



# **‘From Molecules to Devices: Can we Create Disruptive Technologies based on 3D Functionality at Multiple Dimensions to Solve Global Challenges?’**

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**Invited Seminar Presented at  
Henkel Ireland**

**26<sup>th</sup> January 2016**

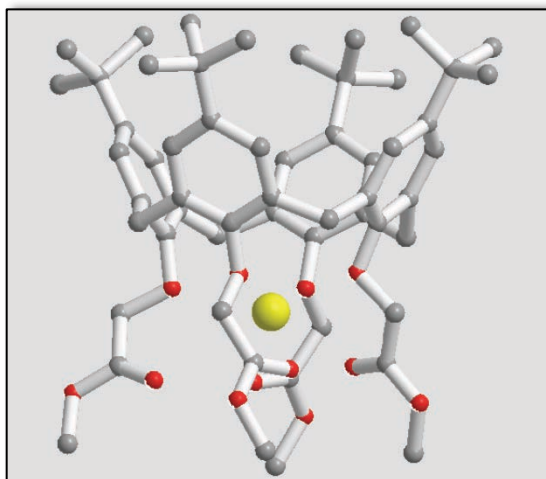
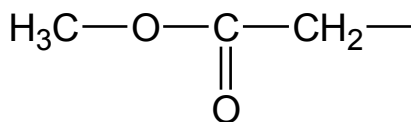
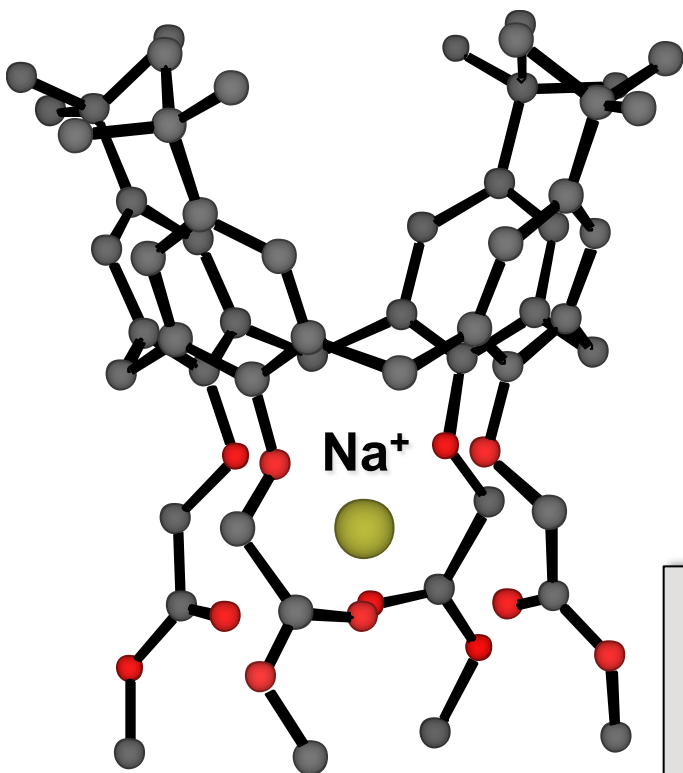




# Calixarene Ionophores – controlling the selectivity

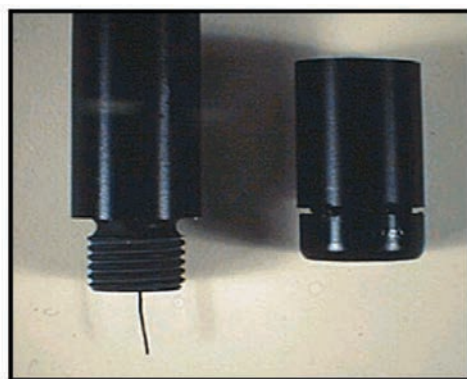
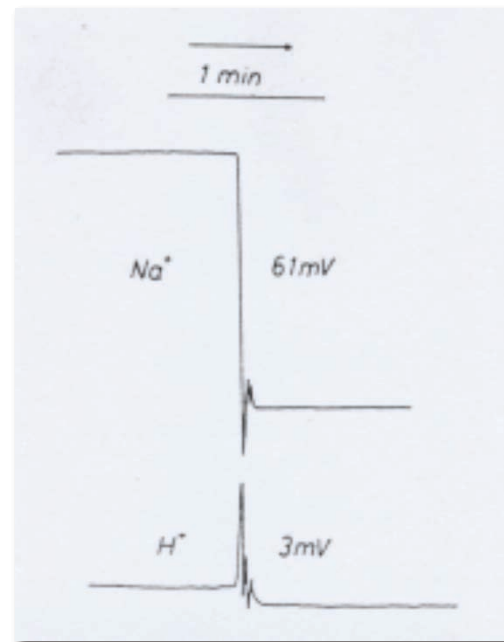
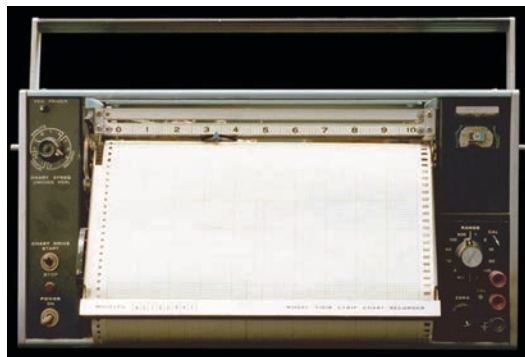
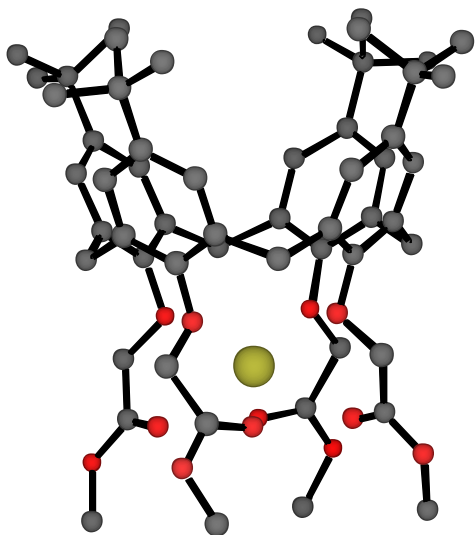


Gyula Svehla





# Selectivity, Response Time, Stability...



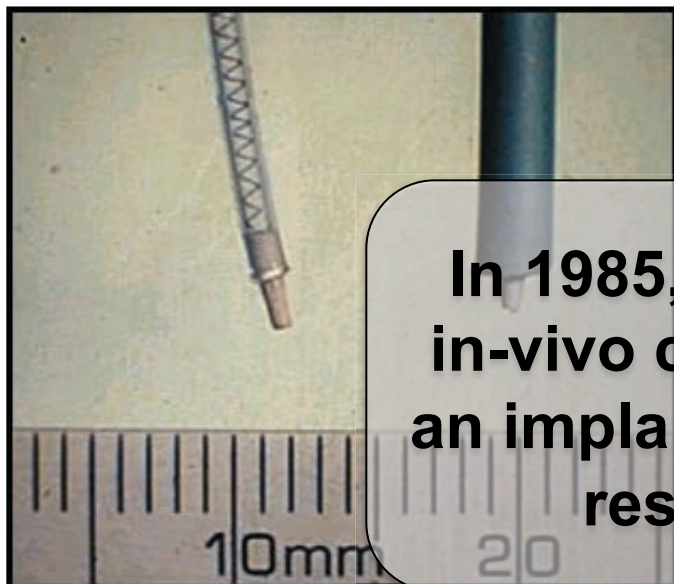
Neutral Carrier Based Ion-Selective Electrodes, D.Diamond, Anal. Chem. Symp. Ser., 25 (1986) 155.

