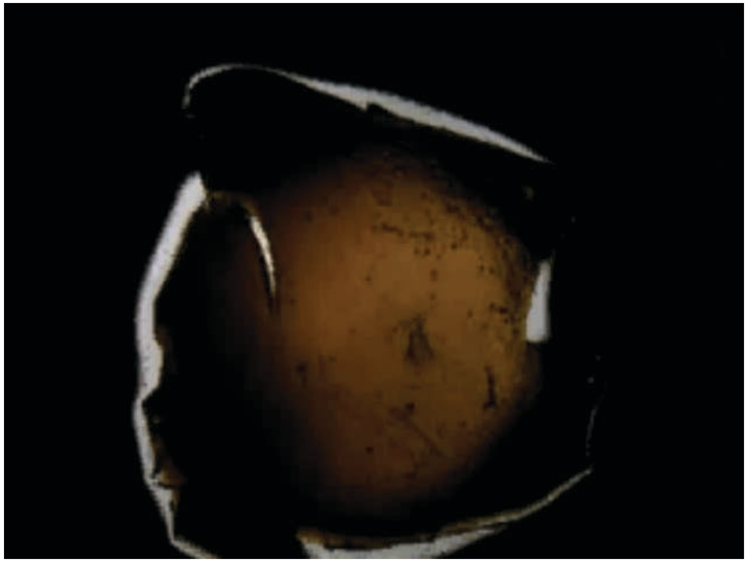
Figure 3. (a, b) Images of the pSPNIPAAm hydrogel layer just after the micropatterned light irradiation. Duration of irradiation was (●, red) 0, (◇) 1, and (■, green) 3 s. (c) Height change of the hydrogel layer in (●) non-irradiated and (○) irradiated region as a function of time after 3 s blue light irradiation.

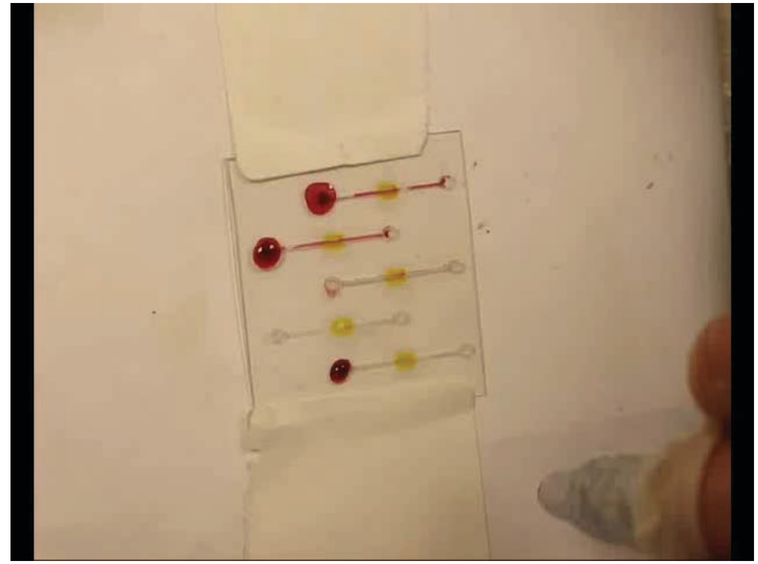


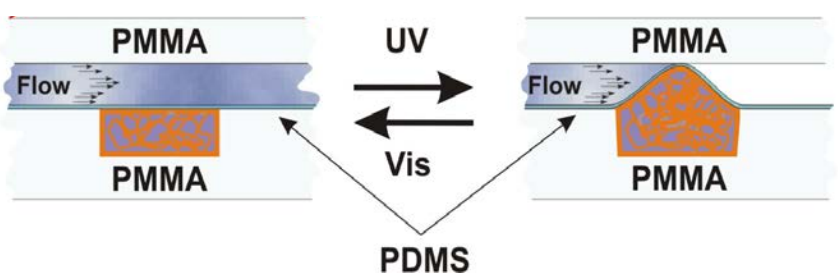
X:Y:Z = 1:99:5

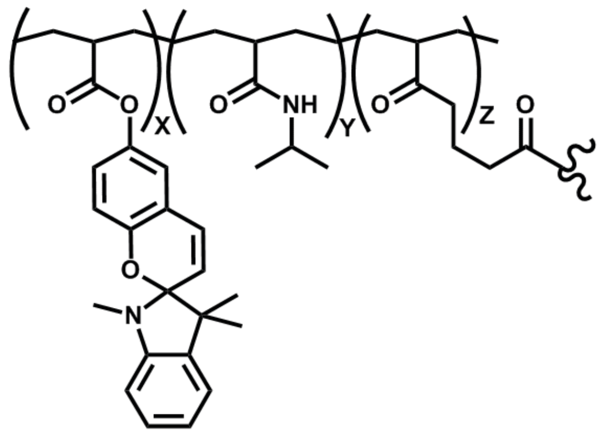
poly(N-isopropylacrylamide) (PNIPAAm)
Formulation as by Sumaru et al[1]
***1) Chem. Mater.*, 19 (11), 2730 -2732, 2007.**

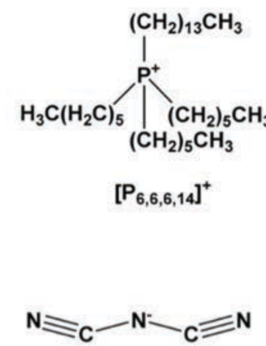
Photo-actuator polymers as microvalves in microfluidic systems









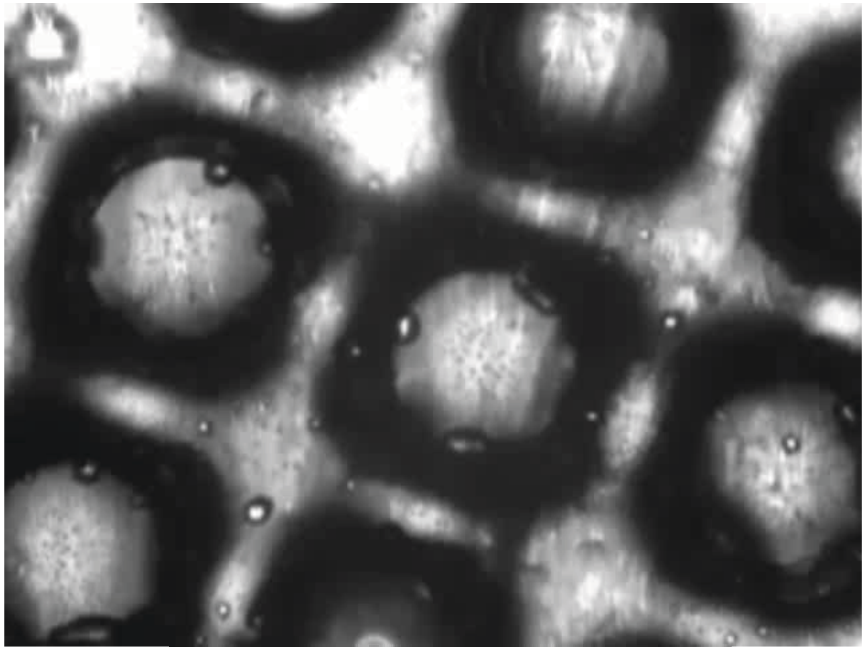


(b)

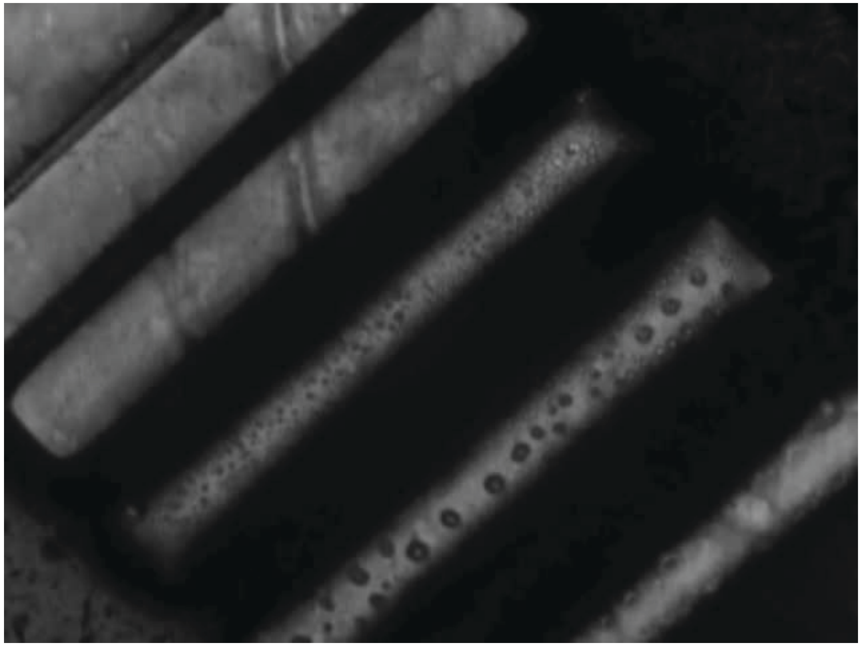
trihexyltetradecylphosphonium dicyanoamide $[P_{6,6,6,14}]^{+}[dca]^{-}$

Ionogel-based light-actuated valves for controlling liquid flow in micro-fluidic manifolds, Fernando Benito-Lopez, Robert Byrne, Ana Maria Raduta, Nihal Engin Vrana, Garrett McGuinness, Dermot Diamond, Lab Chip, 10 (2010) 195-201.

