NCSR
National Centre for Sensor Research

DCU

Insight

Biomimetic Microfluidics and Stimuli-responsive Materials: The Key to Realising Chemical Sensing Platforms with Revolutionary Capabilities

Prof. Dermot Diamond
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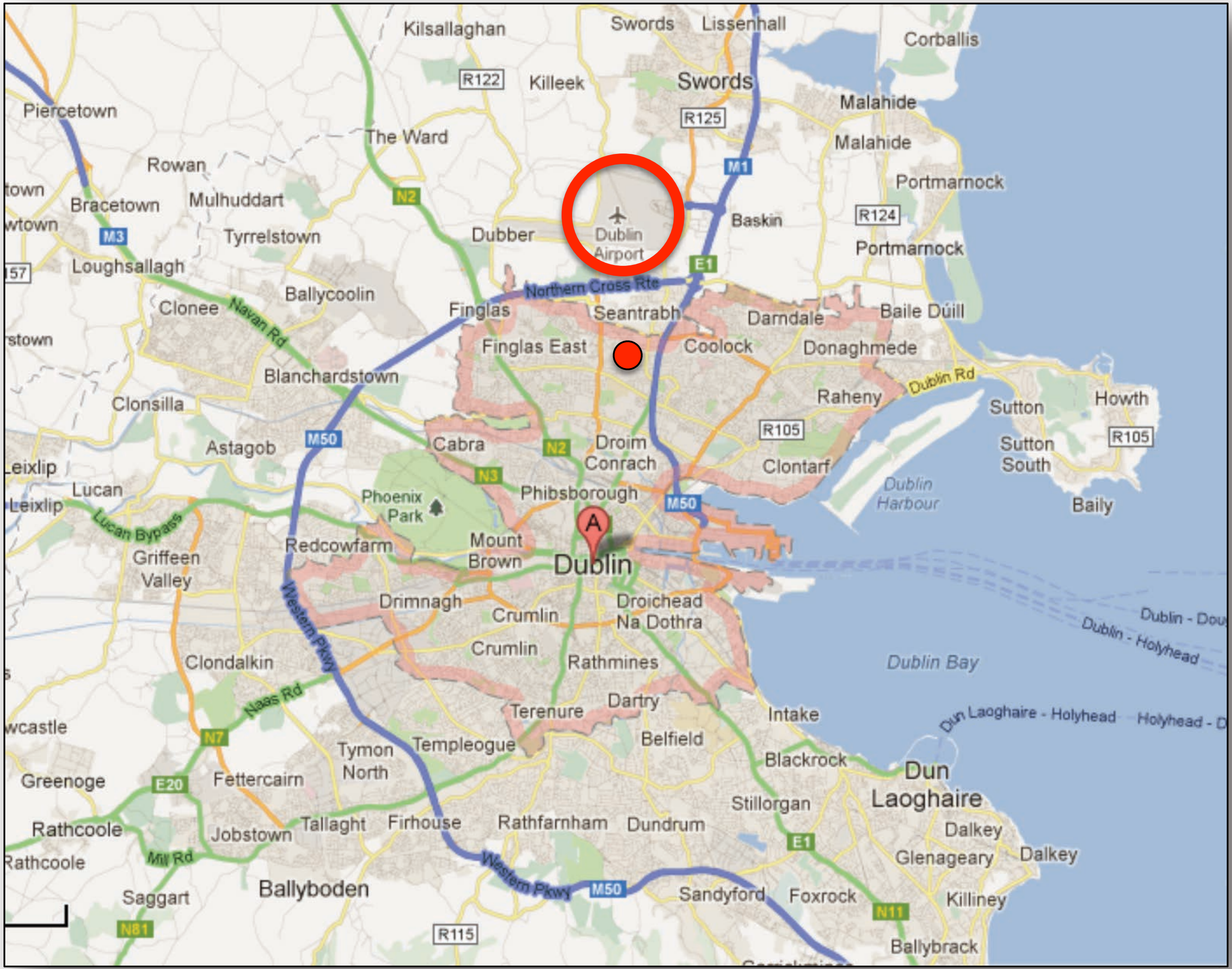
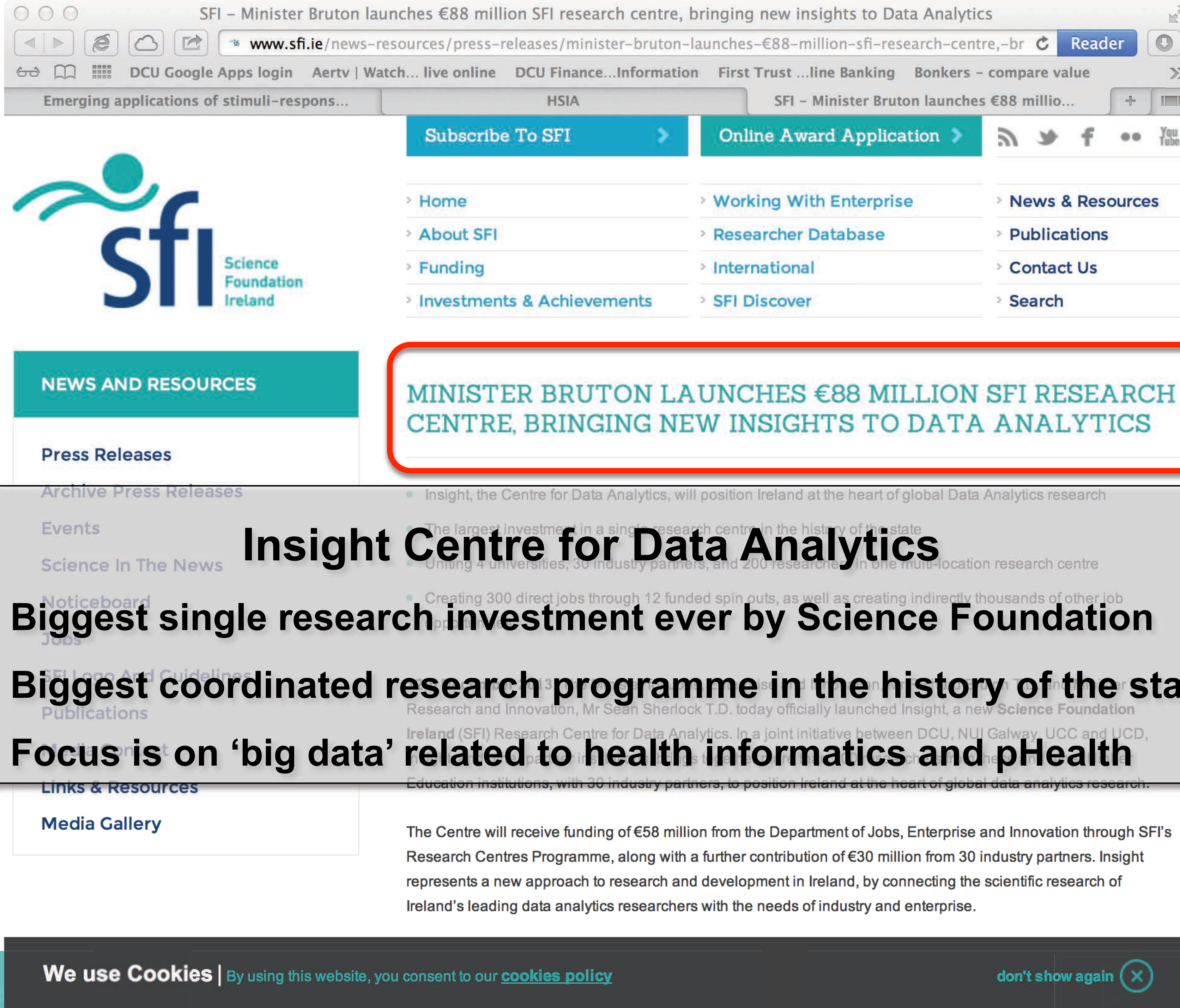
Funded Investigator, INSIGHT Centre for Data Analytics
Dublin City University

Lecture presented at
1st OrgBio Marie Curie ITN Workshop
Bari, Italy, 30 March – April 1 2015

Dublin & DCU Location





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

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.

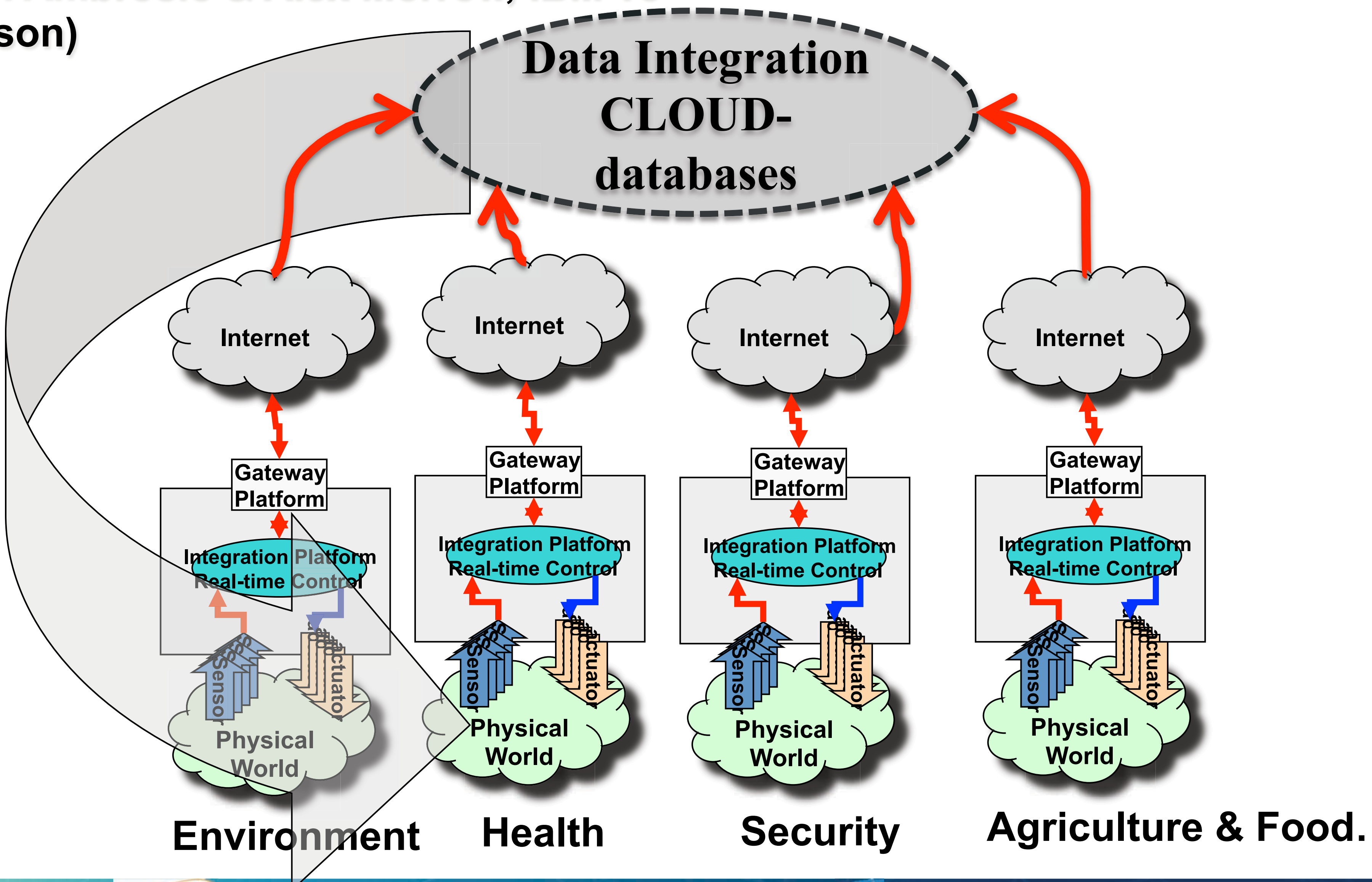
Digital communications networks are at the heart of modern society. The digitization of communications, the development of the Internet, and the availability of relatively inexpensive but powerful mobile computing technologies have established a global communications network capable of linking billions 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)

Internet-scale sensing and control

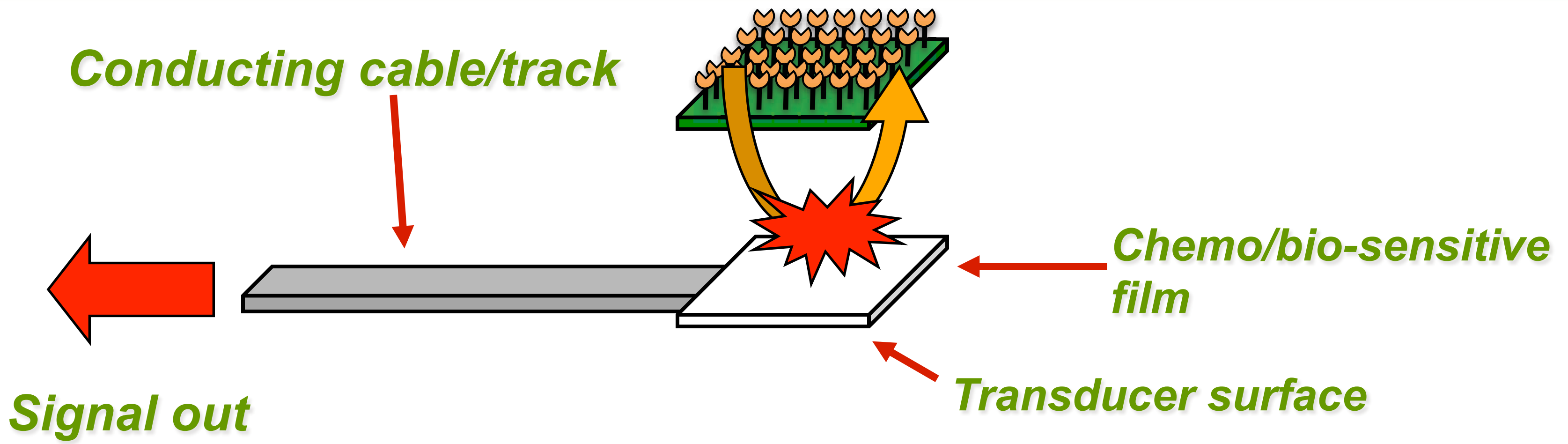
(Ron Ambrosio & Alex Morrow, IBM TJ Watson)



Scalability depends fundamentally of the availability of **affordable** Chem/Bio-sensing devices that can function **autonomously** for **years** in inaccessible/remote locations?

What is a Chemo/Bio-Sensor?

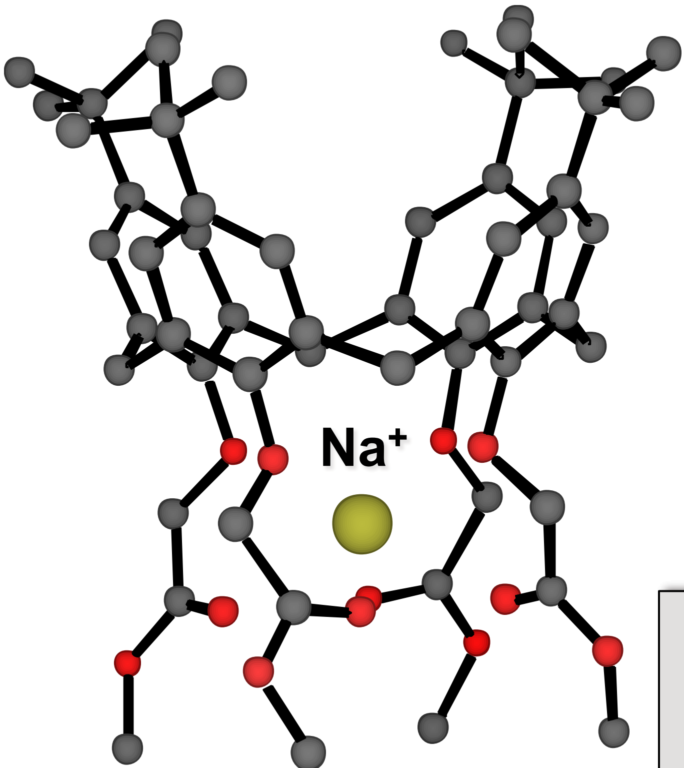
'a device, consisting of a transducer and a chemo/bio-sensitive film/membrane, that generates a signal related to the concentration of particular target analyte in a given sample'

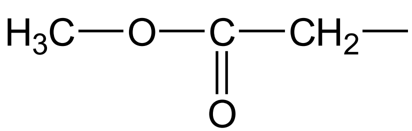


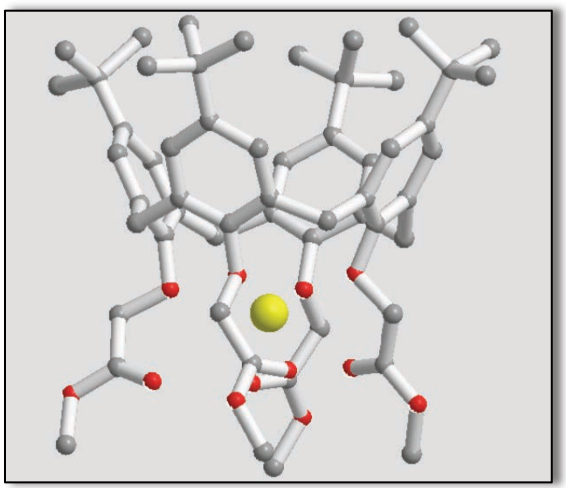
Chemo/Bio-sensing involves selective **BINDING** & **TRANSDUCTION** on the device surface; this also implies the target analyte MUST meet the device surface (**LOCATION** & **MOVEMENT**). It provides a signal observable in the macroscopic world (**COMMUNICATION**)

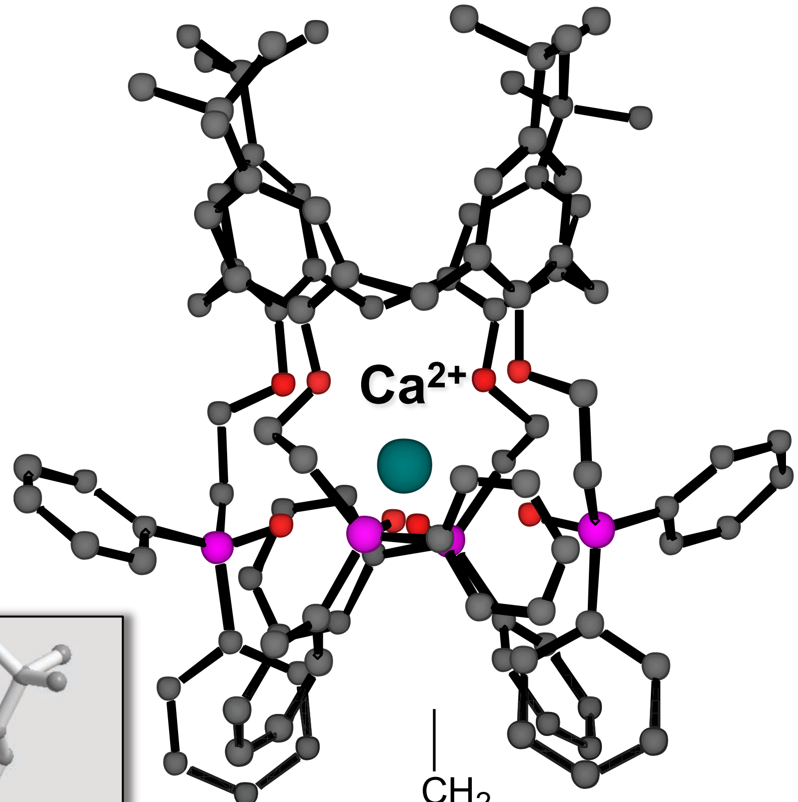
Calixarene Ionophores – controlling the selectivity

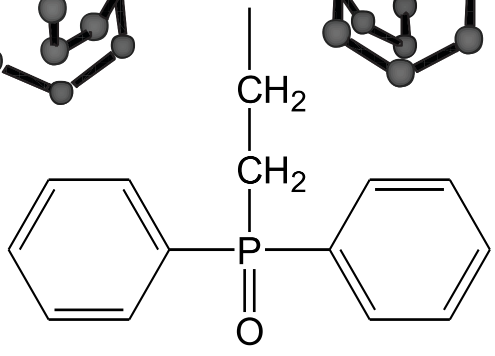
Neutral Carrier Based Ion-Selective Electrodes, D.Diamond, Anal. Chem. Symp. Ser., 25 (1986) 155.