A sodium Ion-Selective Electrode based on Methyl p-t-Butyl Calix[4]aryl Acetate as the Ionophore, D.Diamond, G.Svehla, E.Seward, and M.A.McKervey, Anal. Chim. Acta., 204 (1988) 223-231





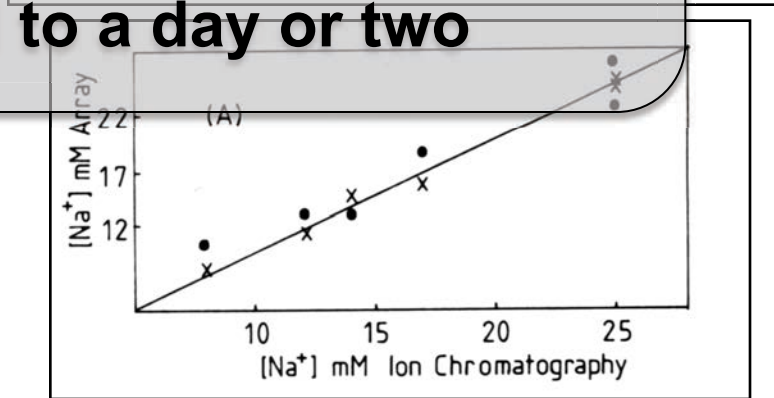
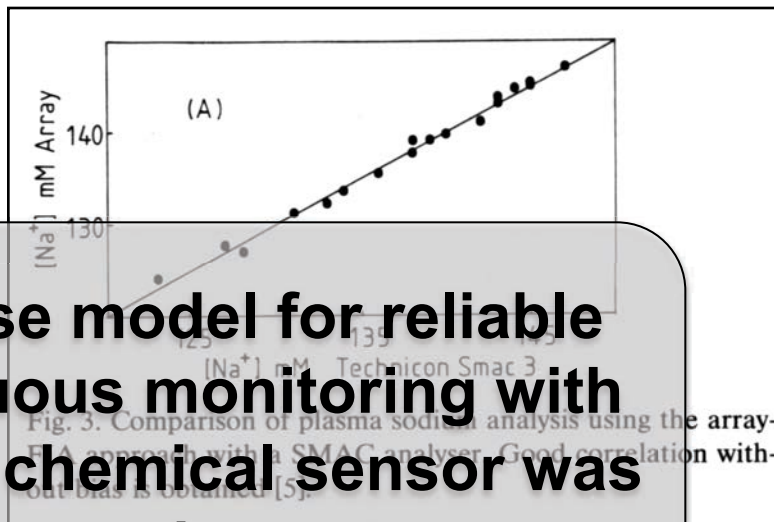
# Blood Analysis; Implantable Sensors



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



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

Ligand (and variations of) used in many clinical analysers for blood Na<sup>+</sup> profiling





# Artificial Pancreas



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

Used a Technicon segmented flow colorimetric glucose analyser

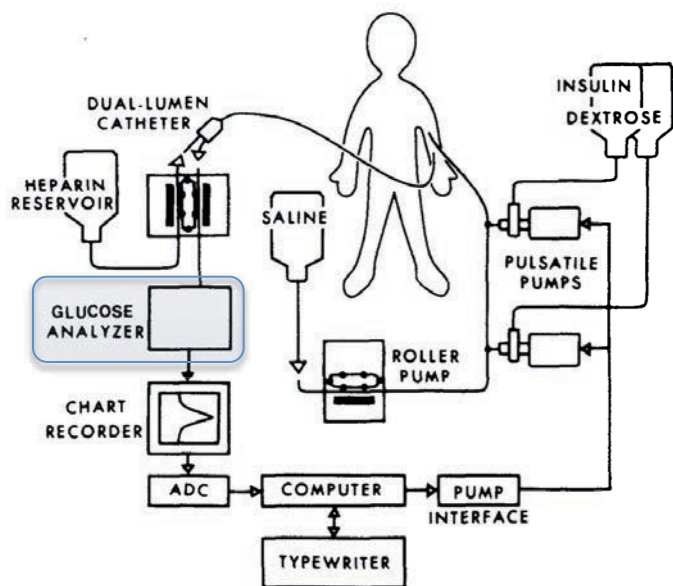
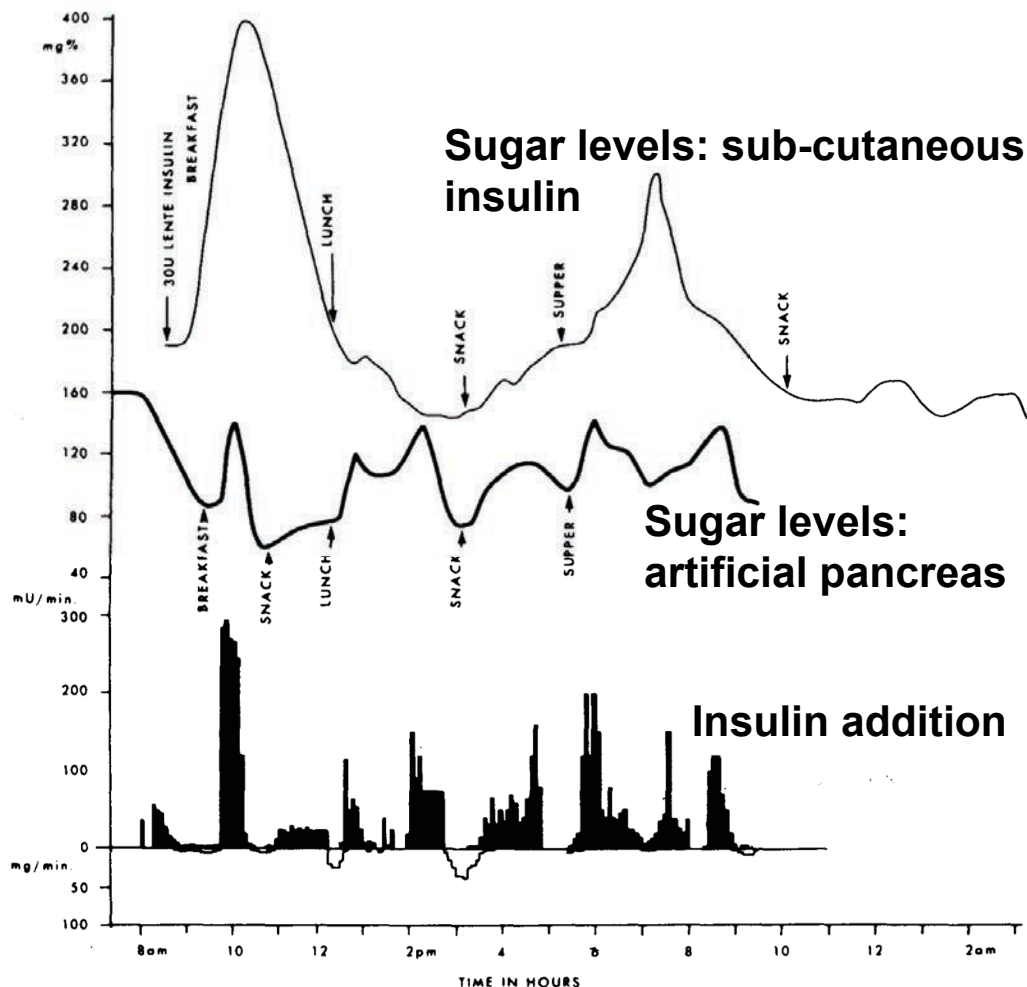


FIG. 1. Schematic diagram of apparatus used for monitoring and automatic regulation of blood sugar.



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)





# The (broken) promise of biosensors.....



## BIOSENSORS THE MATING OF BIOLOGY AND ELECTRONICS



Implanted sensors control the flow of insulin in a diabetic patient. The Utah model is a field-effect transistor.

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

In medicine and industry, a wide range of biological reactions

Sometime within the next three or four years, a physician will insert a centimeter of platinum wire into the bloodstream of a diabetic patient.

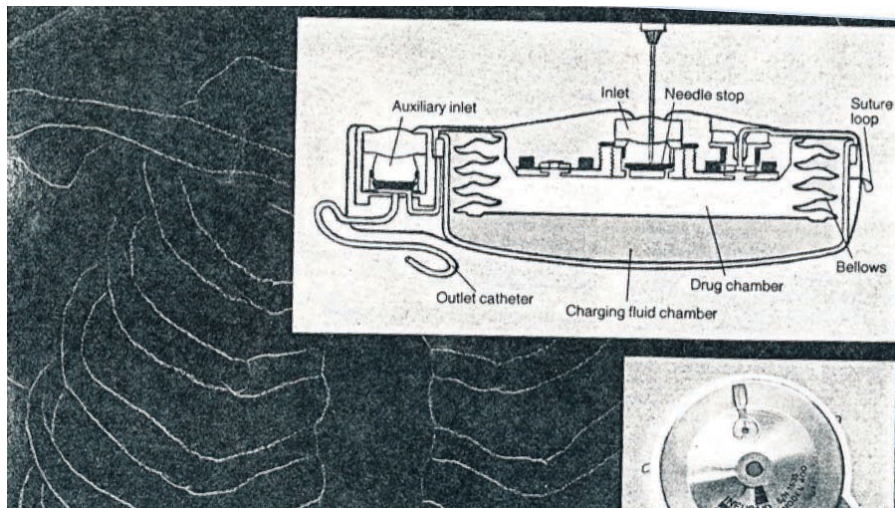
At its tip will be a barely visible membrane containing a bit of enzyme.

Hair-thin wires will lead from the other end of the platinum to an insulin reservoir implanted in the patient's abdomen.

Within seconds, a chemical reaction will begin at the tip of the wire.....