Flexible creation of μ-dimensioned features in flow channels using in-situ photo-polymerisation



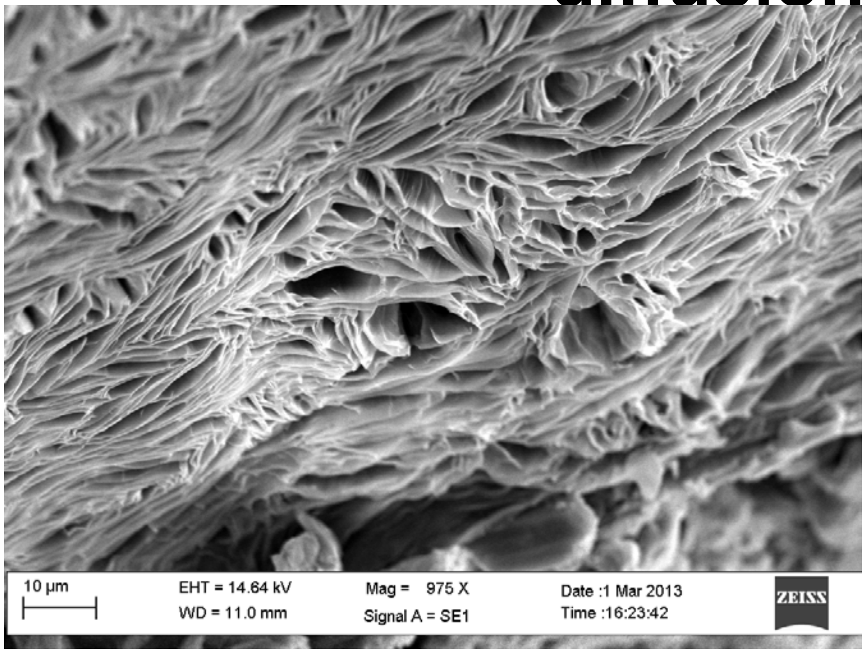
Ntf2 pillars speed x3

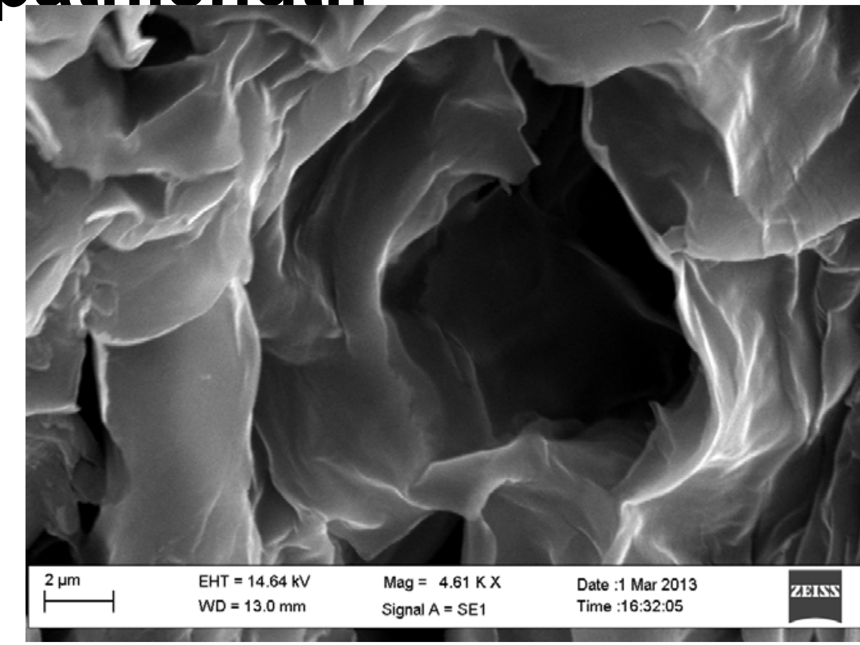


DCA lines speed x4

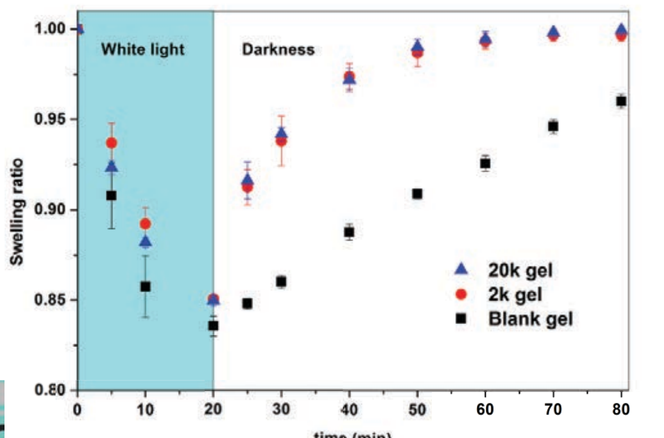
With Dr Peer Fischer, Fraunhofer-Institut für Physikalische Messtechnik (IPM), Freiburg

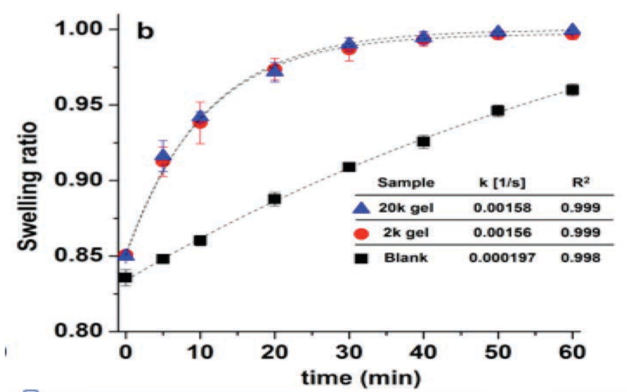
Improve response time: Porous Gels →reduce diffusion pathlength





Highly porous pNIPAAm gel structures generated using PEG as the porogen. This dramatically increases the surface area to bulk ratio, reducing the diffusion pathlength for water to penetrate to the gel interior, which in turns results in faster swelling/contraction rates

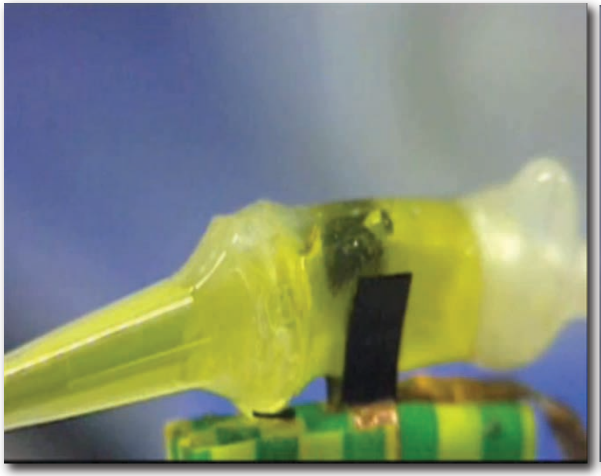


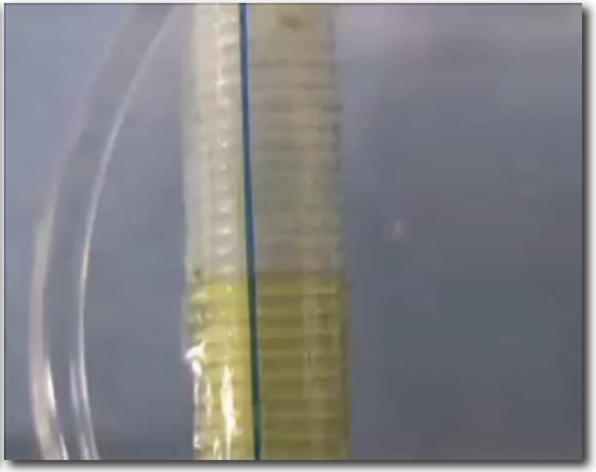


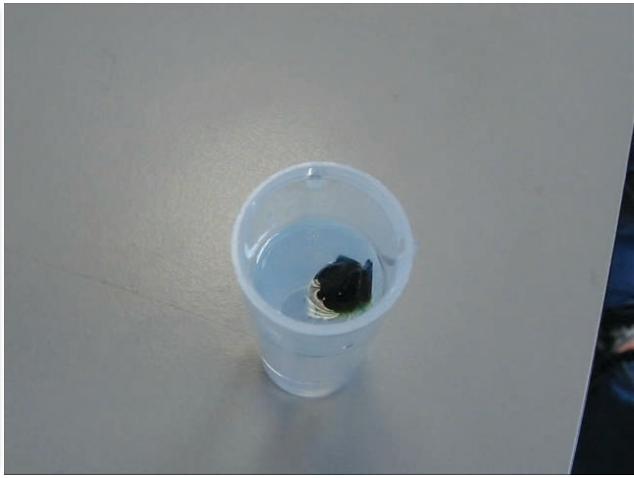
On the re-swelling side; highly porous gels now recover ca. an order of magnitude faster;

$k = 1.6x10^{-3}$ S^{-1}
vs. $2.0x10^{-4}$ S^{-1}

Biomimetic low-power soft pump







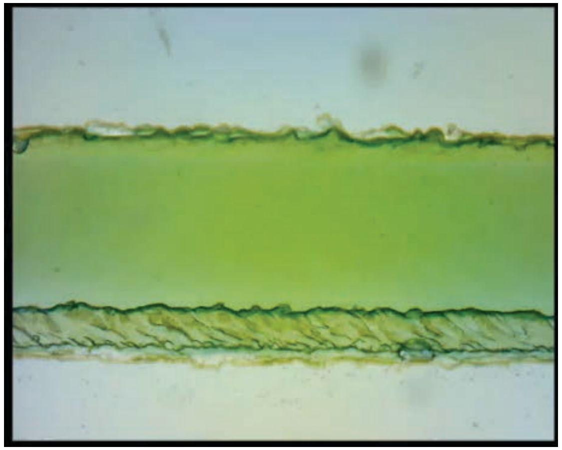
Low Power control of fluid movement in channels and on surfaces is possible using electrochemically switched actuators!

