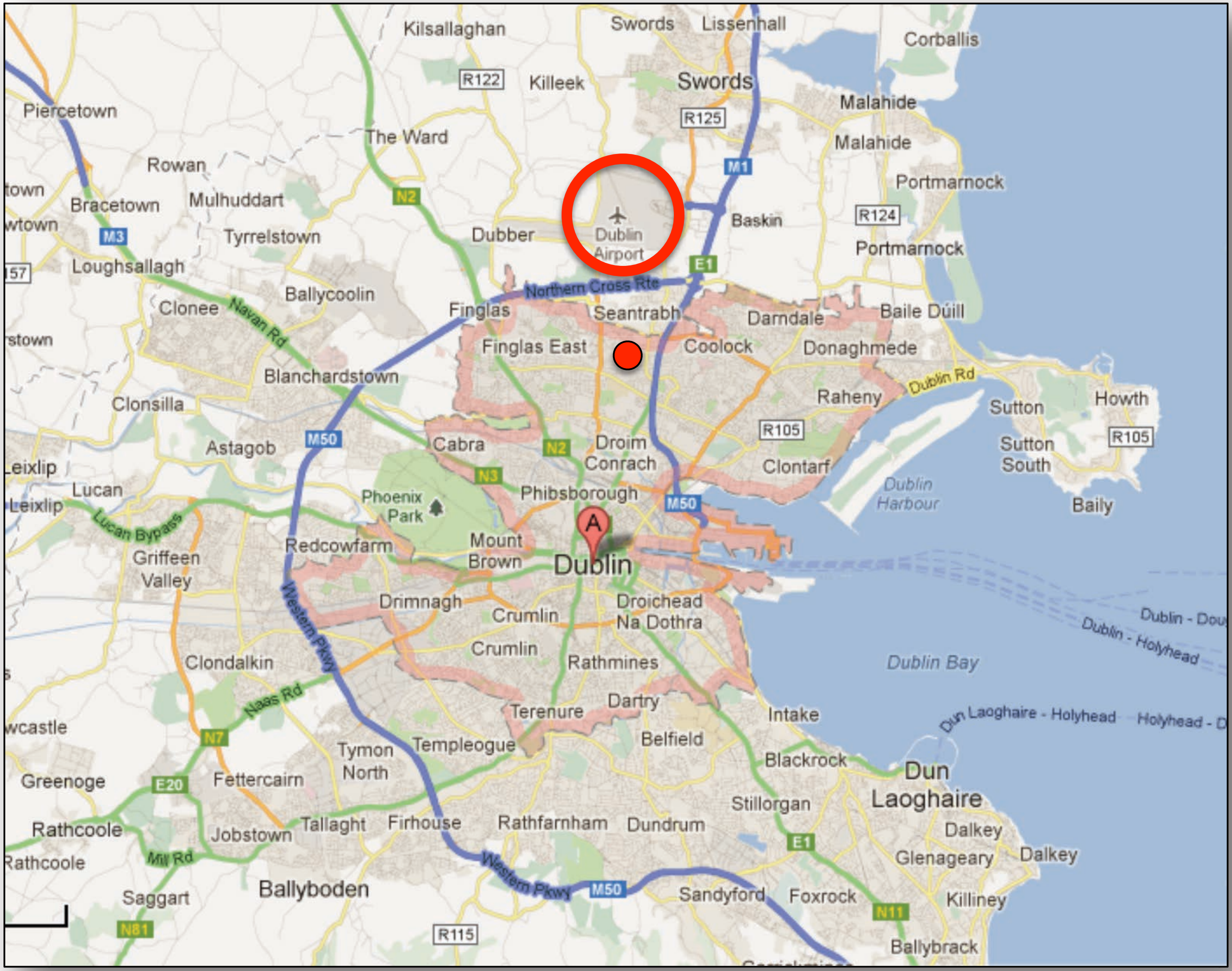
’Monitoring Biochemical Parameters - Diagnostics, Wearables and Implants’

Professor Dermot Diamond
Insight Centre for Data Analytics
National Centre for Sensor Research
Dublin City University

Invited Keynote Lecture Presented at
Neuroengineering Workshop
Weetword Hall
University of Leeds
September 22nd 2015

Dublin & DCU Location



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SFI – Minister Bruton launches €88 million SFI research centre, bringing new insights to Data Analytics

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MINISTER BRUTON LAUNCHES €88 MILLION SFI RESEARCH CENTRE, BRINGING NEW INSIGHTS TO DATA ANALYTICS

- Insight, the Centre for Data Analytics, will position Ireland at the heart of global Data Analytics research

Insight Centre for Data Analytics

- **Biggest single research investment ever by Science Foundation**
- **Biggest coordinated research programme in the history of the state**
- **Focus is on 'big data' related to health informatics and pHealth**

The Centre will receive funding of €58 million from the Department of Jobs, Enterprise and Innovation through SFI's Research Centres Programme, along with a further contribution of €30 million from 30 industry partners. Insight represents a new approach to research and development in Ireland, by connecting the scientific research of Ireland's leading data analytics researchers with the needs of industry and enterprise.

NAPES Consortium

NAPES
NEXT GENERATION ANALYTICAL PLATFORMS FOR ENVIRONMENTAL SENSING

DCU

institutCurie

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UNIVERSITÀ DEGLI STUDI DI MILANO

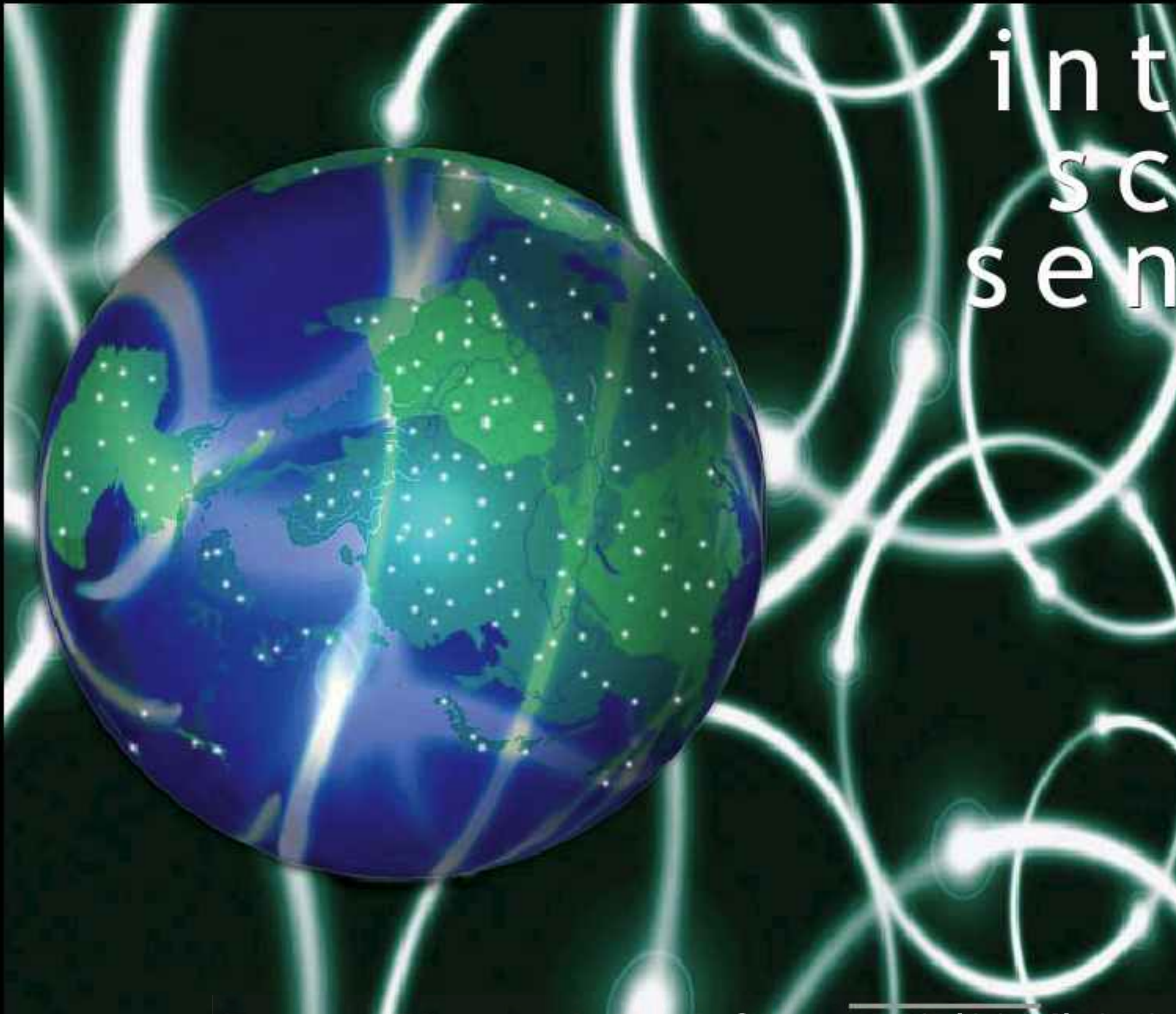
Aquila Bioscience

MARCO BUSCAGLIA & ROBERTA LANFRANCO

Funded under grant agreement No. 604241 of the European Union's Seventh Framework Programme

SEVENTH FRAMEWORK PROGRAMME

Keynote Article: August 2004, Analytical Chemistry (ACS)



internet scale sensing

Dermot Diamond
Dublin City University
(Ireland)

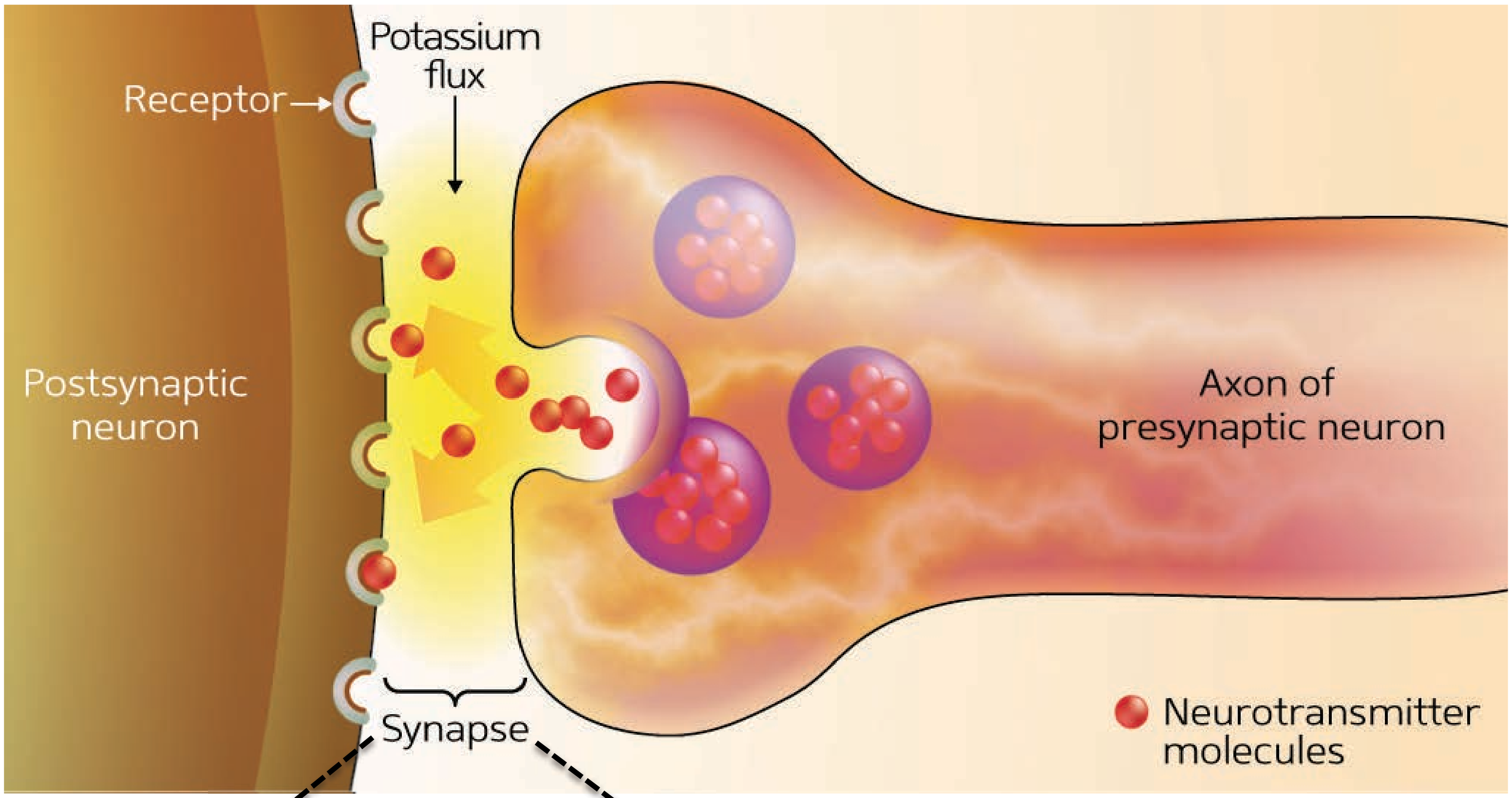
Incredible advances in digital communications and computer power have profoundly changed our lives. One chemist shares his vision of the role of analytical science in the next communications revolution.

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)

Dimensions of a Synapse



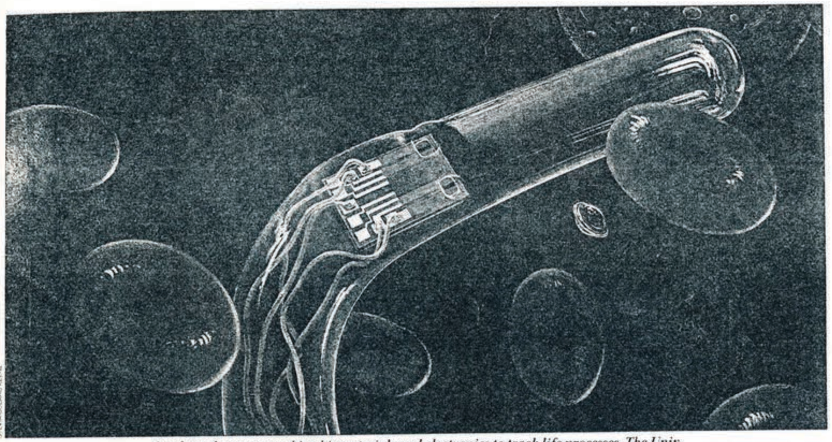
20-40 nanometers

Amplifying communication between neurons,
Riken Research Highlights, January 17, 2014.
http://www.riken.jp/en/research/rikenresearch/highlights/7603

The promise of biosensors…..

BIOSENSORS

THE MATING OF BIOLOGY AND ELECTRONICS



Implanted sensors combine biomaterials and electronics to track life processes. The Univ. of Utah model is a field-effect transistor in which the gate is a membrane and an enzyme.

Sometime within the next three or four years, a physician will insert a centimeter of platinum wire into the bloodstream of a diabetic patient. At its tip will be a barely visible membrane containing a bit of enzyme. Hair-thin wires will lead from the other end of the platinum to an insulin reservoir—a titanium device about the size and shape of a hockey puck—implanted in the patient's abdomen.

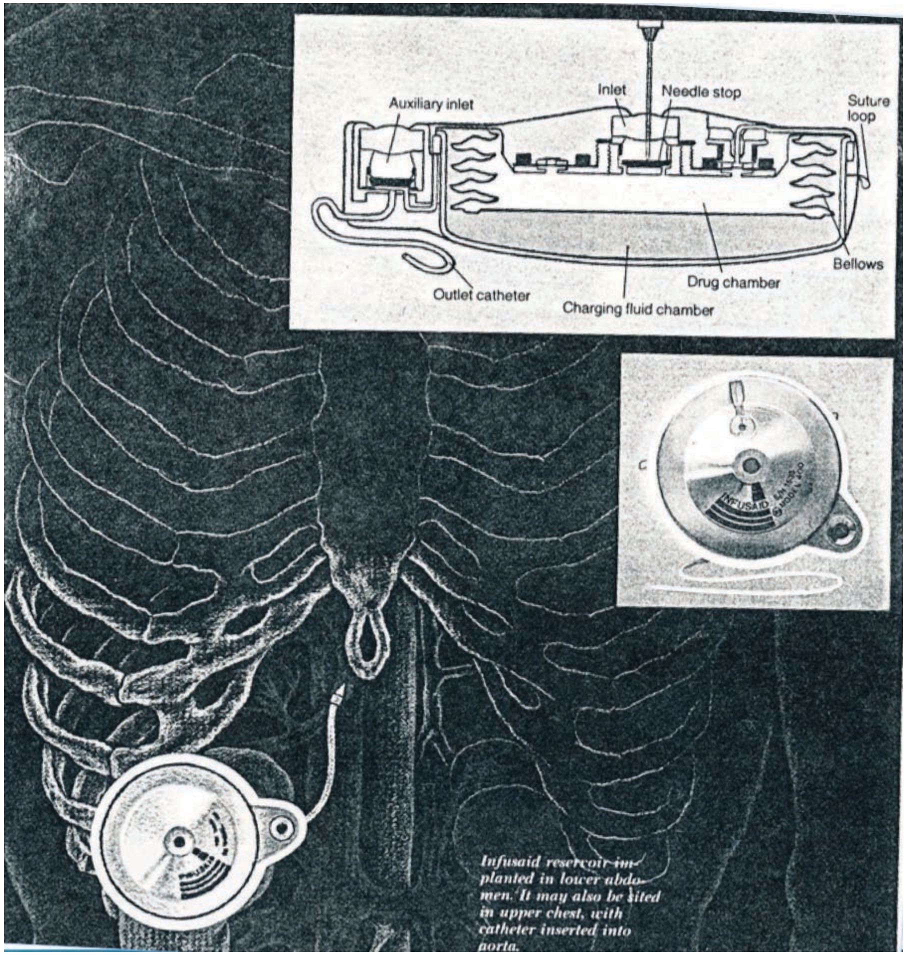
Within seconds a chemical reaction will begin at the tip of the wire. A few molecules of glucose in the blood will adhere to the membrane and be attacked by the enzyme, forming hydrogen peroxide and another product. The peroxide will migrate to a thin oxide layer on the platinum, generating a slight electrical potential between the platinum and a nearby silver wire. The higher the glucose concentration, the higher the peroxide levels and the greater the potential. A current thus generated will signal the insulin reservoir to increase or decrease its flow.

The simple implantable glucose sensor is just one of several experimental biosensors—the promising but still immature offspring of the marriage between biology and electronics. Several new biosensors being readied for market in the U.S., Japan, and England monitor not just one or two but up to eight variables at the same time. Within the next few years, several additional types of biosensors will be providing valuable real-time information about medical treatment, environmental contamination, and industrial processes such as fermentation and chemical production.

Research into biosensor design and application is still in an early stage in the U.S., and sources agree that serious problems must be overcome. Many present devices monitor only a single variable, for example; commercially successful products will have to perform a dozen or more analyses on a surface area of only a few square millimeters.