.....And (by implication) it will work for years reliably and regulate glucose through feedback to insulin pump

High Technology, Nov. 1983, 41-49

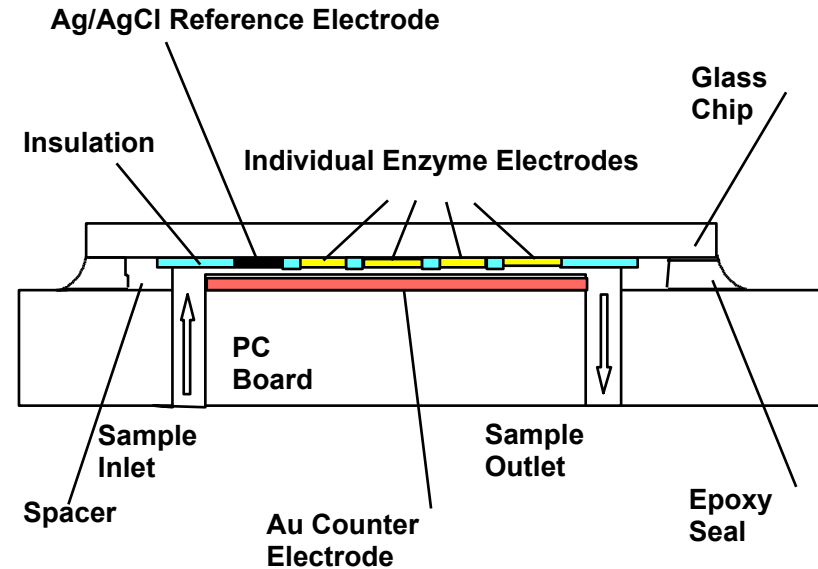
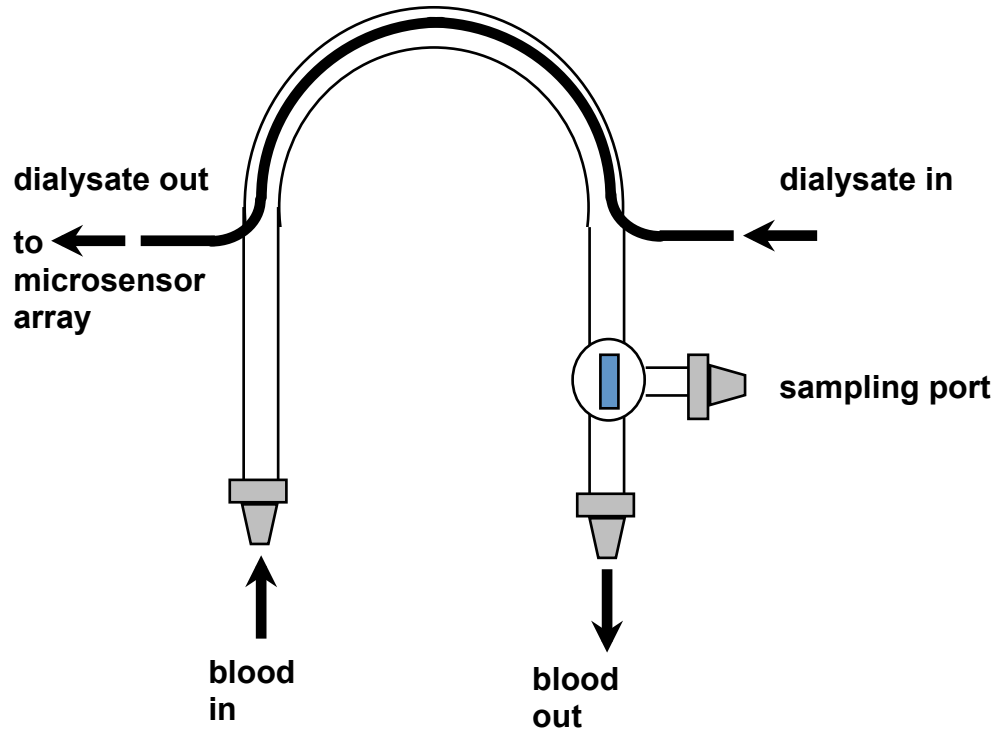


A large blue-bordered box containing the main text of the article, including the introductory paragraph and the concluding sentence. The text is overlaid on a background image of a human torso with a biosensor implanted in the abdomen.





# Microdialysis sampling via arterio-venous shunt



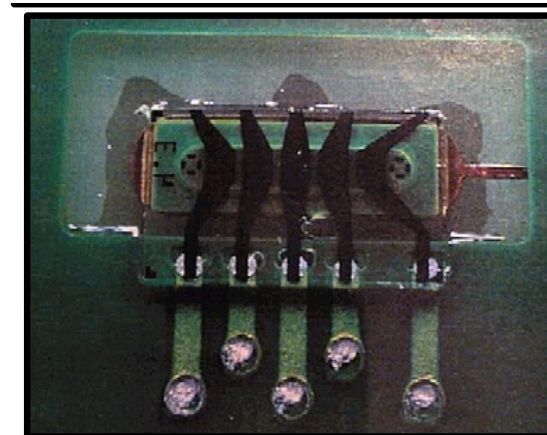
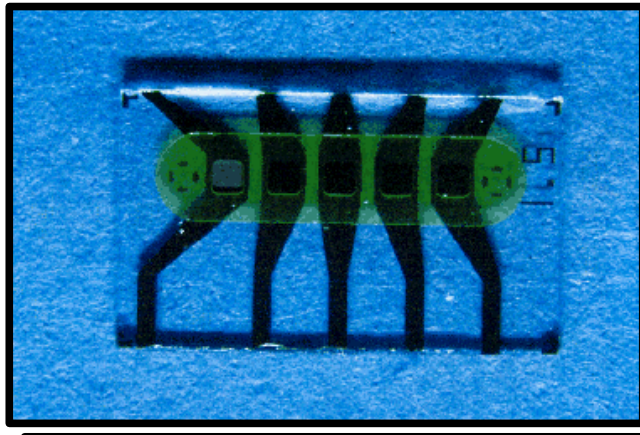
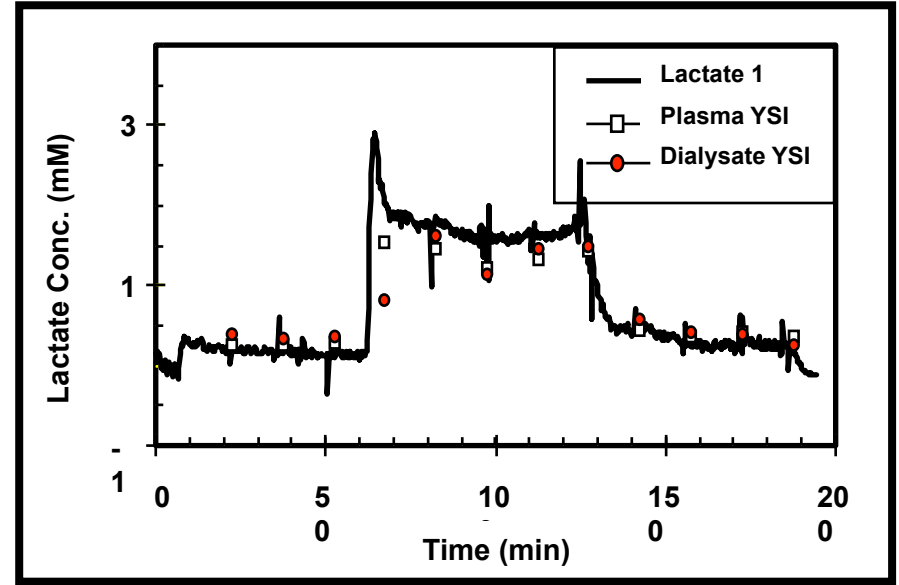
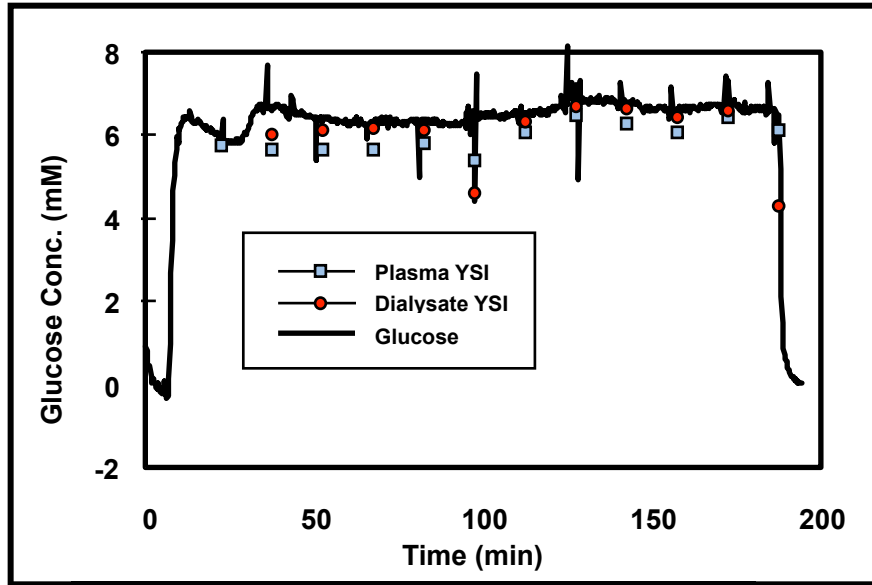
**Novel Instrumentation for Real-Time Monitoring Using Miniaturised Flow Cells with Integrated Biosensors**, R. Freaney, A. McShane, T.V. Keavney, M. McKenna, K. Rabenstein, F.W. Scheller, D. Pfeiffer, G. Urban, I. Moser, G. Jobst, A. Manz, E. Verpoorte, M.W. Widmer, D. Diamond, E. Dempsey, F.J. Saez 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!**





# Abbott Freestyle 'Libre'



The days of routine glucose testing with lancets, test strips and blood are over.<sup>2</sup>

Welcome to flash glucose monitoring!