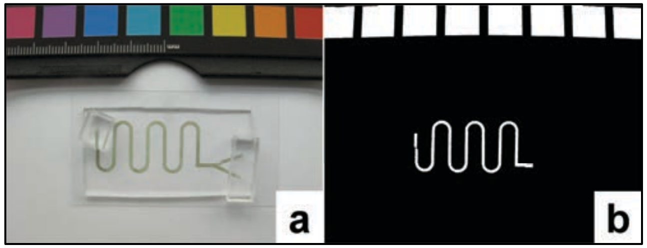
Internet-scale Sensing: Are Biomimetic Approaches the Answer?, Sonia Ramirez-Garcia and Dermot Diamond, Journal of Intelligent Material Systems and Structures, 18 (2) (2007) 159-164.

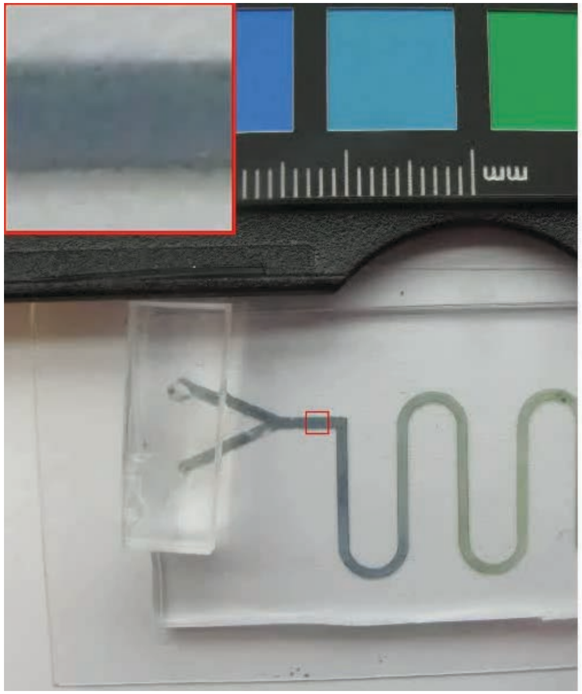
Biomimetic, low power pumps based on soft actuators, Sonia Ramirez-Garcıa and Dermot Diamond, Sensors and Actuators A 135 (2007) 229–235.

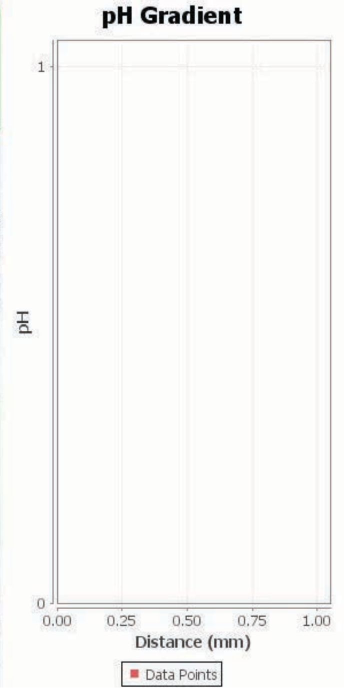
Even better is to use the power of chemistry! ‘Beating Heart’ with no external power requirement; solvent exchange in a ionogel polymer causes a rhythmic movement

Inherently sensing flexible channels



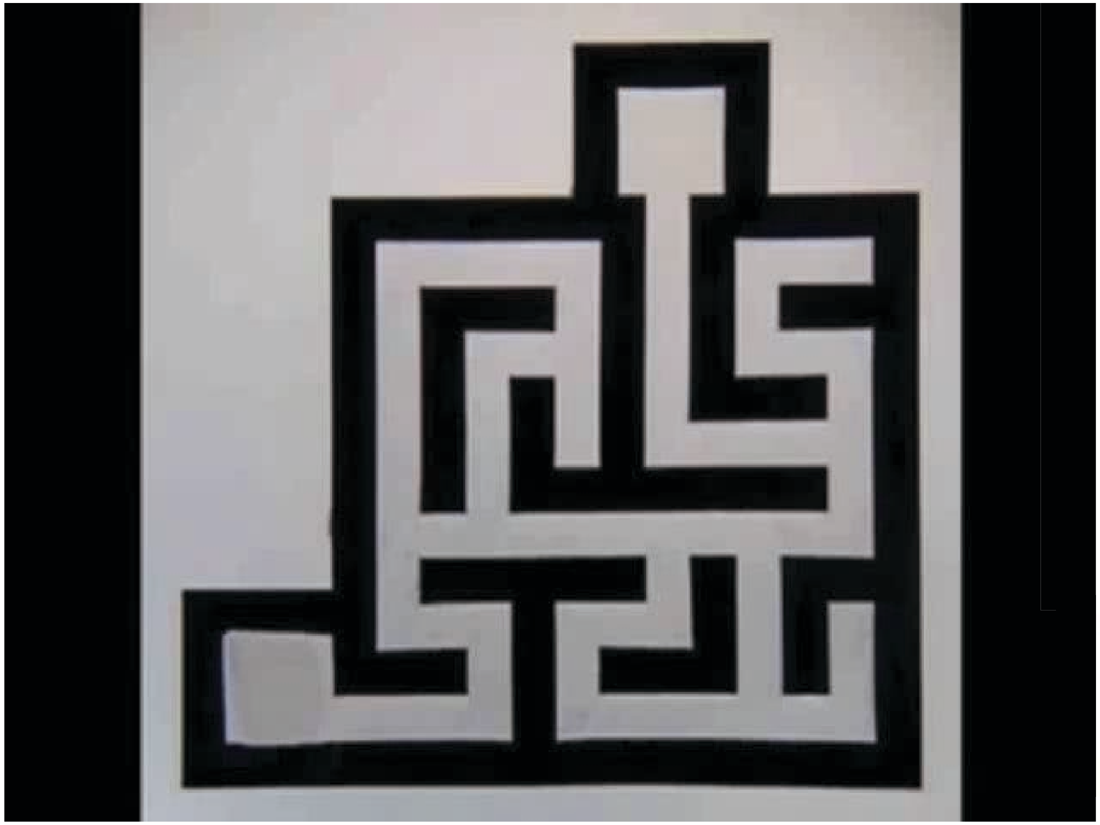






- **PANi deposited on channel walls - Channels are now inherently responsive e.g. pH sensitive**
- **Status can be determined at any location within the channels using low cost digital imaging**