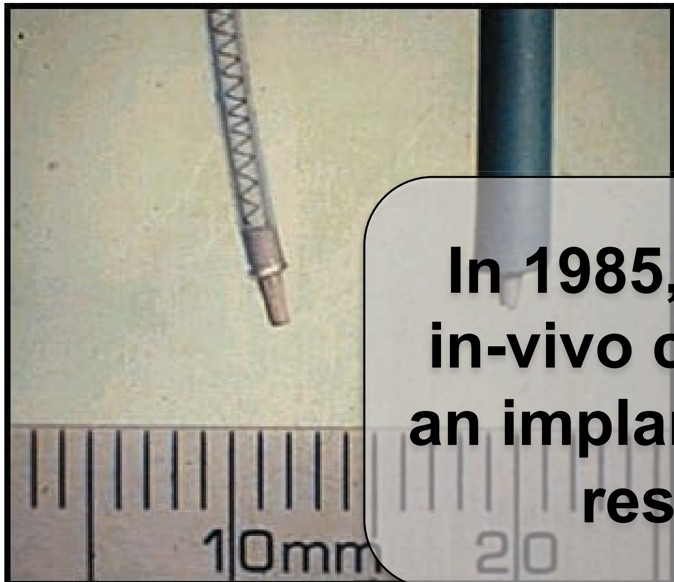
The chemically harsh environment of the human body is another obstacle.

In medicine and industry, tiny high-speed devices will track a wide range of biological reactions □ by H. Garrett DeYoung



High Technology, Nov. 1983, 41-49

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

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

Dr. David Band, St Thomas's Hospital London

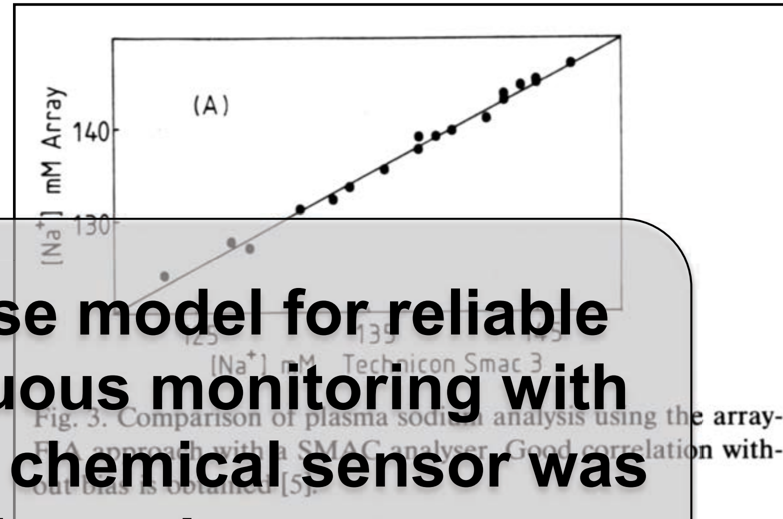
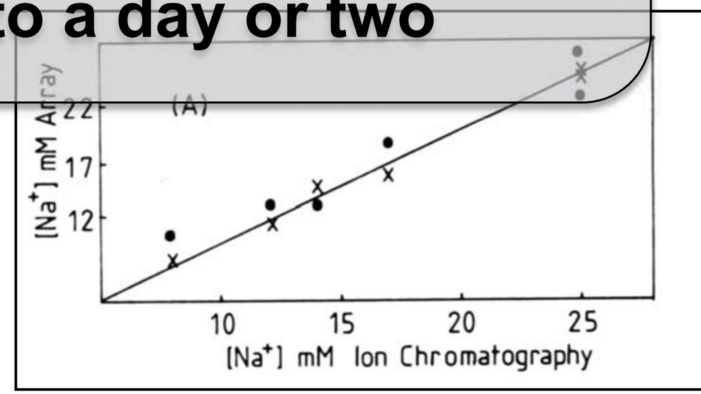


Fig. 3. Comparison of plasma sodium analysis using the array-FIA approach with a SMAC analyser. Good correlation without bias is obtained [5].



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

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

Artificial Pancreas

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

Used a Technicon segmented flow colorimetric glucose analyser

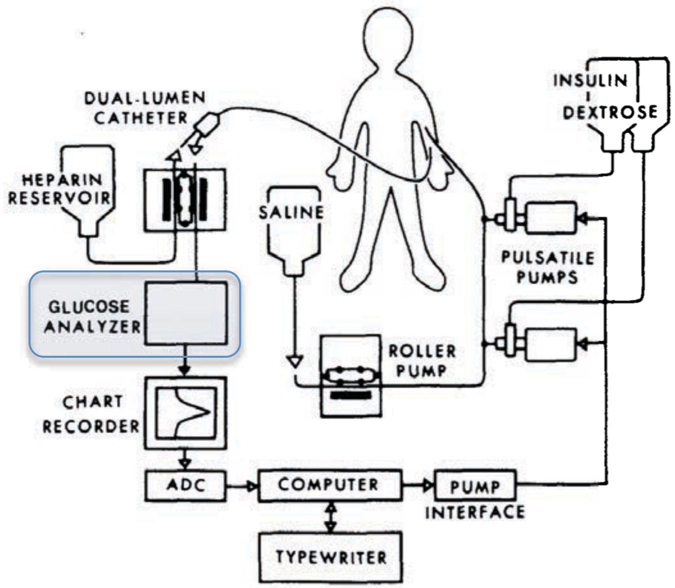
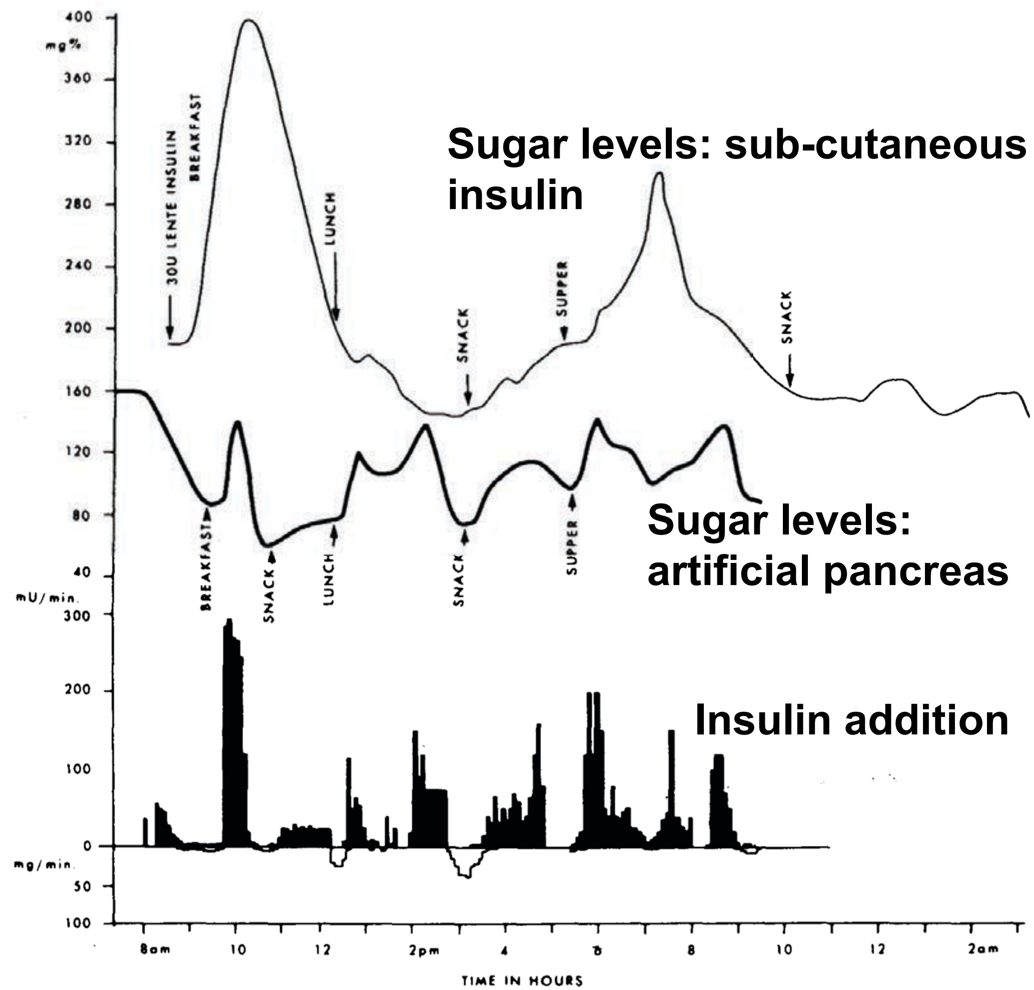


FIG. 1. Schematic diagram of apparatus used for monitoring and automatic regulation of blood sugar.



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**'

μ-TAS: The Original Concept

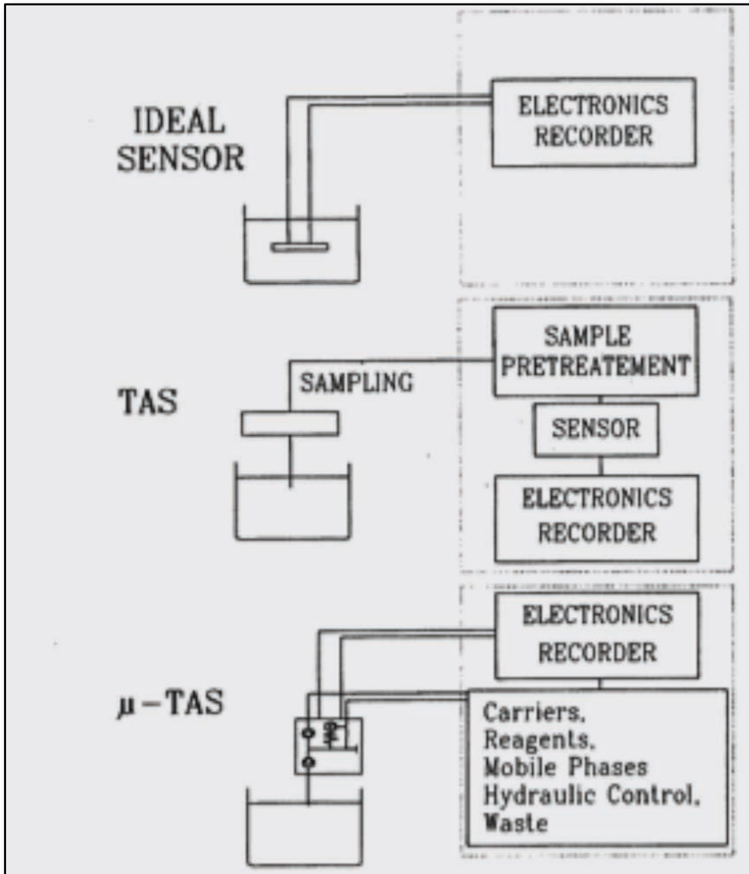


Fig. 3. Schematic diagram of an ideal chemical sensor, a 'total chemical analysis system' (TAS) and a miniaturized TAS (μ-TAS).

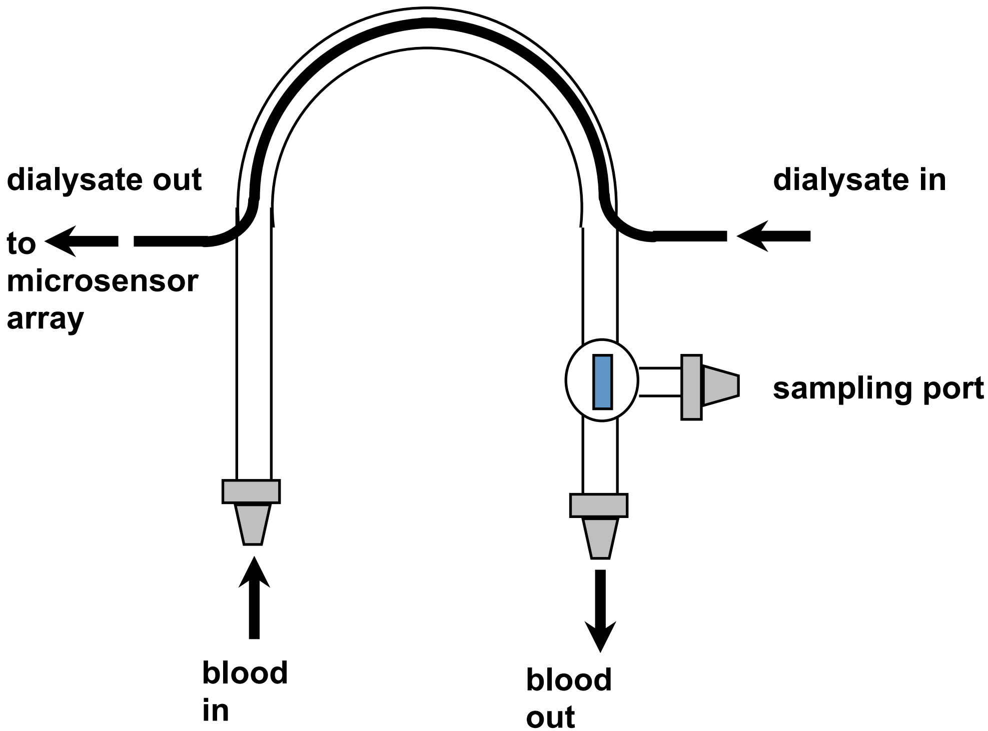
Integrate all operations required to obtain an analytical measurement

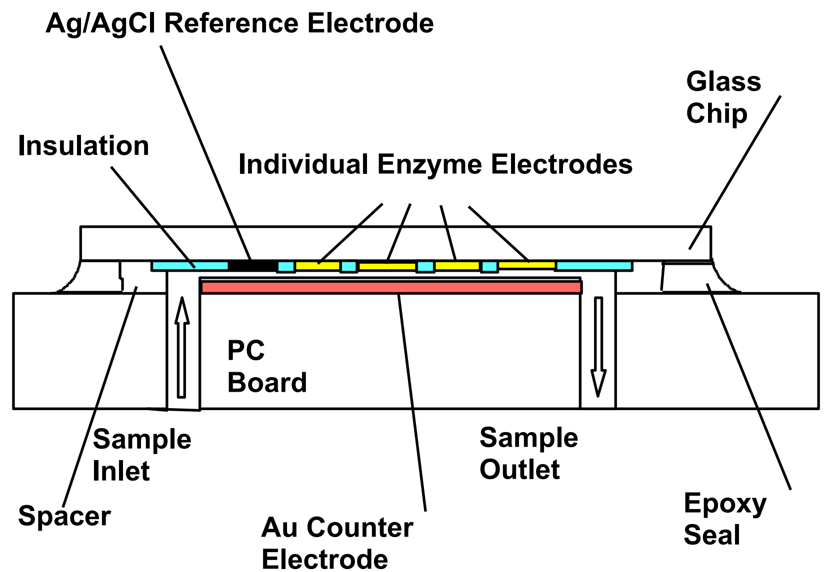
- Take samples
- Add reagents
- Process samples
- Perform analysis
- Perform calibrations

Microdimensioned channels leads to dramatic reductions in reagent consumption, waste generation, energy demand, sample turnaround….

Miniaturized Total Chemical Analysis Systems: A Novel Concept for Chemical Sensing; A Manz, N. Graber and H.M. Widmer, Sens. Actuator, B1 (1990) 244-248.

Microdialysis sampling via arterio-venus shunt



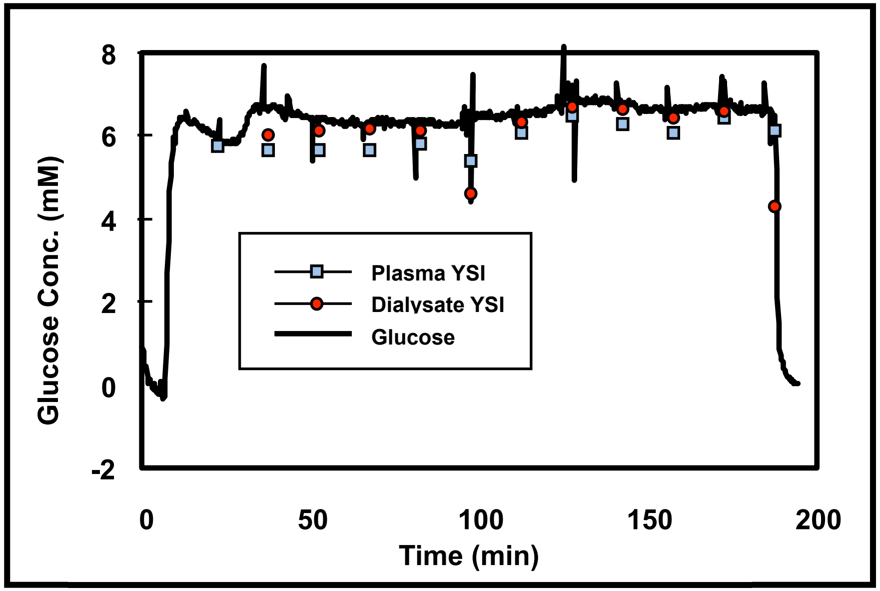


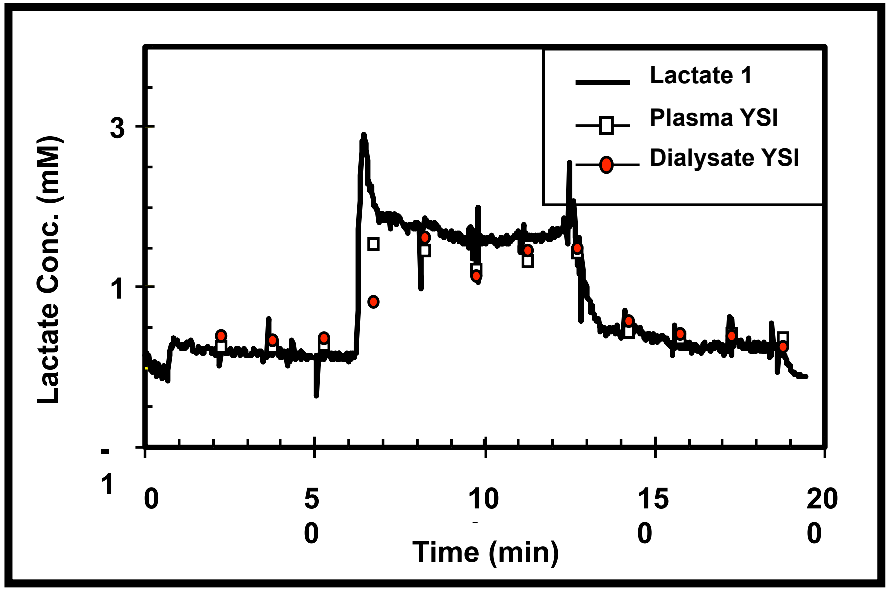
Novel Instrumentation for Real-Time Monitoring Using Miniaturised Flow Cells with Integrated Biosensors, R. Freaney, A. McShane, T.V. Keavney, M.McKenna, K. Rabenstein, F.W. Scheller, D. Pfeiffer, G. Urban, I. Moser, G. Jobst, A. Manz, E. Verpoorte, M.W. Widmer, D. Diamond, E. Dempsey, F.J. Saez de Viteri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

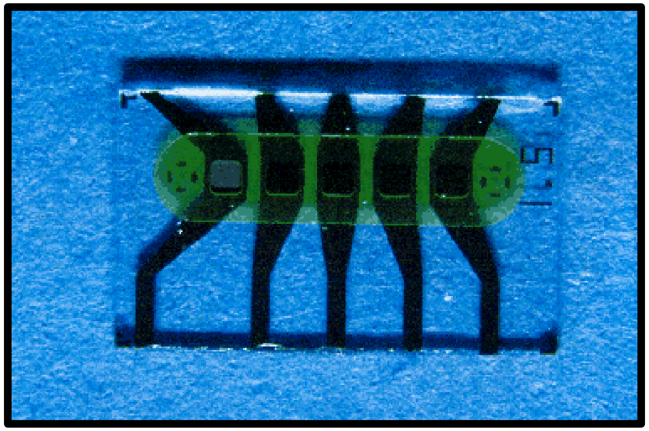
In Vitro Optimisation of a Microdialysis System with Potential for On-Line Monitoring of Lactate and Glucose in Biological Samples, E. Dempsey, D. Diamond, M.R. Smyth, M. Malone, K. Rabenstein, A. McShane, M.McKenna, T.V. Keavney and R Freaney, Analyst, 122 (1997) 185-189.