## How to use the FreeStyle Libre System

The FreeStyle Libre system utilises advanced technology that is easy to use.

### 1 Apply sensor with applicator



- 'Small fibre' used to access interstitial fluid
- Data downloaded at least once every 8 hr via 1s contactless scan (1-4 cm)
- Waterproof to 1 metre
- Replace every 2 weeks

- A thin flexible sterile fibre (5mm long) is inserted just below the skin. Most people reported that applying the sensor was painless\*
- The 14-day sensor stays on the back of your upper arm and automatically captures glucose readings day and night.
- The sensor is water resistant and can be worn while bathing, swimming and exercising<sup>7</sup>

<sup>6</sup> Most people did not feel any discomfort under the skin while wearing the FreeStyle Libre sensor. In a study conducted by Abbott Diabetes Care, 93.4% of patients surveyed (n=30) strongly agree or agree that while wearing the sensor, they did not feel any discomfort under their skin. [29 persons have finished the study; 1 person terminated the study after 3 days due to skin irritations in the area where the sensor touched the skin.]

<sup>7</sup> Sensor is water-resistant: in up to 1 metre (3 feet) of water for a maximum of 30 minutes





# HYPEwatch: 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

May 7<sup>th</sup> 2014

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

## How will they integrate biosensing with the iWatch.....?

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.'

Apple Inc CEO Tim Cook



"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.





# Google Contact Lens

United States Patent Application 20140107445

Google Smart Contact Lenses Move

Kind Code A1 Liu; Zenghe April 17, 2014

Closer to Reality

Microelectrodes • Use model is 24 hours max, then

Sensor

Abstract

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

replace;

likely to leverage Google Glass\*

infrastructure;

Novartis now working with Google.

350  
300  
250  
200  
150  
100  
50  
0

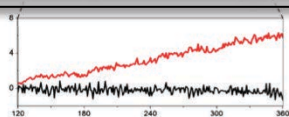


Google's Smart Contact Lens is like your contact lens, except it's a whole lot smarter.

\*Google Glass project abandoned!

(Jan 15 2015) see

<https://plus.google.com/+GoogleGlass/posts/9uiwXY42tvc>



monitoring tear glucose level, H. F. Yao, A. J. Shum, M. Cowan, I. Lahdesmaki and B. A. Parviz, *Biosensors & Bioelectronics*, 2011, 26, 3290-3296.

Google's plan to bring smart contact lenses to diabetes sufferers in closer to reality as

Known among scientists as "Ophthalmic Electrochemical Sensors," these contact lenses will feature flexible electronics that include sensors and an antenna. The sensors are designed to read chemicals in the tear fluid of the wearer's eye and alert her, possibly through a little embedded LED light, when her blood sugar falls to dangerous levels.

\*Human tear fluid contains a variety of inorganic electrolytes (e.g., Ca.sup.2+, Mg.sup.2+, Cl.sup.-), organic solutes (e.g., glucose, lactate, etc.), proteins, and lipids. A

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

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 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 120–360s.





# What is the core issue??



- **Simple, bare chem/biosensors do not function reliably EXCEPT as single shot short-term use devices – regular recalibration required (if they manage to keep functioning)**
- **Sensor surfaces change as soon as they are exposed to the real world – biofouling, interferences, leaching of components....**
- **Current systems work for days (after decades of research)**
- **Implants must work for 10 years!**





# GRAND CHALLENGE (man on the moon!)



**Can we develop the scientific knowledge and technology required to deliver self-aware, self-maintaining and sophisticated implantable devices that will function reliably for a minimum of 10 years inside the body?**

**That's great – but we need specific, focused projects that can deliver tangible outputs in a reasonable timeframe. These projects should be consistent with advancing knowledge towards the ultimate goal, and also leverage knowledge from fundamental advances into the projects.**

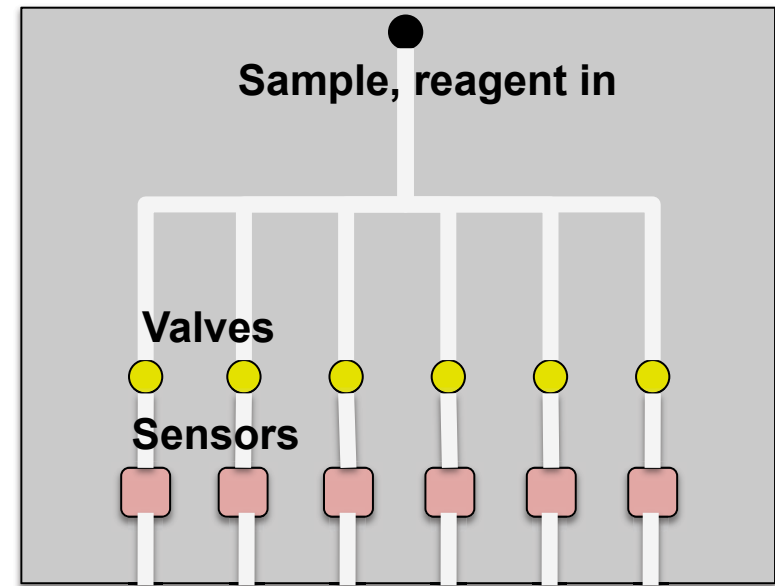




# Extend Period of Use via Multiple short-use Sensors....?



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



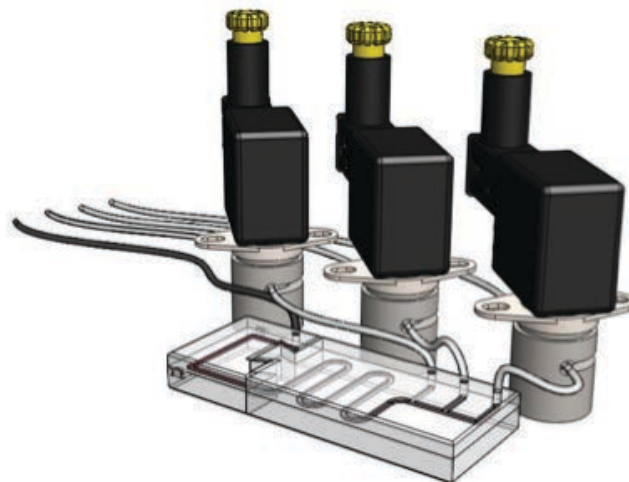
**Then 50 sensors when used sequentially could provide an aggregated in-use lifetime of around 1 year**