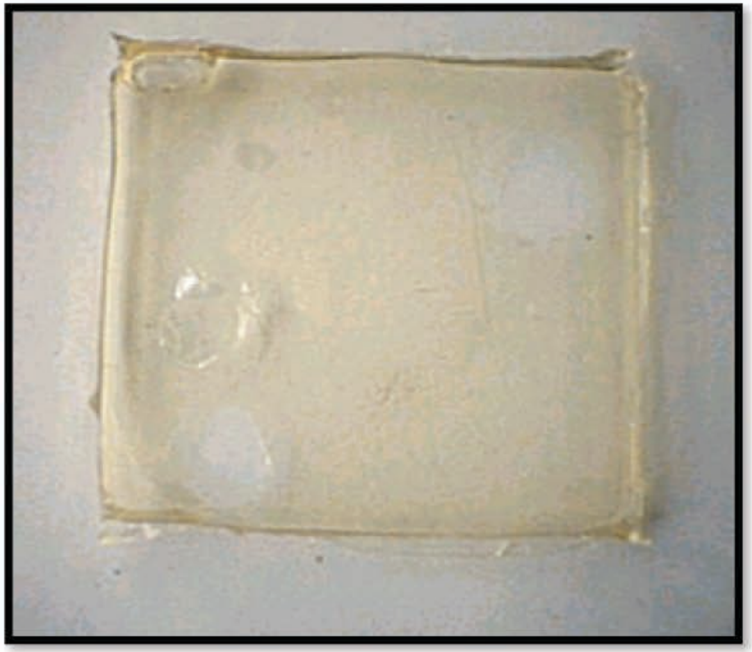


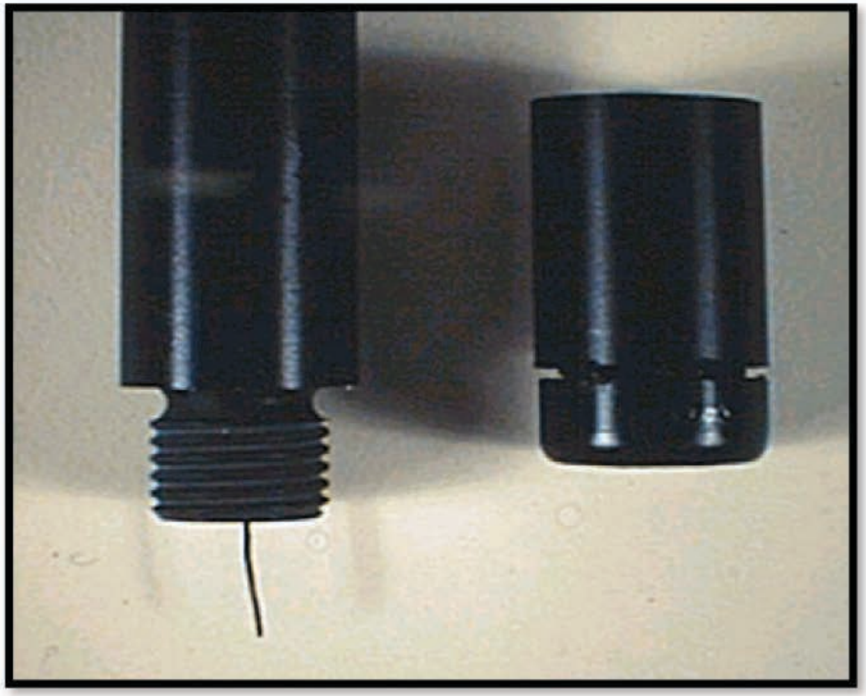






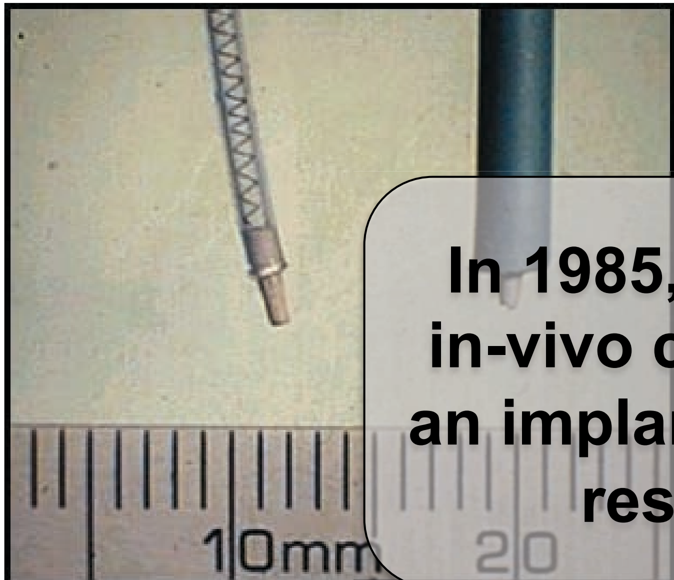
PVC - Membrane ISEs



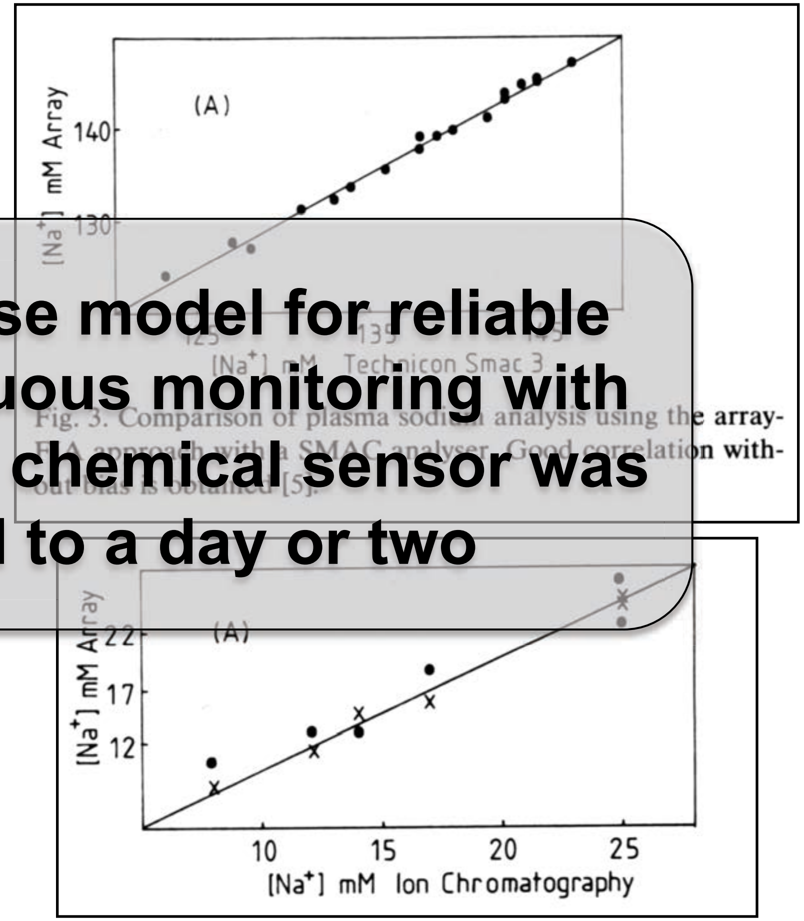


Typical membrane cocktail (%w/w); PVC:33%, NPOE (plasticiser):66%; ionophore/exchanger: 1% (ratio at least 2:1 by mole); dissolve in a volatile solvent e.g. THF and cast membrane from this solution

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



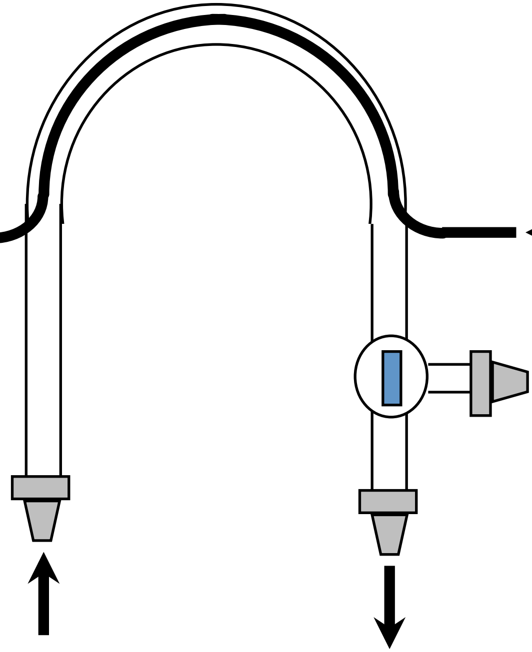
Anal. Chem., *64 (1992) 1721-1728.*

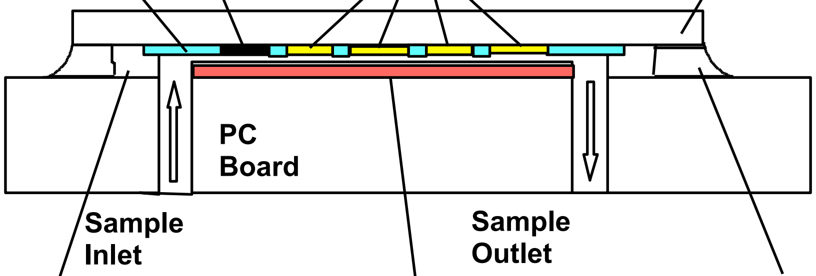
1985: Catheter Electrodes for intensive care – function for 24 hrs

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



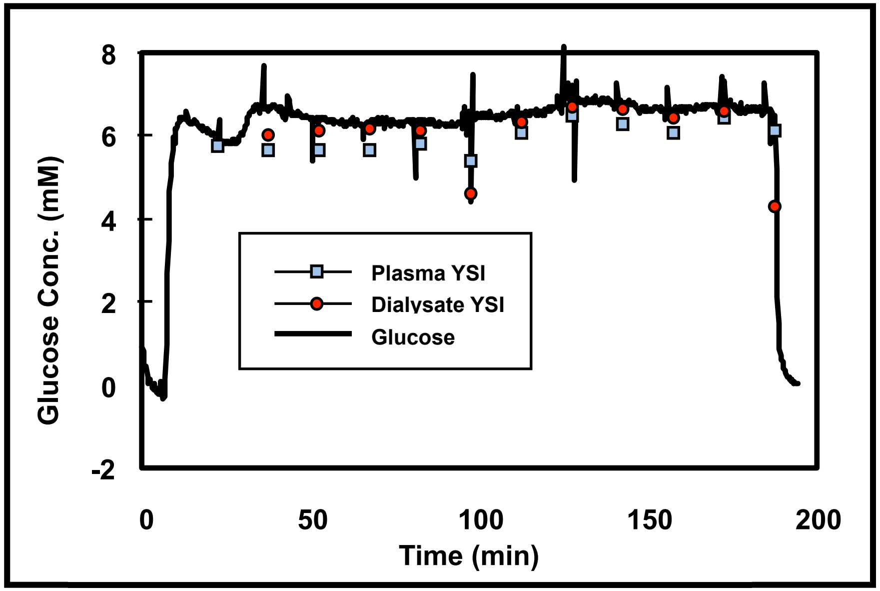


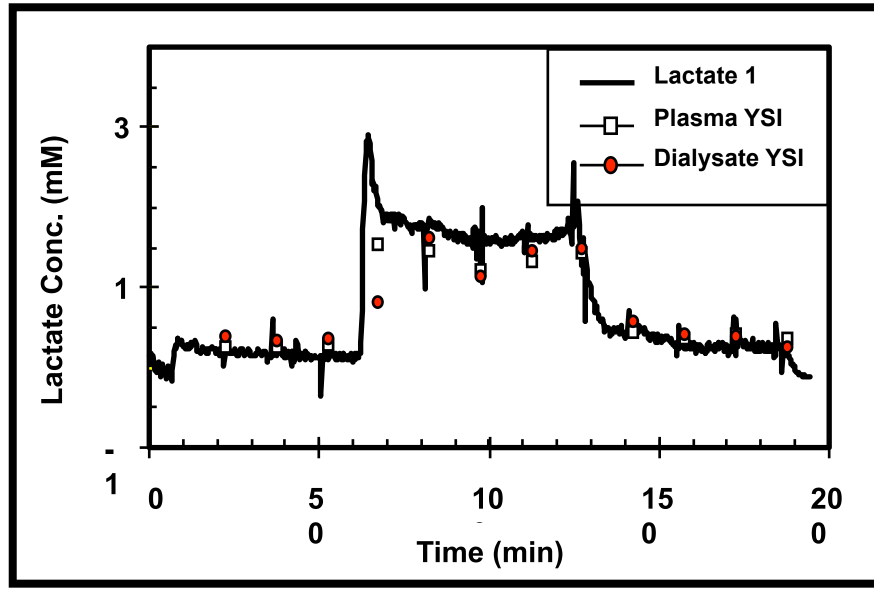
Novel Instrumentation for Real-Time Monitoring Using Miniaturised Flow Cells with Integrated Biosensors, R. Freaney, A. McShane, T.V. Keavney, M.McKenna, K. Rabenstein, F.W. Scheller, D. Pfeiffer, G. Urban, I. Moser, G. Jobst, A. Manz, E. Verpoorte, M.W. Widmer, D. Diamond, E. Dempsey, F.J. Saez de Viteri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

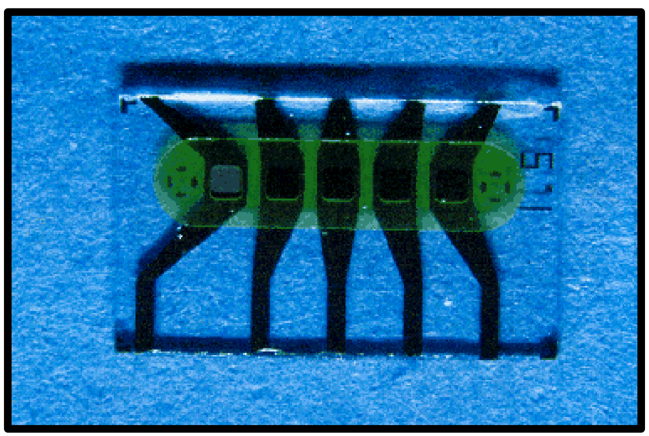
In Vitro Optimisation of a Microdialysis System with Potential for On-Line Monitoring of Lactate and Glucose in Biological Samples, E. Dempsey, D. Diamond, M.R. Smyth, M. Malone, K. Rabenstein, A. McShane, M.McKenna, T.V. Keavney and R Freaney, Analyst, 122 (1997) 185-189.