Chemotactic Systems



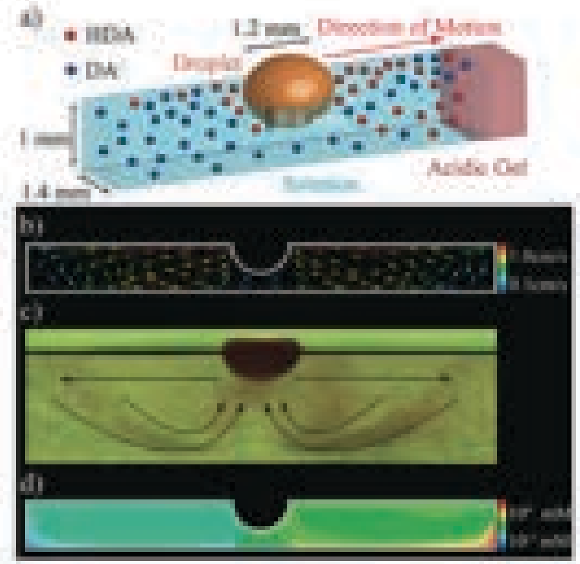


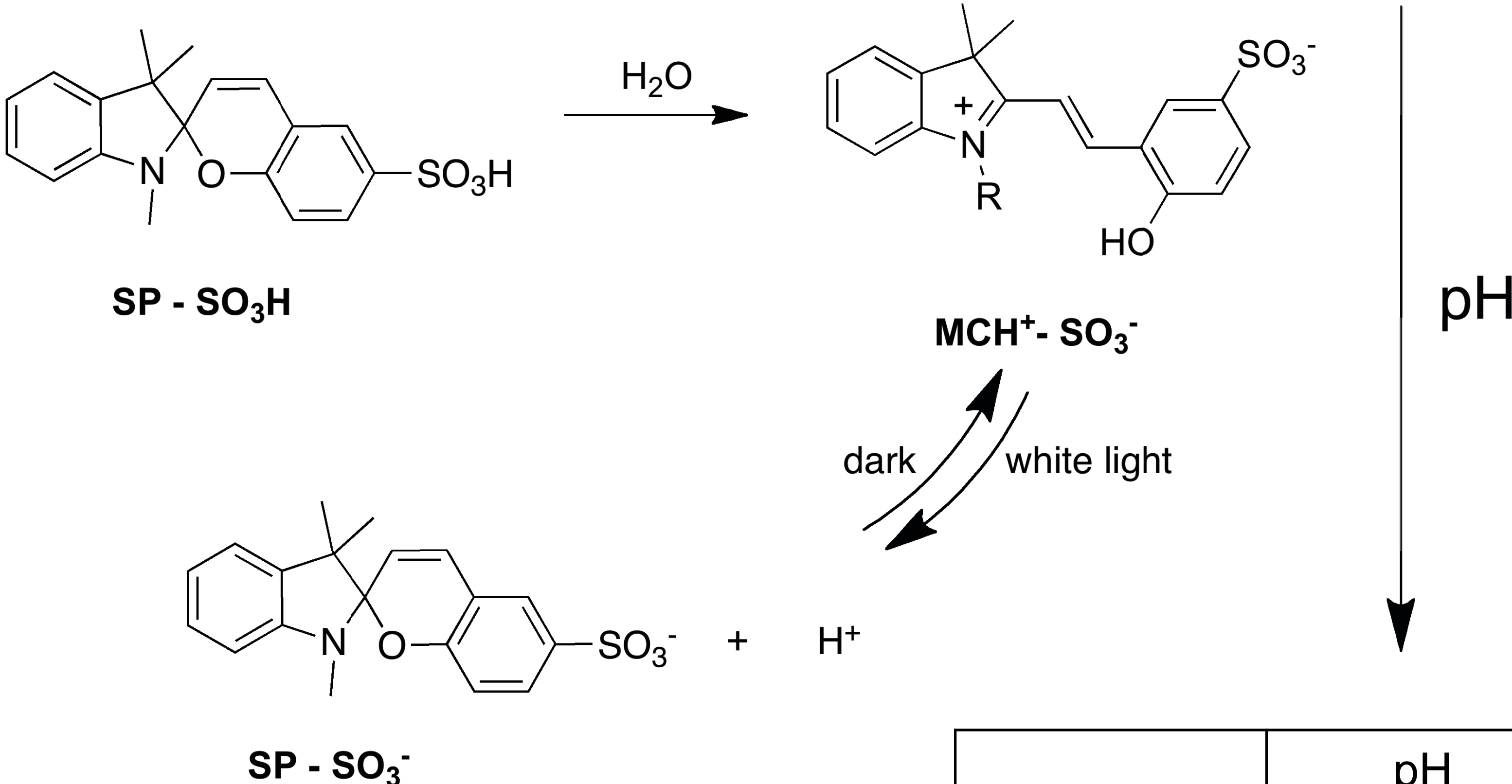
Figure 2. (a) Scheme of a droplet in a channel. The presence of HDA at the liquid−air interface gives rise to convective flows. Since more HDA is present in the direction facing the source of acid, the flows and forces are asymmetric. (b) Velocity field based on the theoretical model described in the main text (calculated using the Fluent computational fluid dynamics package from Ansys). (c) Experimental image of the convection rolls visualized using Neutral Red indicator (see also video 3 in the SI). (d)

Published on Web 11/01/2010 (speed ~x4): channels filled with KOH (pH 12.0-12.3 + surfactant; agarose gel soaked in HCl (pH 1.2) sets up the pH gradient; droplets of mineral oil or DCM containing 20-60% 2-hexyldecanoic acid + dye. Droplet speed ca. 1-10 mm/s; movement caused by convective flows arising from concentration gradient of HDA at droplet-air interface (greater concentration of HDA towards lower pH side); **HDA <-> H^+ + DA^-**

Maze Solving by Chemotactic Droplets; Istvan Lagzi, Siowling Soh, Paul J. Wesson, Kevin P. Browne, and Bartosz A. Grzybowski; **J. AM. CHEM. SOC. 2010, *132, 1198–1199***

Fuerstman, M. J.; Deschatelets, P.; Kane, R.; Schwartz, A.; Kenis, P. J. A.;Deutch, J. M.; Whitesides, G. M. *Langmuir 2003, 19, 4714.*

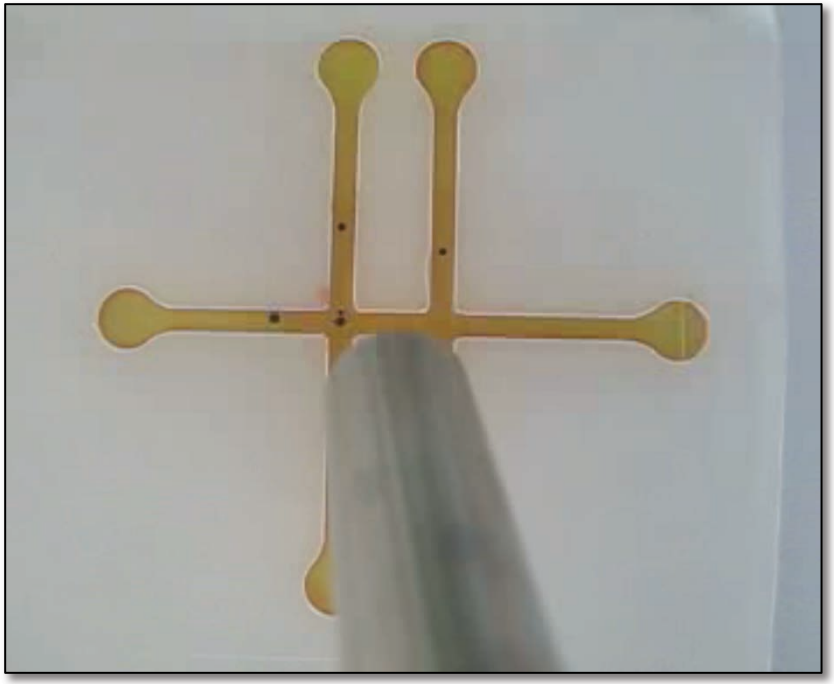
Photo-modulation of pH

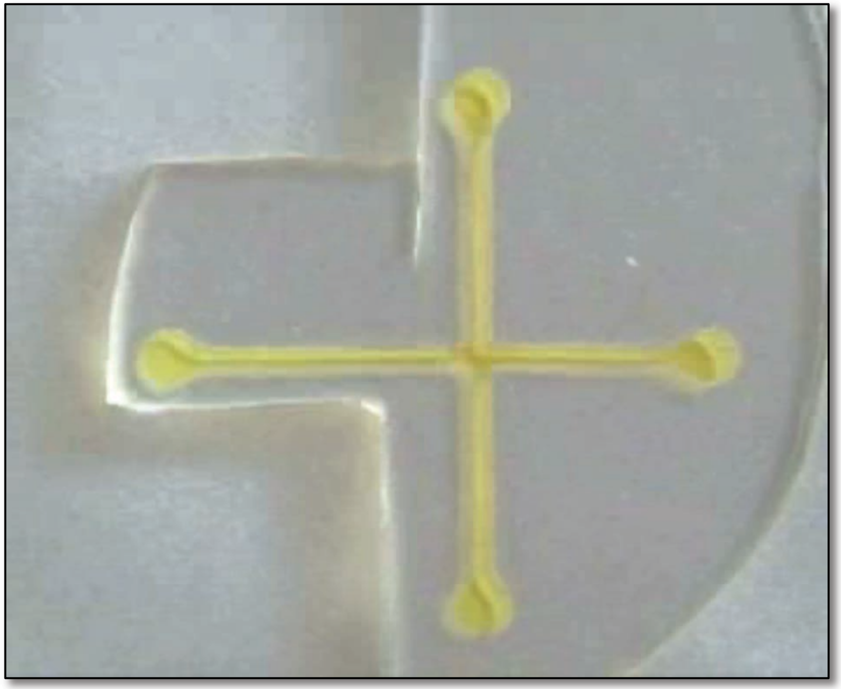


	pH
H_2O	6.5
MCH^+-SO_3^-	4.8
SP-SO_3^-	3.4

Channel Solution: Spiropyran Sulfonic Acid 10^{-3}M (H_2O)

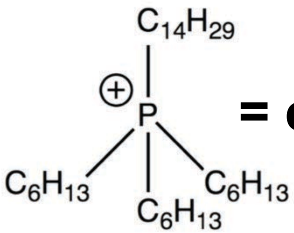
Movement of Droplets in Channels using Light