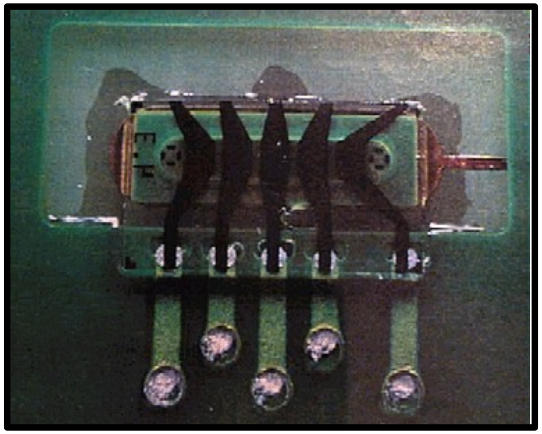
Design and Development of a Miniaturized Total Chemical-Analysis System for Online Lactate and Glucose Monitoring in Biological Samples, Ethna Dempsey, Dermot Diamond, Malcolm R. Smyth, Gerald Urban, Gerhart Jobst, I. Moser, Elizabeth MJ Verpoorte, Andreas Manz, HM Widmer, Kai Rabenstein and Rosemarie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

Real Time Blood Glucose and Lactate









System functioned continuously for up to three hours!

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

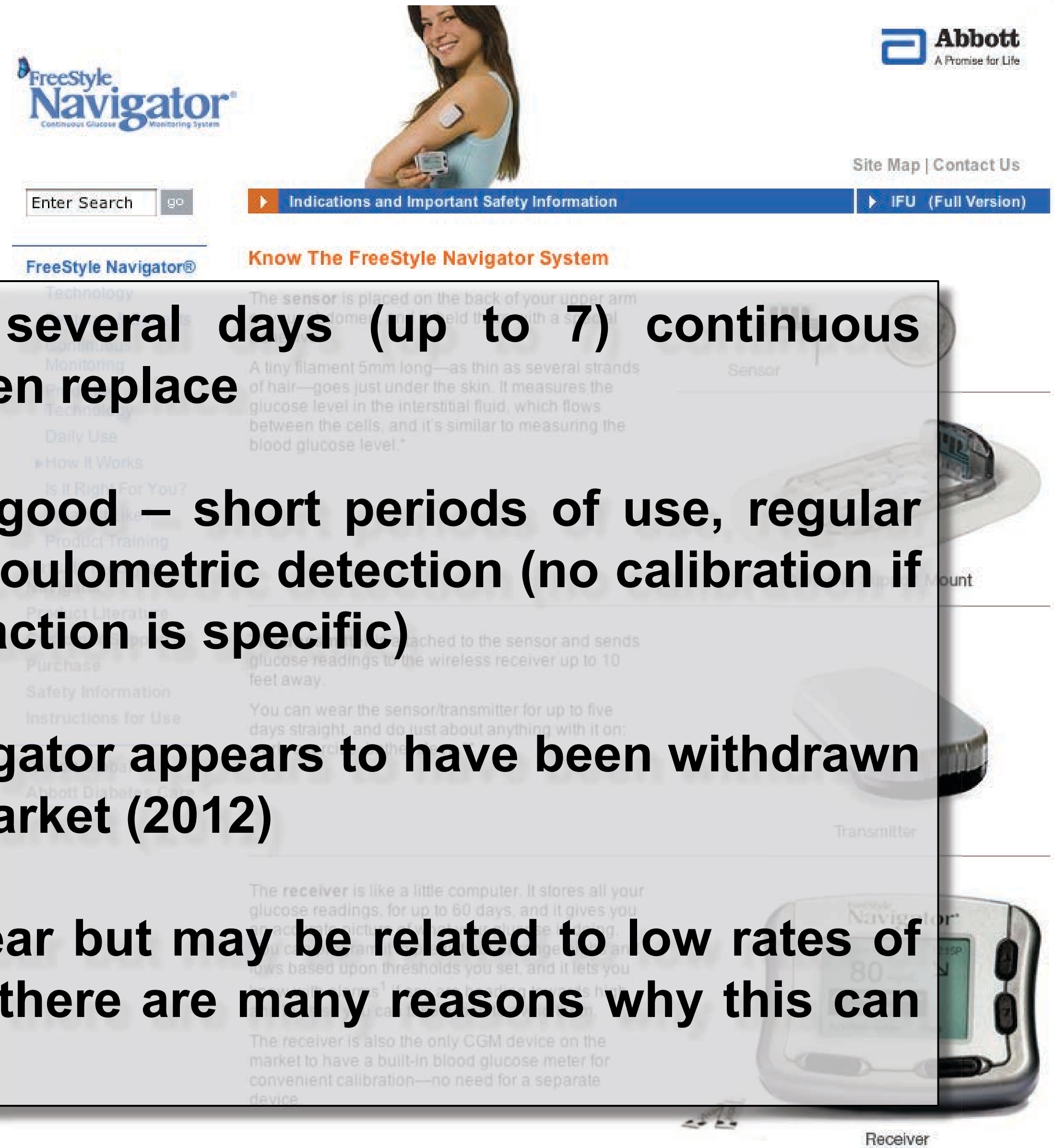
'Abbott completes TheraSense acquisition'

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 designe... 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 t... advance.
- Wireless communications used to ha... 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

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.

How will they integrate biosensing with the iWatch….?

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.**

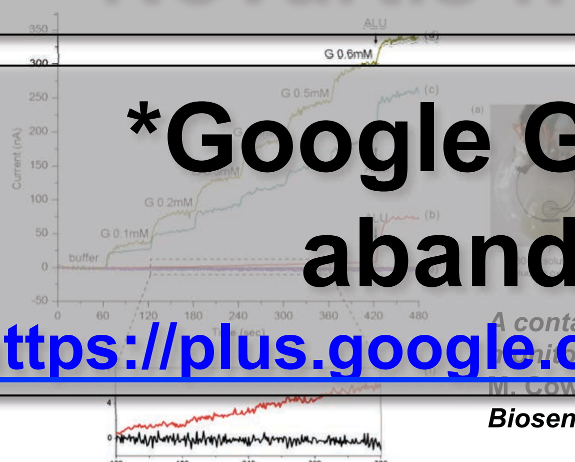


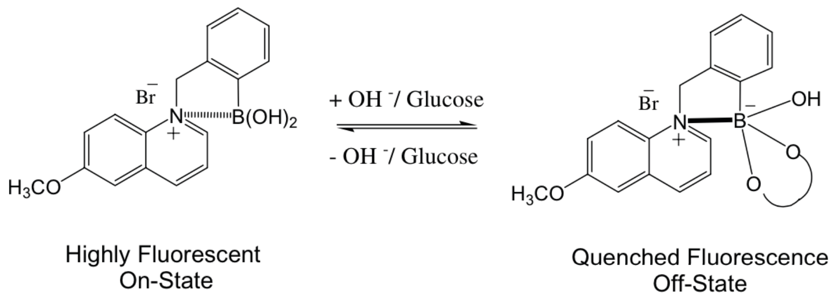
Fig. 2. Images of the sensor as it goes through surface functionalization and the related measured responses: (a) sequential images of sensor pre-treatment with GOD/titania/Nafion®; (b) measured amperometric response for the sensor just incubated with GOD; (c) measured amperometric response for the sensor prepared with GOD/titania/Nafion®; (d) measured amperometric response for the sensor prepared with GOD/titania sol–gel film; (d) measured amperometric response for the sensor prepared with GOD/titania/Nafion®; (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.

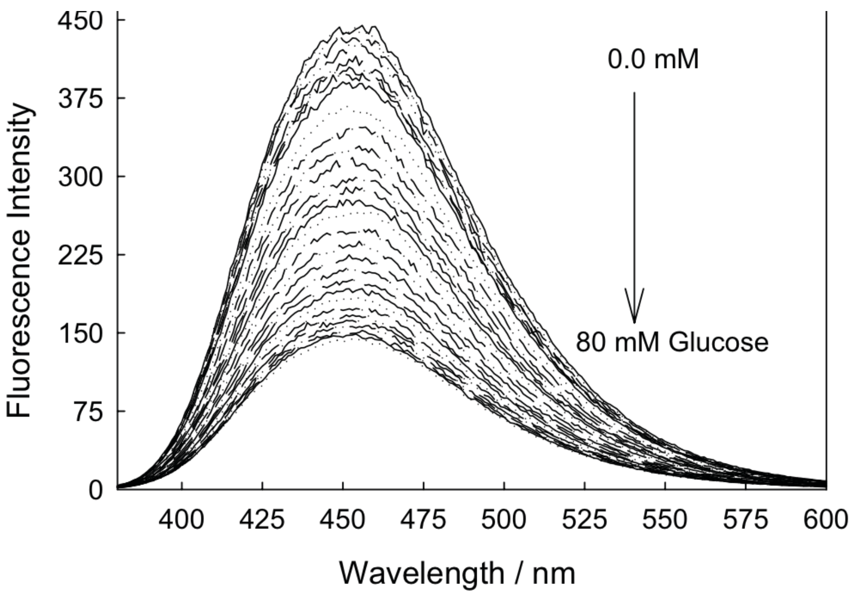
***Google Glass project has been abandoned! (Jan 15 2015) see https://plus.google.com/+GoogleGlass/posts/9uiwXY42tvc**

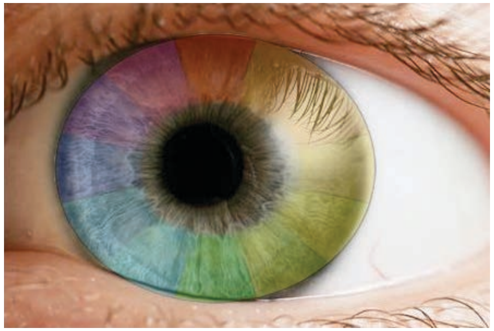
A contact lens with embedded sensor for monitoring tear glucose level, M. Cowan, I. Landesmaki and B. A. Parviz, ***Biosensors & Bioelectronics*, 2011, 26**, 3290-3296.

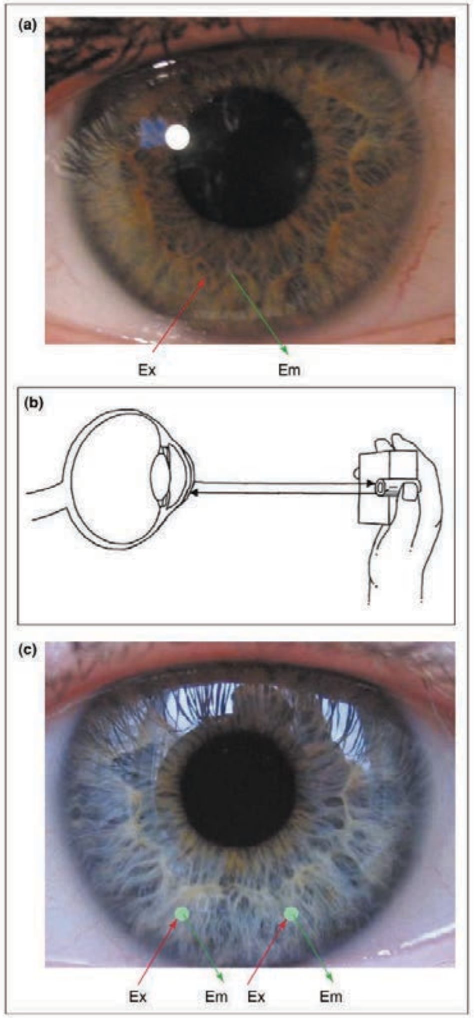
http://www.gmanetwork.com/news/story/360331/scitech/technology/google-s-smart-contact-lenses-may-arrive-sooner-than-you-think

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.

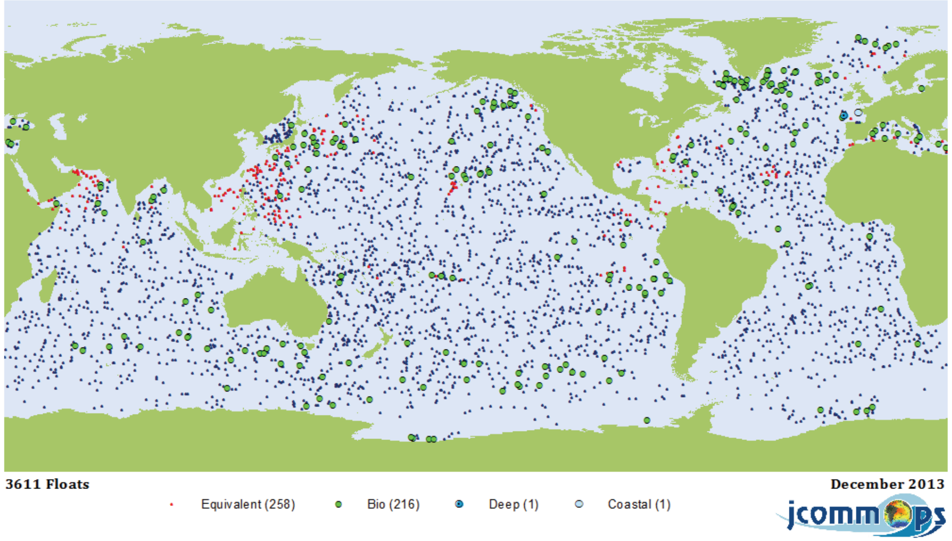
[2] Jin Zhang*, William Hodge, Cindy Hutnick, and Xianbin Wang, "Non-invasive diagnostic technology for diabetes through monitoring ocular glucose", J. Diabetes Sci. Tech. 5,166, (2011)

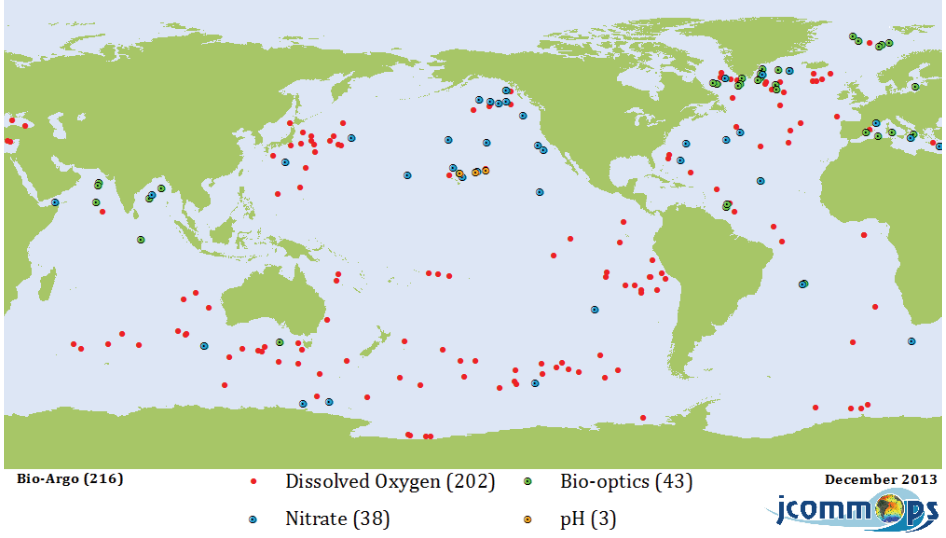
After decades of intensive research, our capacity to deliver chemo/bio-sensors capable of long-term autonomous use for in-vivo monitoring is still very limited.

Blood is by far the best diagnostic medium, but no chem/bio-sensor will function acceptably for more than a few days continuous exposure to blood without calibration.

The trend is to try and measure key markers from outside or from peripheral locations.

Argo Project (accessed March 9 2014)





- **Ca. 3,600 floats: temperature and salinity**
- **Only 216 reporting chem/bio parameters (ca. 6%)**
- **Of these nitrate (38), DO (202), Bio-optics (43), pH (3)**

@€60K ea!