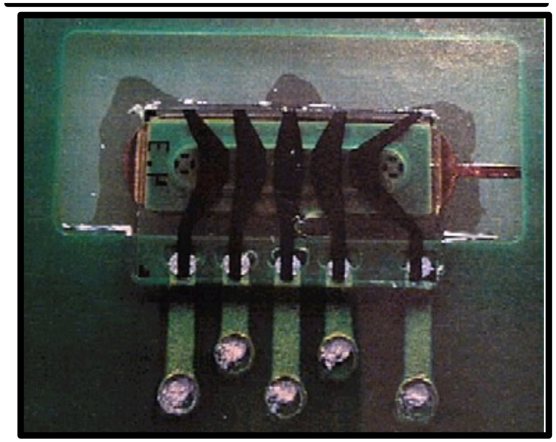
Design and Development of a Miniaturized Total Chemical-Analysis System for Online Lactate and Glucose Monitoring in Biological Samples, Ethna Dempsey, Dermot Diamond, Malcolm R. Smyth, Gerald Urban, Gerhart Jobst, I. Moser, Elizabeth MJ Verpoorte, Andreas Manz, HM Widmer, Kai Rabenstein and Rosemarie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

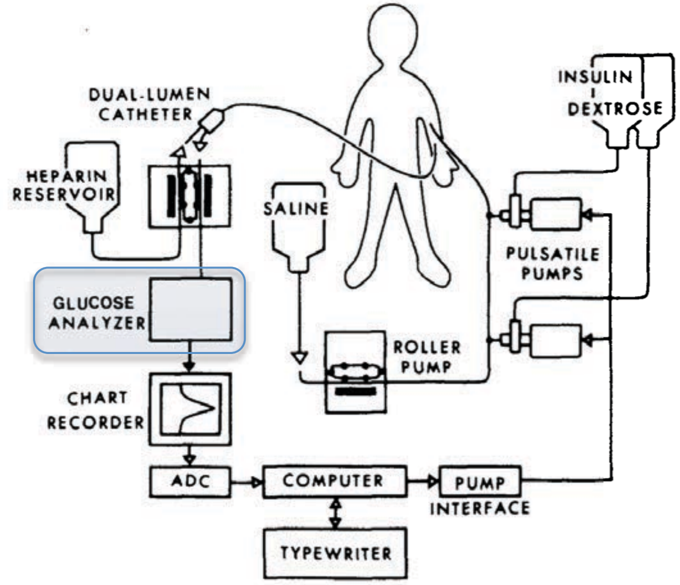
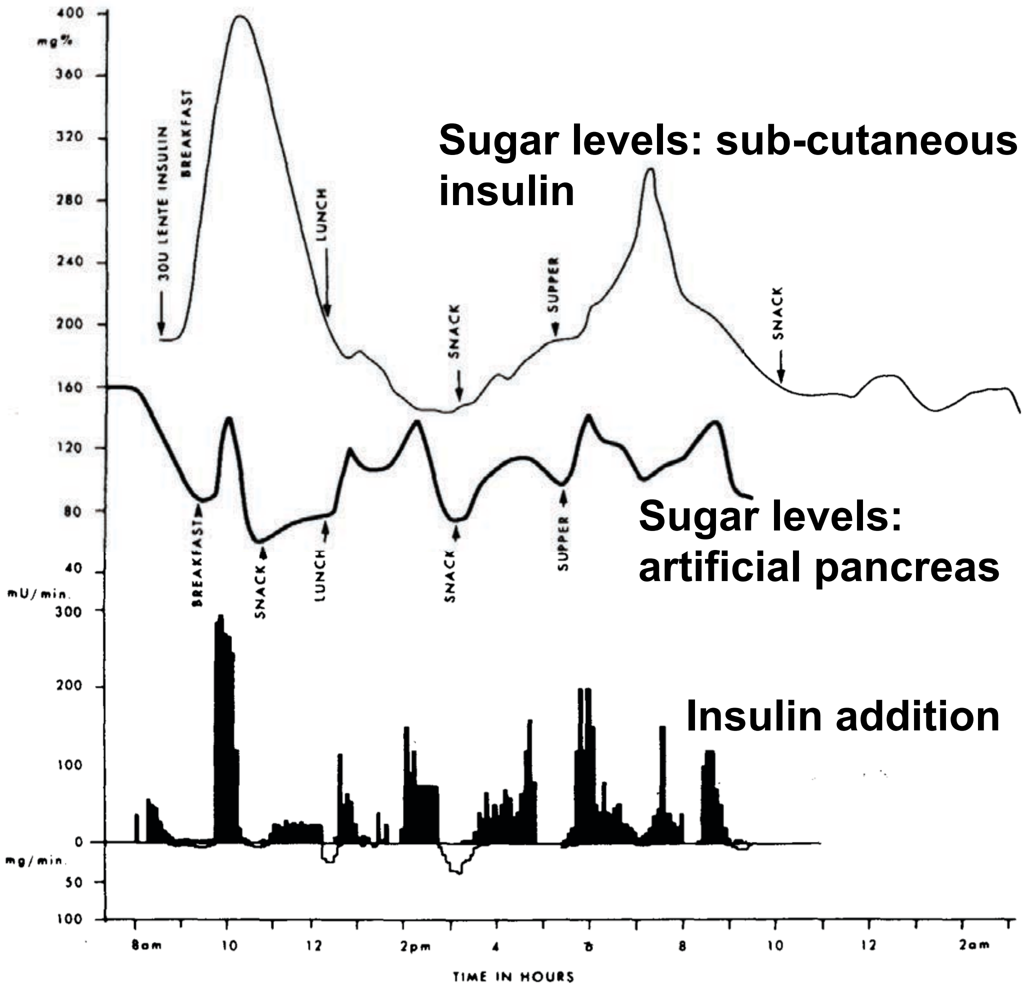


FIG. 1. Schematic diagram of apparatus used for monitoring and automatic regulation of blood sugar.



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

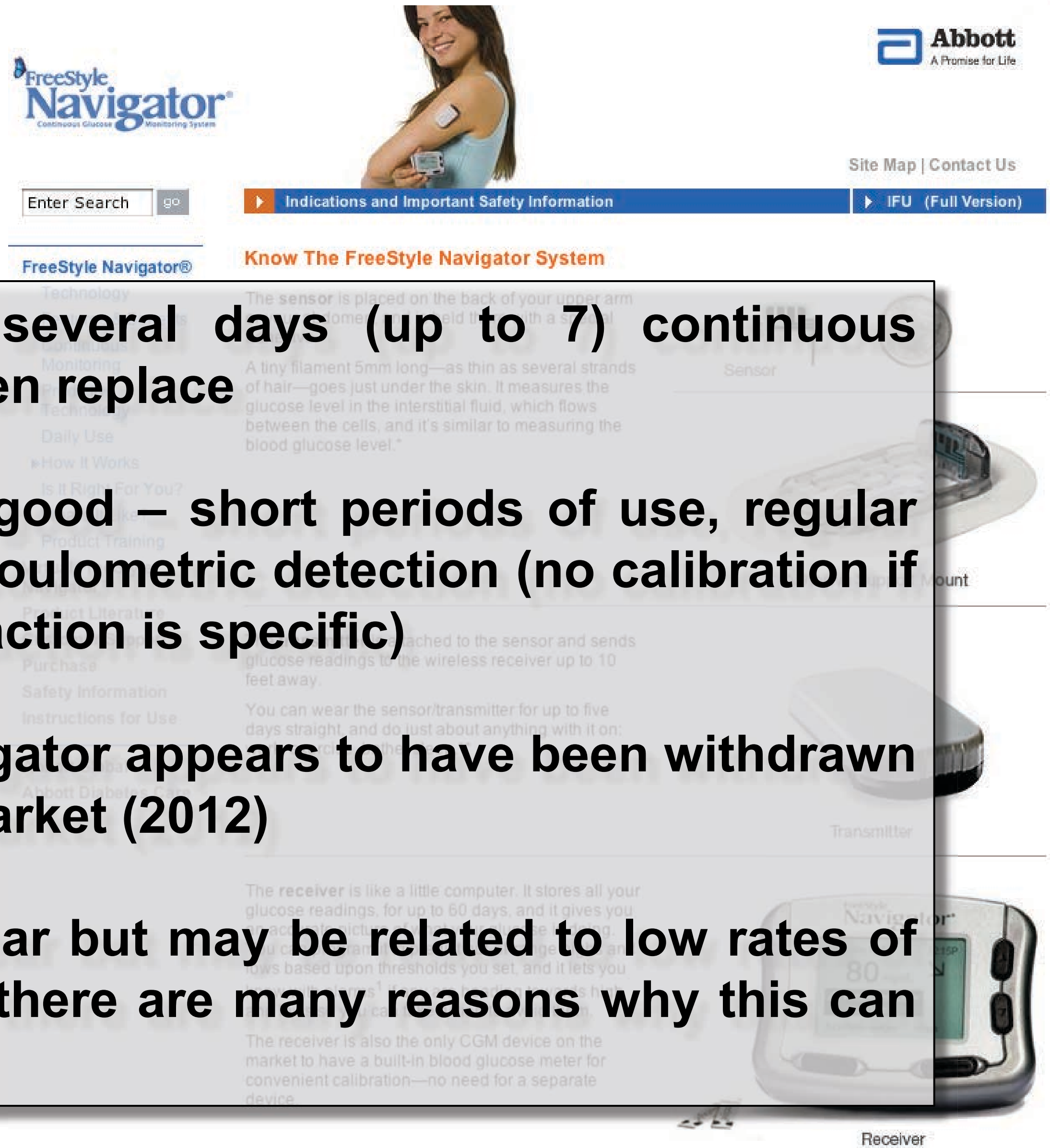
'Abbott completes TheraSense acquisition'

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


Independent.ie
Wednesday 7 May 2014
News | Sport | Business | Woman | Entertainment | Lifestyle | Videos
Independent.ie > Business > Technology

Apple hiring medical device staff, shares break $600 mark

0 Comments | Recommend 7 | Tweet 89 | g+1 3 | Share

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

Google's Smart Contact Lens is like your contact lens, except it's a whole lot smarter.

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

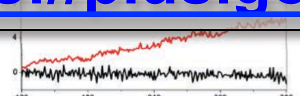


Fig. 2. Images of the sensor as it goes through surface functionalization and the related measured responses: (a) sequential images of sensor pre-treatment with GOD/titania/Nafion®; (b) measured amperometric response for the sensor just incubated with GOD; (c) measured amperometric response for the sensor 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, M. Cowan, I. Lahdesmaki 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 for in-vivo monitoring 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

What about the environment?

Remote (Continuous) Sensing Challenges: Platform and Deployment Hierarchies

Physical Transducers –low cost, reliable, low power demand, long life-time

Thermistors (temperature), movement, location, power,, light level, conductivity, flow, sound/audio, ……

Chemical Sensors – more complicated, need regular calibration, more costly to implement

Electrochemical, Optical, .. For metal ions, pH, organics…

Biosensors – the most challenging, very difficult to work with, die quickly, single shot (disposable) mode dominant use model

Due to the delicate nature of biomaterials enzymes, antibodies….

Increasing difficulty & cost

Increasing scalability

Gas/Air Sensing – easiest to realise

Reliable sensors available, relatively low cost

Integrate into platforms, develop IT infrastructure, GIS tools, Cloud Computing

On-land Water/ Monitoring

More accessible locations

Target concentrations tend to be higher

Infrastructure available

Marine Water

Challenging conditions

Remote locations & Limited infrastructure

Concentrations tend to be lower and tighter in range

pH sensing – wasn't that solved by Nikolskii in the 1930's?

EVENT	DATE
Launch (San Francisco)	September 2013
PHASE 1: Innovation Phase	
Registration opens	January 1, 2014
Early-bird Registration deadline	March 2014
OA Solutions Fair and Kick-Off Event	March 2014

Overview

Competition Guidelines

Competition Schedule

Registration Process

OVERVIEW

The Challenge: Improve Our Understanding of Ocean Acidification

The Wendy Schmidt Ocean Health XPRIZE is a $2 million global competition that challenges teams of engineers, scientists and innovators from all over the world to create pH sensor technology that will affordably, accurately and efficiently measure ocean chemistry from its shallowest waters… to its deepest depths.

There are two prize purses available (teams may compete for, and win, both purses):

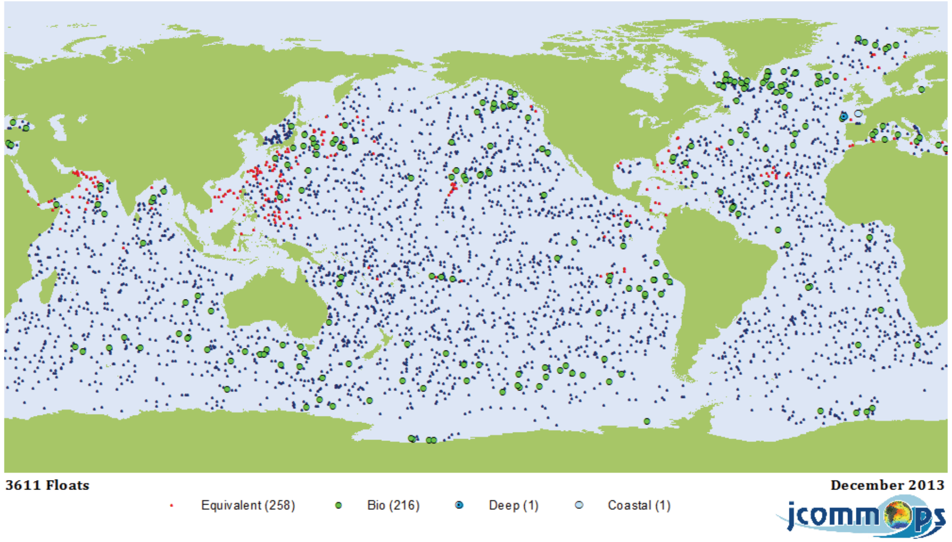
A. $1,000,000 Accuracy award – Performance focused ($750,000 First Place, $250,000 Second Place): To the teams that navigate the entire competition to produce the most accurate, stable and precise pH sensors under a variety of tests.

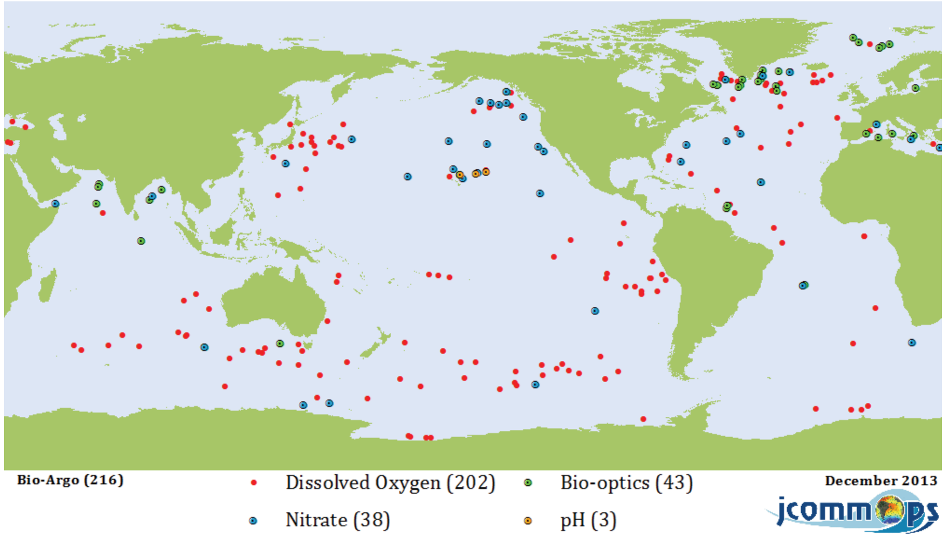
Wendy Schmidt Ocean Health XPRIZE

$2,000,000 up for grabs!
Task is to provide a way to do reliable measurements of pH in the ocean environment

The winner will almost certainly be a reagent based platform, not a conventional chemical sensor

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)

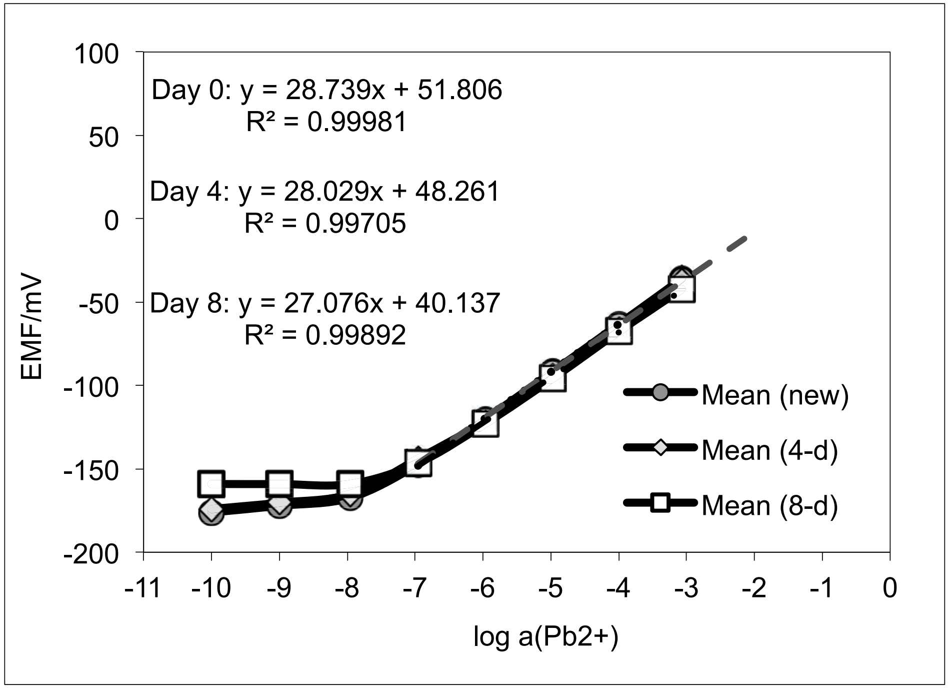
See https://picasaweb.google.com/JCOMMOPS/ArgoMaps?authuser=0&feat=embedwebsite

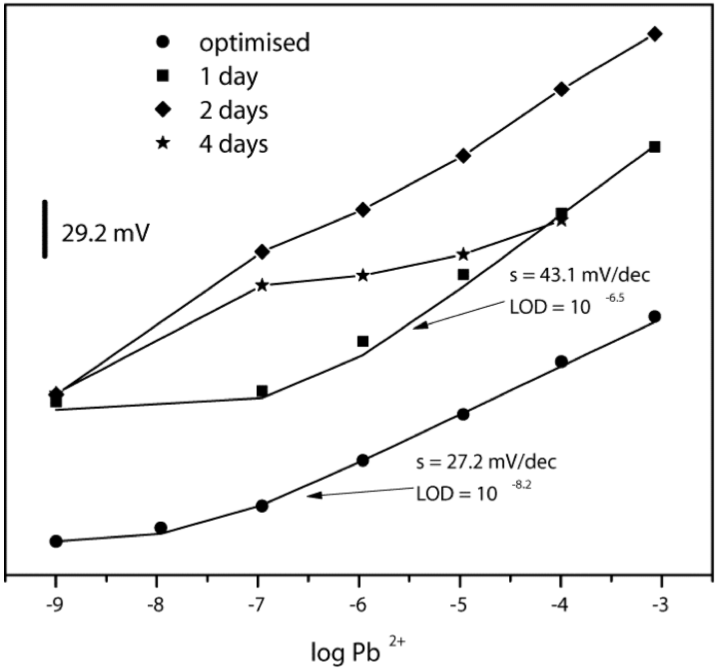
'calibration of the DO measurements by the SBE sensor remains an important issue for the future', Argo report 'Processing Argo OXYGEN data at the DAC level', September 6, 2009, V. Thierry, D. Gilbert, T. Kobayashi

And for nutrients….