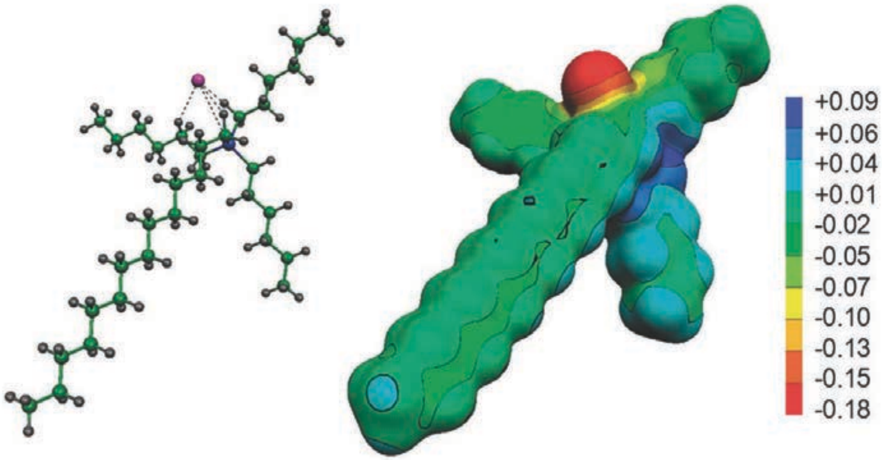


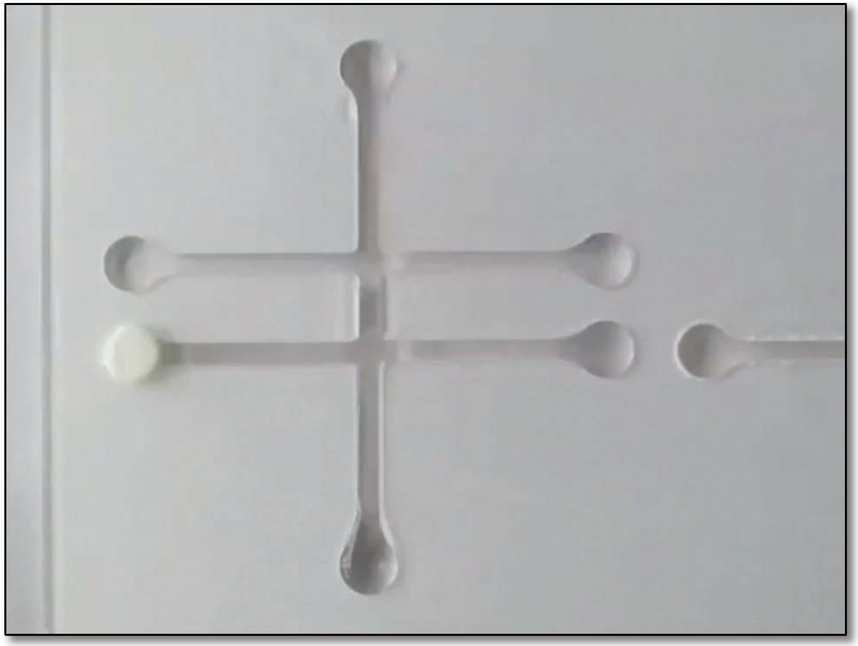
- We use light to create a localised pH gradient
- This disrupts an ion pair at the droplet interface
- Surfactant is expelled and movement of the droplet occurs
- Interested in exploring how to use droplets for sensing and for transport & release of active components

We can do the same with IL Droplets



= cationic surfactant





Trihexyl(tetradecyl)phosphonium chloride ($[P_{6,6,6,14}][Cl]$) droplets with a small amount of 1-(methylamino)anthraquinone red dye for visualization. The droplets spontaneously follow the gradient of the Cl^- ion which is created using a polyacrylamide gel pad soaked in 10^{-2} M HCl; A small amount of NaCl crystals can also be used to drive droplet movement.

Electronic structure calculations and physicochemical experiments quantify the competitive liquid ion association and probe stabilisation effects for nitrobenzospiropyran in phosphonium-based ionic liquids, D. Thompson et al., *Physical Chemistry Chemical Physics*, 2011, 13, 6156-6168.

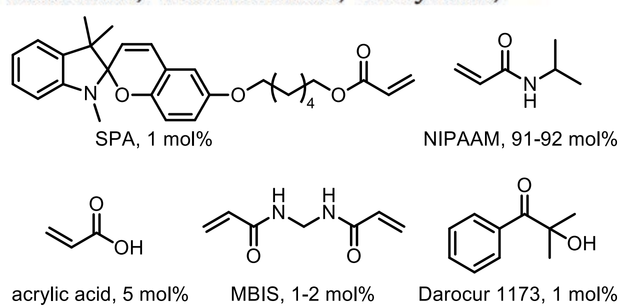
Photocontrol of Assembly and Subsequent Switching of Surface Features

ACS APPLIED MATERIALS & INTERFACES
Research Article
www.acsami.org

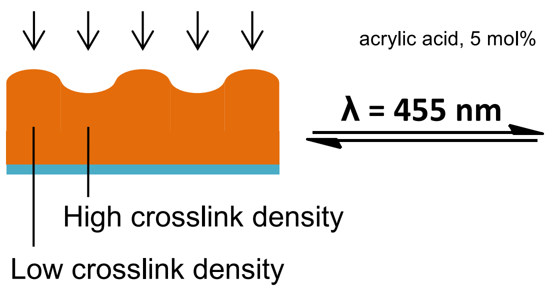
ACS applied materials & interfaces, 6 (2014) 7268-7274

Photoswitchable Ratchet Surface Topographies Based on Self-Protonating Spiropyran–NIPAAM Hydrogels

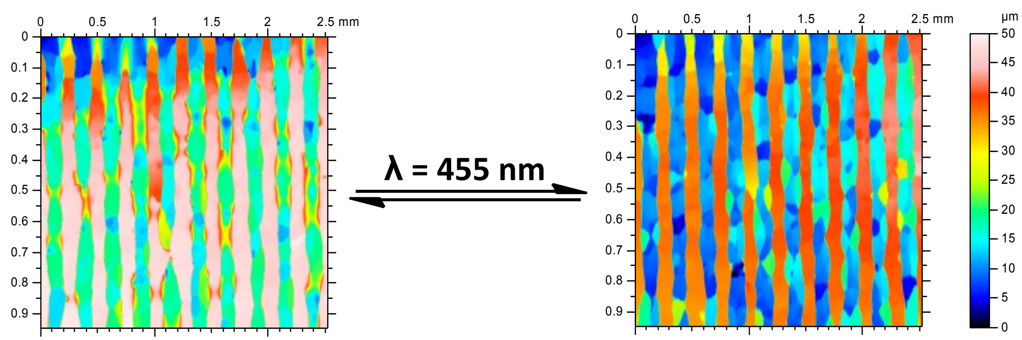
Jelle E. Stumpel,[†] Bartosz Ziółkowski,[‡] Larisa Florea,[‡] Dermot Diamond,[‡] Dirk J. Broer,[*,†,§] and Albertus P. H. J. Schenning[*,†,§]

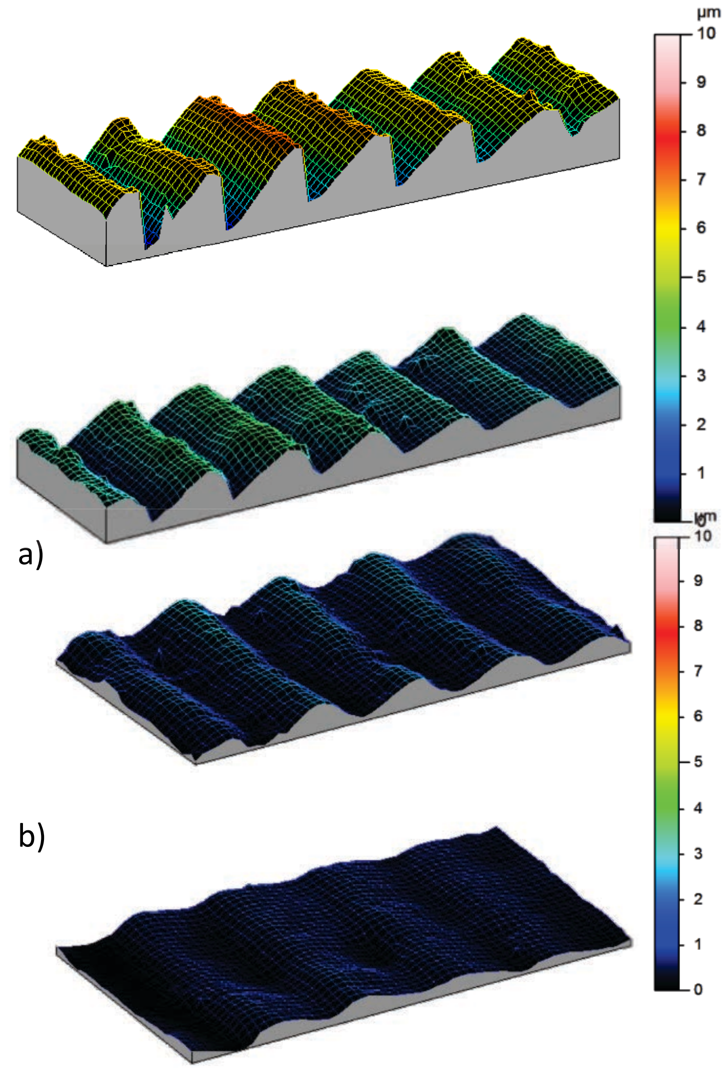


a)