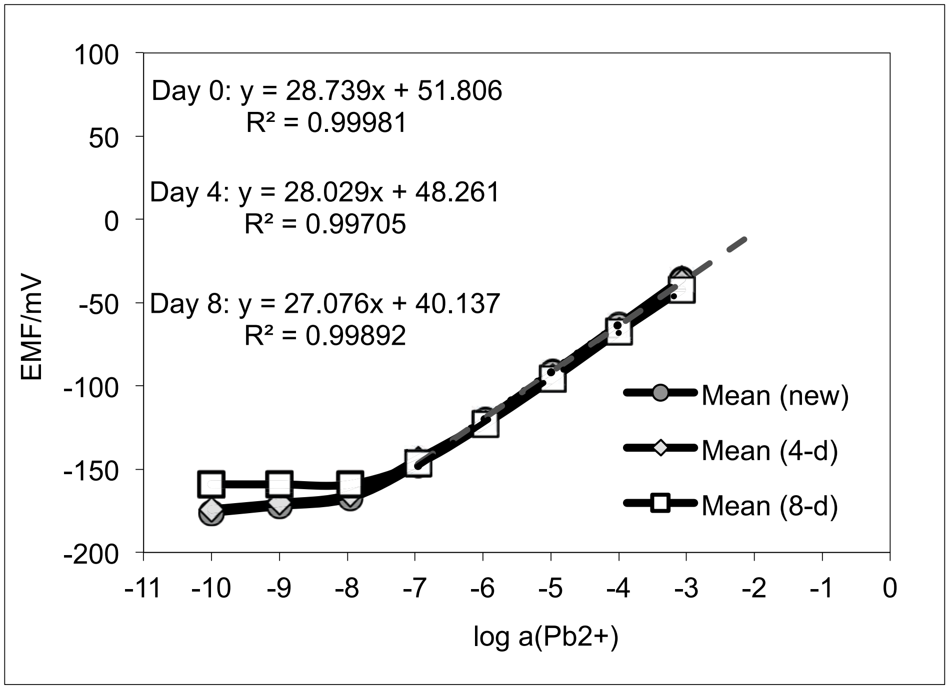
DO is by Clark Cell (Sea Bird Electronics) or Dynamic fluorescence quenching (Aanderaa)

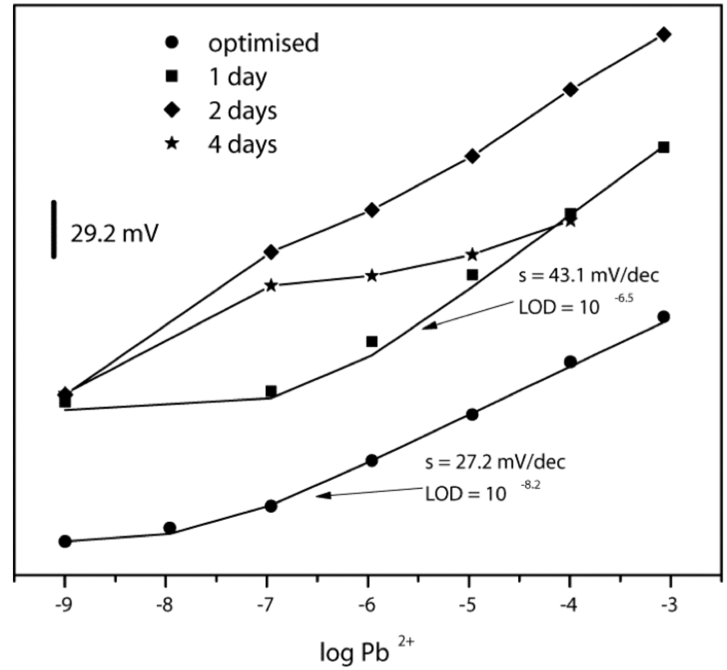
See https://picasaweb.google.com/JCOMMOPS/ArgoMaps?authuser=0&feat=embedwebsite

‘calibration of the DO measurements by the SBE sensor remains an important issue for the future’, Argo report ‘Processing Argo OXYGEN data at the DAC level’, September 6, 2009, V. Thierry, D. Gilbert, T. Kobayashi

Change in Electrode Function over Time

See Electrochimica Acta 73 (2012) 93–97



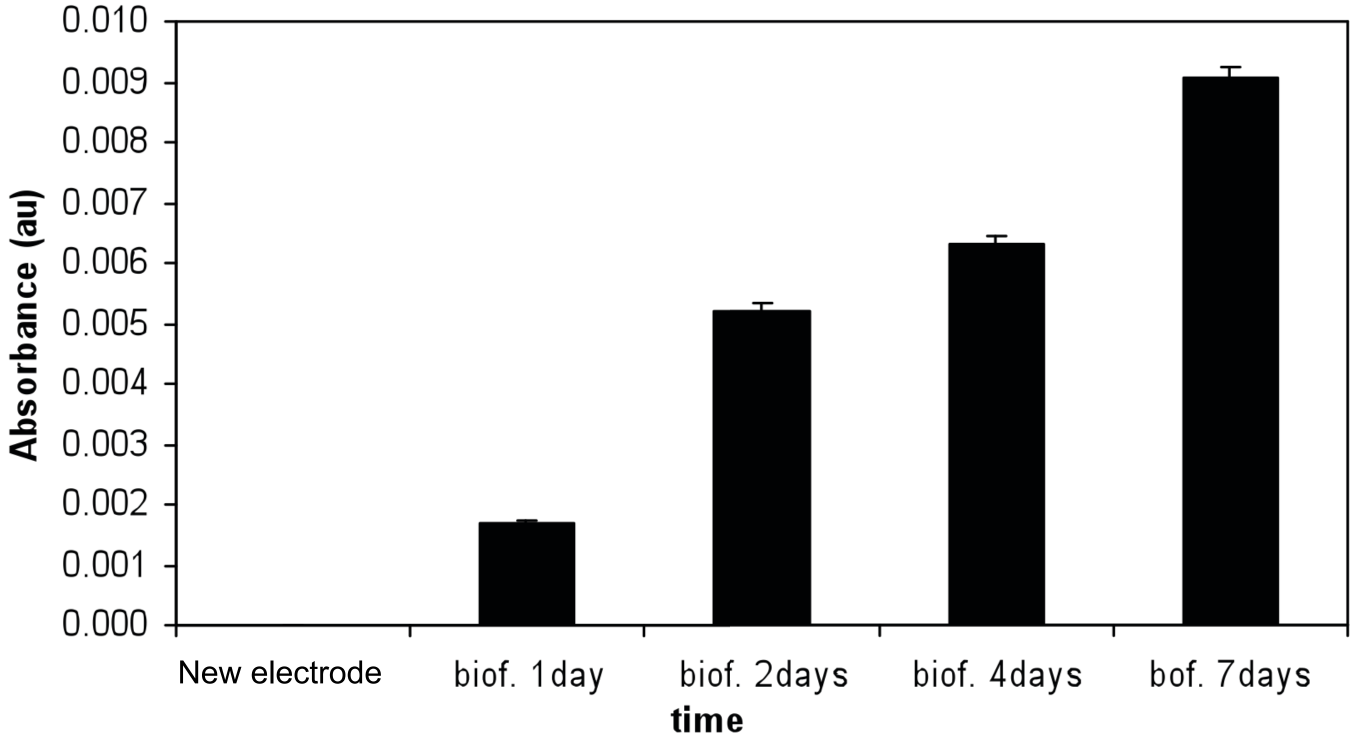


stored in 10^{-9}M Pb^{2+}, pH=4

Continuous contact with river water

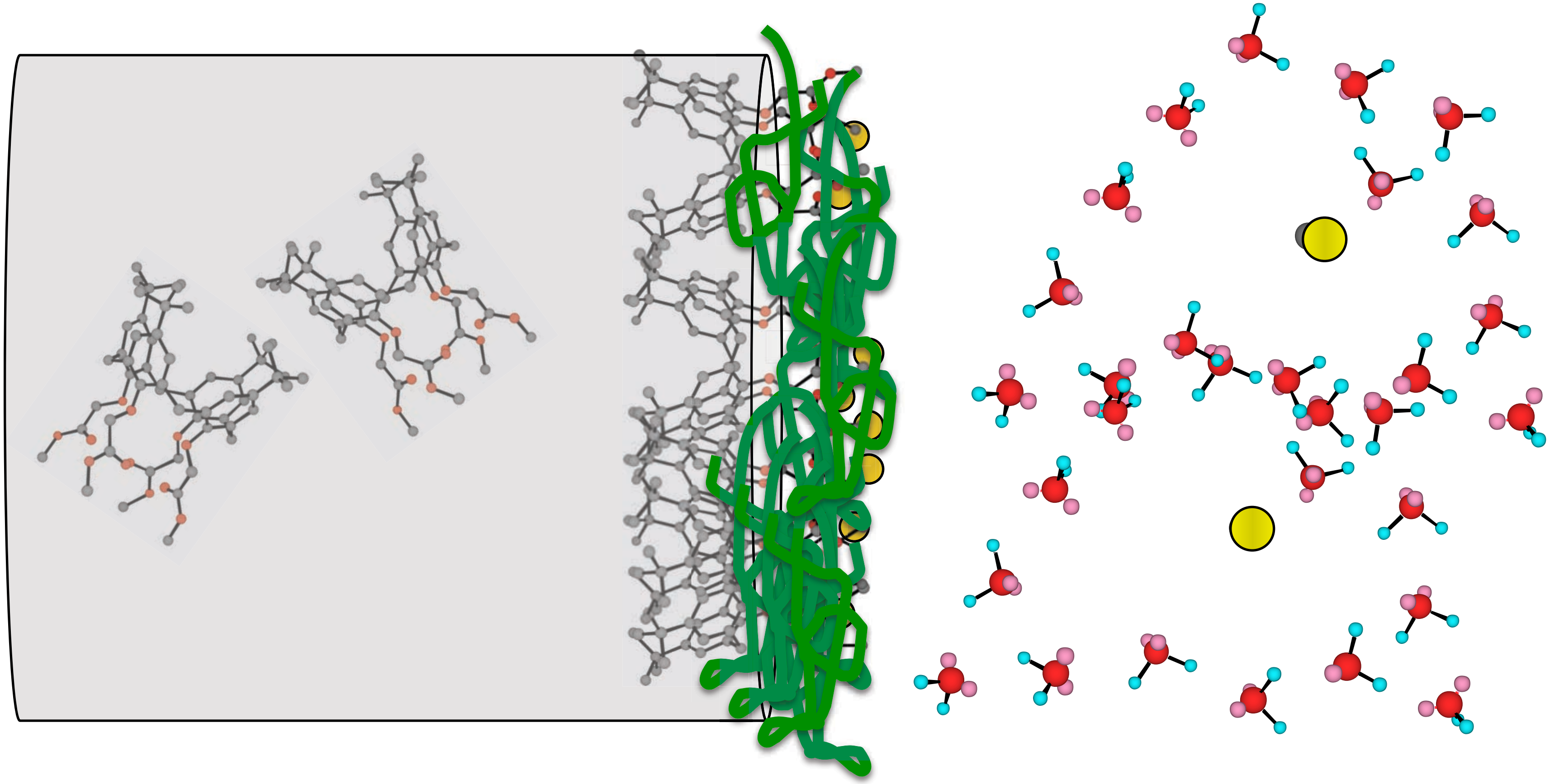
PVC-membrane based ISEs

Biofilm Formation on Sensors



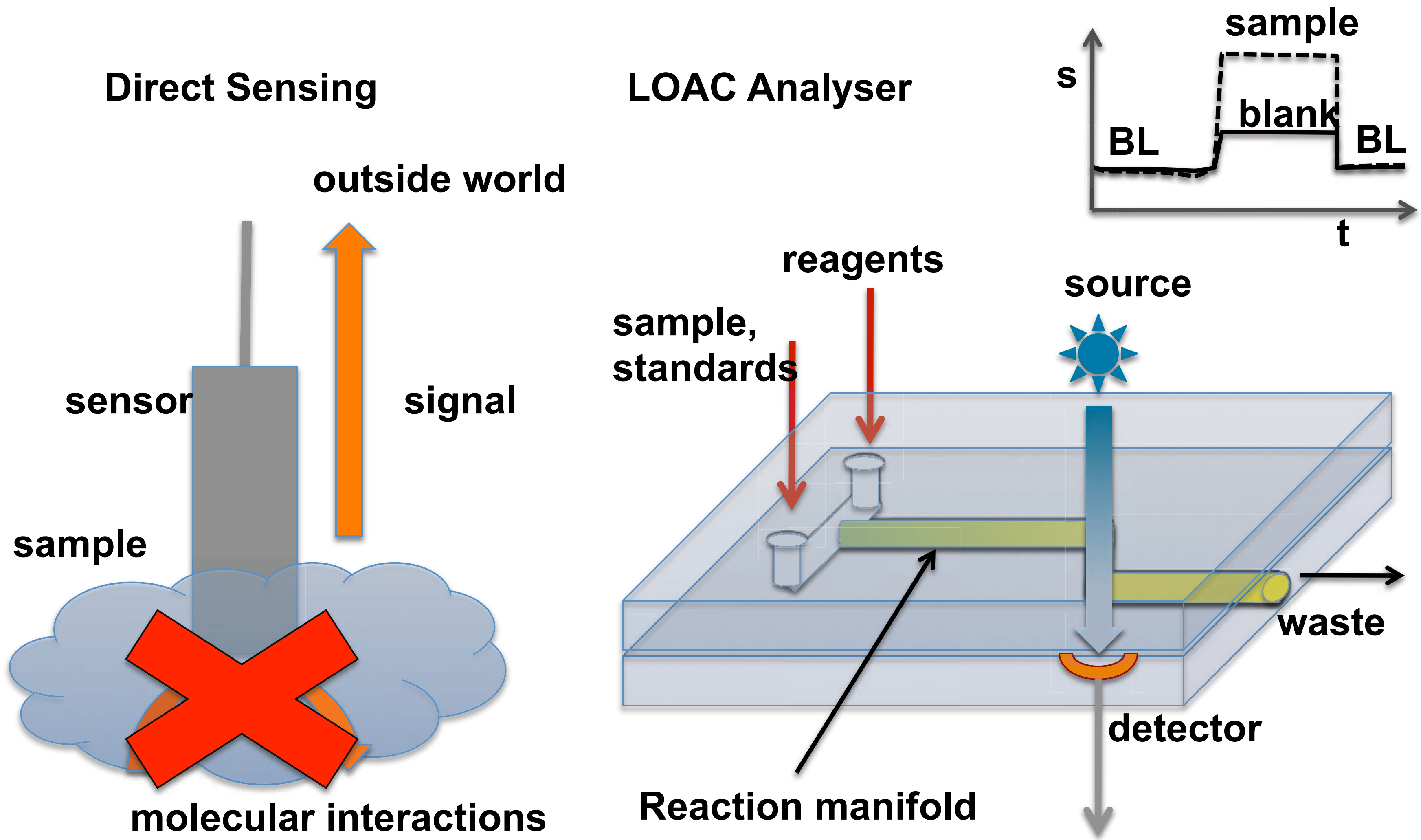
- **Electrodes exposed to local river water (Tolka)**
- **'Slime test' shows biofilm formation happens almost immediately and grows rapidly**

Control of membrane interfacial exchange & binding processes



Remote, autonomous chemical sensing is a tricky business!

Direct Sensing vs. Reagent Based LOAC/ufluidics



Many people, myself included, expected that the ability to manipulate fluid streams, in microchannels, easily, would result in a proliferation of commercial LoC systems, and that we would see applications of these devices proliferating throughout science. In fact, it has not (yet) happened.

Microfluidics, to date, has been largely focused on the development of science and technology, and on scientific papers, <u>rather than on the solution of problems</u>

Editorial 'Solving Problems', George Whitesides, Lab Chip 10 (2010) 2317-2318

Phosphate: The Yellow Method

Mixture (Reagent)

$(NH_4VO_3) + (NH_4)_6Mo_7O_{24}.4H_2O$, HCl conc.

\+

Sample

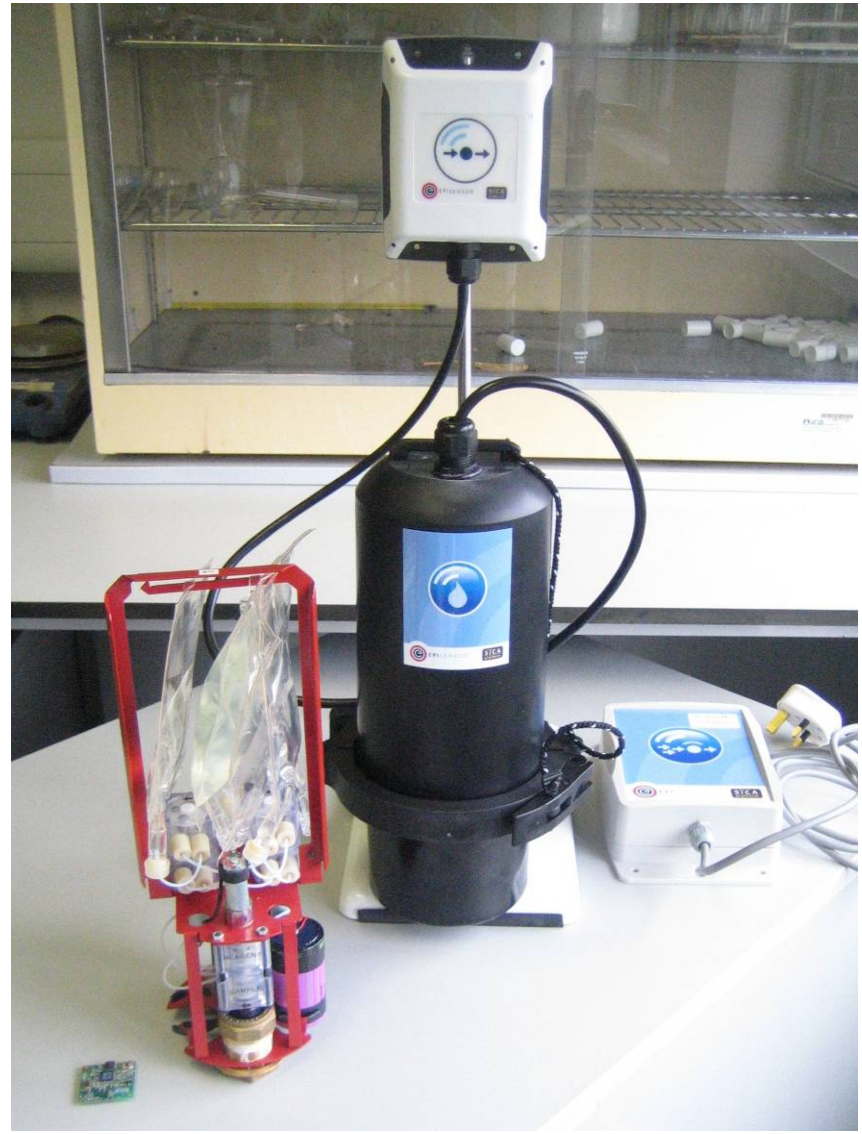
$H_2PO_4^-$

$(NH_4)_3PO_4.NH_4VO_3.16MoO_3$

- Yellow vanaomolybdophosphoric acid is formed when ammonium metavanadate and ammonium molybdate (mixture) reacts with phosphate (acidic conditions)
- In conventional (molybdate) method, **ascorbic acid** is used to generate the well-known deep blue complex (**v. fine precipitate**)
- **Could not be exploited in LOAC devices until UV-LEDs became available!!!!**

2nd Generation Analyser: Design

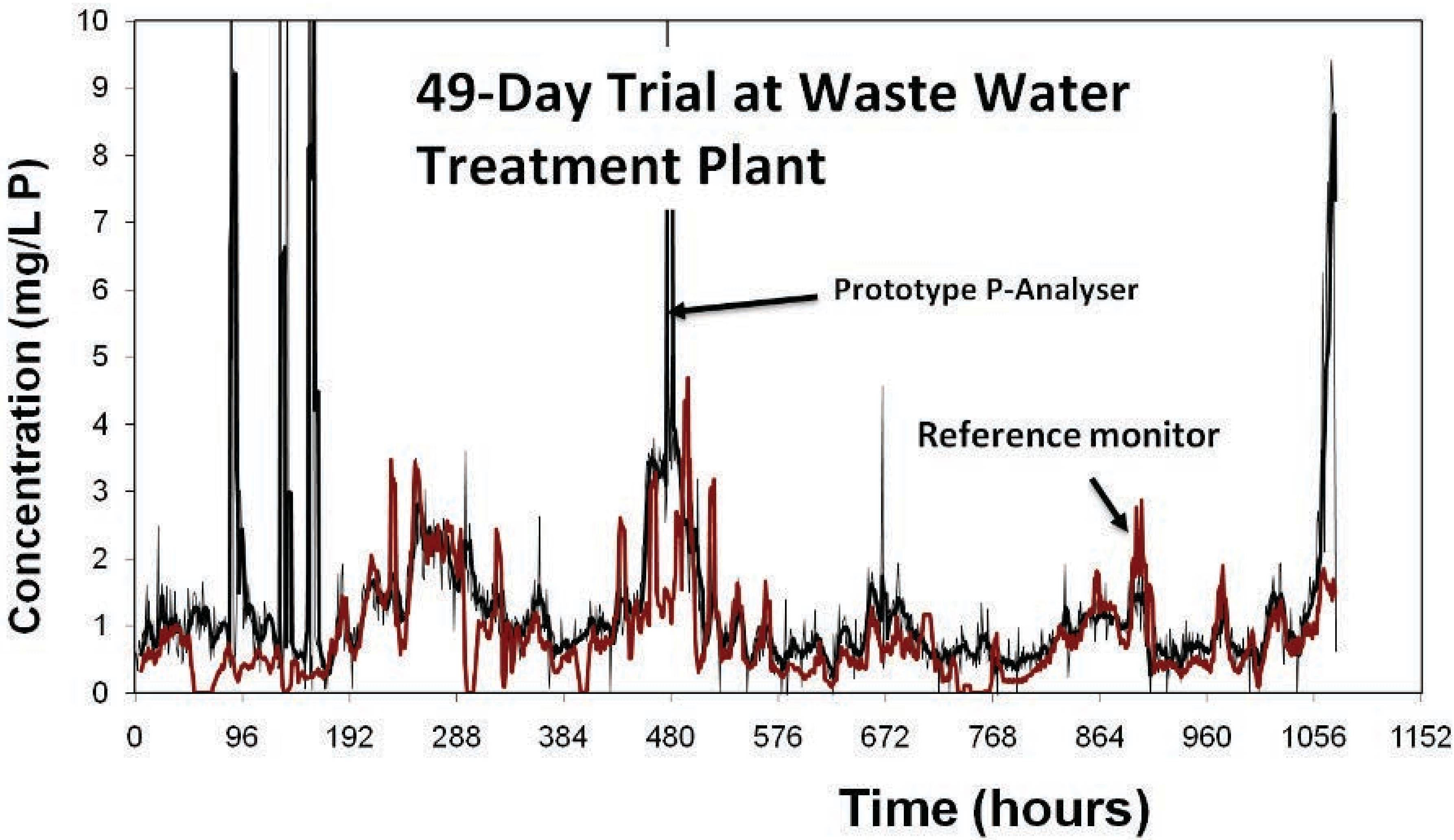
Sampling port



Deployment at Osberstown WWTP

- Phosphate monitoring unit deployed
- System is fully immersed in the treatment tank
- Wireless communications unit linked by cable
- Data transmitted to web