Change in Electrode Function over Time

See Electrochimica Acta 73 (2012) 93–97



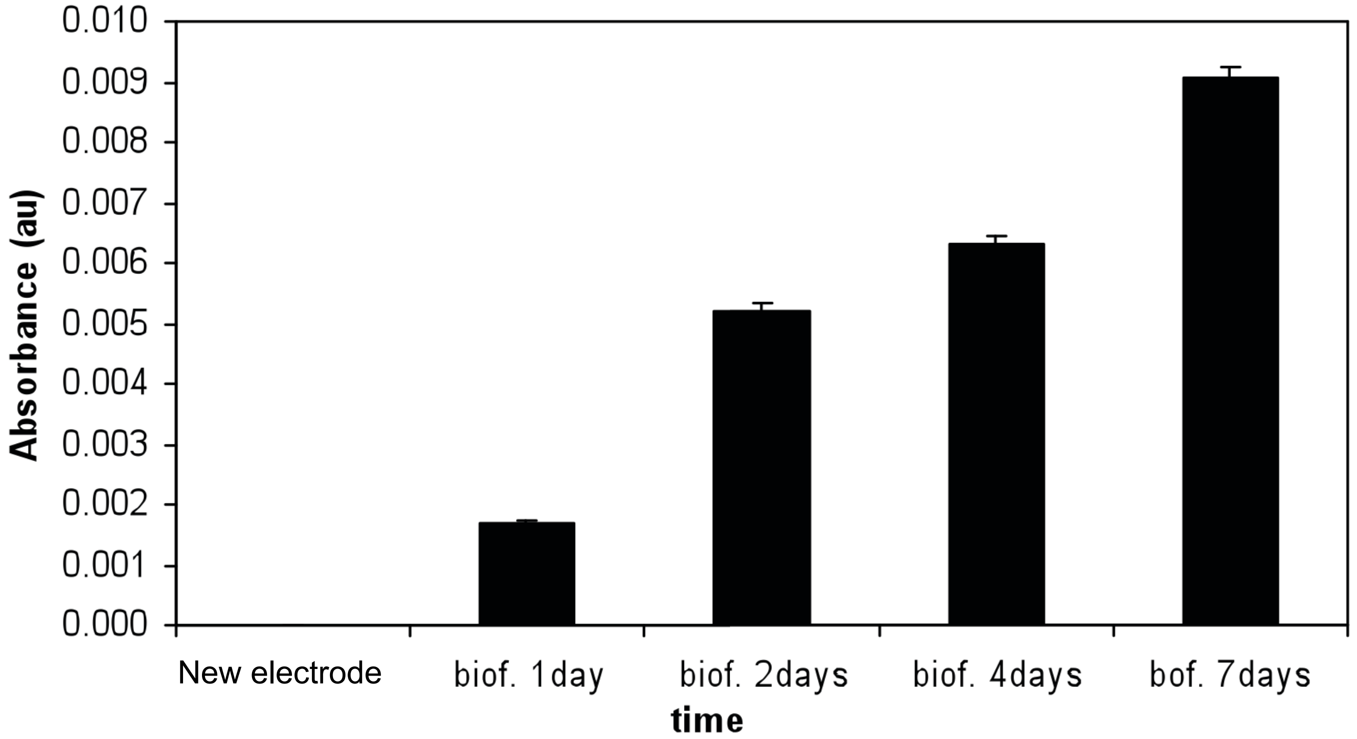


stored in 10^{-9}M Pb^{2+}, pH=4

Continuous contact with river water

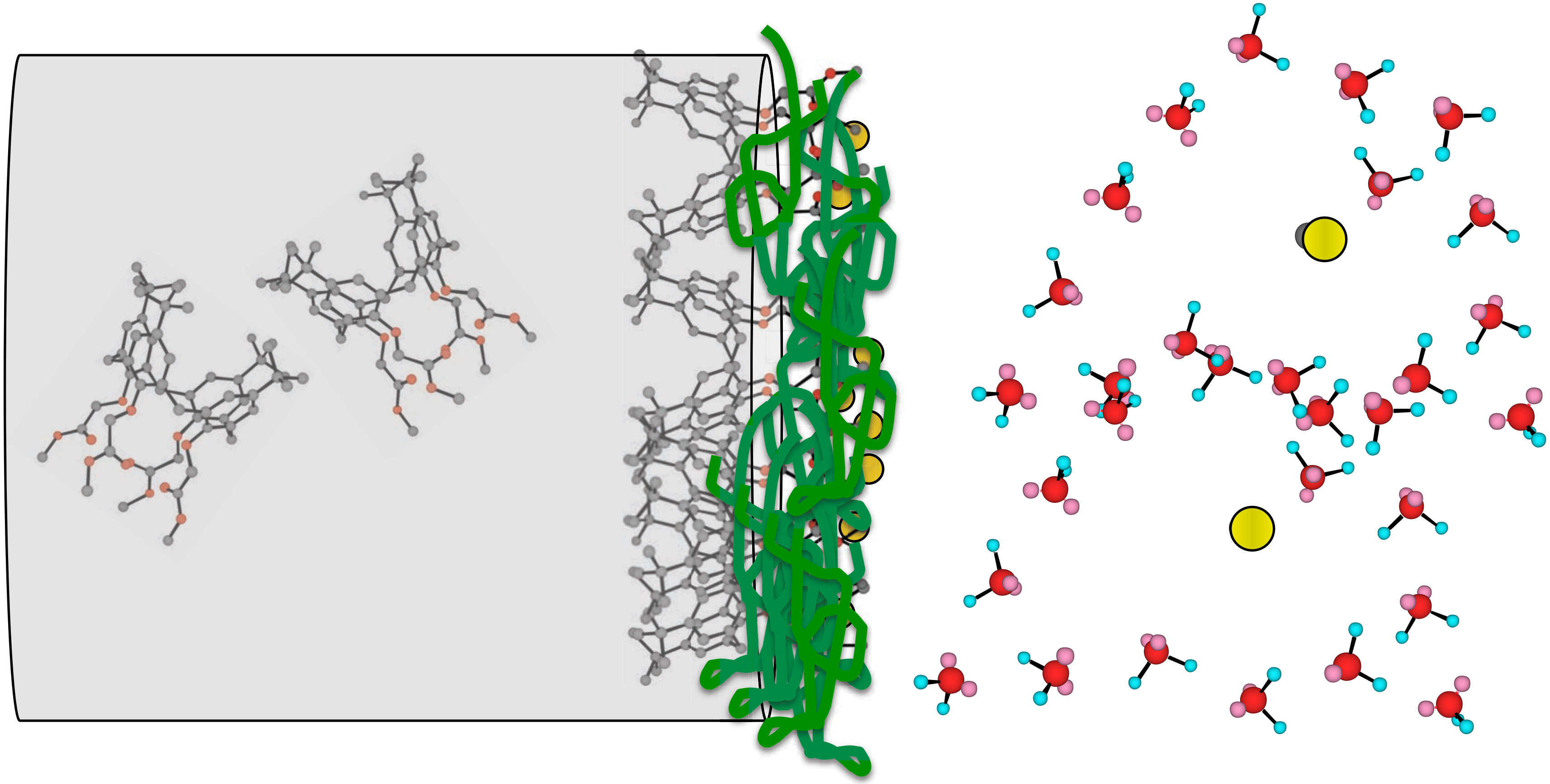
PVC-membrane based ISEs

Biofilm Formation on Sensors



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

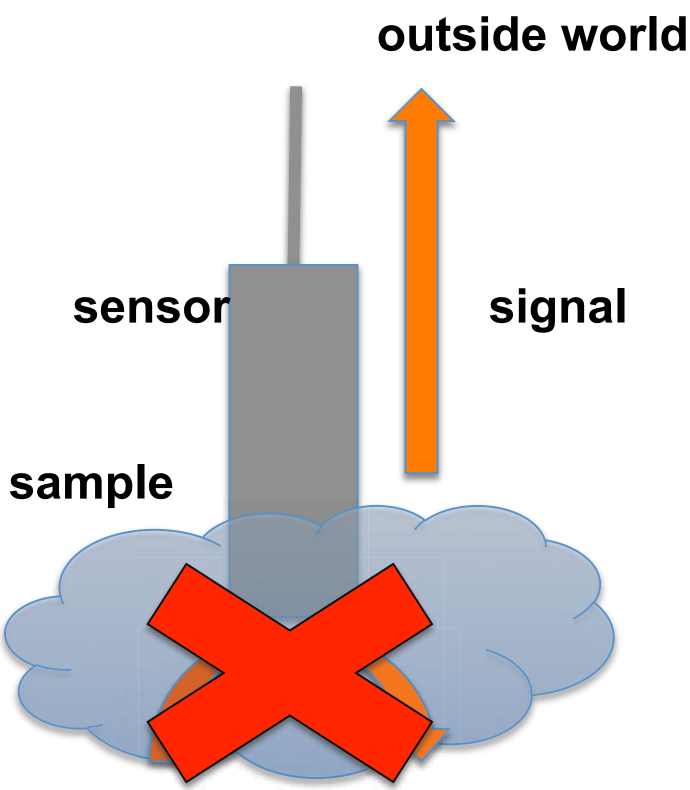
Control of membrane interfacial exchange & binding processes



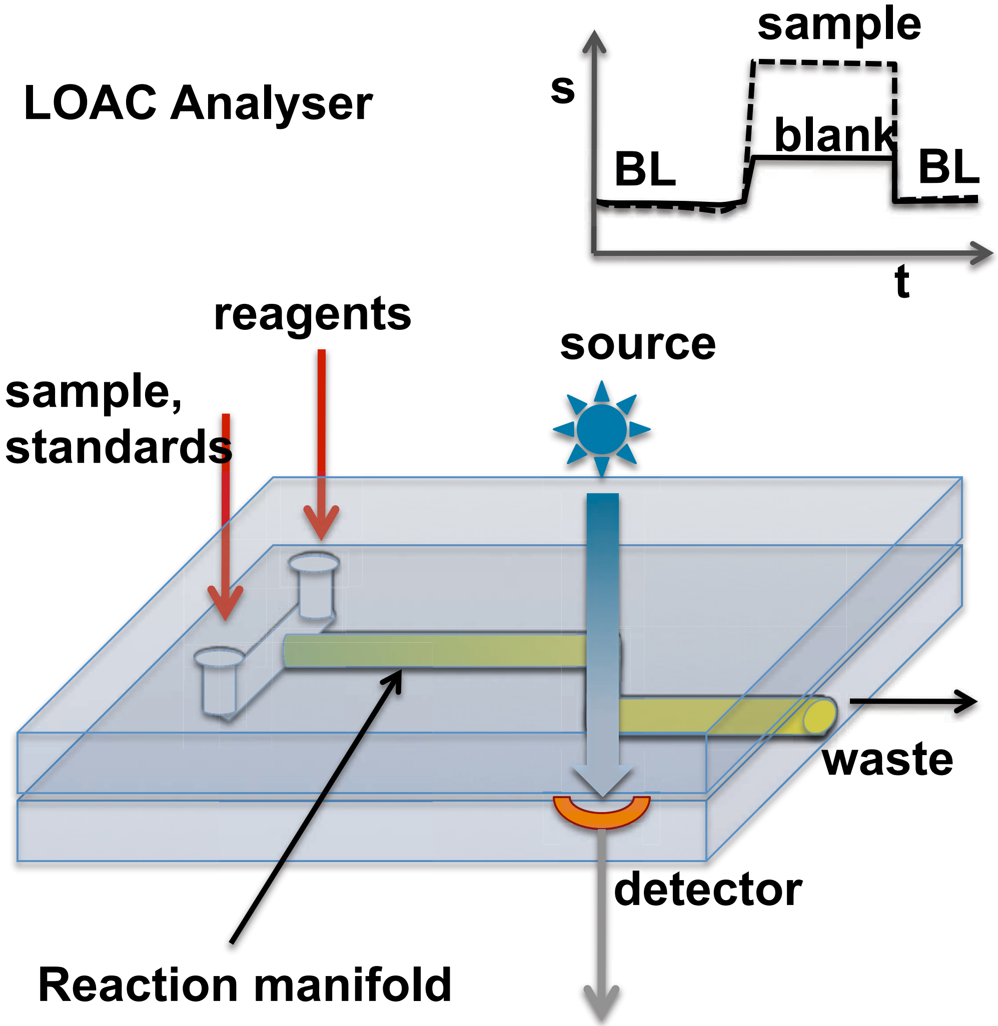
Remote, autonomous chemical sensing is a tricky business!

Direct Sensing vs. Reagent Based LOAC/ufluidics

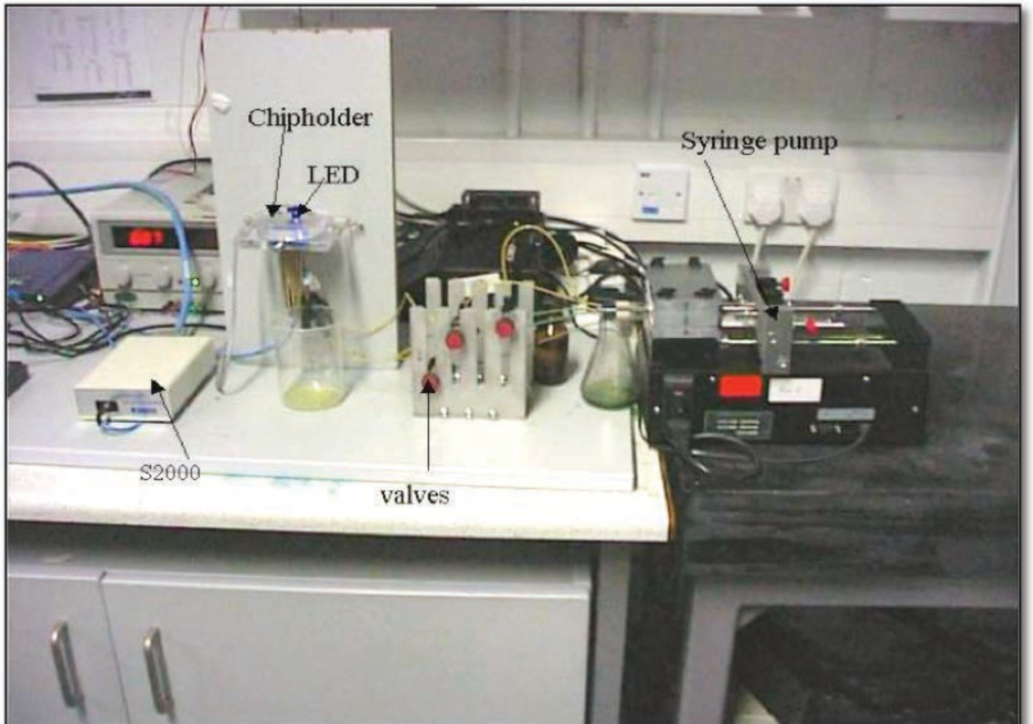
Direct Sensing



LOAC Analyser

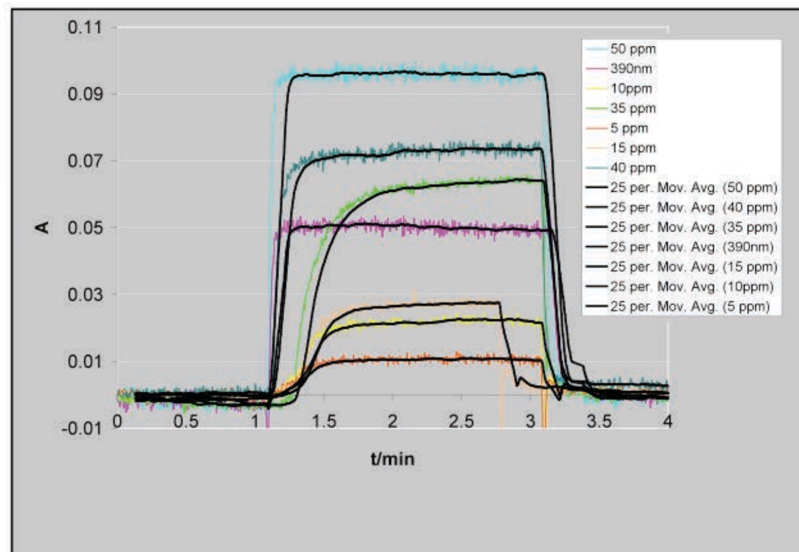


Reagent based Nutrient Analyser



- Setup ca. 1999
- Worked well but not an integrated system

Chemical Sensing using an Integrated uFluidic System based on Colorimetrics: A Comparative Kinetic Study of the Bertholet Reaction for Ammonia Determination in Microfluidic and Spectrophotometric Systems, A Daridon, M Sequiera, G. Pennarun-Thomas, J Lichtenberg, E Verpoorte, D Diamond and NF de Rooij, Sensors and Actuators B, 76/1-3, (2001) 235-243.



Phosphate: The Yellow Method

Mixture (Reagent)

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

+

Sample

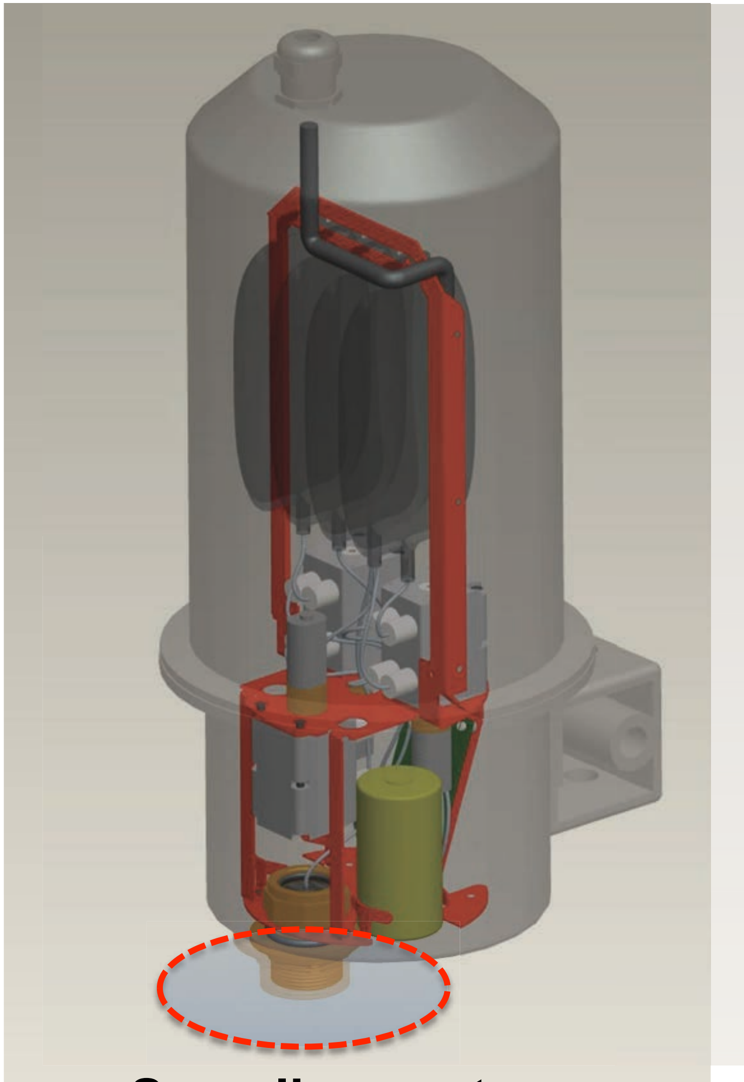
(KH_2PO_4)