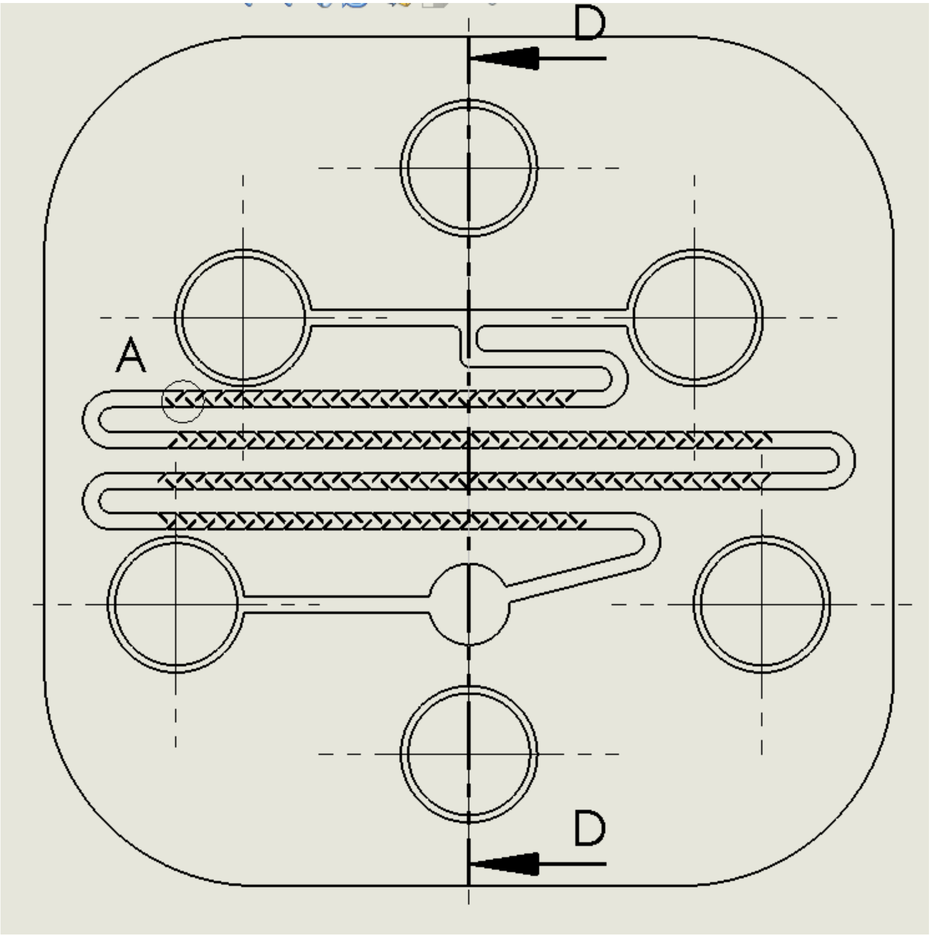


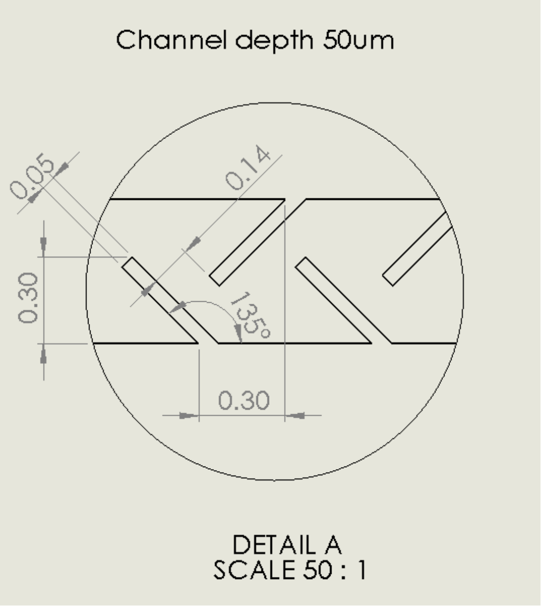
b)