**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)!

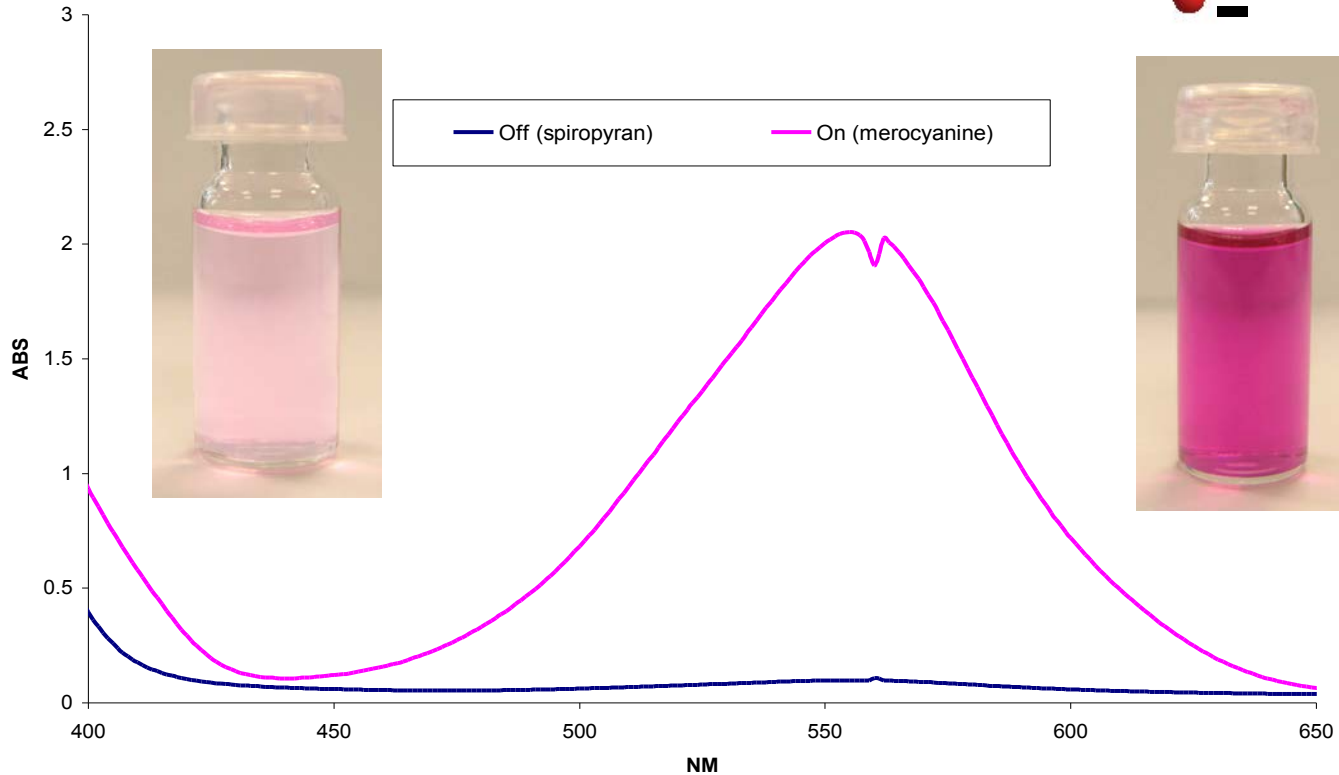
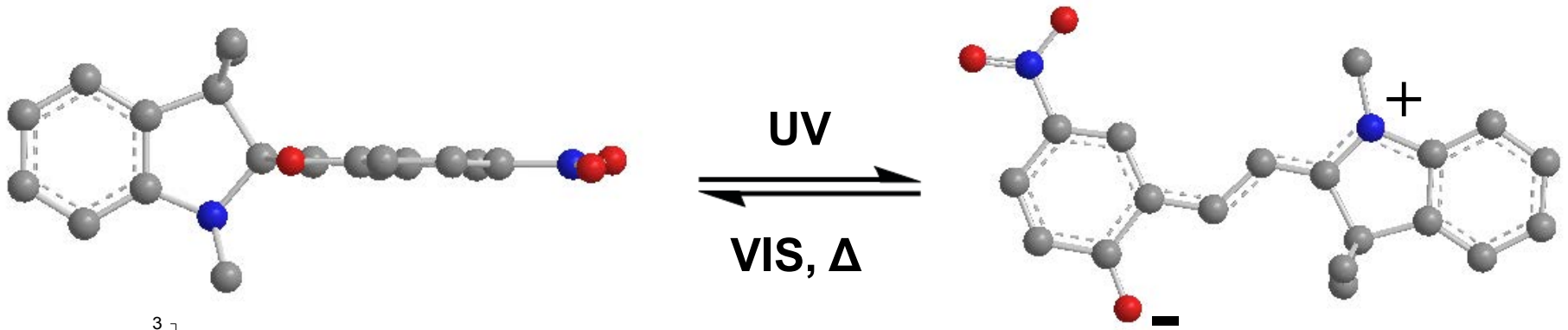
- **Conventional valves cannot be easily scaled down - Located off chip: fluidic interconnects required**
  - Complex fabrication
  - Increased dead volume
  - Mixing effects
- **Based on solenoid action**
  - Large power demand
  - Expensive



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



# Photoswitchable Actuators



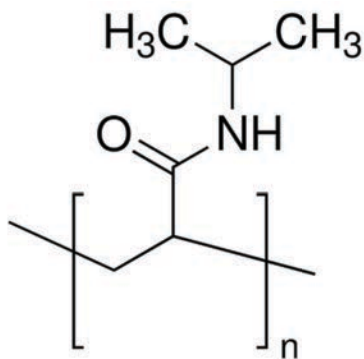




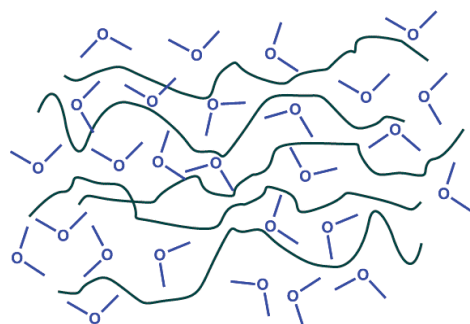
# Poly(*N*-isopropylacrylamide)

- pNIPAAm exhibits inverse solubility upon heating
- This is referred to as the LCST (Lower Critical Solution Temperature)
- Typically this temperature lies between 30-35°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



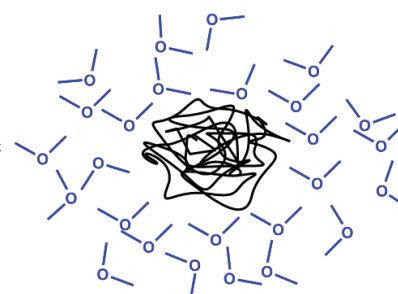
Hydrophilic



Hydrated Polymer Chains



Hydrophobic

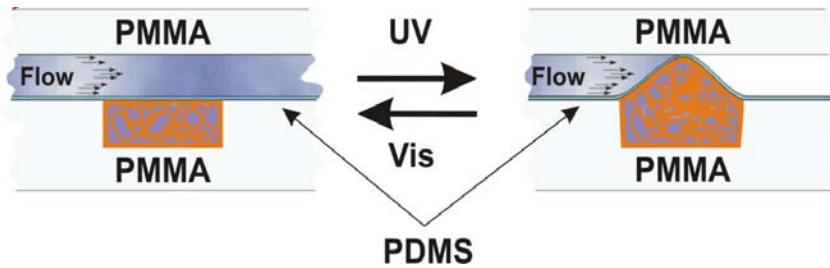
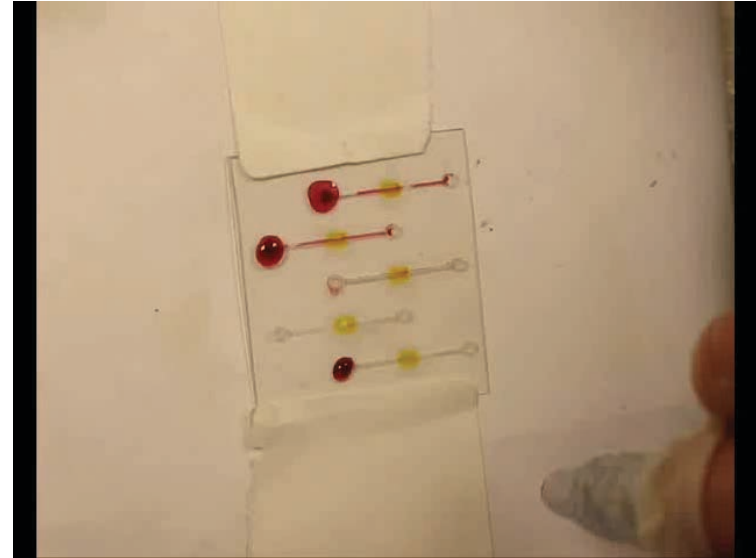
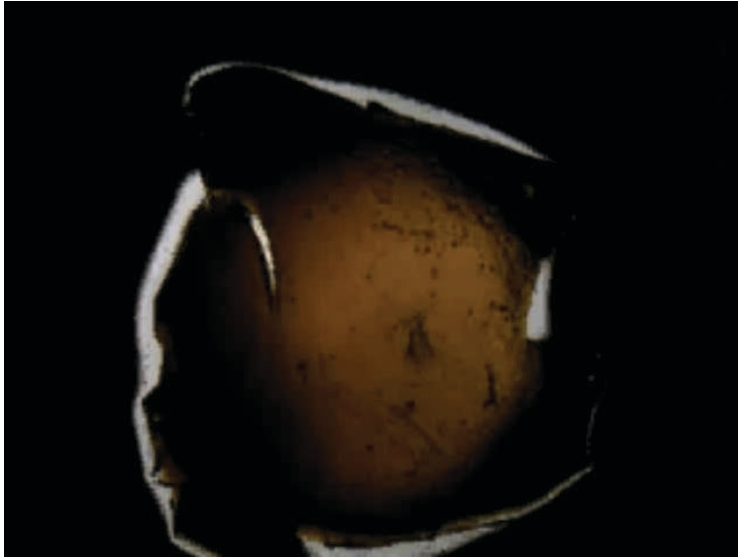