→

$(NH_4)_3PO_4.NH_4VO_3.16MoO_3$

- 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

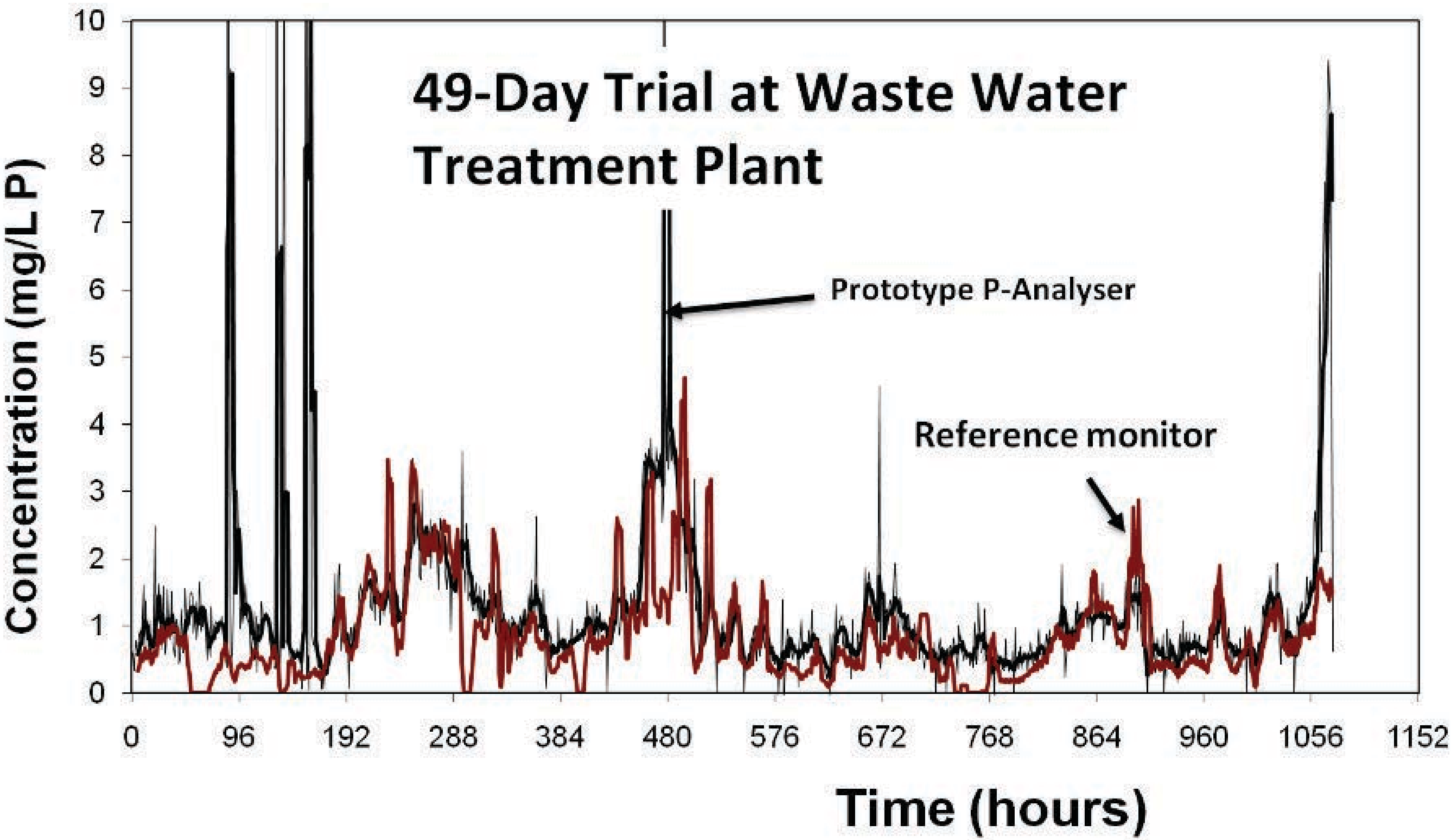


Sampling port

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

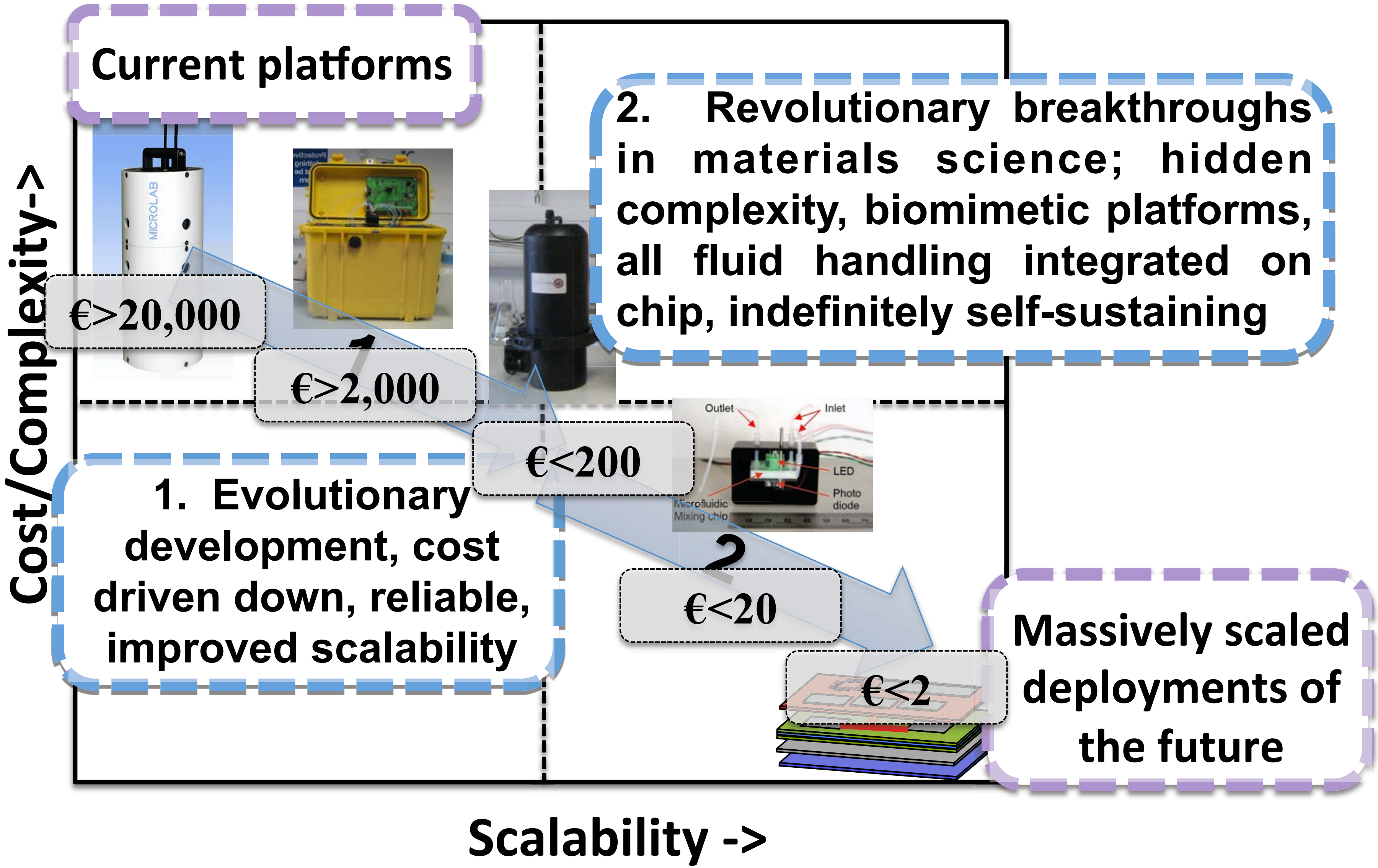


Phosphate monitoring using the Yellow Method

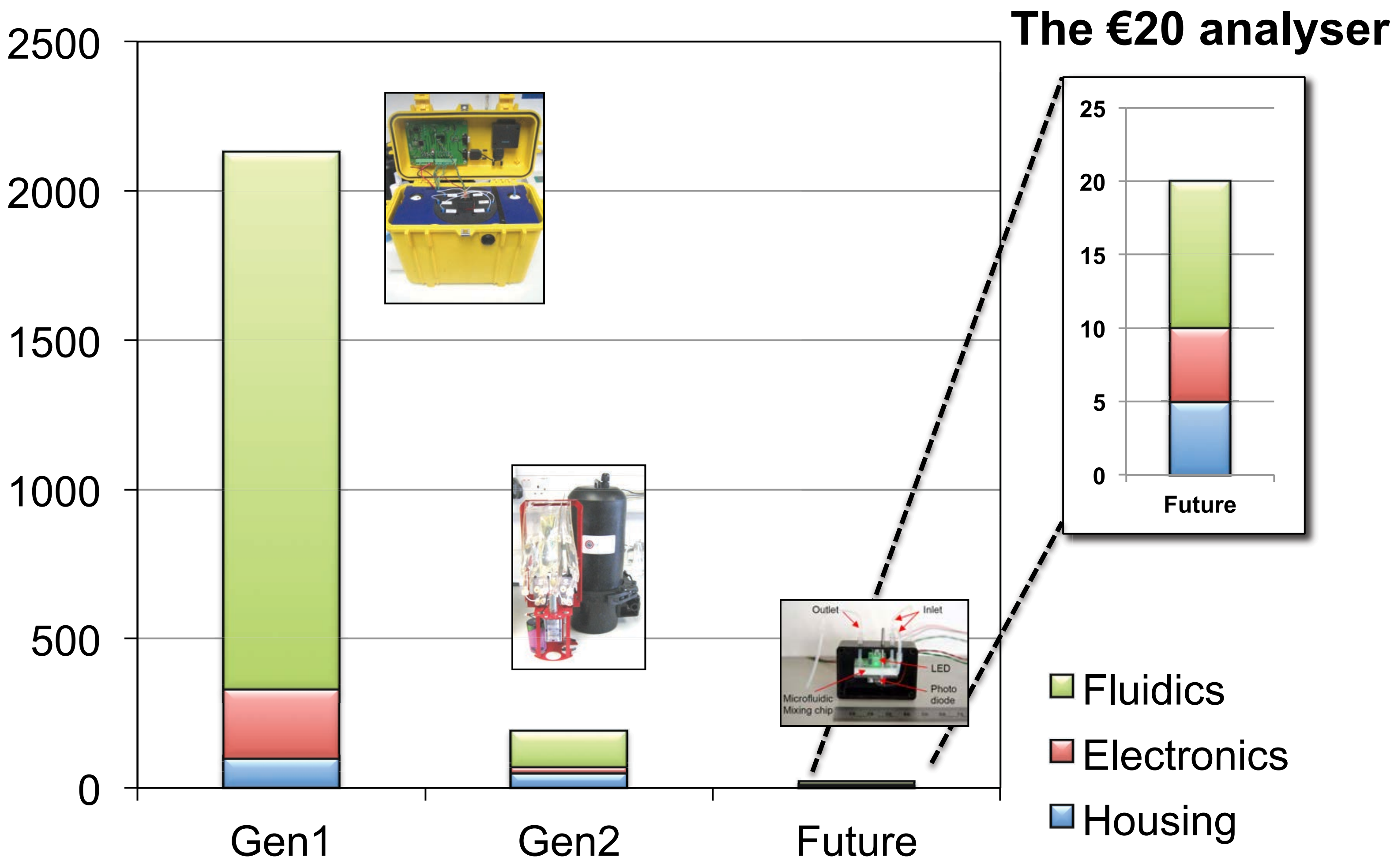
Osberstown – 3 week deployment

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

Achieving Scale-up

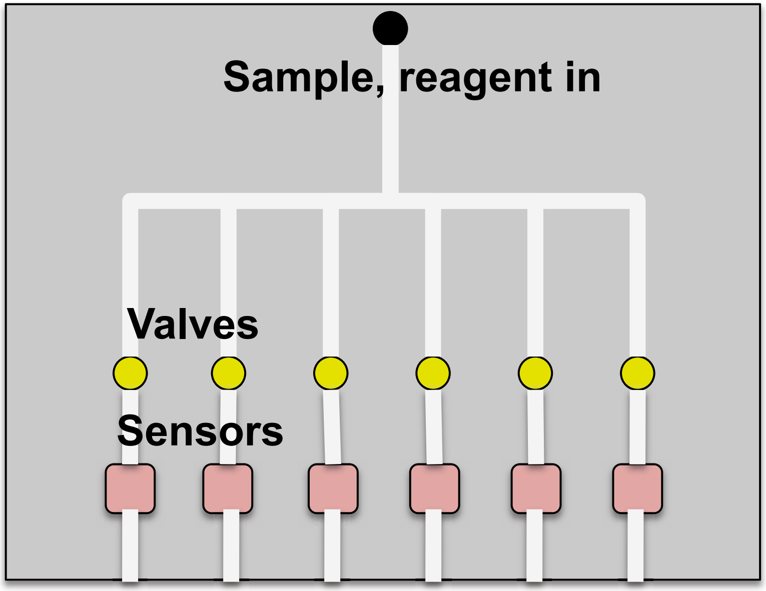


Cost Comparison Analyser (€)



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)….

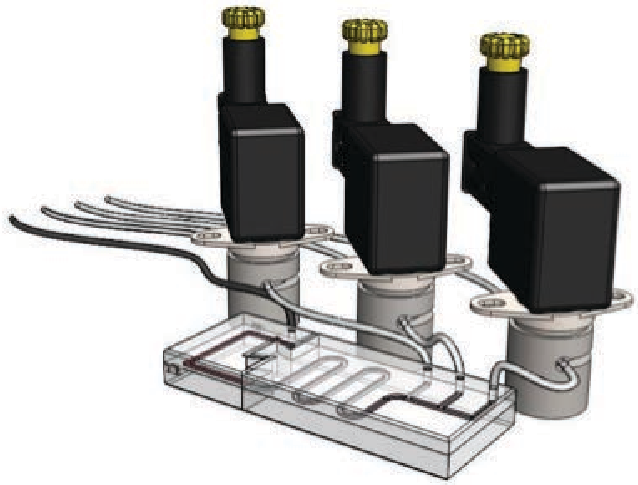


Then 50 sensors when used sequentially could provide an aggregated in-use lifetime of around 1 year

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

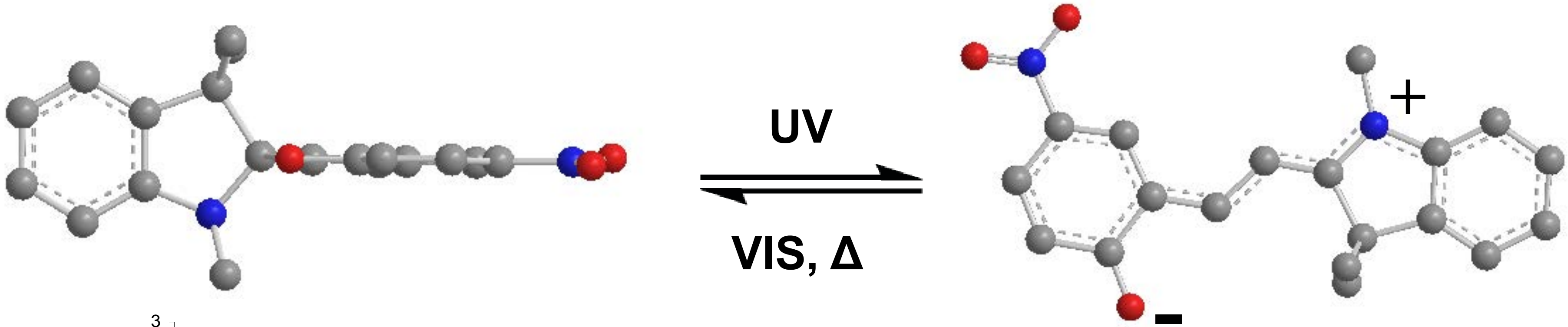
How to advance fluid handling in LOC platforms: re-invent valves (and pumps)!

- **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



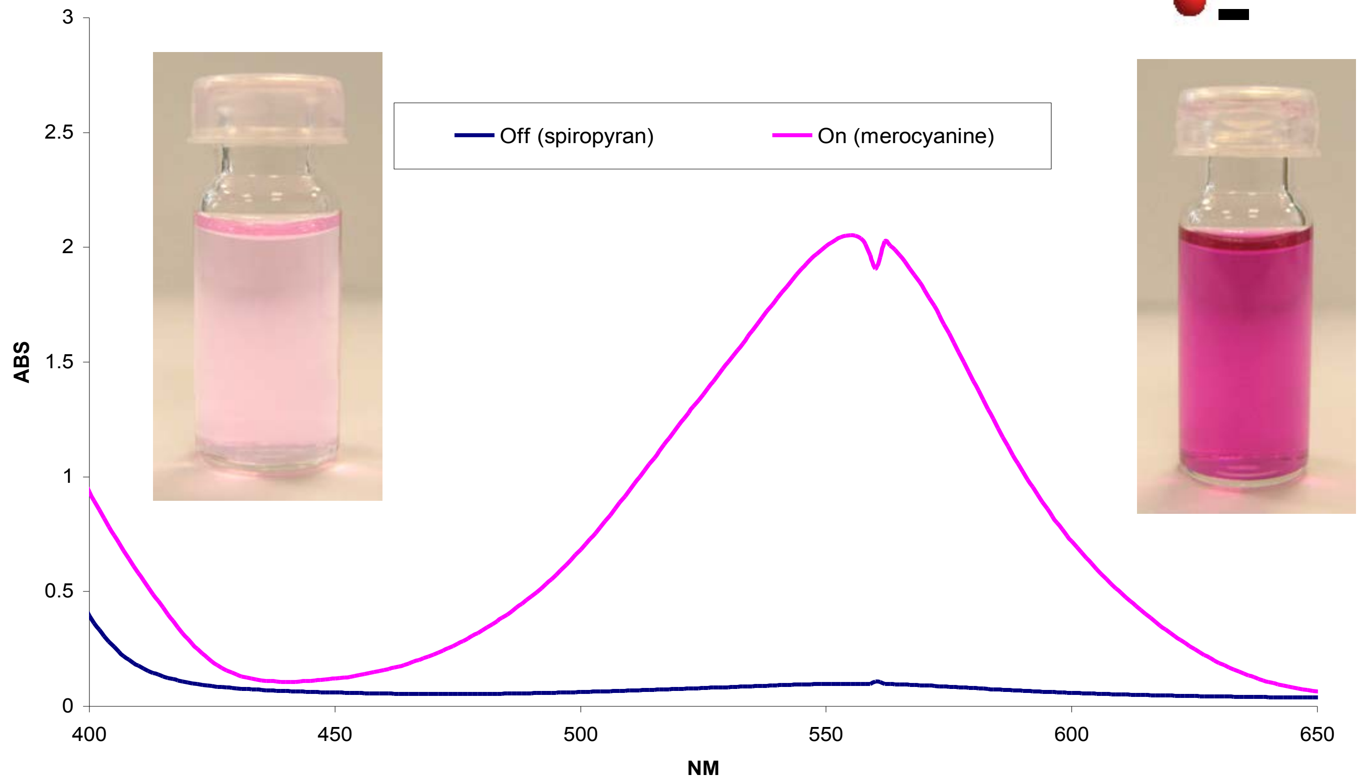
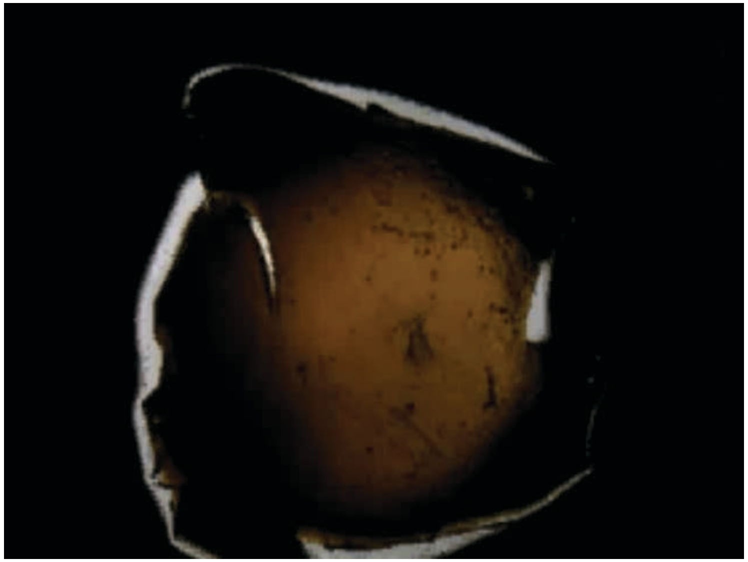
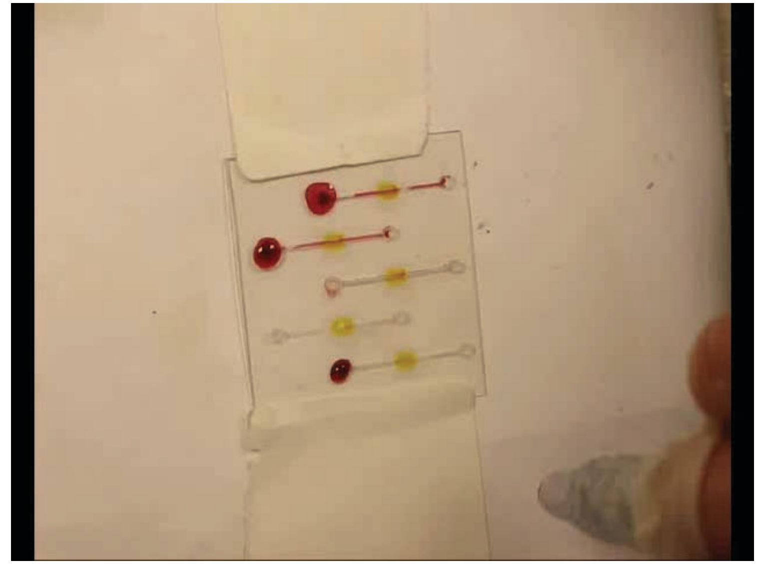
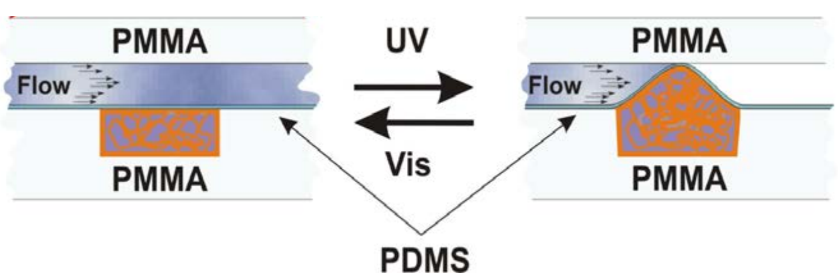
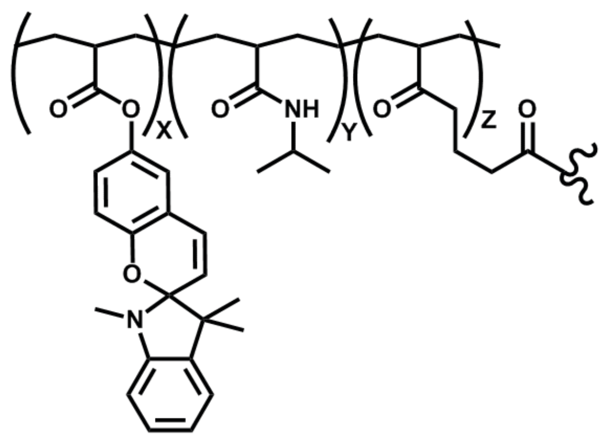