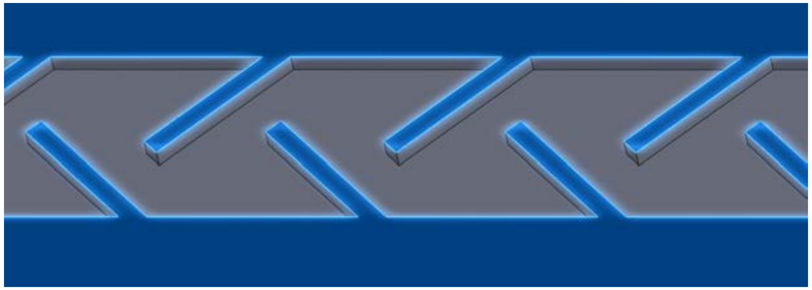




Mixing Baffles

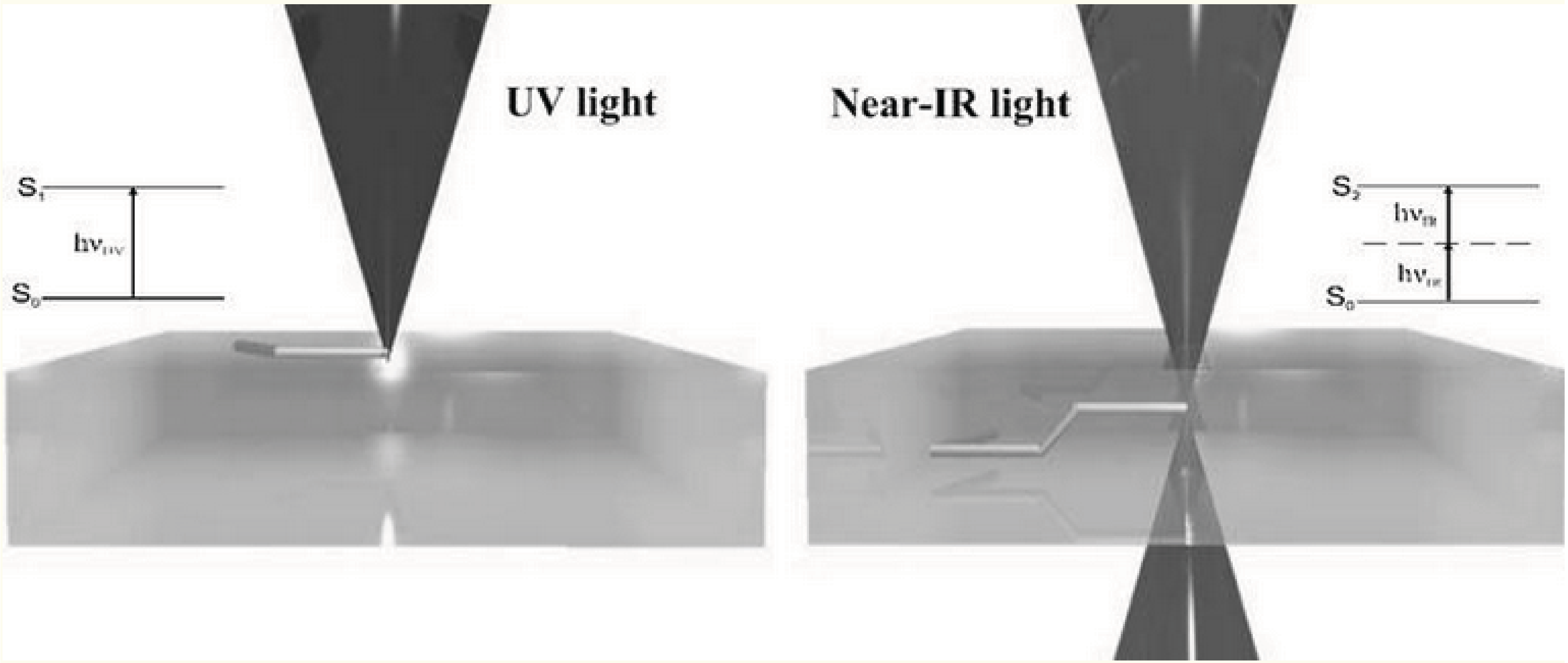






Background

Stereolithography | **Two-photon polymerisation**



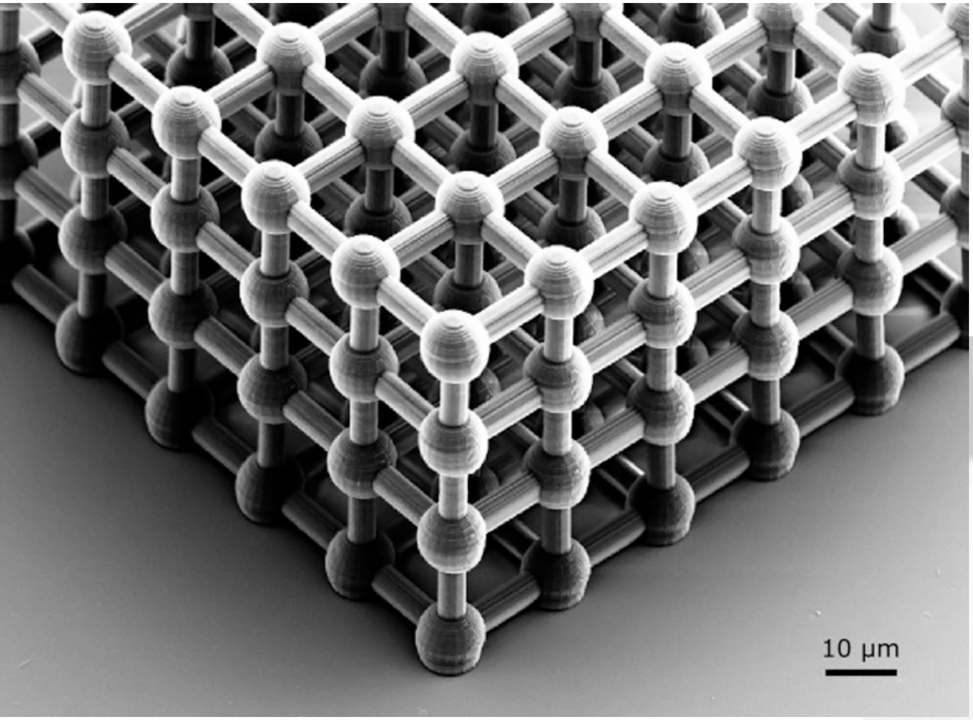
Stereolithography

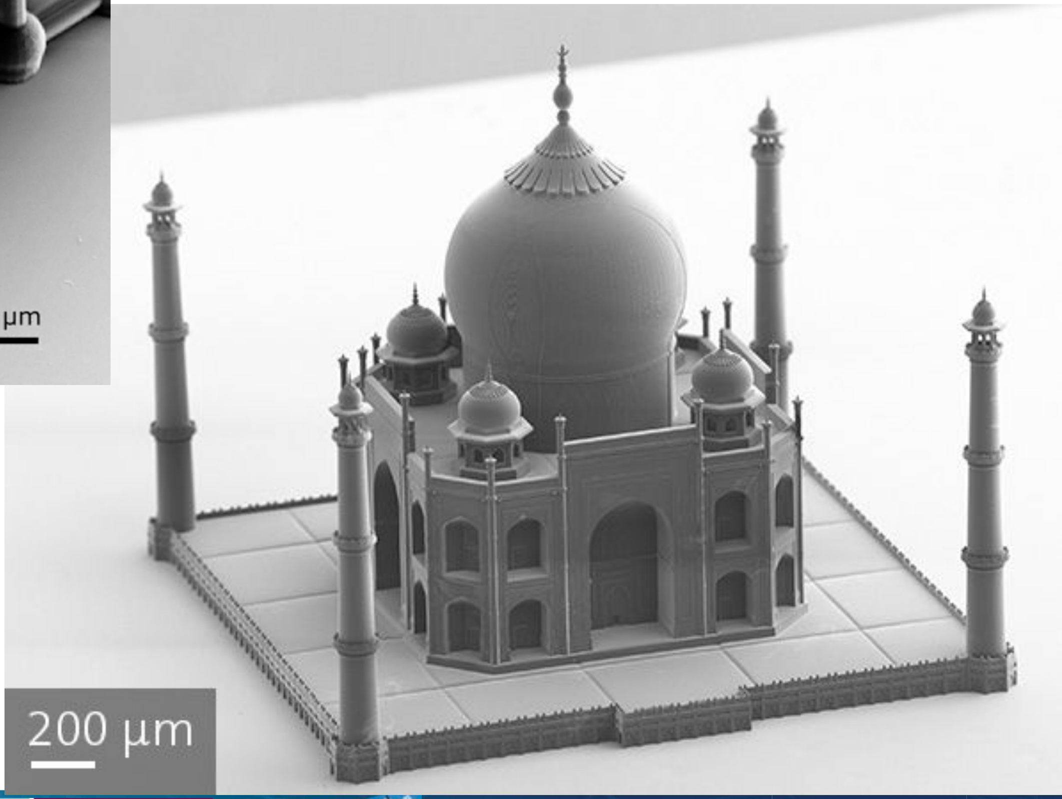
- Single photon absorption
- 2D patterns