Loss of bound water  
-> polymer collapse

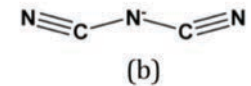
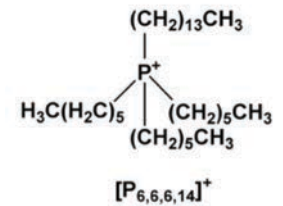
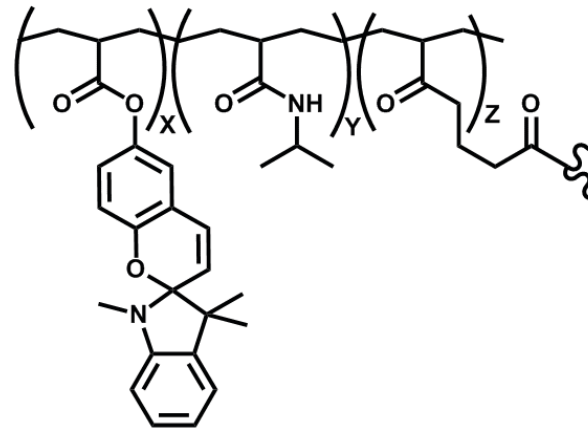




# Photo-actuator polymers as microvalves in microfluidic systems



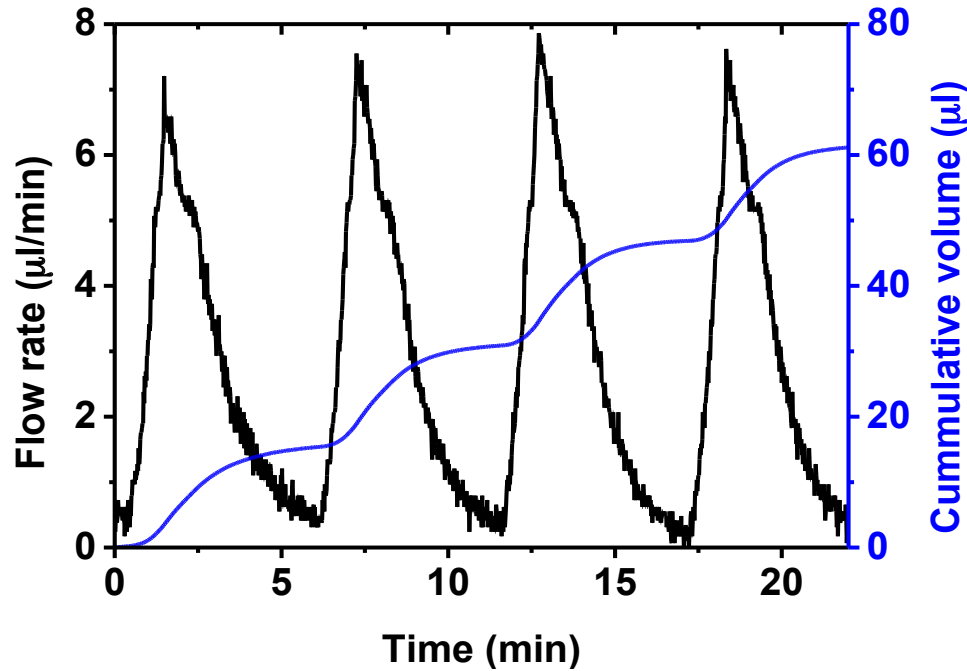
trihexyltetradecylphosphonium dicyanoamide  $[P_{6,6,6,14}]^+[dca]^-$



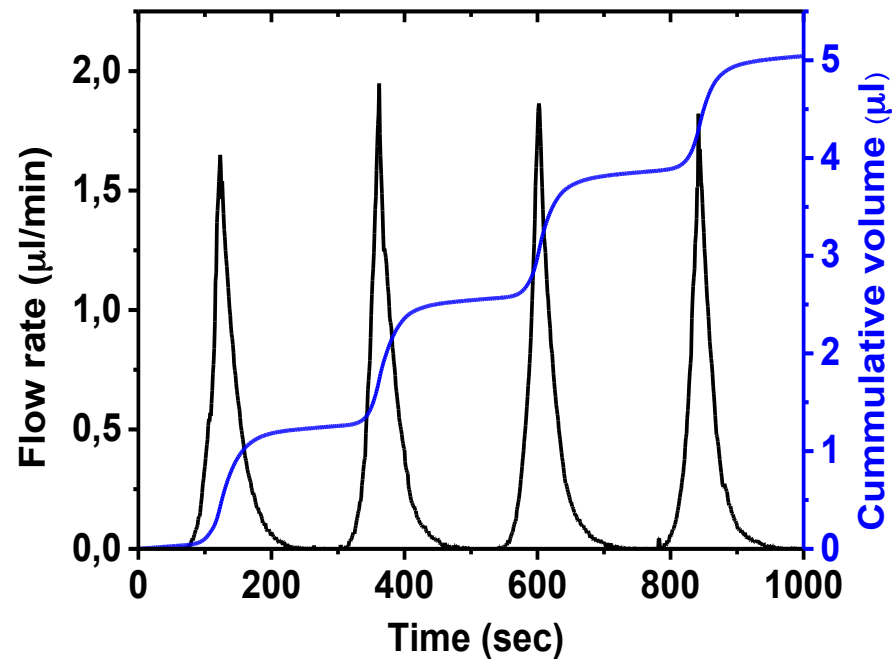
Ionogel-based light-actuated valves for controlling liquid flow in micro-fluidic manifolds, Fernando Benito-Lopez, Robert Byrne, Ana Maria Raduta, Nihal Engin Vrana, Garrett McGuinness, Dermot Diamond, Lab Chip, 10 (2010) 195-201.



# Optimisation of valve dimensions



1.7 mm mask



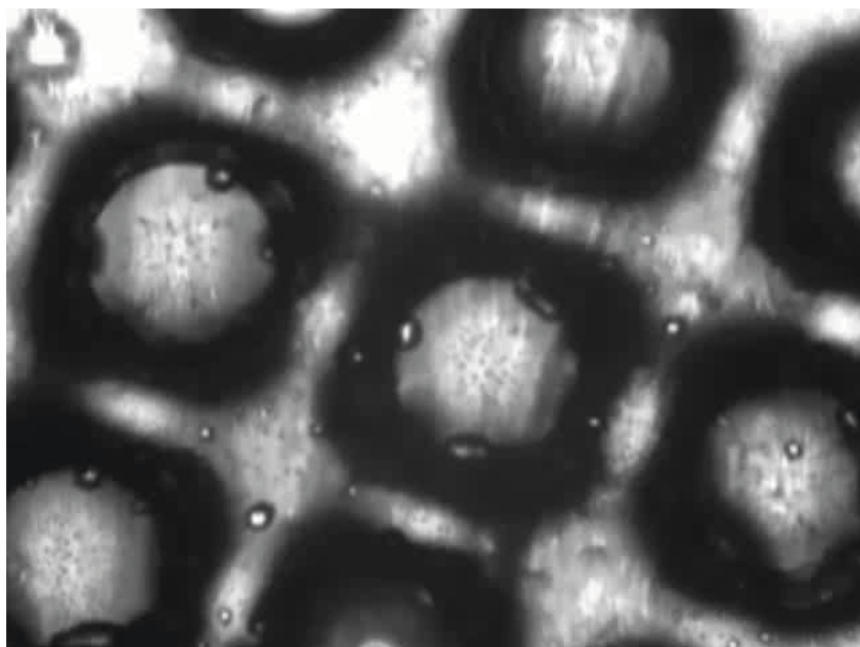
1.6 mm mask

**First example of actuating polymer gels as reusable valves for flow control on minute time scales (> 50 repeat actuations)**