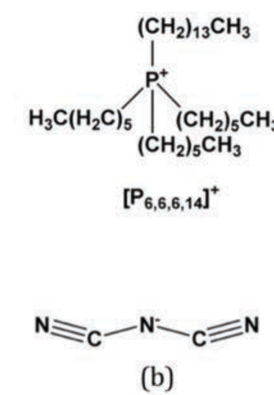
Photo-actuator polymers as microvalves in microfluidic systems









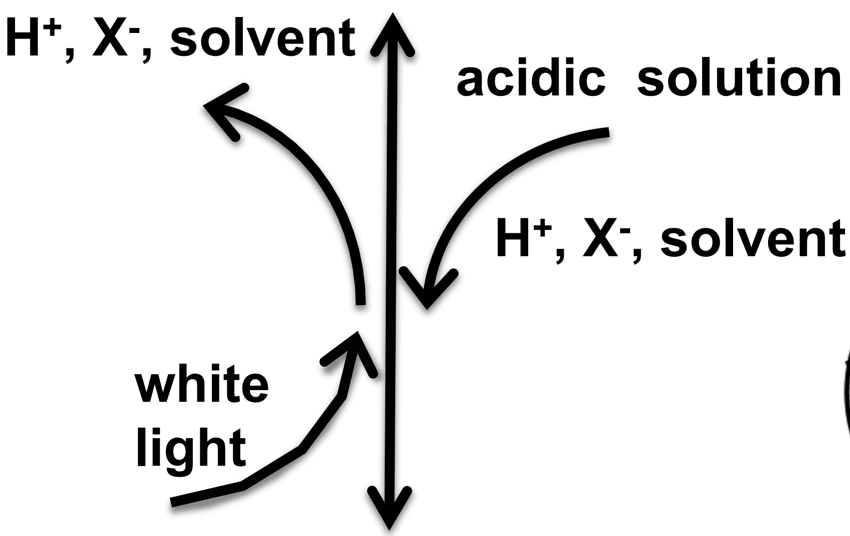


trihexyltetradecylphosphonium dicyanoamide $[P_{6,6,6,14}]^+[dca]^-$

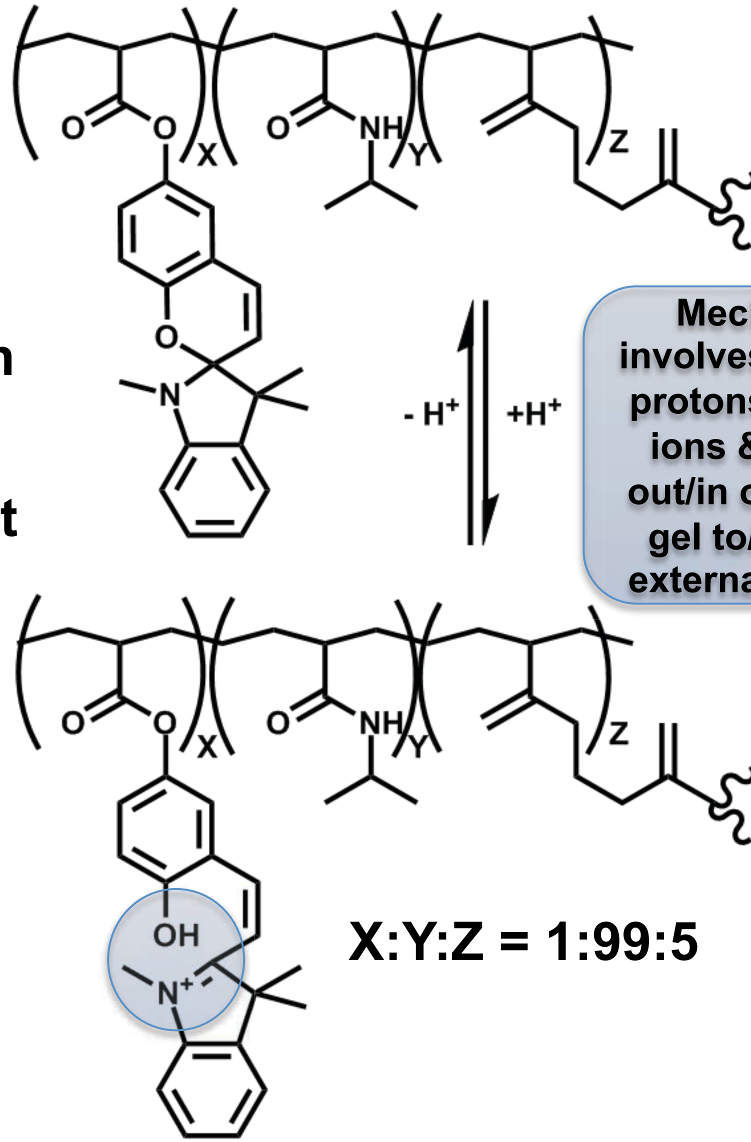
Ionogel-based light-actuated valves for controlling liquid flow in micro-fluidic manifolds, Fernando Benito-Lopez, Robert Byrne, Ana Maria Raduta, Nihal Engin Vrana, Garrett McGuinness, Dermot Diamond, Lab Chip, 10 (2010) 195-201.

Actuation Mechanism

SPIRO (contracted)



MERO-H^{+} (expanded)



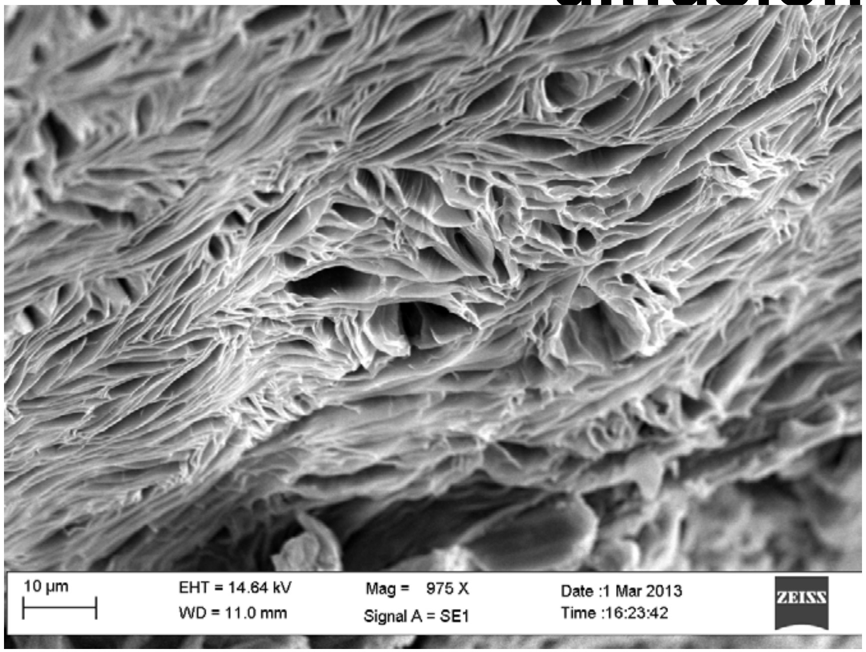
Mechanism involves diffusion protons, counter ions & solvent out/in of the bulk gel to/from the external solution

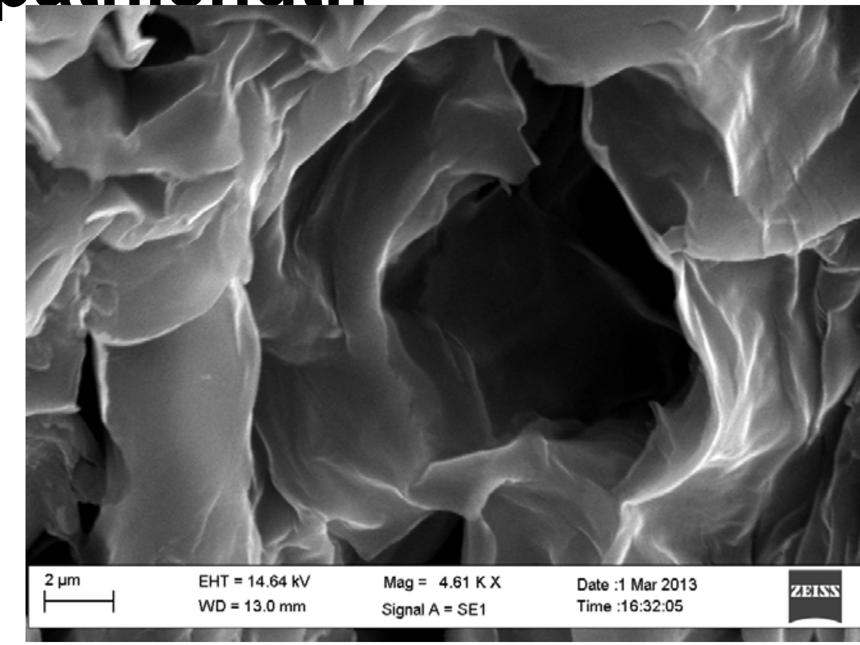
X:Y:Z = 1:99:5

So far, so good: but what are the limitations?

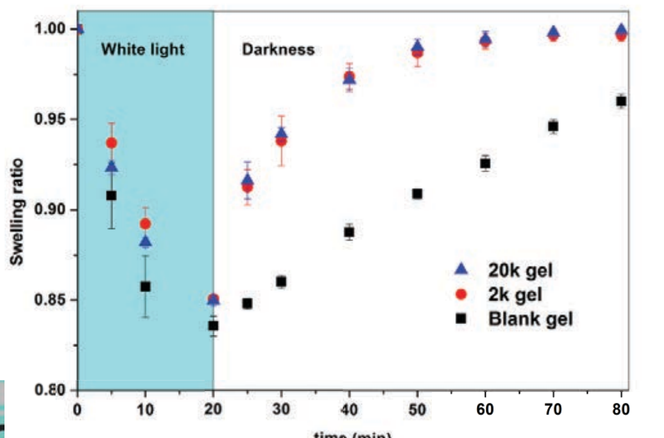
- Response time for re-swelling is slow - 10's of minutes due to diffusion mechanism
- Swelling requires protonation of the MC to MC-H^+ within the ionogel by the external bathing solution – which must be acidic, typically pH 3
- These issues more or less limit the applicability of the valves to single use

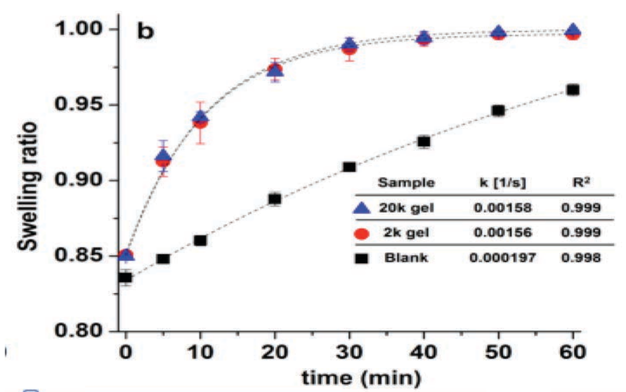
Improve response time: Porous Gels → reduce diffusion pathlength





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



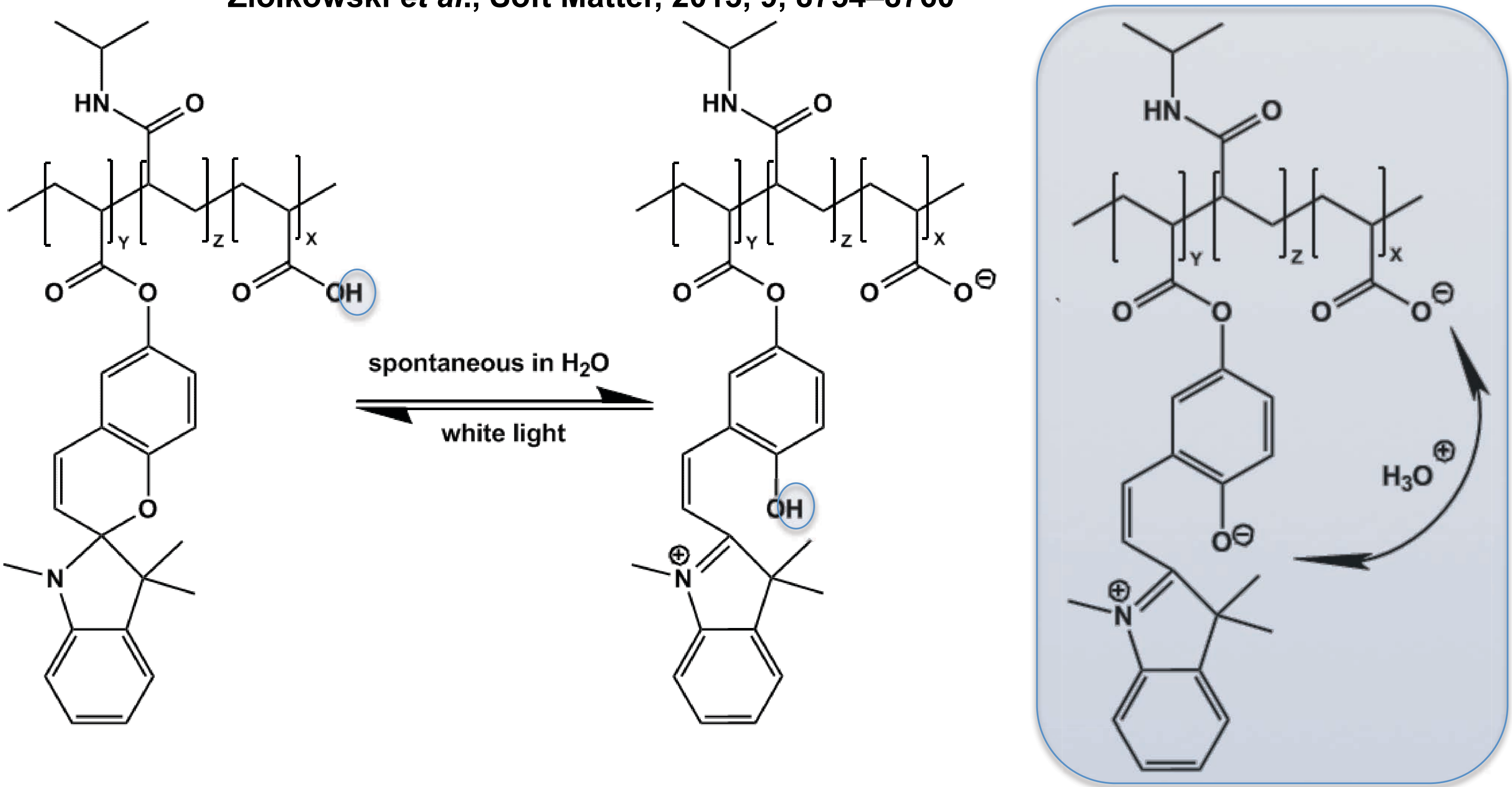


On the re-swelling side; highly porous gels now recover ca. an order of magnitude faster;

k = 1.6×10^{-3} S^{-1} vs. 2.0×10^{-4} S^{-1}

Self protonating photoresponsive gel

Ziolkowski *et al.*, Soft Matter, 2013, 9, 8754–8760



Previously proton source was external (acidic soln. required)
Protons, counter ions & solvent diffuse into/out of the gel

Now the proton exchange is 'internalised'
The proton population is essentially conserved

Spontaneous Reformation of Acidified Merocyanine during Actuation Cycling in non-acidified water