Autonomous Chemical Analyser

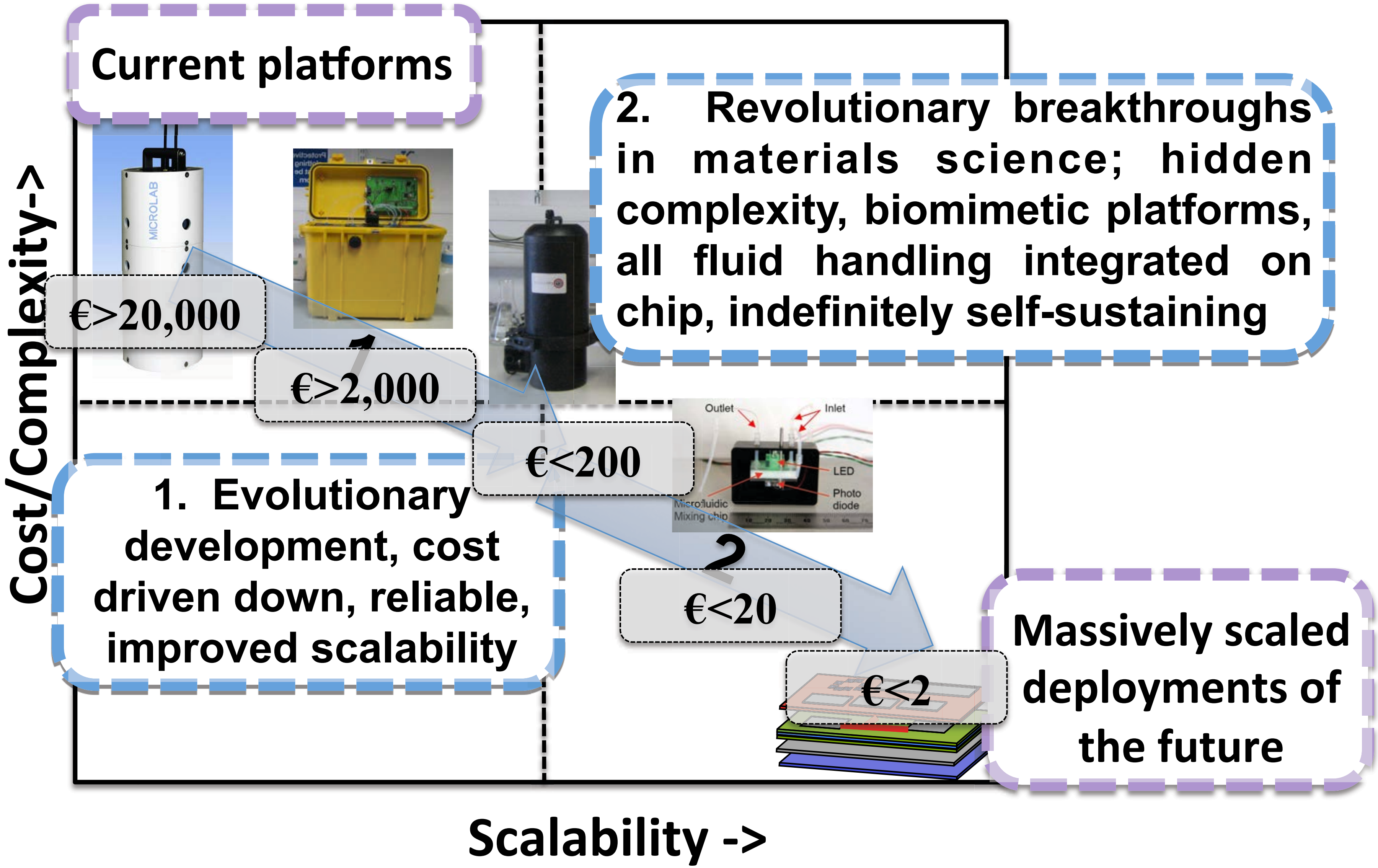


Phosphate monitoring using the Yellow Method

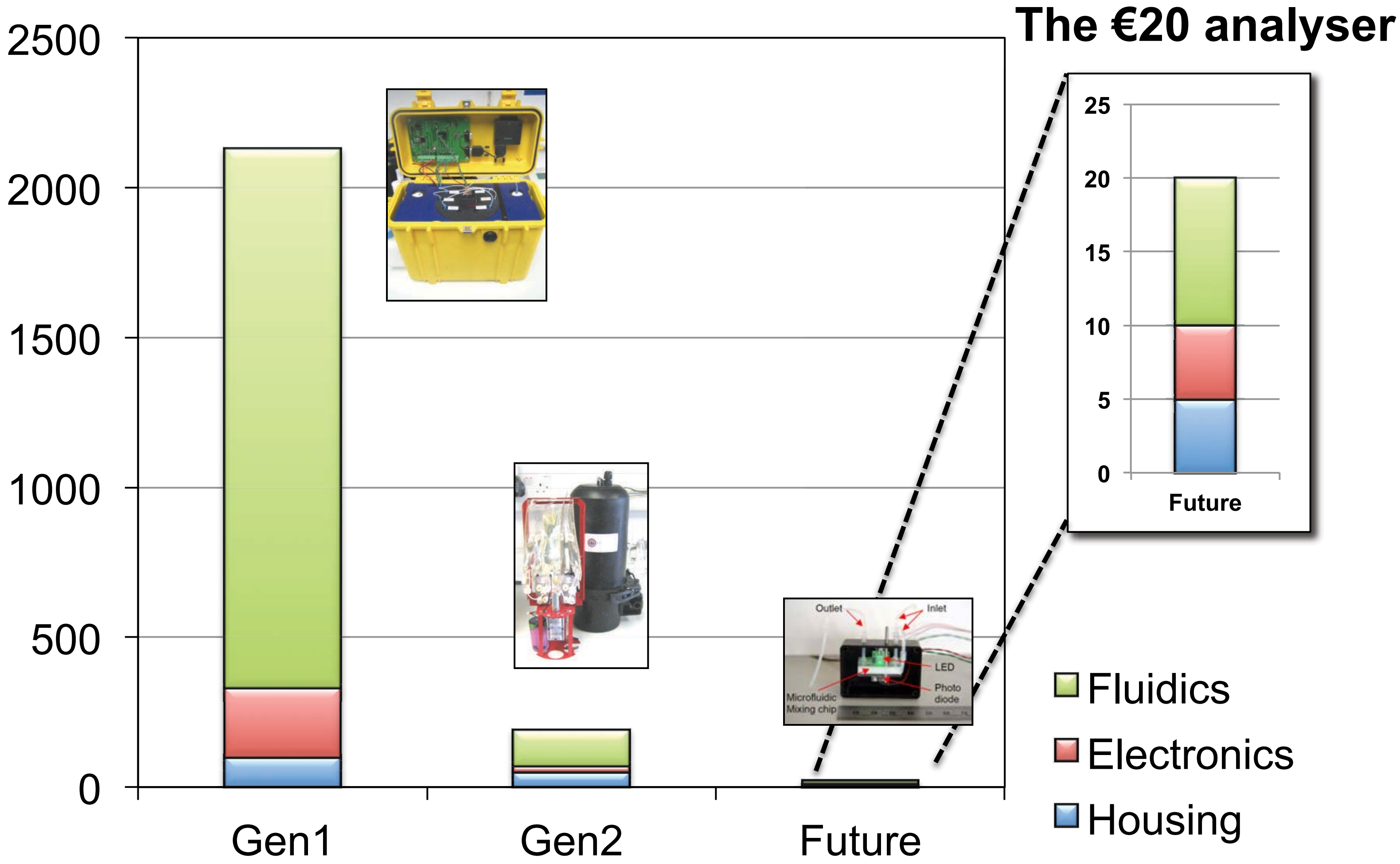
Osberstown – 3 week deployment

Biofouling of sensor surfaces is a major challenge for remote chemical sensing – both for the environment and for implantable sensors

Achieving Scale-up

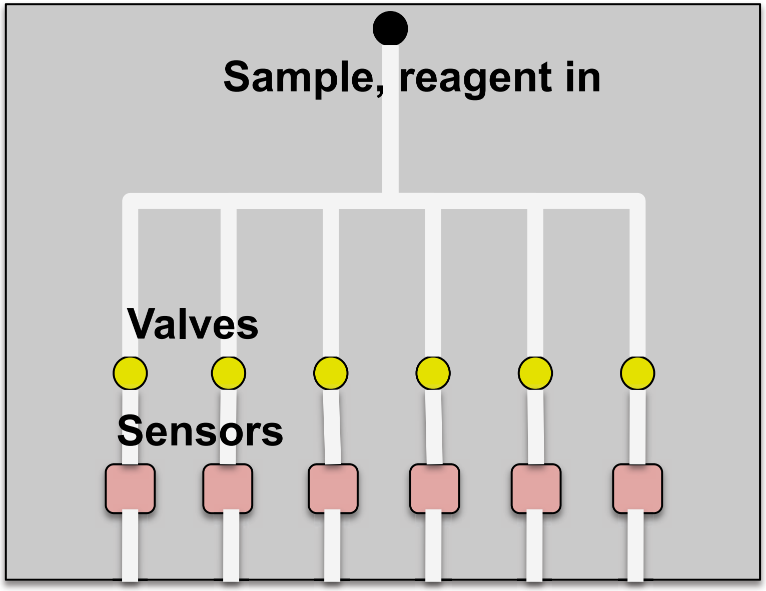


Cost Comparison Analyser (€)



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)….

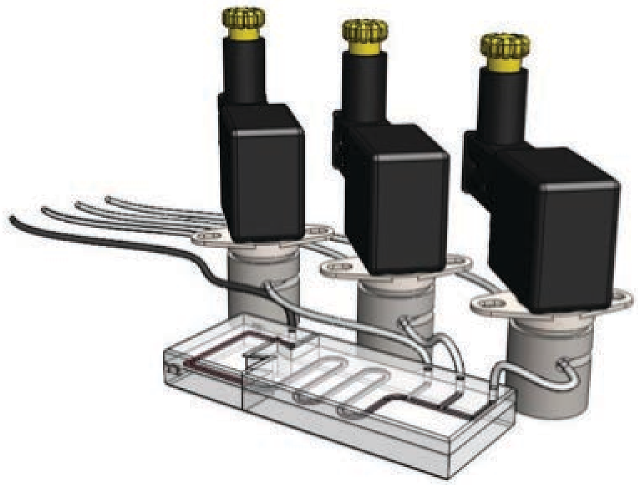


Then 50 sensors when used sequentially could provide an aggregated in-use lifetime of around 1 year

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

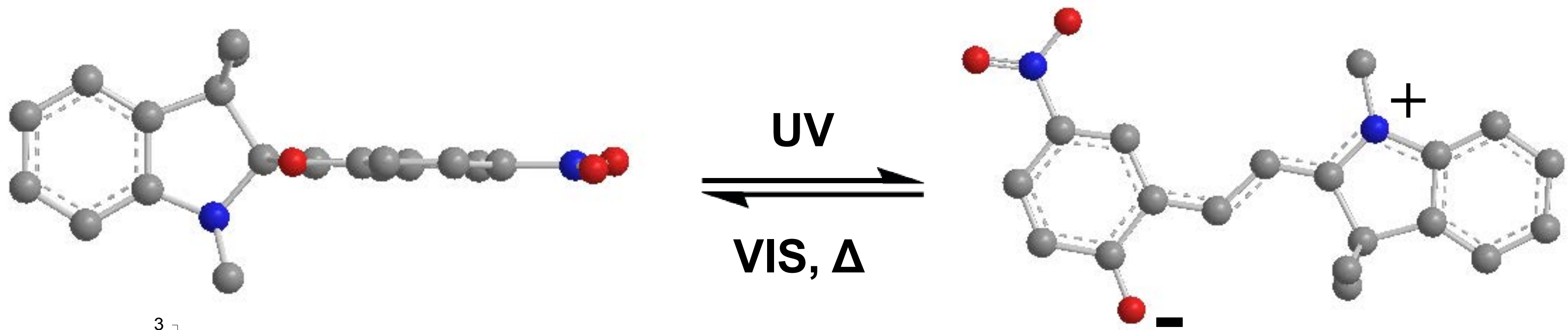
How to advance fluid handling in LOC platforms: re-invent valves (and pumps)!

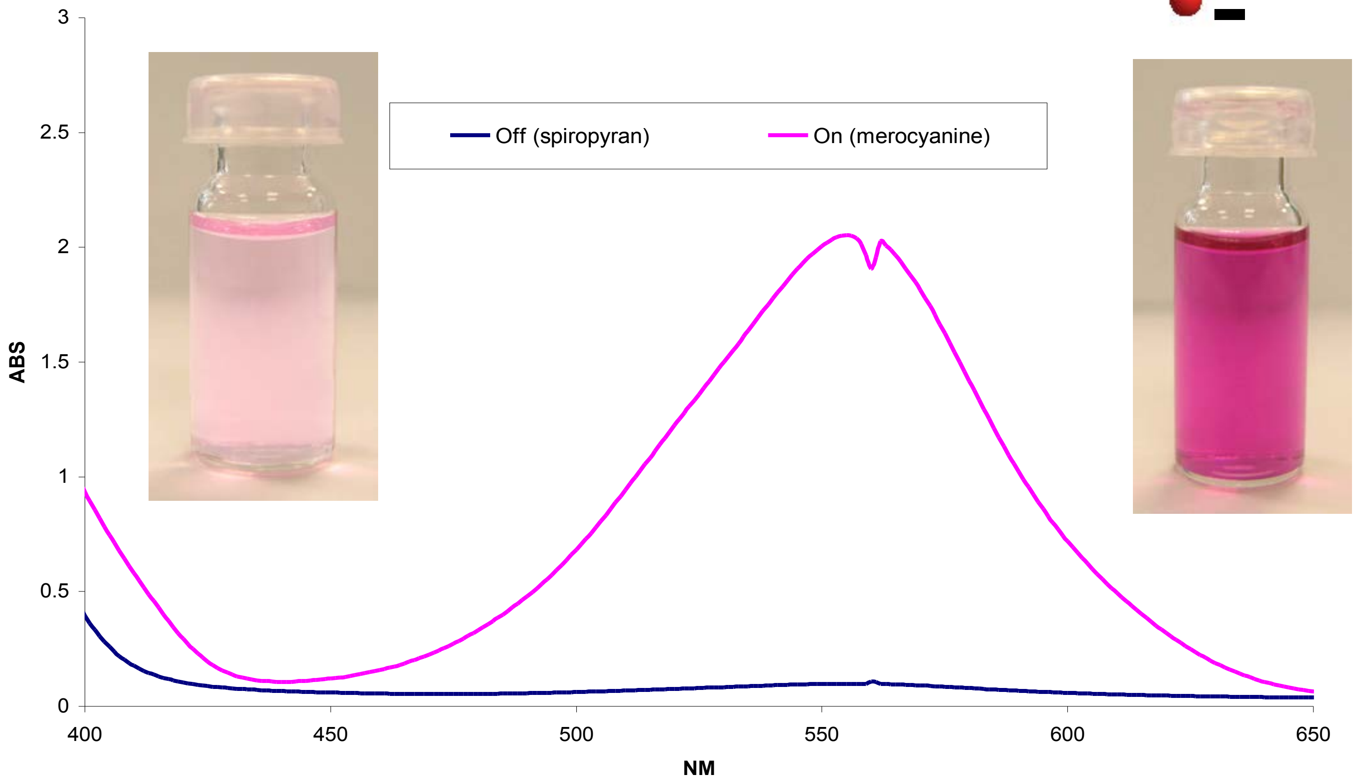
- **Conventional valves cannot be easily scaled down - Located off chip: fluidic interconnects required**
  - Complex fabrication
  - Increased dead volume
  - Mixing effects
- **Based on solenoid action**
  - Large power demand
  - Expensive



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

Photoswitchable Actuators





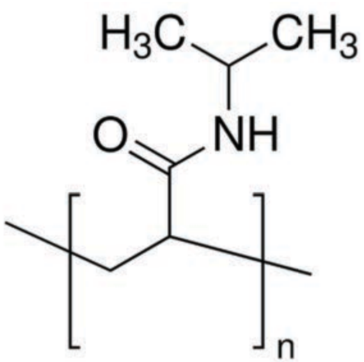
Famous Molecule….