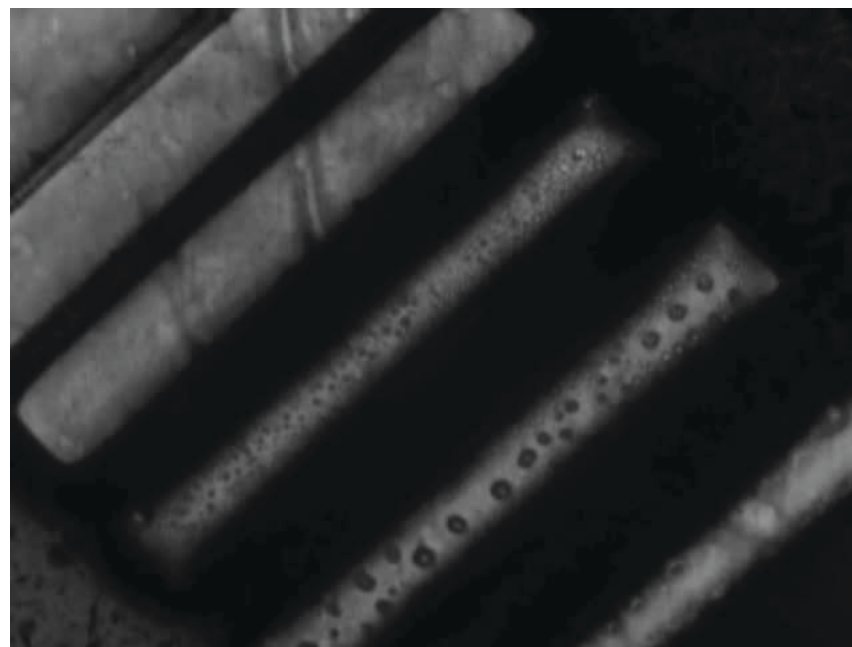




# Flexible creation of $\mu$ -dimensioned features in flow channels using in-situ photo-polymerisation



Ntf2 pillars speed x3



DCA lines speed x4

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



# Photocontrol of Assembly and Subsequent Switching of Surface Features



ACS APPLIED MATERIALS & INTERFACES

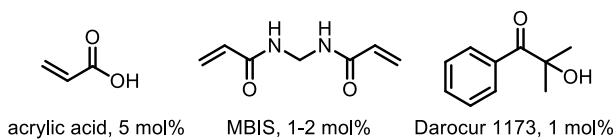
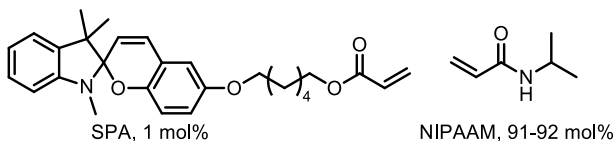
Research Article

www.acsami.org

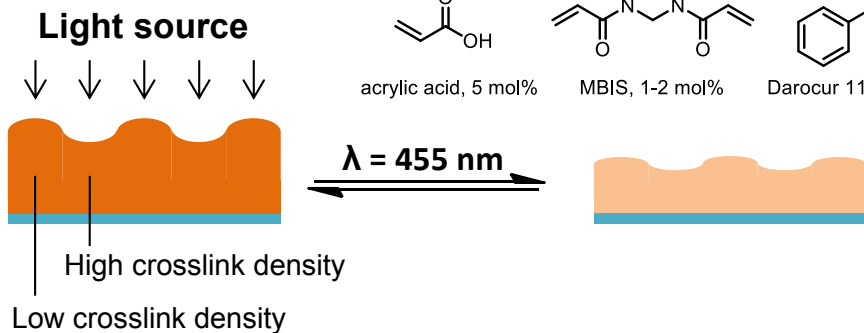
ACS applied materials & interfaces, 6 (2014) 7268-7274

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

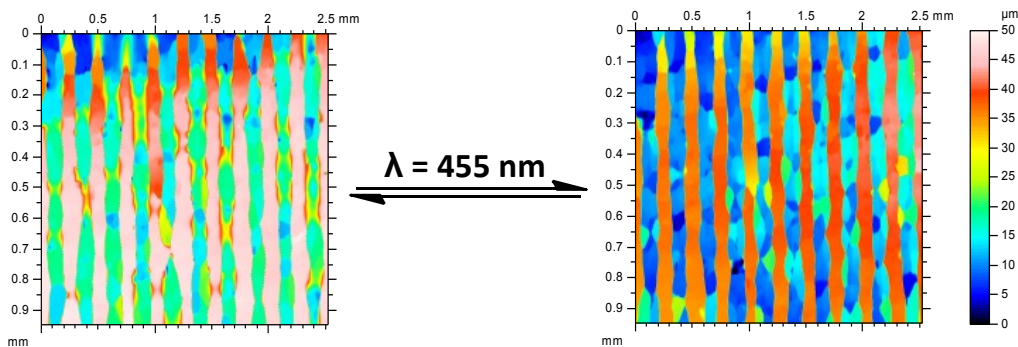
Jelle E. Stumpel,<sup>†</sup> Bartosz Ziolkowski,<sup>‡</sup> Larisa Florea,<sup>‡</sup> Dermot Diamond,<sup>‡</sup> Dirk J. Broer,<sup>\*,†,§</sup> and Albertus P. H. J. Schenning<sup>\*,†,§</sup>



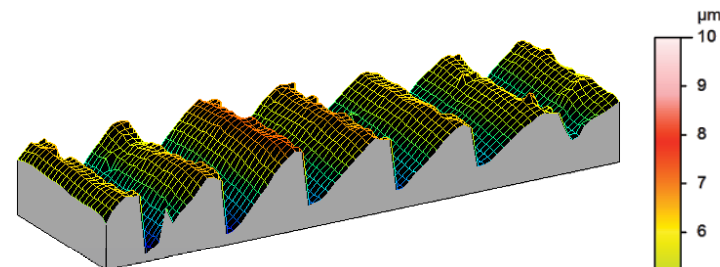
a)



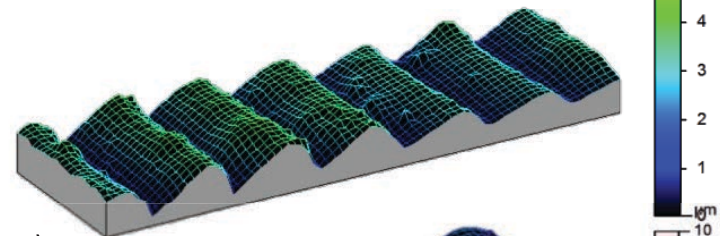
b)



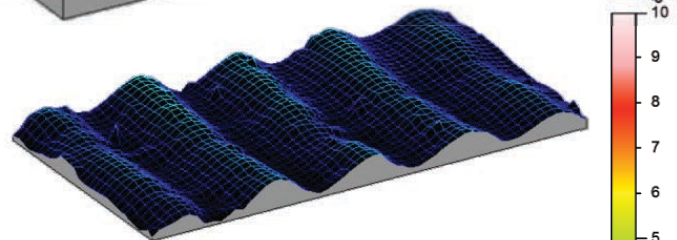
a)



b)



a)

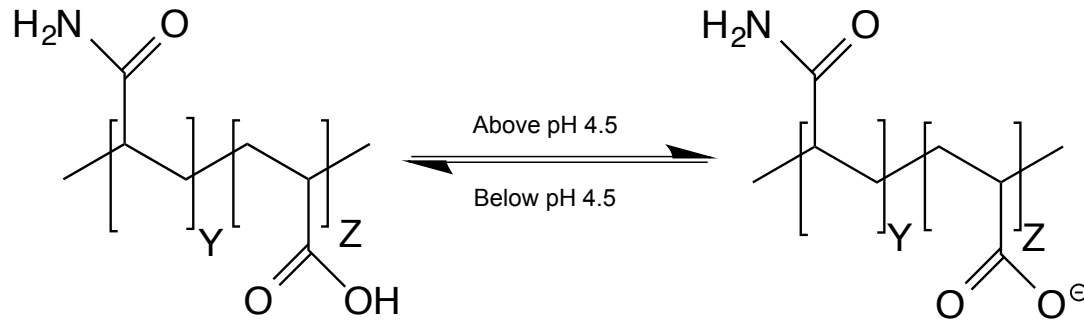


b)