Ziolkowski *et al*., Soft Matter, 2013, 9, 8754–8760

Gel with 0 % AA

Colour gradually changing from yellow to purple as H^+ leaves the gel on each cycle

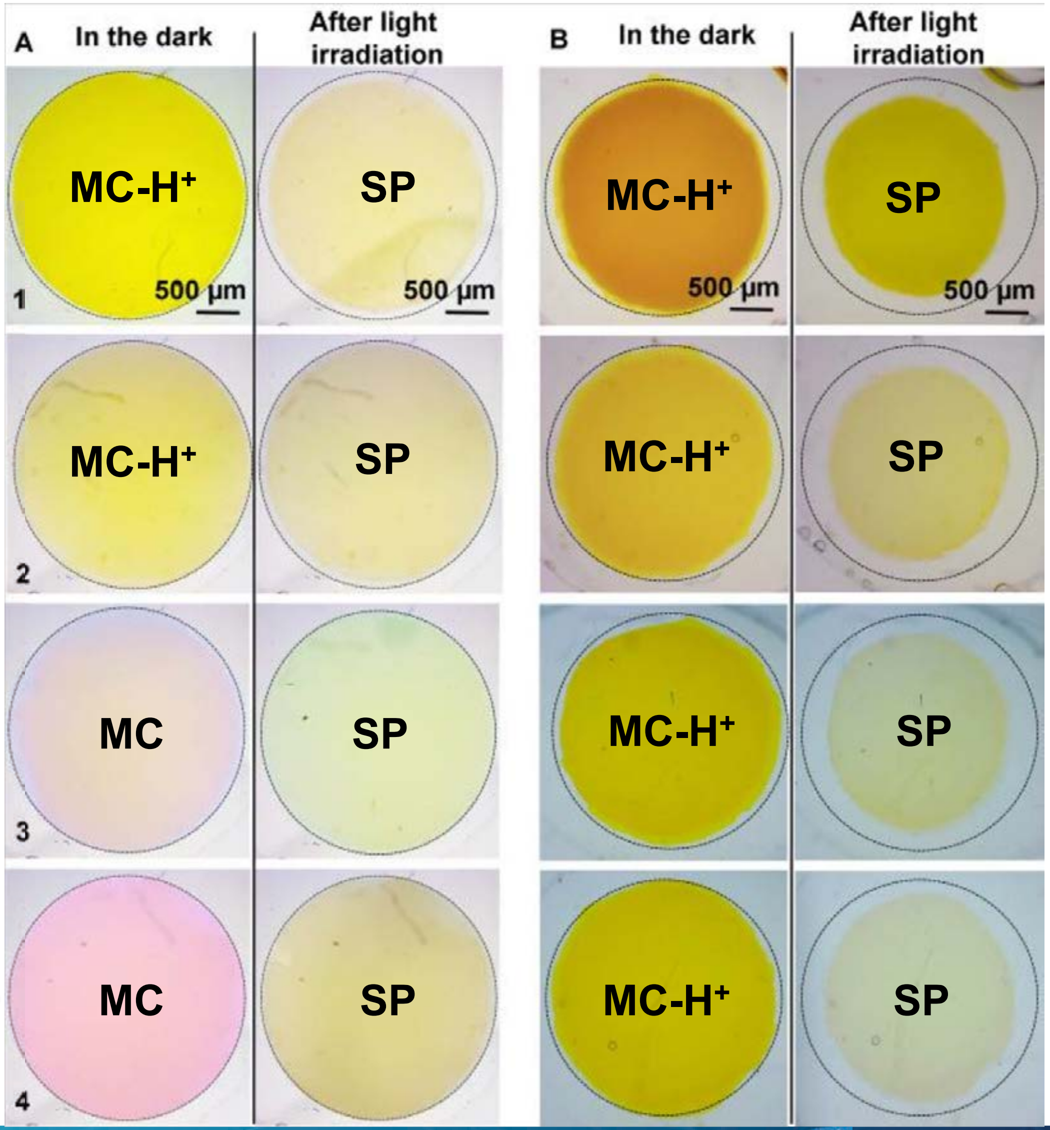
Switching changes from primarily

$MC\text{-}H^+ \rightarrow SP + H^+$

to

$MC \rightarrow SP$

Gel actuation stops



Gel with 5 % AA

Colour remains essentially the same, as H^+ stays in the gel during cycling

Switching stays primarily as

$MC\text{-}H^+ \rightarrow SP + H^+$

Gel actuation continues

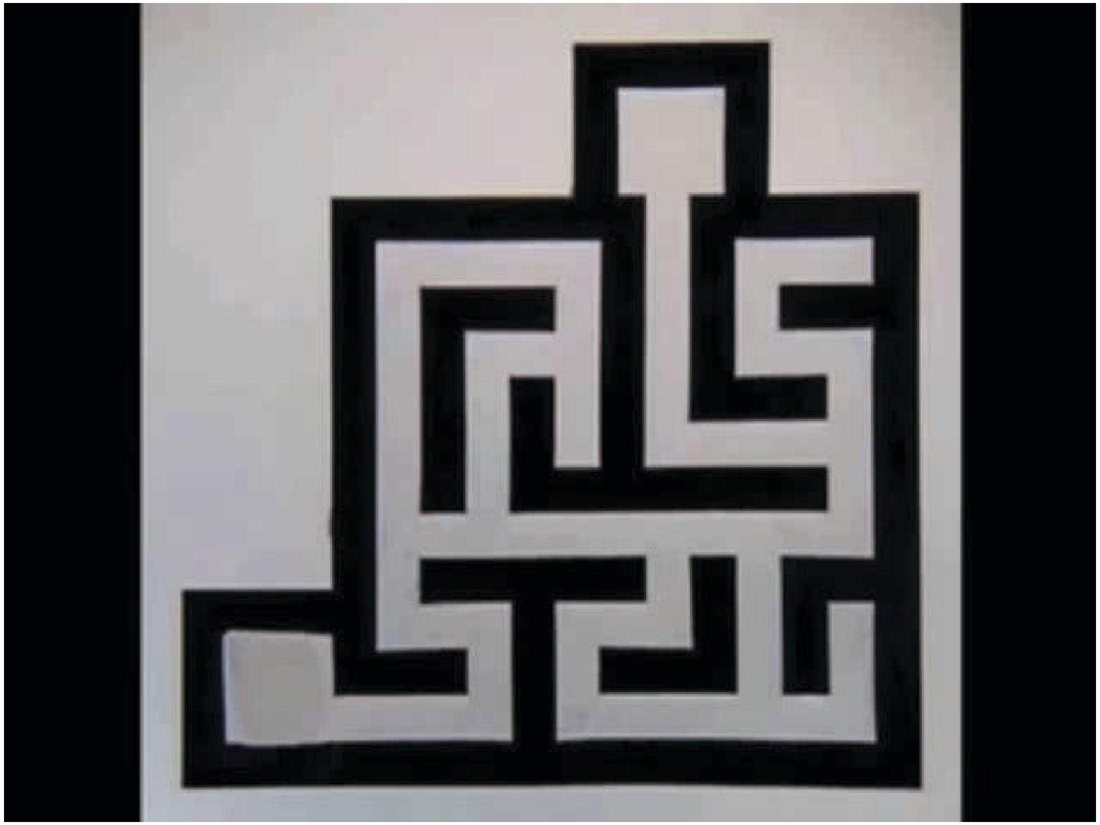
Why move the solvent at all?

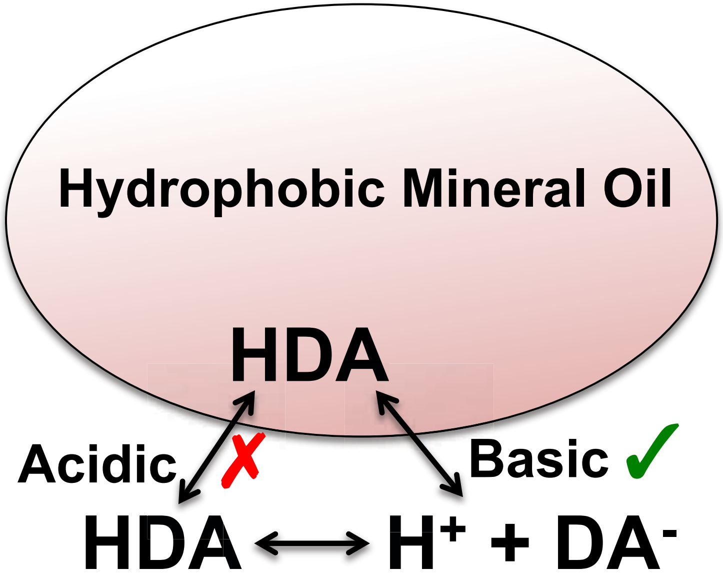
[sample]/mol l^{-1}	Ratio H_2O/Sample
$1.0x10^{-6}$	$5.56x10^{7}$
$1.0x10^{-9}$	$5.56x10^{10}$
$1.0x10^{-12}$	$5.56x10^{13}$

Strategy:
Move multifunctional micro/ nano-vehicles such as beads, vesicles, micelles, capsules, droplets through the sample to perform tasks……

- **These vehicles should be able to;**
  - Spontaneously move under an external stimulus (e.g. chemical, thermal gradient) to preferred locations
  - Report selective binding of guest species
  - Release active payload to modify local environment

Chemotactic Systems





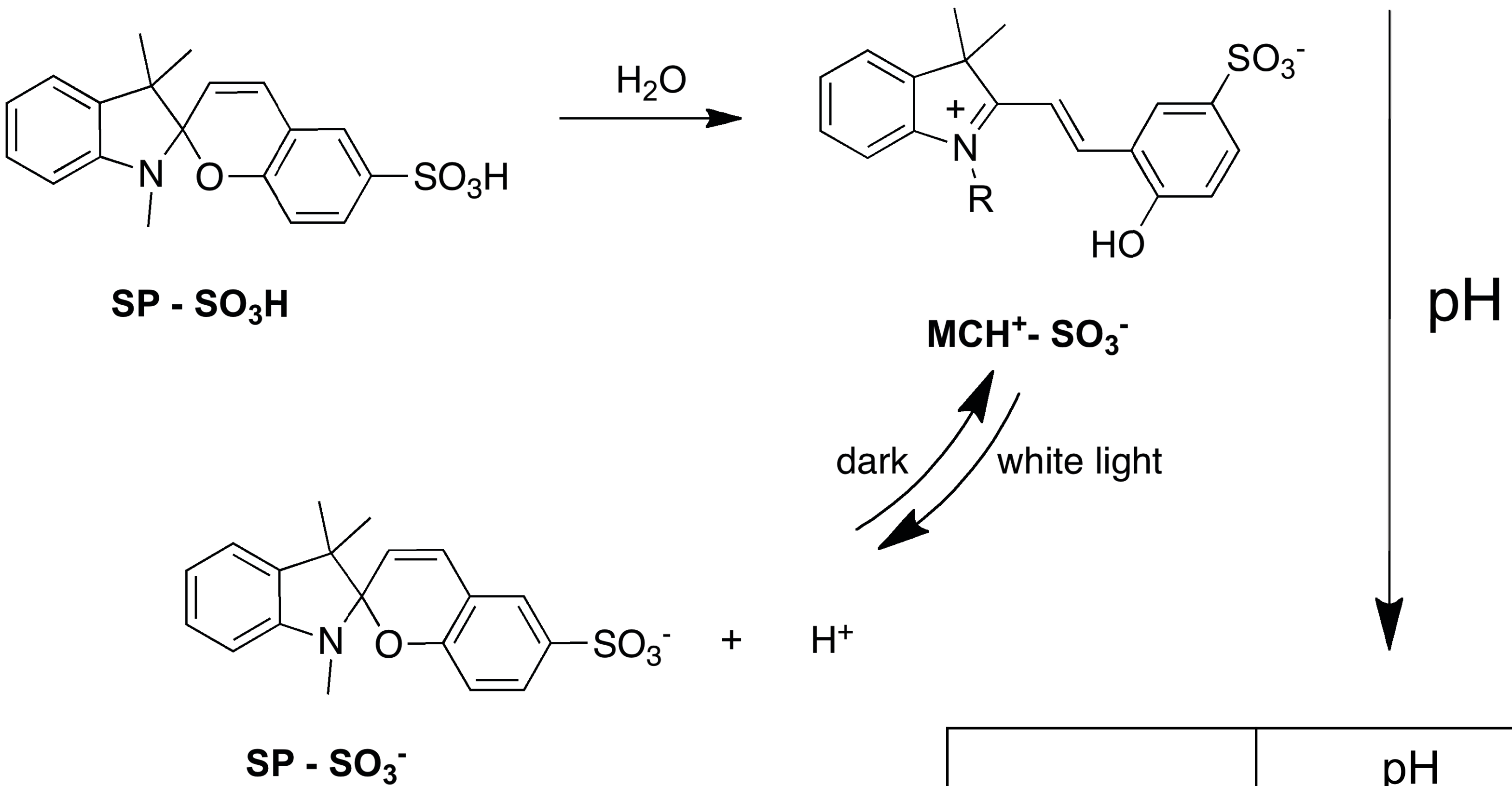
In a pH gradient, DA$^-$ is preferentially transferred to the aqueous phase at the more basic side of the drop.

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 DA$^-$ towards higher 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.*

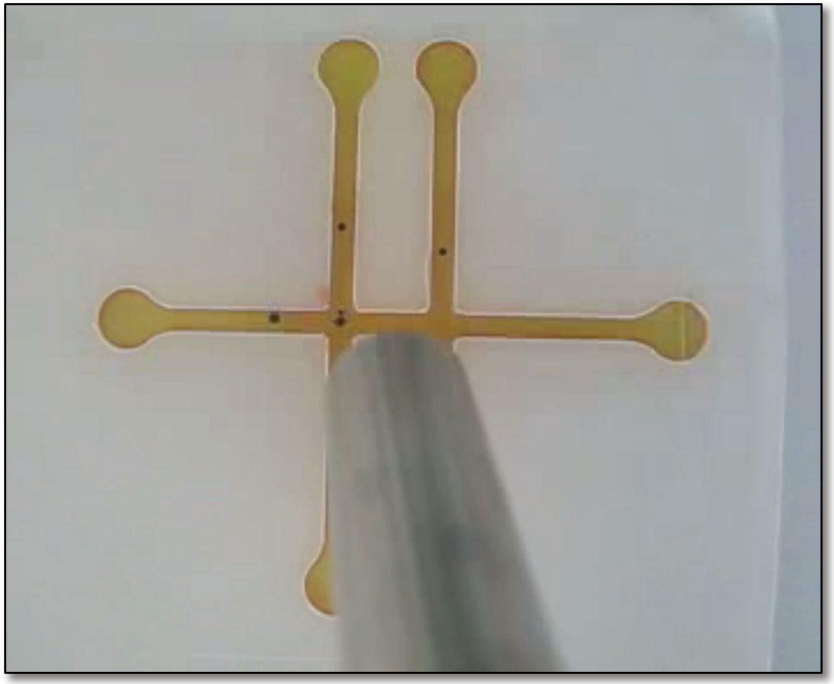
Photo-modulation of pH



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

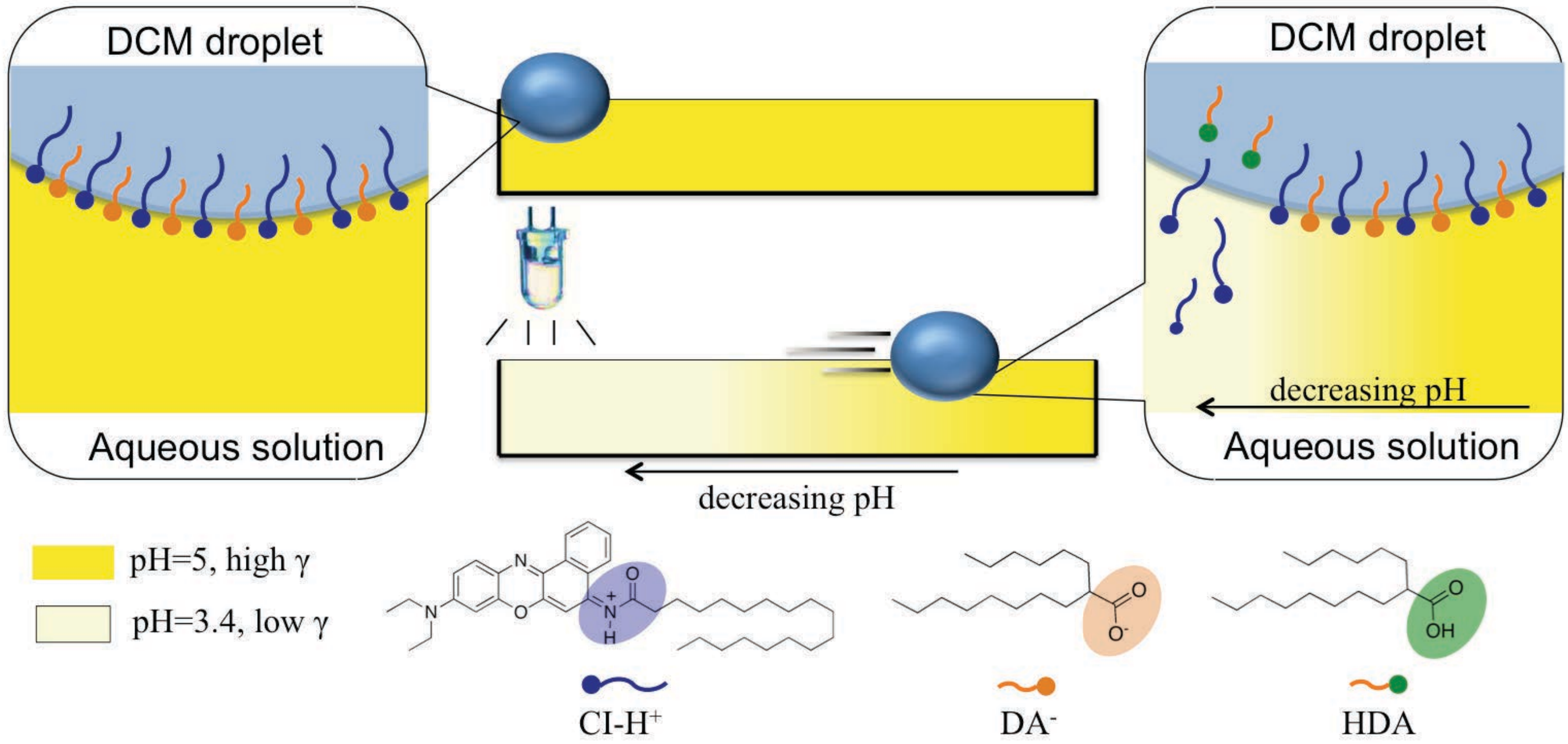
Channel Solution: Spiropyran Sulfonic Acid 10^{-3}M (H_2O)

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

Mechanism of Photo-Stimulated Droplet Movement (with David Officer, UOW)