From Prof. Thorfinnur Gunnlaugsson, TCD School of Chemistry
Spotted on Nickelodeon Cartoons February 2015

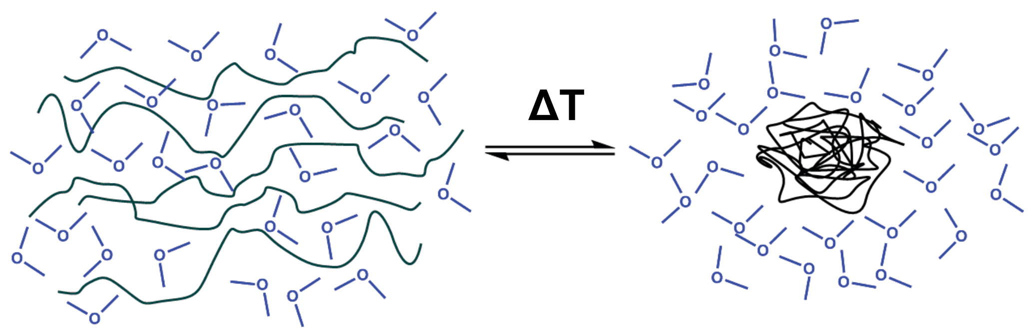
Poly(*N*-isopropylacrylamide)

- **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

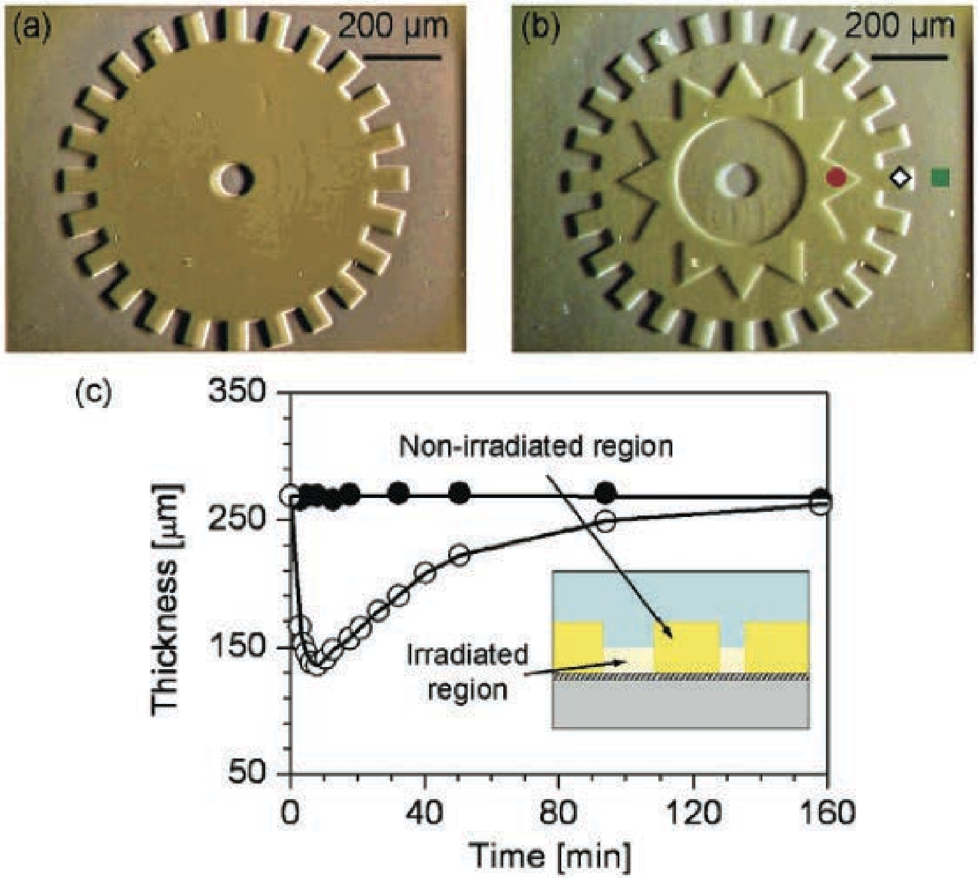
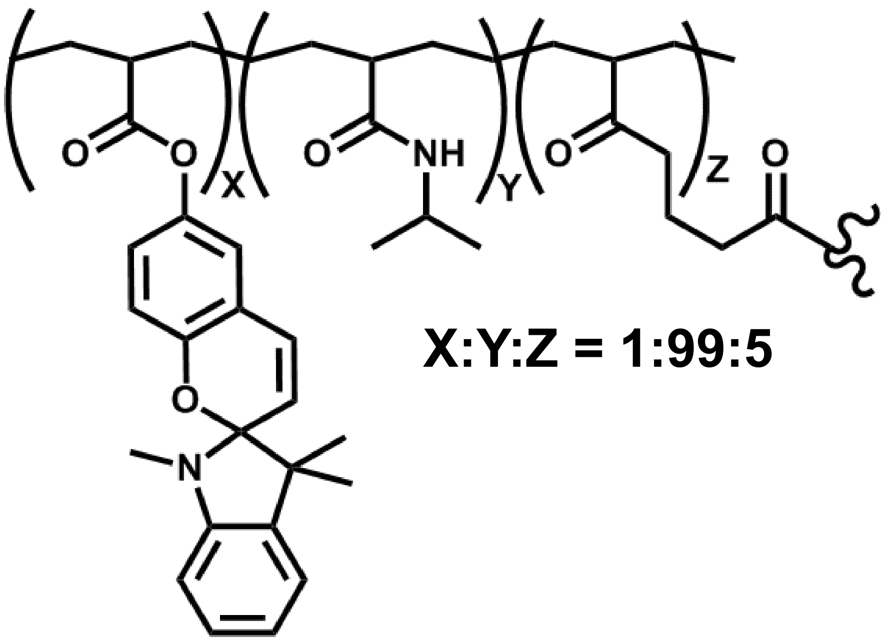


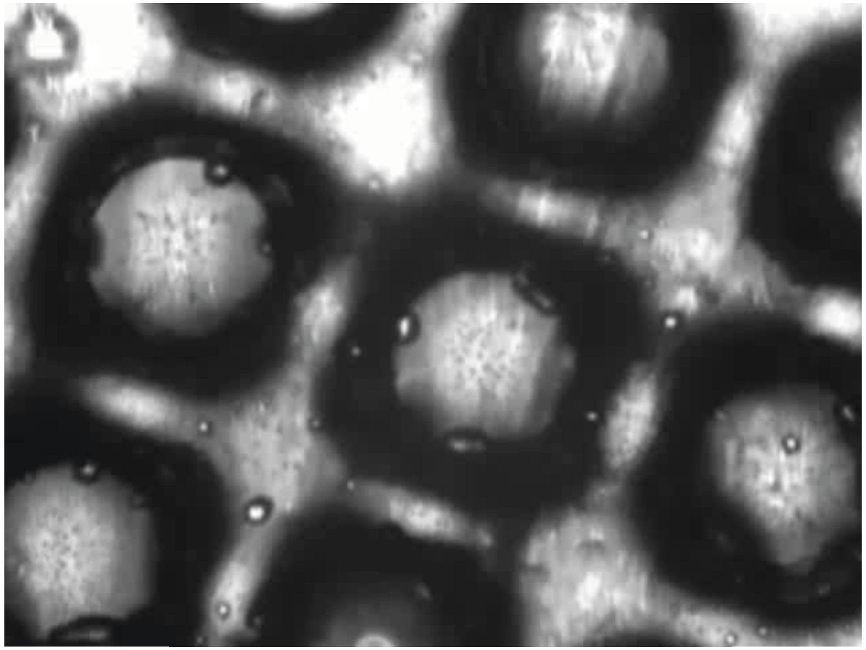
Figure 3. (a, b) Images of the pSPNIPAAm hydrogel layer just after the micropatterned light irradiation. Duration of irradiation was (●, red) 0, (◇) 1, and (■, green) 3 s. (c) Height change of the hydrogel layer in (●) non-irradiated and (○) irradiated region as a function of time after 3 s blue light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



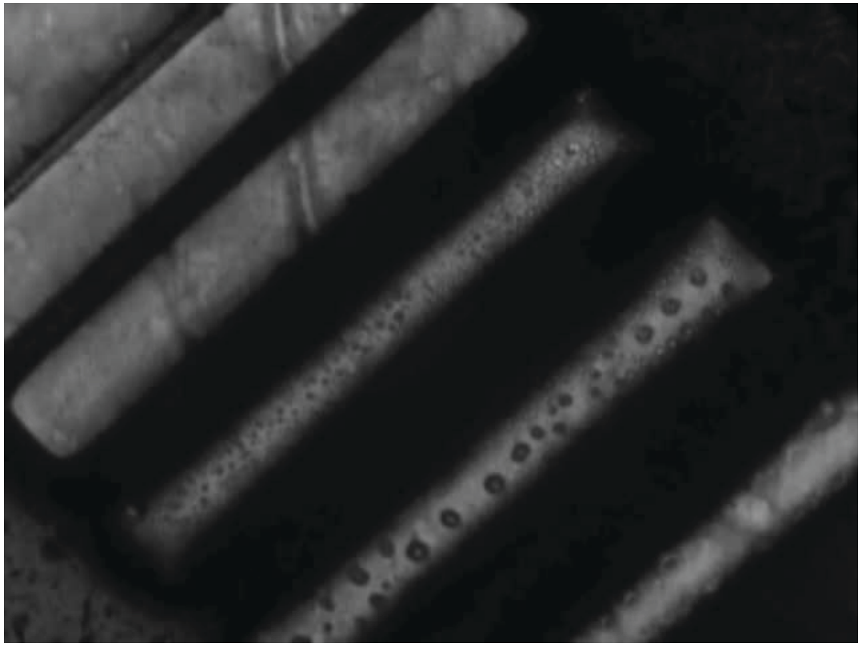
X:Y:Z = 1:99:5

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

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



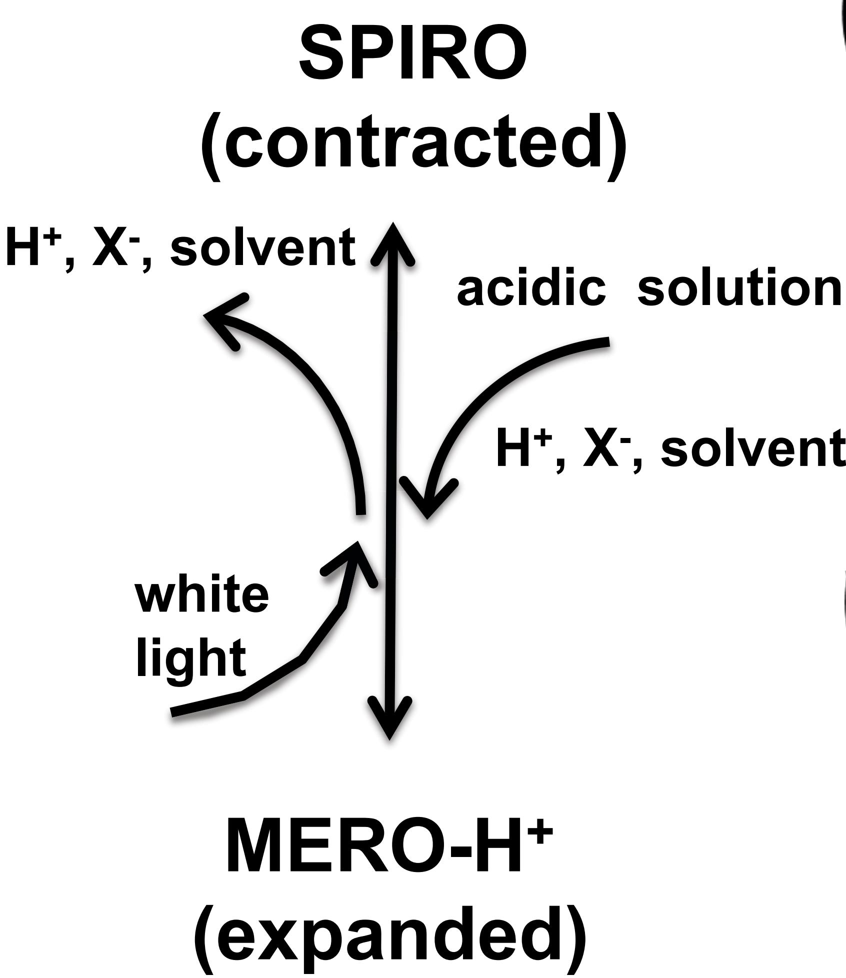
Ntf2 pillars speed x3

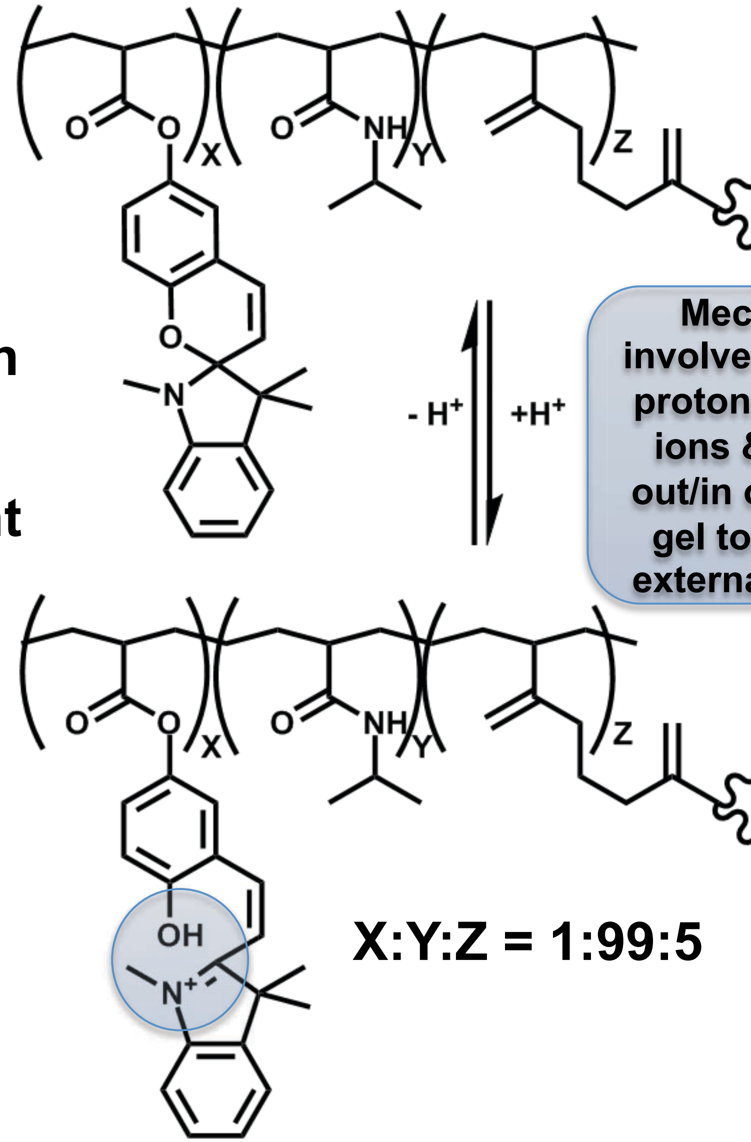


DCA lines speed x4

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

Actuation Mechanism

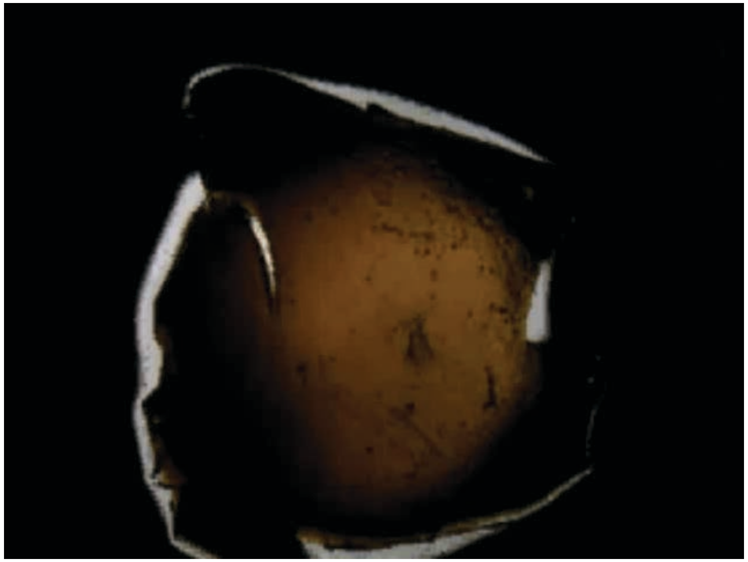


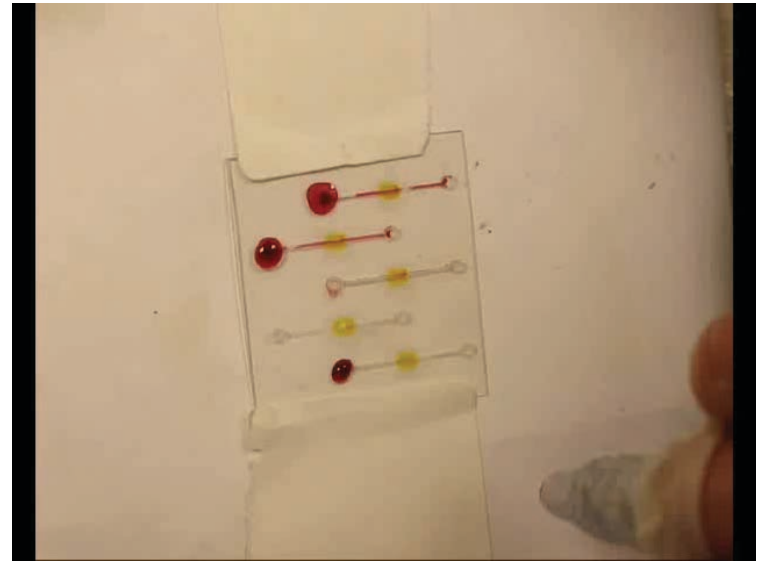


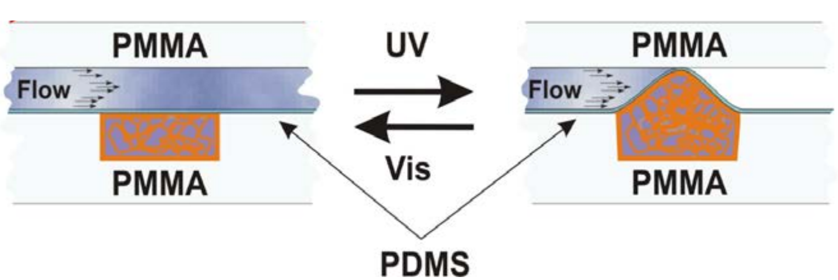
Mechanism involves diffusion protons, counter ions & solvent out/in of the bulk gel to/from the external solution

X:Y:Z = 1:99:5

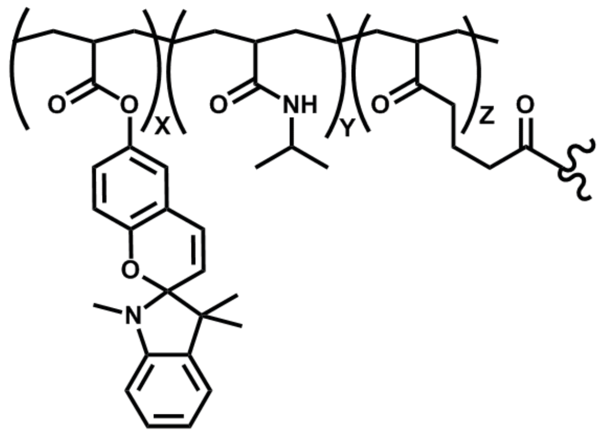
Photo-actuator polymers as microvalves in microfluidic systems