Two-photon polymerisation

- Two photon absorption
- 3D structures

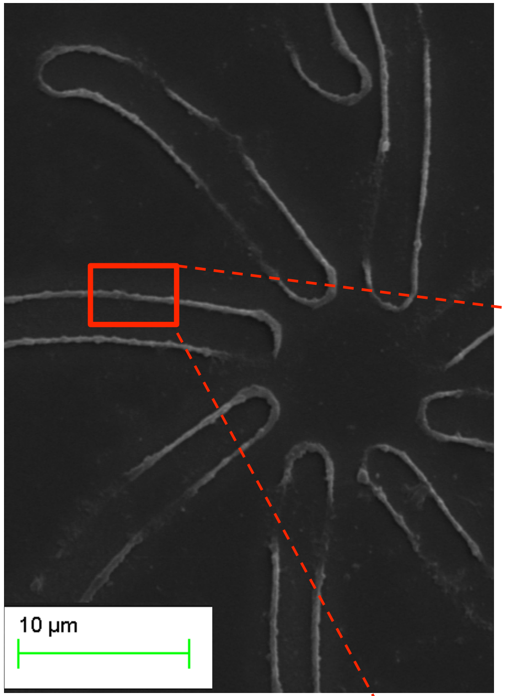
Background

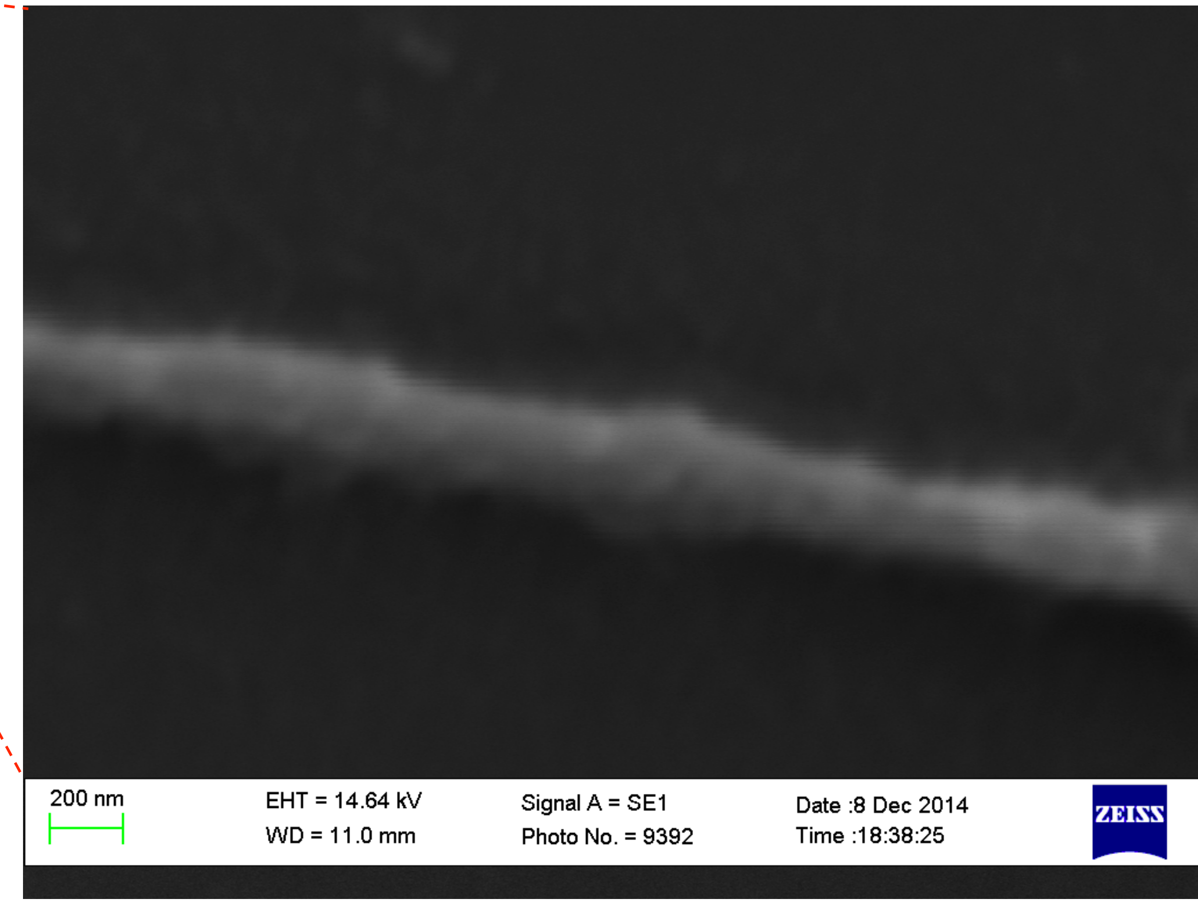




http://www.nanoscribe.de/

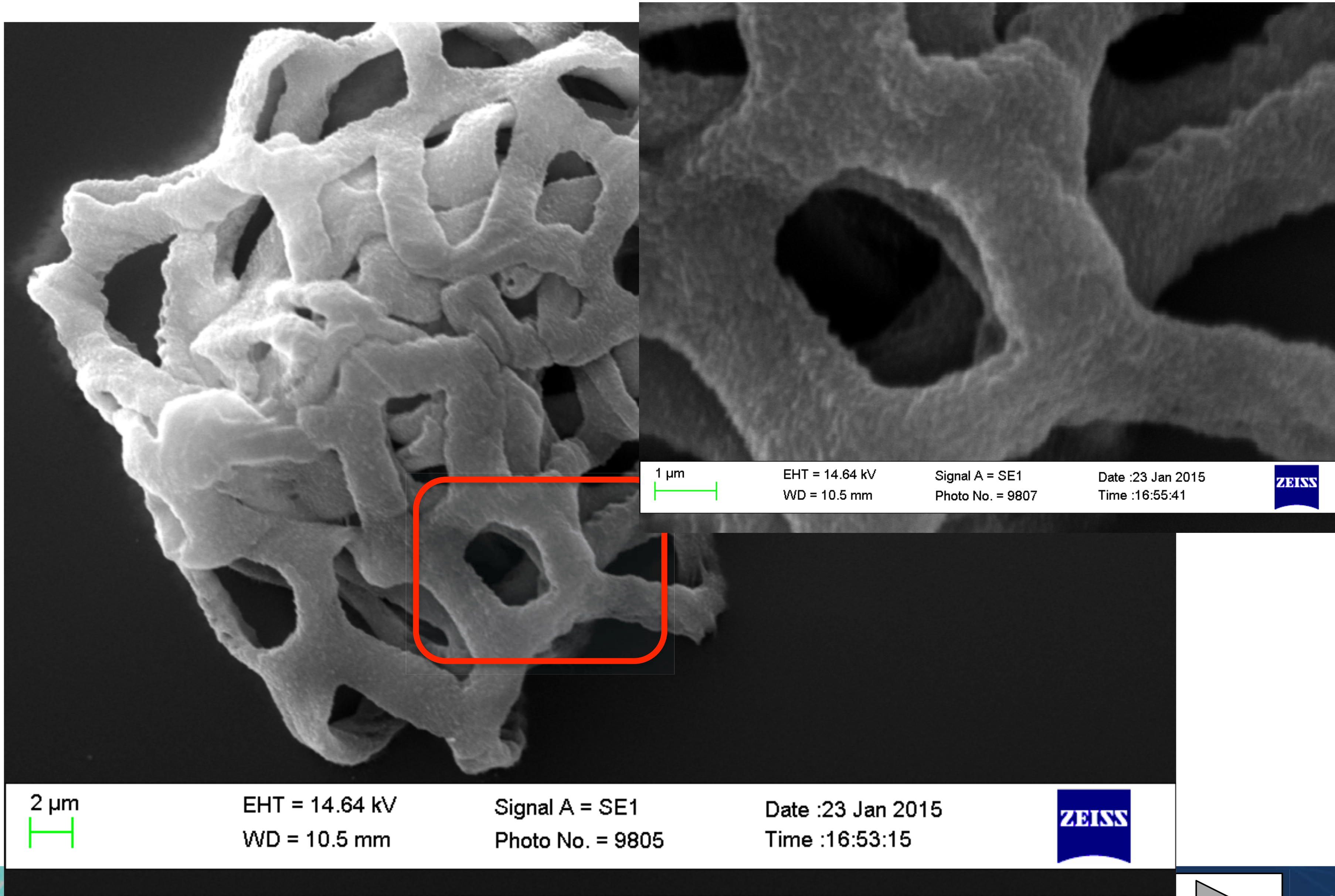
The Exciting Potential of Stimuli-responsive Materials and Biomimetic Microfluidics
Larisa Florea[1], Vincenzo Curto[2], Alexander J. Thompson[2], Guang-Zhong Yang[2], and Dermot Diamond[1]*
[1]Insight Centre for Data Analytics, NCSR, Dublin City University
[2]The Hamlyn Centre for Robotic Surgery, Imperial College London, London, SW7 2AZ
Submitted to Euronanoforum, Riga, Latvia, June 2015



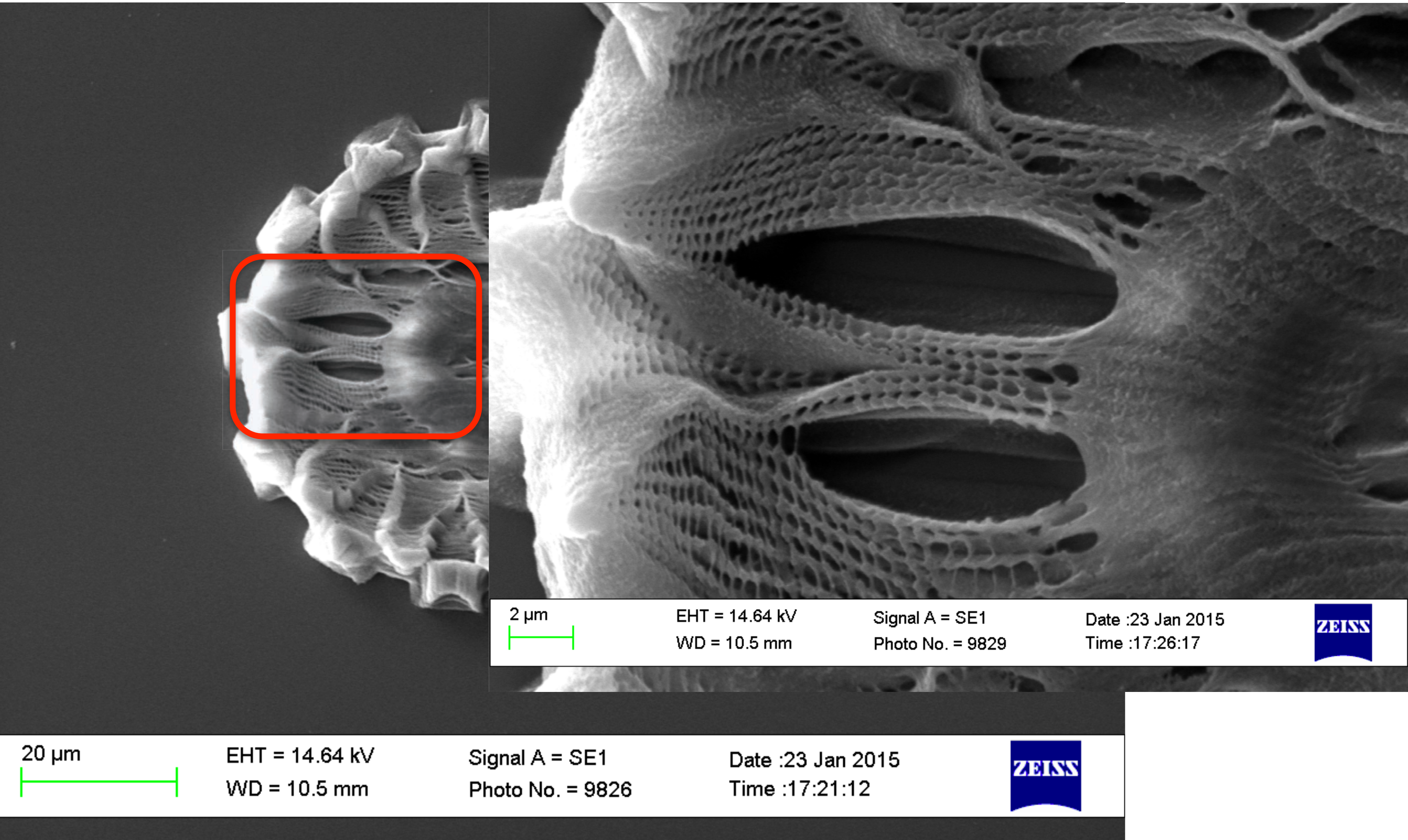


Creating 3D soft gel structures with a line resolution of ca. 200 nm

Globular Porous Structure



'Daisy' – Micro/Nano Scaled Porous Structure




'Micro-Rose'
2 µm
EHT = 14.64 kV
WD = 10.5 mm
Signal A = SE1
Photo No. = 9753
Date :23 Jan 2015
Time :12:31:01
2 µm
EHT = 14.64 kV
WD = 10.5 mm
Signal A = SE1
Photo No. = 9755
Date :23 Jan 2015
Time :12:33:11
'Micro-Stoma'
2 µm
EHT = 14.64 kV
WD = 11.0 mm
Signal A = SE1
Photo No. = 9763
Date :23 Jan 2015
Time :12:39:59
2 µm
EHT = 14.64 kV
WD = 11.0 mm
Signal A = SE1
Photo No. = 9764
Date :23 Jan 2015
Time :12:40:59

Time to re-think the game!!!

- New materials with exciting characteristics and unsurpassed potential…
- Combine with emerging technologies and techniques for exquisite control of 3D morphology
- And greatly improved methods for characterisation of structure and activity

We have the tools – now we need creativity!

Getting it all to Work Together…

Industry Partners

Zero
Concepts
Ideas
Modeling
Thought experiments
Discussions
Workshops

Nano/Micro Fab
2-photon deposition
Molecular self-assembly
Photolithography
3D Printing
Micromachining
Screen/inkjet printing

Materials
Biomaterials
Molecular recognition
Polymers and gels
Stimuli-responsive
Ceramics
Silicon

Macro & Prototyping
3D printing
Industrial design
Mech. Eng.
Electronics
App development
Cloud computing

Characterisation
NMR
X-Ray crystallography
Chromatography
SEM/optical microscopy
Imaging systems
Surface analysis
AFM/STM…..
Impedance spectrscopy
Particle size…..

Application Space
- Personal Health Monitoring
- Environment and water
- Printed electronics
- Food quality & smart packaging
- Medical devices
- Flexible electronics
- Photovoltaics
- Biomimetic systems
- Smart implants
- ………..

Catalysing Social and Economic Impact

Thanks to…..

Thanks for the invitation