N-OCTADECANOYL-NILE BLUE

Photo-Chemopropulsion – Light-Stimulated Movement of Microdroplets, *Larisa Florea, Klaudia Wagner, Pawel Wagner, Gordon G. Wallace, Fernando Benito-Lopez, David L. Officer, and Dermot Diamond, Adv. Mater. 2014, DOI: 10.1002/adma.201403007*

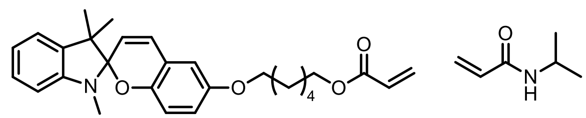
Photocontrol of Assembly and Subsequent Switching of Surface Features

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

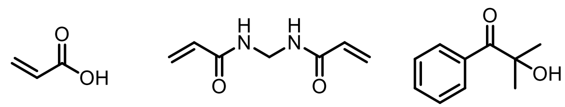
ACS applied materials & interfaces, 6 (2014) 7268-7274

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[*,†,§]

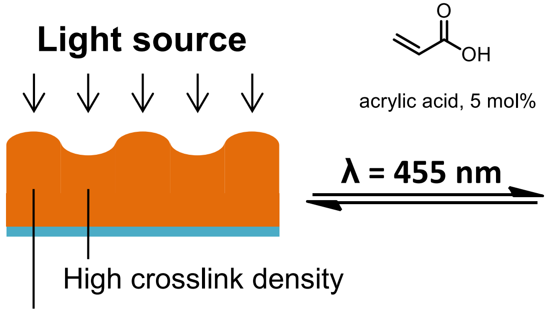


SPA, 1 mol%   NIPAAM, 91-92 mol%

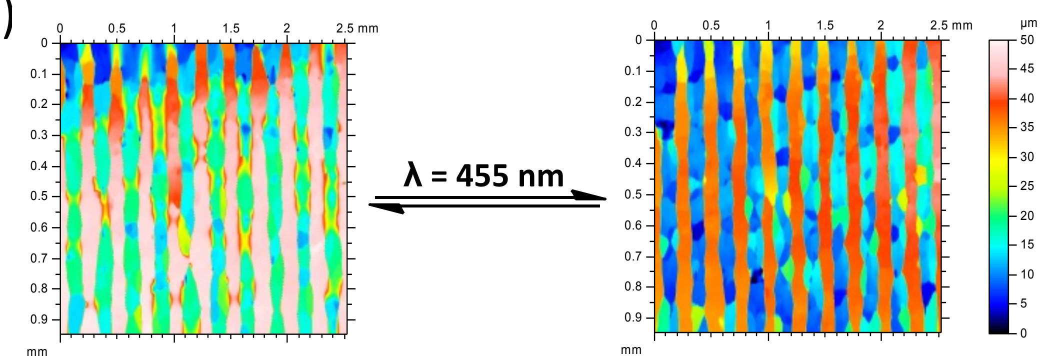


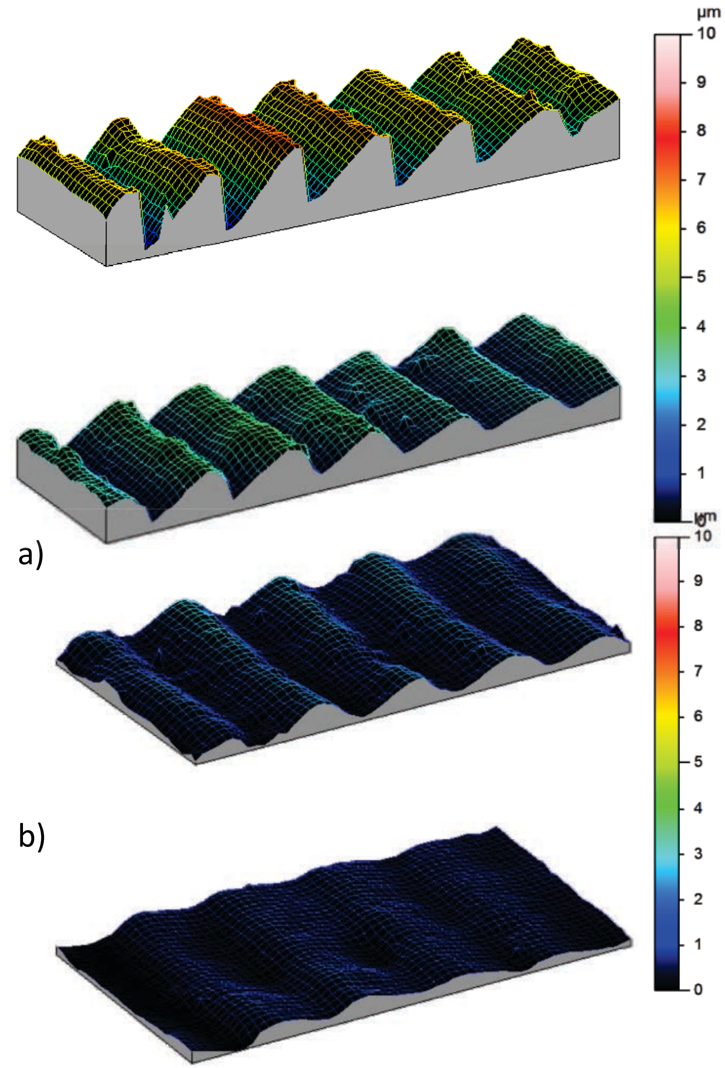
acrylic acid, 5 mol%   MBIS, 1-2 mol%   Darocur 1173, 1 mol%

a)

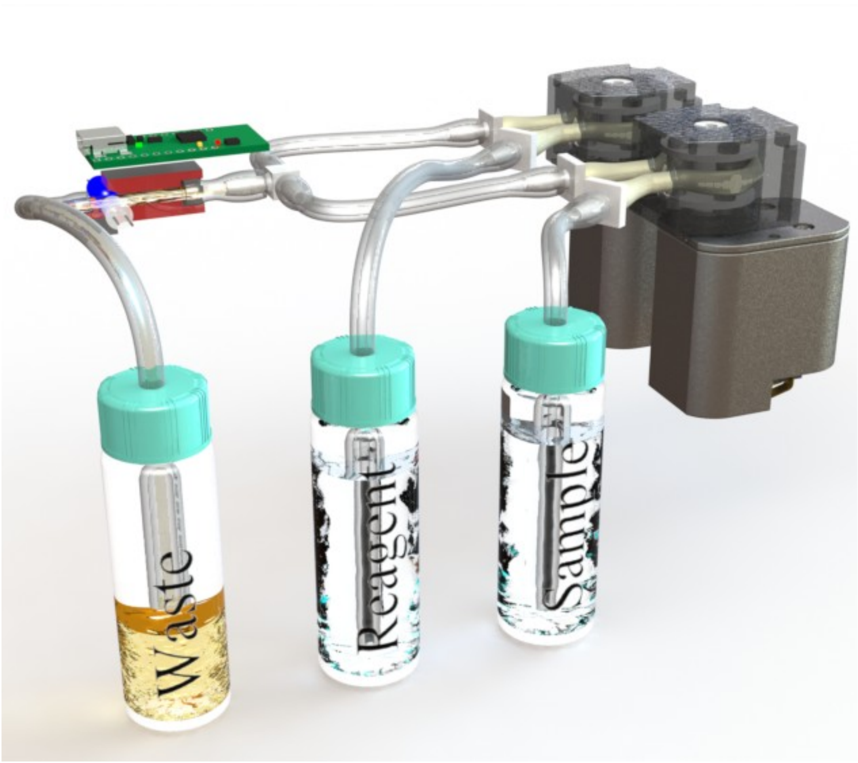


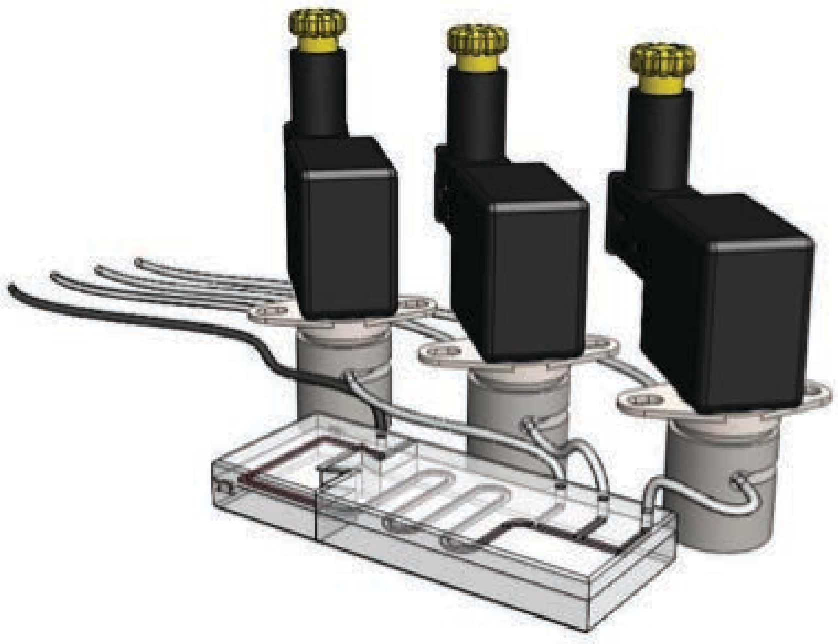
b)



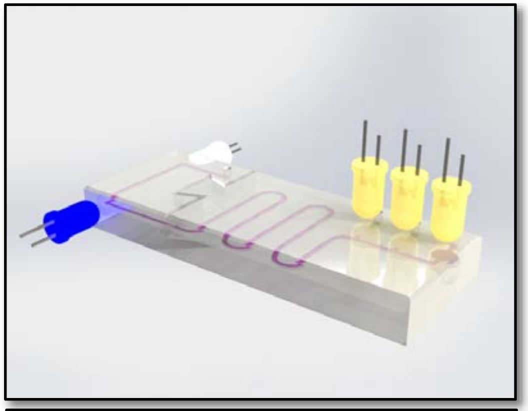


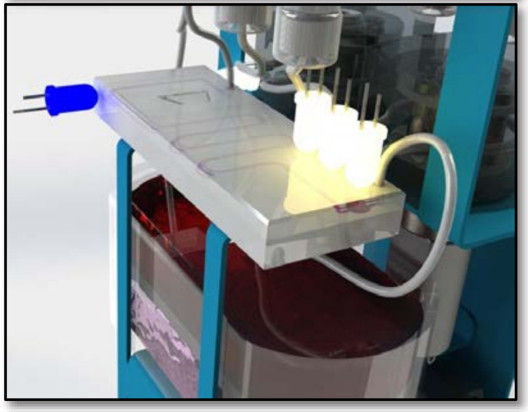
Can we go from this:

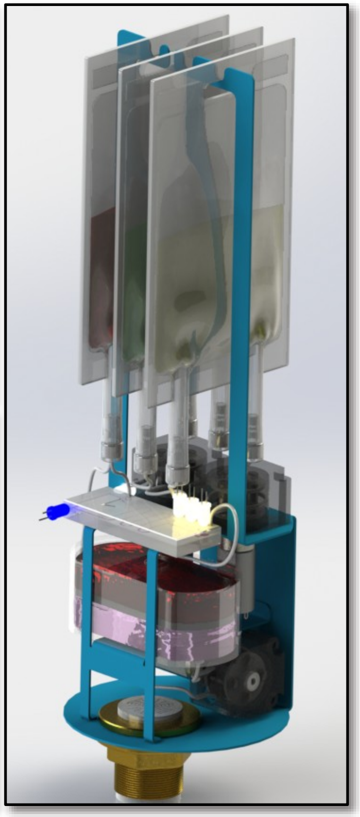


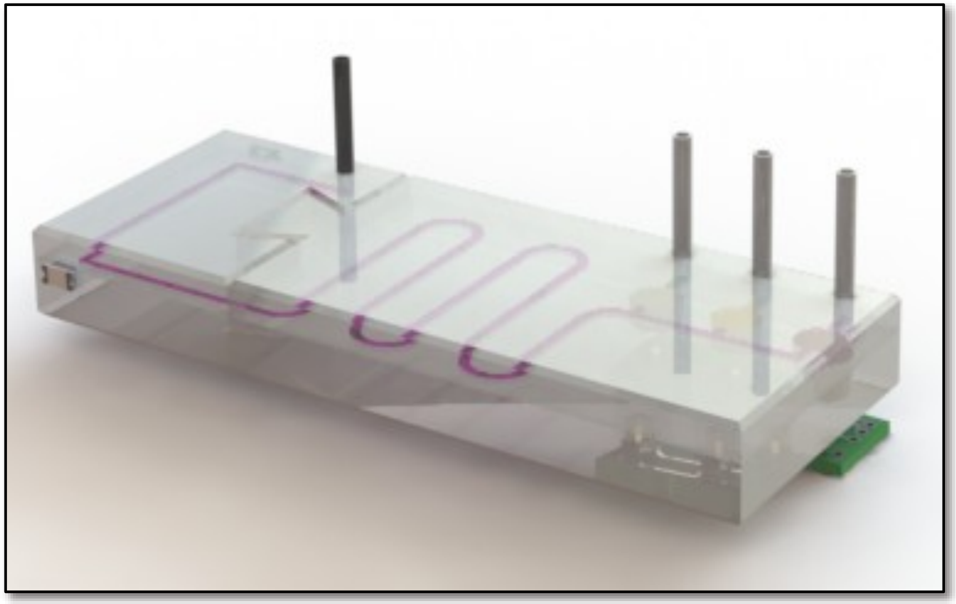


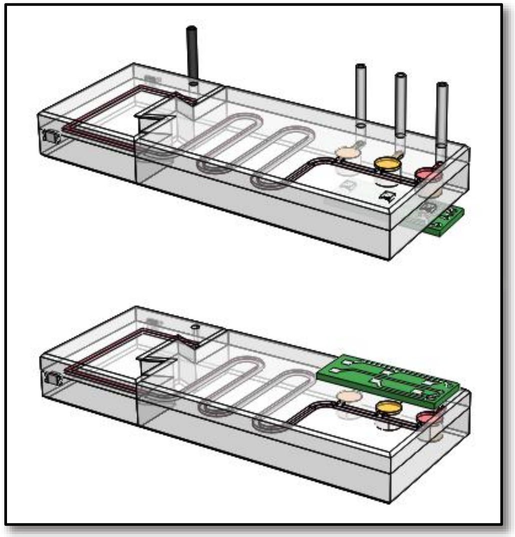
To Photo-Fluidics & Detection











- **Fluidic handling completely integrated into the microfluidic chip**
  - **Valves actuated remotely using light (LEDs)**
  - **Detection is via LED colorimetric measurements**
  - **Photo-controlled uptake and release**

Sensor Research Clustering: Steering Committee

Chairman: Michele Penza
Observer: Hans Hartmann Pedersen (EC)

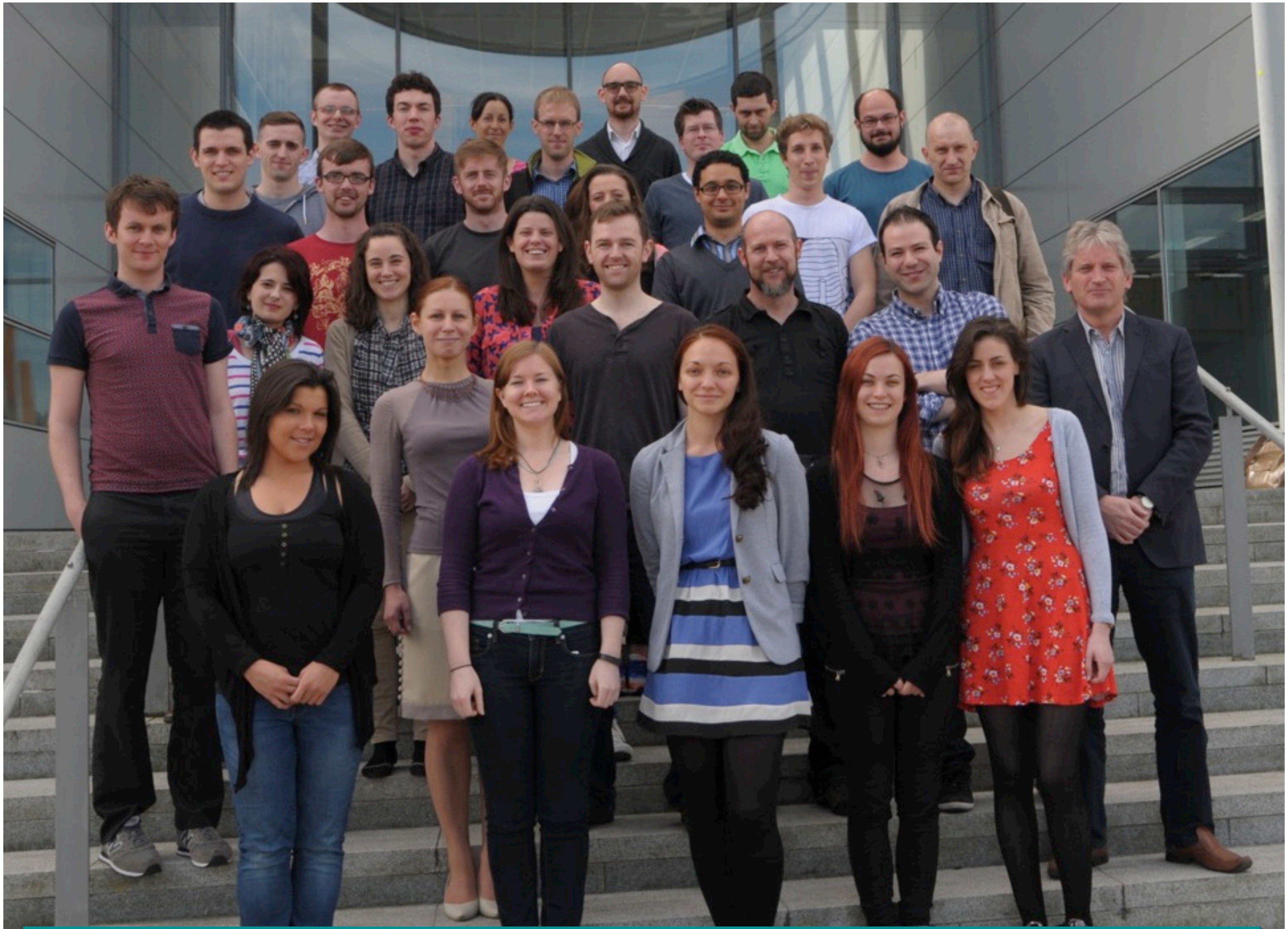
Towards to a cluster on Characterization

Environmental sensors	• D. Diamond
Indoor quality sensors	• A. Schütze (O. Martimort)
Health monitoring sensors	• P. Galvin (A. Prina Mello)
Monitoring of industrial processes	• T. Mayr
Integration and commercialization	• O. Martimort
Dissemination and Outreach	• T. Simmons (Eurice)

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