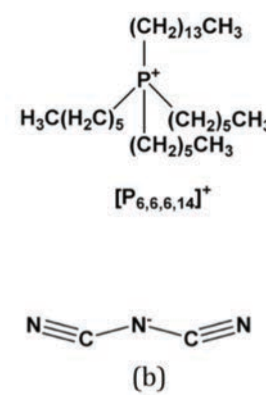






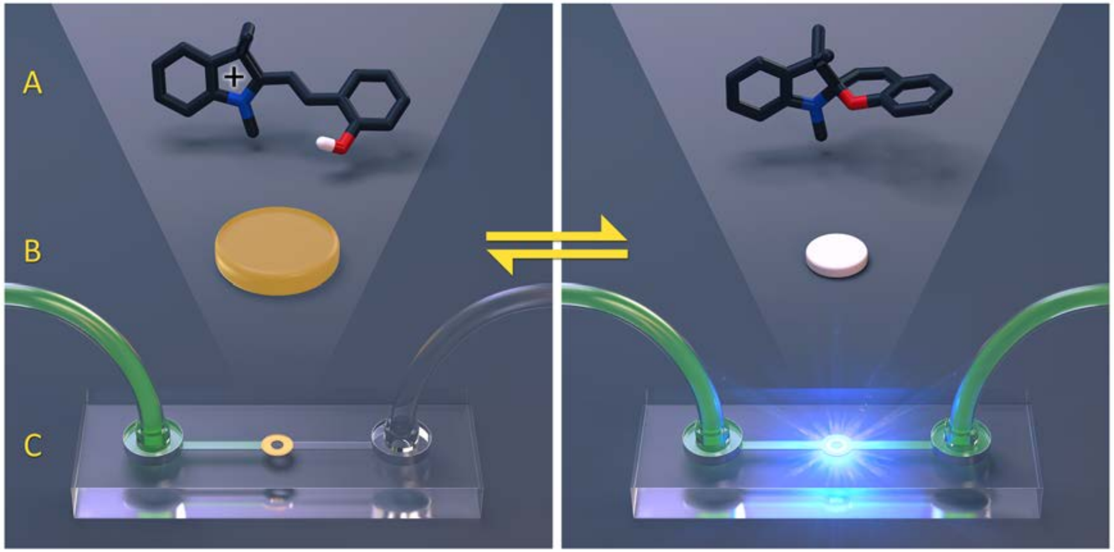
trihexyltetradecylphosphonium dicyanoamide $[P_{6,6,6,14}]^+[dca]^-$

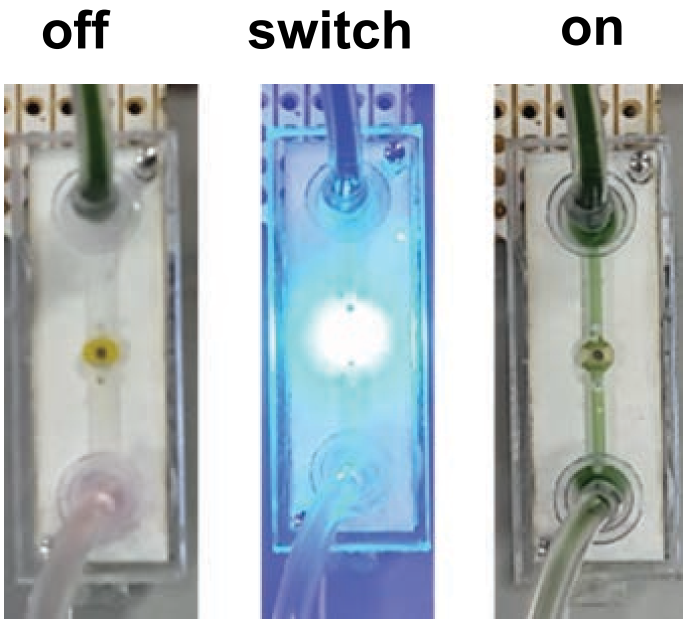




Ionogel-based light-actuated valves for controlling liquid flow in micro-fluidic manifolds, Fernando Benito-Lopez, Robert Byrne, Ana Maria Raduta, Nihal Engin Vrana, Garrett McGuinness, Dermot Diamond, Lab Chip, 10 (2010) 195-201.

Reversible Photo-Switching of Flow

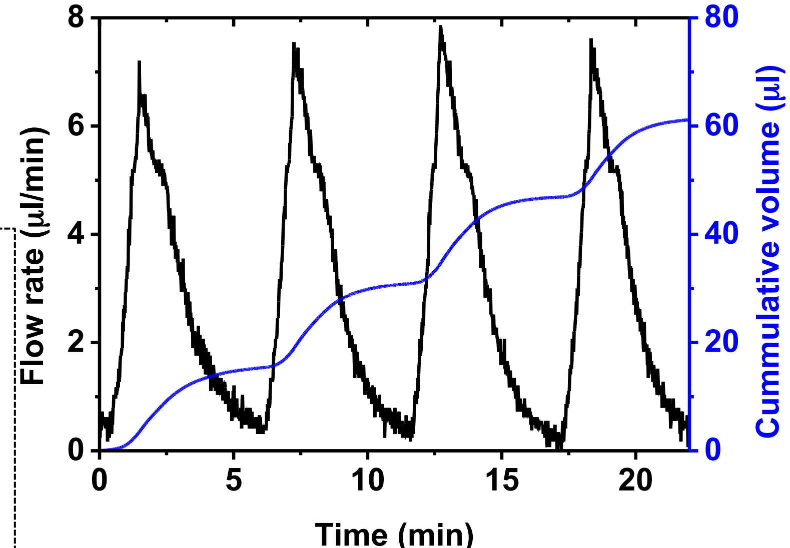




Above: scheme showing switching process protonated MC-H$^+$ photoswitched to SP triggering p(NIPAAM-*co*-AA-*co*-SP) gel contraction and opening of the channel.

Right, Top: Photos of the valve in operation before (flow OFF) and after (flow ON) one minute of blue light irradiation.

Right, Bottom: Flowrate and cumulative volume measurements showing repeated opening and closing of microvalve: 1 min blue light irradiation opens valve followed by ~5.5 min thermal relaxation to close.



From: 'Molecular design of light-responsive hydrogels, for in-situ generation of fast and reversible valves for microfluidic applications ' (submitted for publication)

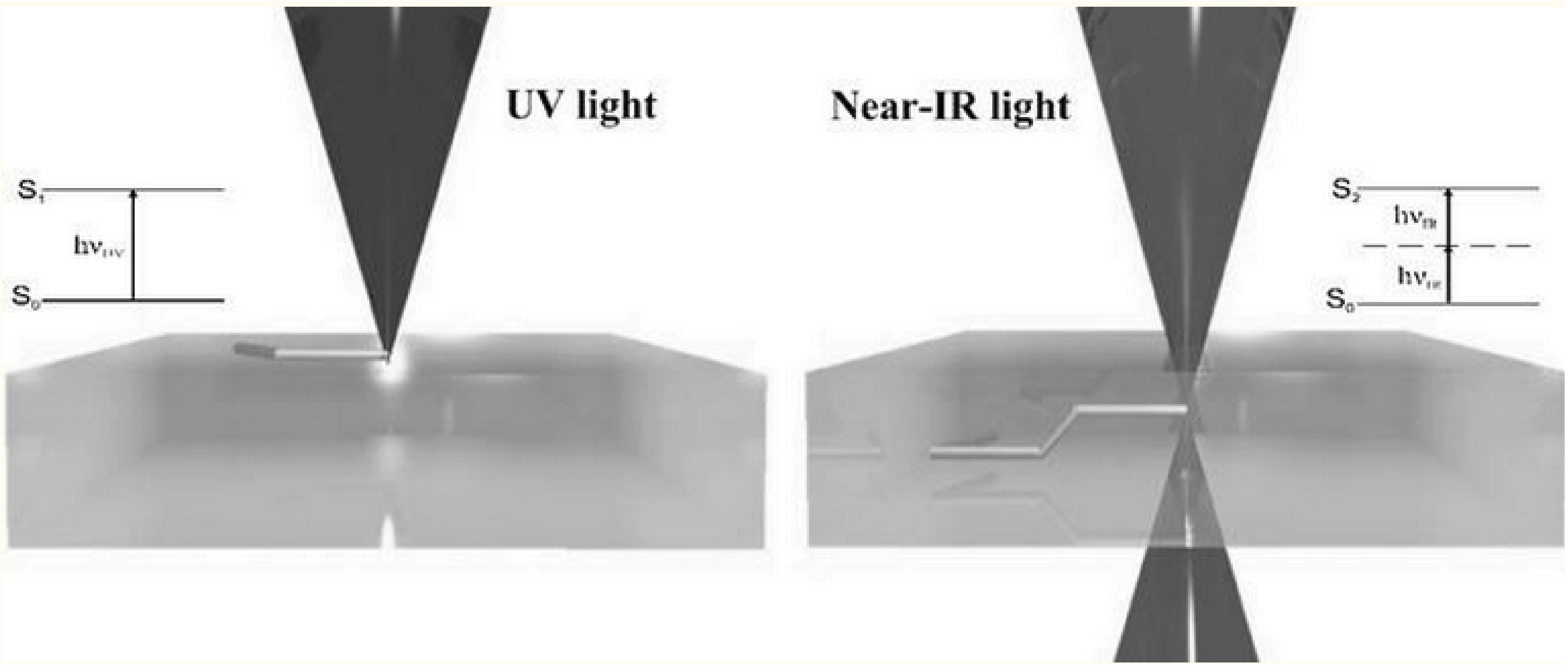
Jeroen ter Schiphorst,[†,#] Simon Coleman,[‡,#] Jelle E. Stumpel,[†] Aymen Ben Azouz,[‡] Dermot Diamond[*,‡] and Albertus P.H.J. Schenning[*,†,§]

†Functional Organic Materials and Devices, Department of Chemical Engineering and Chemistry, and §Institute for Complex Molecular Systems, Eindhoven University of Technology, P.O. Box 513, 5600 MB, Eindhoven, The Netherlands

‡ INSIGHT Centre for Data Analytics, National Center of Sensor Research, Dublin City University, Dublin 9, Ireland

Background

Stereolithography | **Two-photon polymerisation**



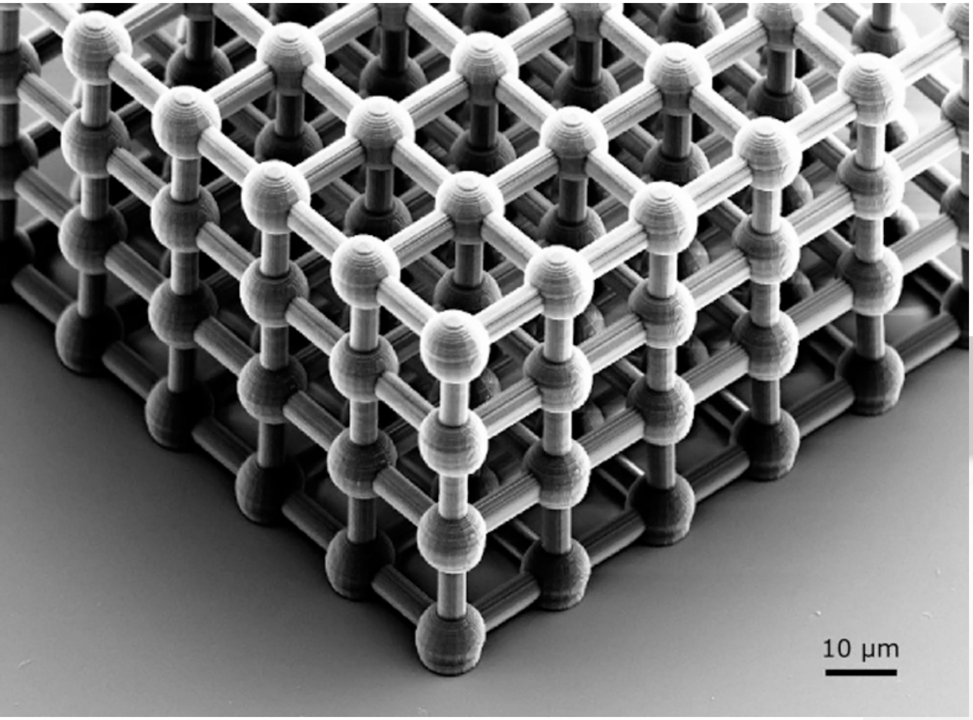
Stereolithography:

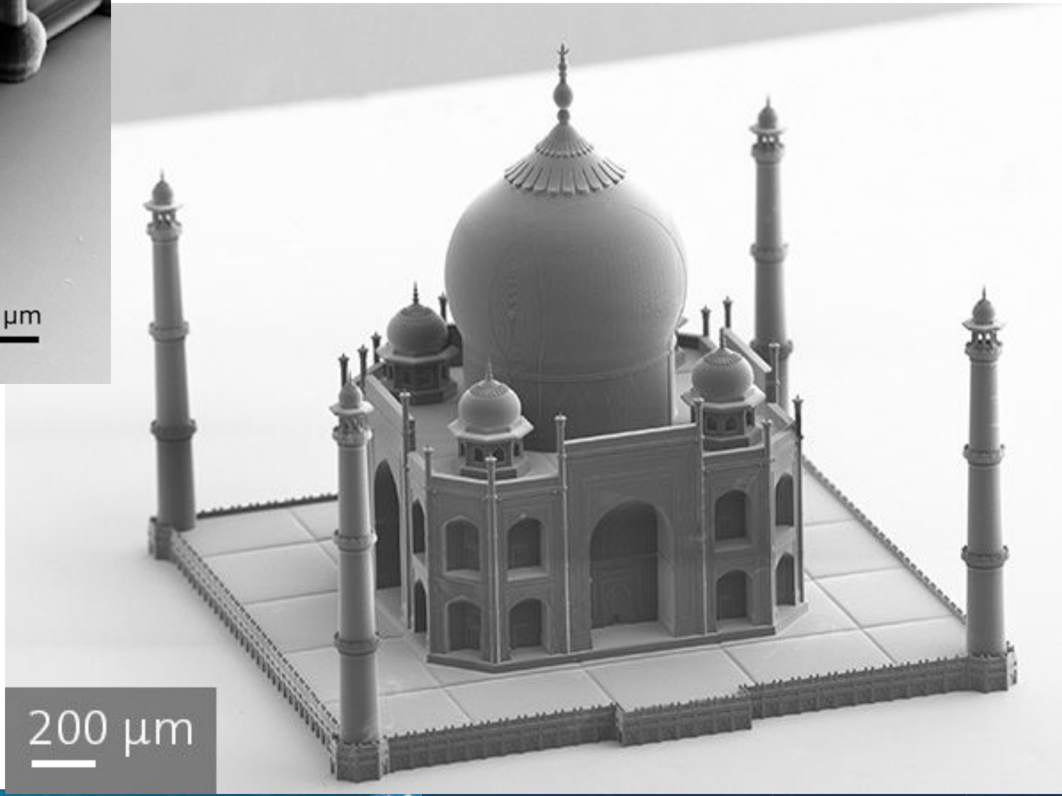
- Single photon absorption
- 2D patterns

Two-photon polymerisation:

- Two photon absorption
- 3D structures

Background



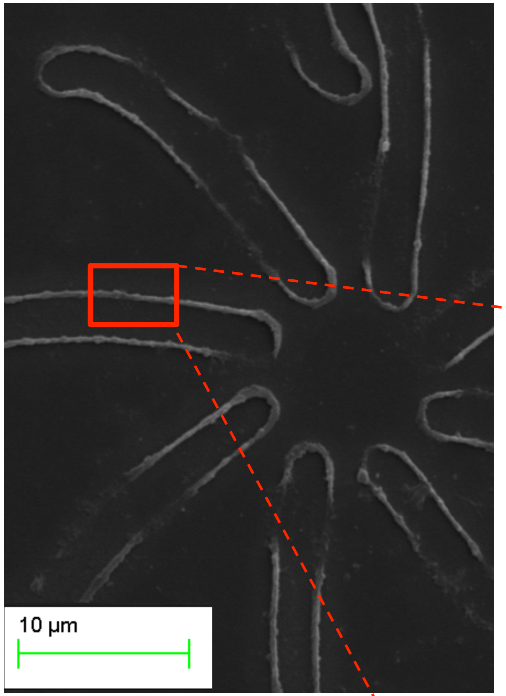


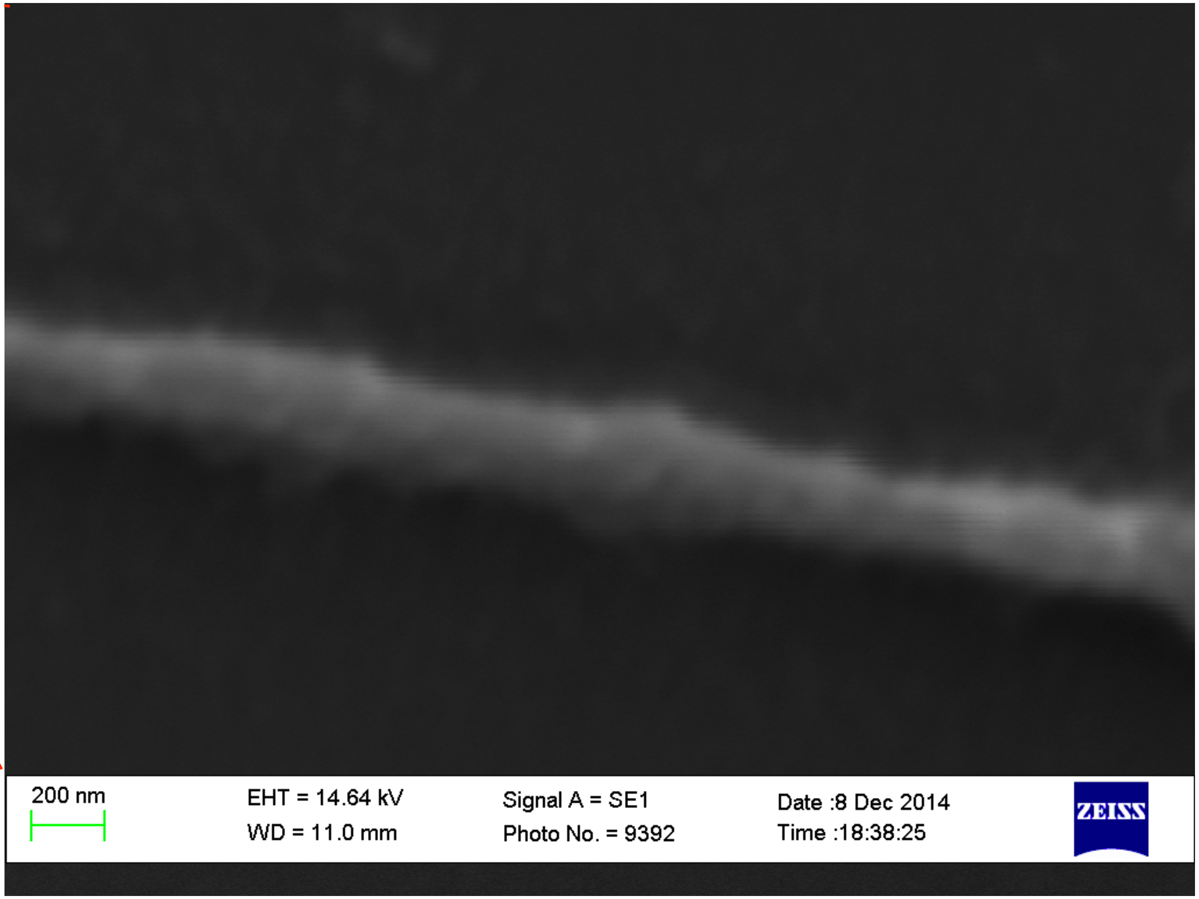
http://www.nanoscribe.de/

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

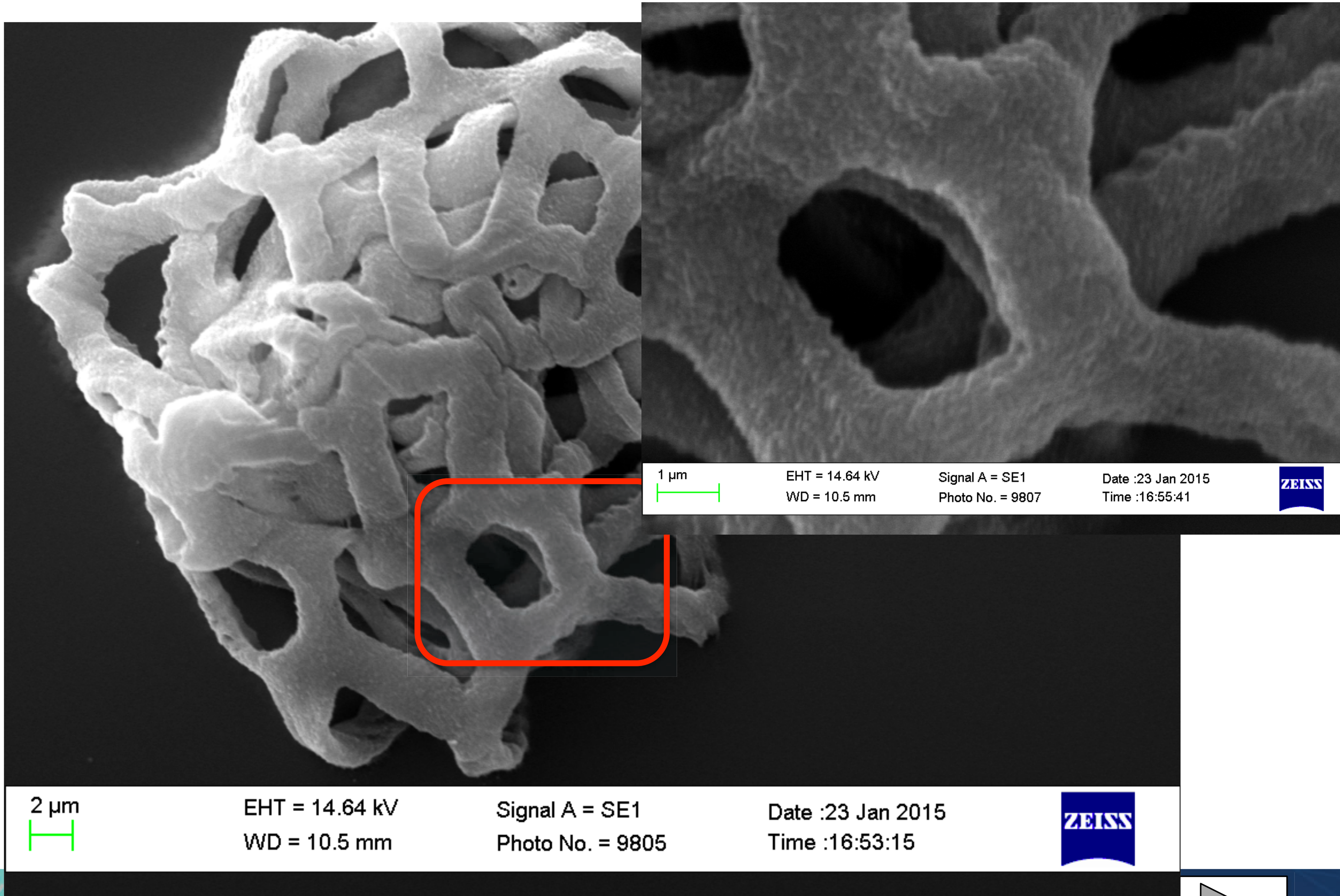
Submitted to Euronanoforum, Riga, Latvia, June 2015





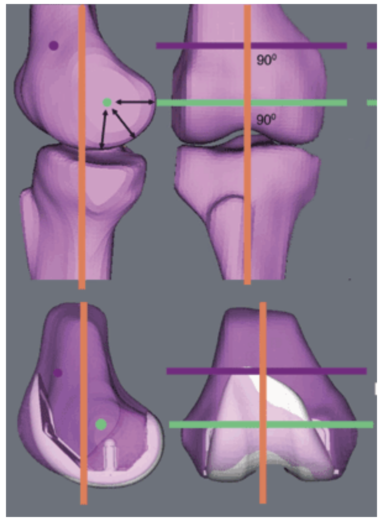
Creating 3D soft gel structures with a line resolution of ca. 200 nm

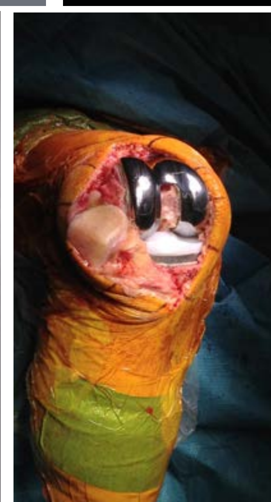
Globular Porous Structure

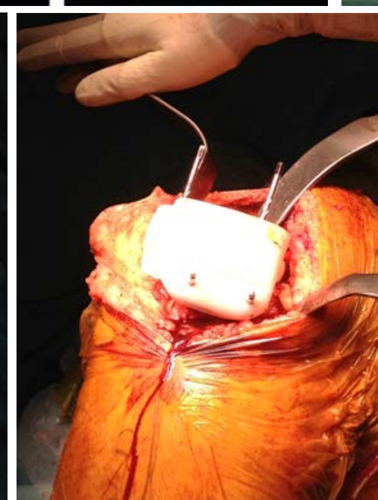


3D Scanning meets 3D Printing: Impact on Implant Surgery

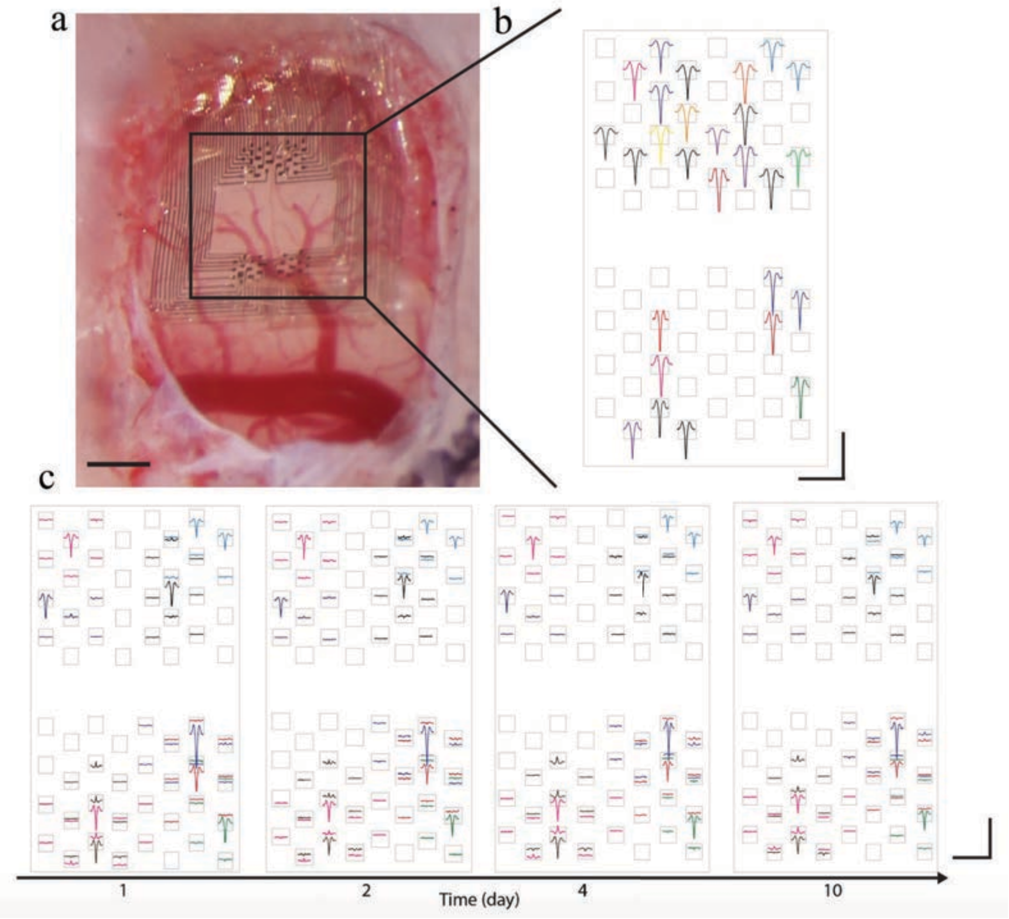
Example: Conor Hurson, Consultant Orthopaedic Surgeon, St. Vincent's University Hospital & Cappagh National Orthopaedic Hospital; working with Engineers at IT Tallaght

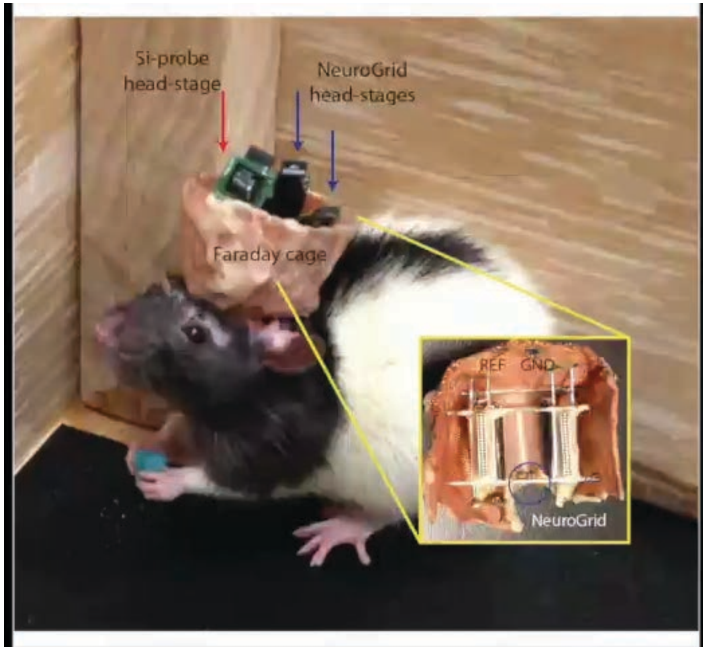






What is the state of the art?





- Highly conformable PEDOT-PSS organic polymer electrode arrays (OECTs)
- Placement of a 64-channel NeuroGrid on rat somatosensory cortex
- Functioned continuously for up to 10 days

NeuroGrid: recording action potentials from the surface of the brain
Dion Khodagholy, Jennifer N Gelinas, Thomas Thesen, Werner Doyle, Orrin Devinsky, George G Malliaras & György Buzsáki, **Nature Neuroscience 18, 310–315 (2015) doi:10.1038/nn.3905**

Conformable electrodes and electronics

Rogers Group, University of Illinois

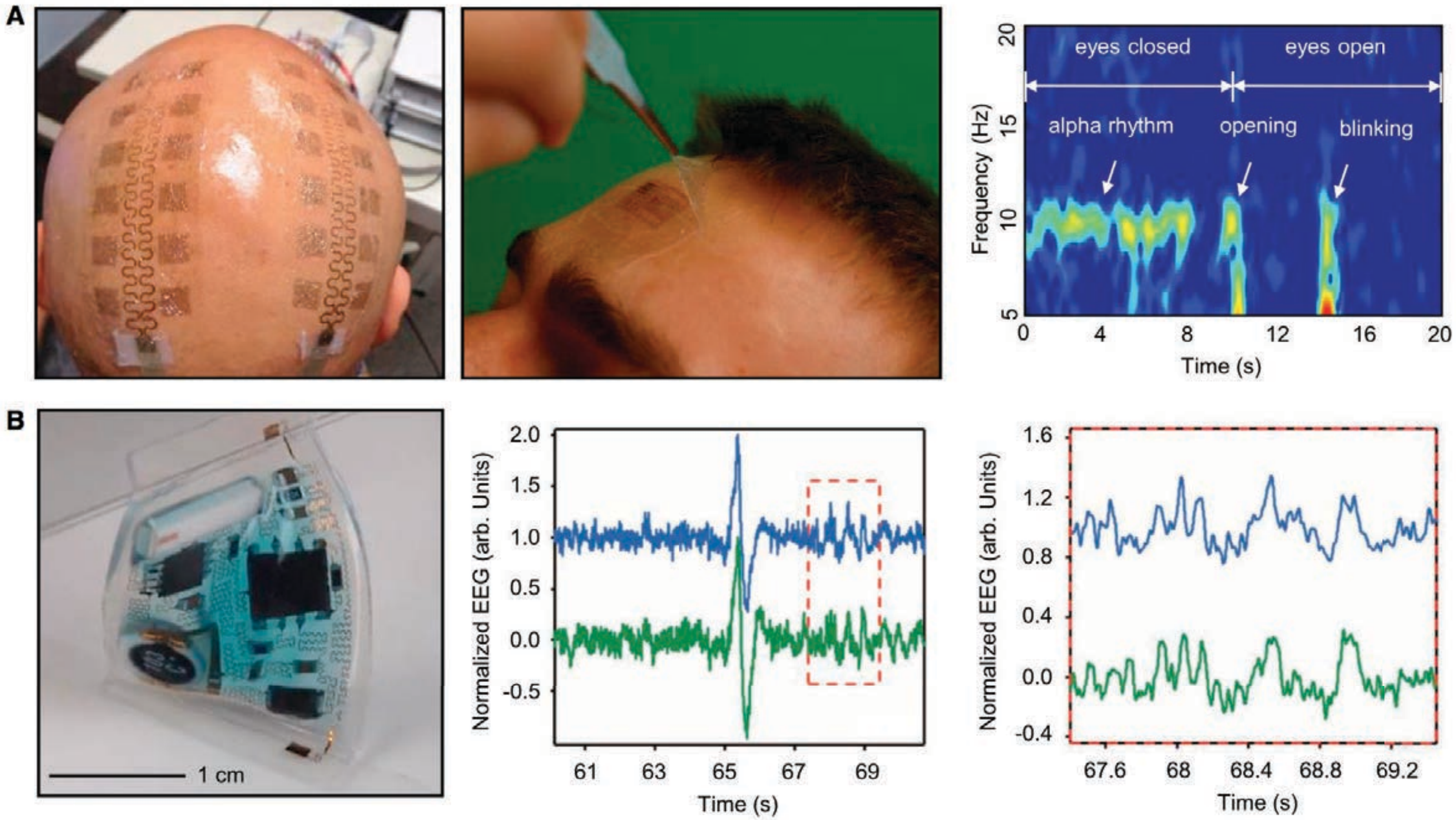


Figure 3. Soft, Conformal Electronics for EEG

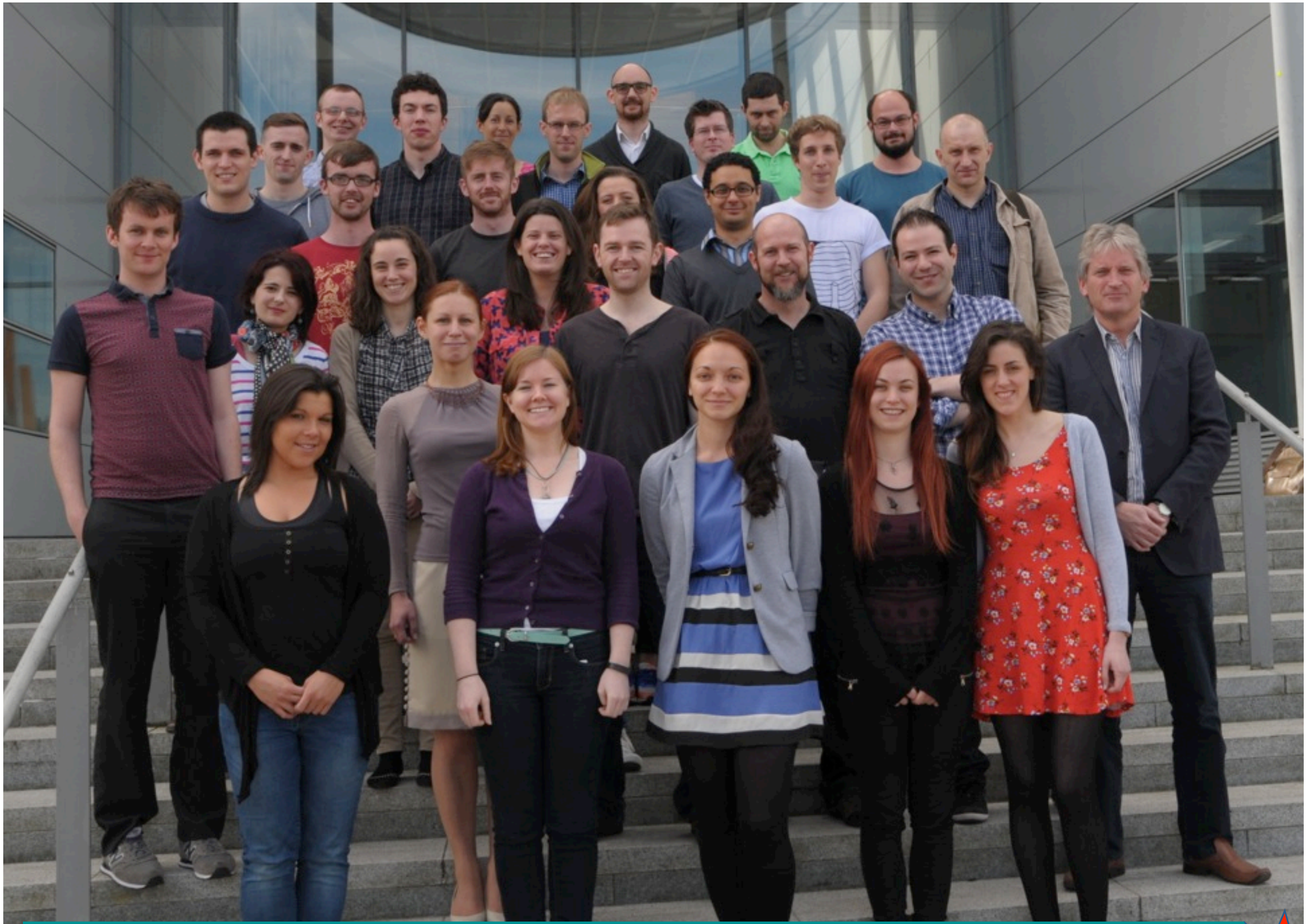
(A) Images of skin-like, or epidermal, electronics that exploit electrodes and semiconductor components in open, filamentary mesh architectures with fractal inspired geometries (left). These devices can softly laminate onto and peel away from (middle) the surface of the skin for stable, non-irritating, long-lived measurement interfaces. Spectrograms of representative EEG data (right) show characteristic alpha rhythm behavior when the eyes are closed (Kim et al., 2011).
(B) Image of a stretchable electronic system that integrates chip-scale components and a free-floating interconnect network for wireless EEG. Data acquired from the forehead (green; middle and right) are quantitatively similar to those simultaneously acquired using a wired commercial device (blue). The large deflections correspond to blinking of the eyes as the subject shifts from performing mental math to resting (Xu et al., 2014).

J.-W. Jeong, G. Shin, S.I. Park, K.J. Yu, L. Xu and J.A. Rogers, "Soft Materials in Neuroengineering for Hard Problems in Neuroscience," Neuron 86(1), 175-186 (2015).

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!



Thanks for listening