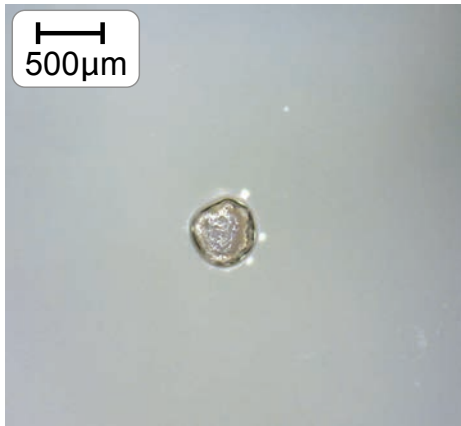




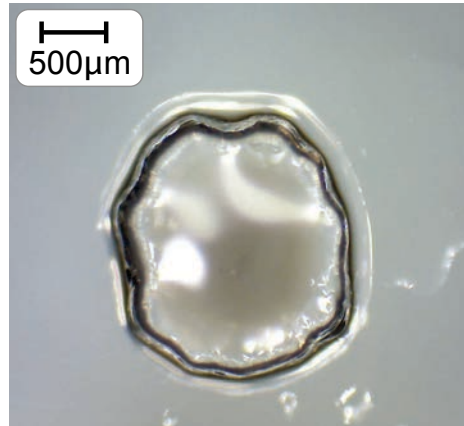
# pH Responsive Gel Actuation



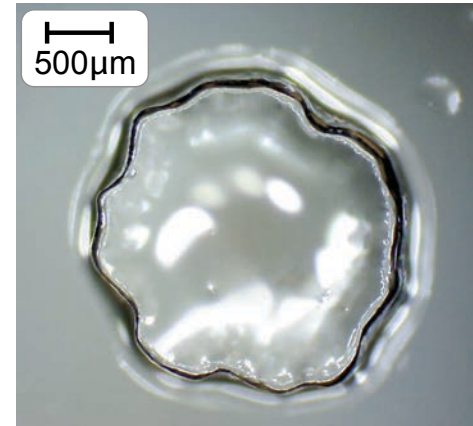
**Y=Z acrylic acid/acrylate**



pH 3



pH 5.5



pH 11

**Ca. 400% change in volume (Aishling Dunne and Larisa Florea)**



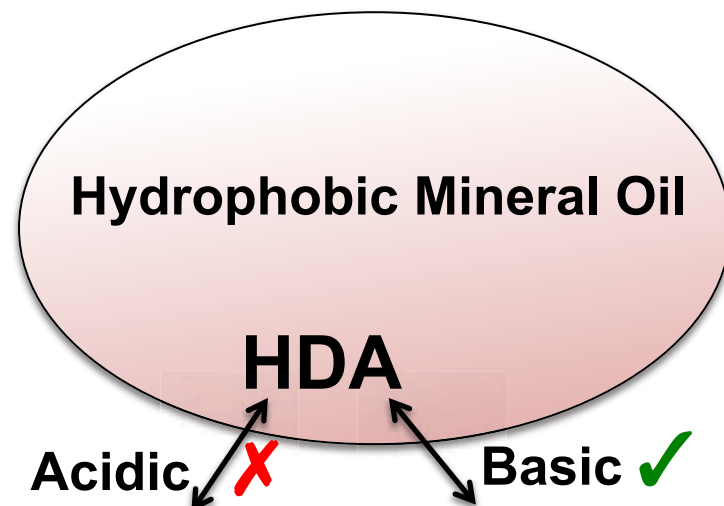
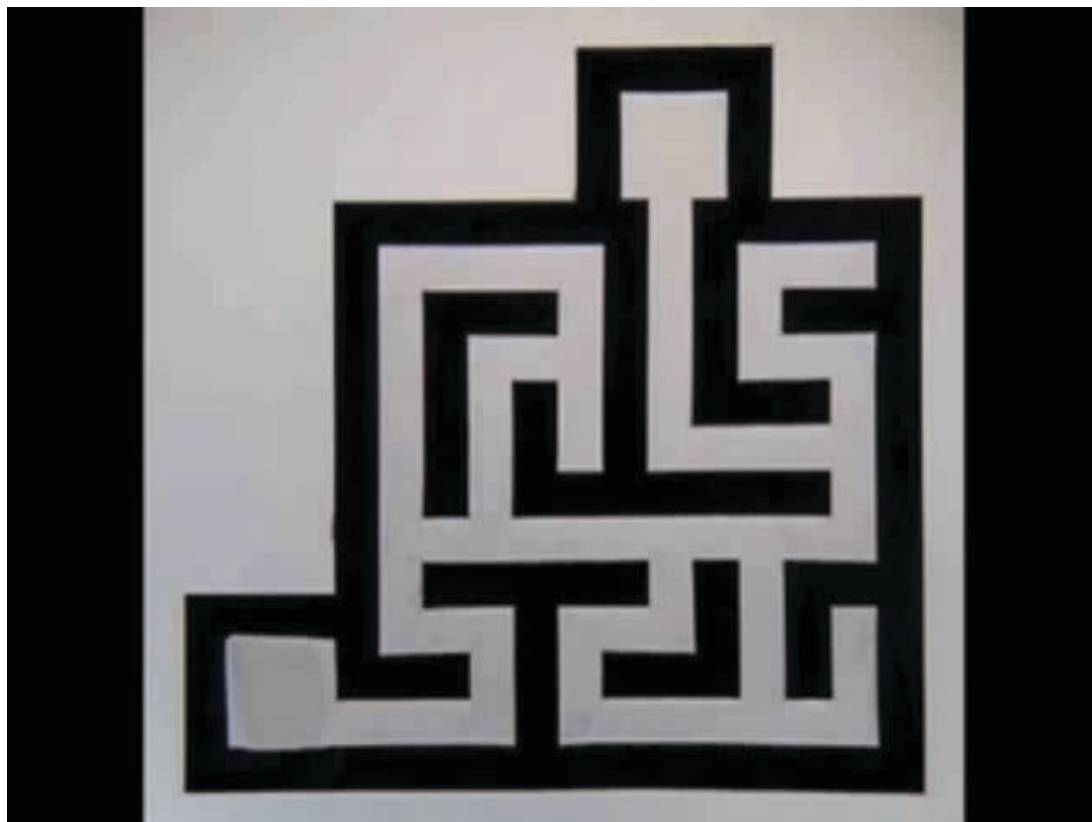


# Multi-Functional Bio-Inspired Fluidics!

- **At present, the fluidic system's function is to;**
  - Transport reagents, samples, standards to the detector
  - Perform relatively simple (but important) tasks like cleaning, mixing
  - Switching between samples, standards, cleaning solutions
- **In the future, the fluidic system will perform much more sophisticated 'bioinspired' functions**
  - System diagnostics, leak/damage detection
  - Self-repair capability
  - Switchable behaviour (e.g. surface roughness, binding/release),
- **These functions will be inherent to the channels and integrated with circulating smart micro/nano-vehicles**
  - Spontaneously move under an external stimulus (e.g. chemical, thermal gradient) to preferred locations



# Chemotactic Systems



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

Published on Web 11/01/2010 (speed  $\sim$ 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  $\text{DA}^-$  towards higher pH side);  $\text{HDA} \leftrightarrow \text{H}^+ + \text{DA}^-$

**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

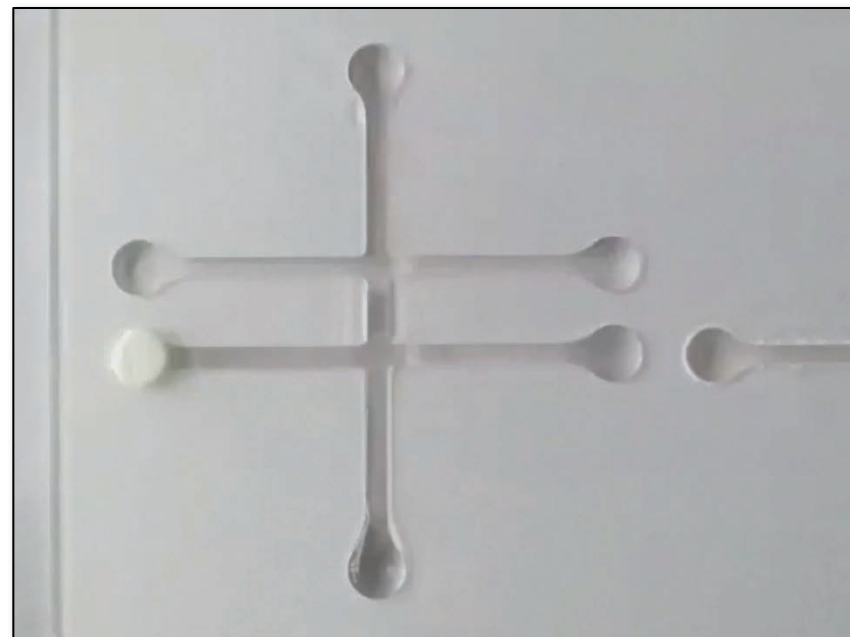
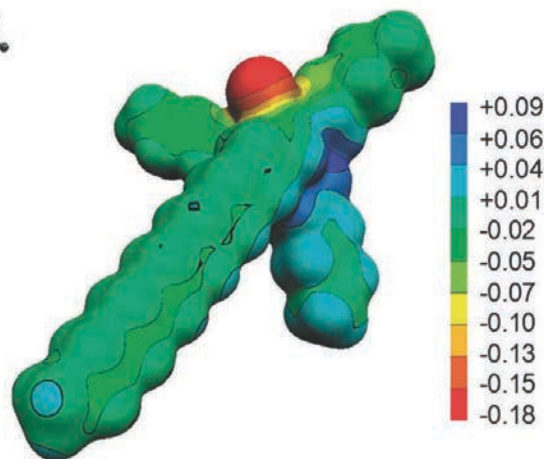
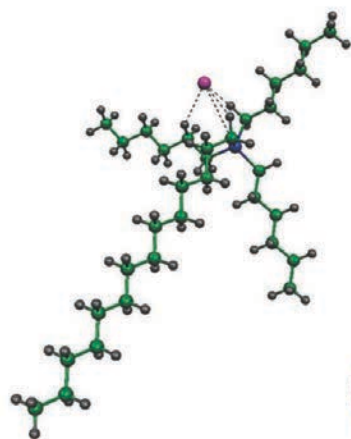
Fuerstman, M. J.; Deschatelets, P.; Kane, R.; Schwartz, A.; Kenis, P. J. A.; Deutch, J. M.; Whitesides, G. M. *Langmuir* 2003, 19, 4714.







# We can do the same with IL Droplets



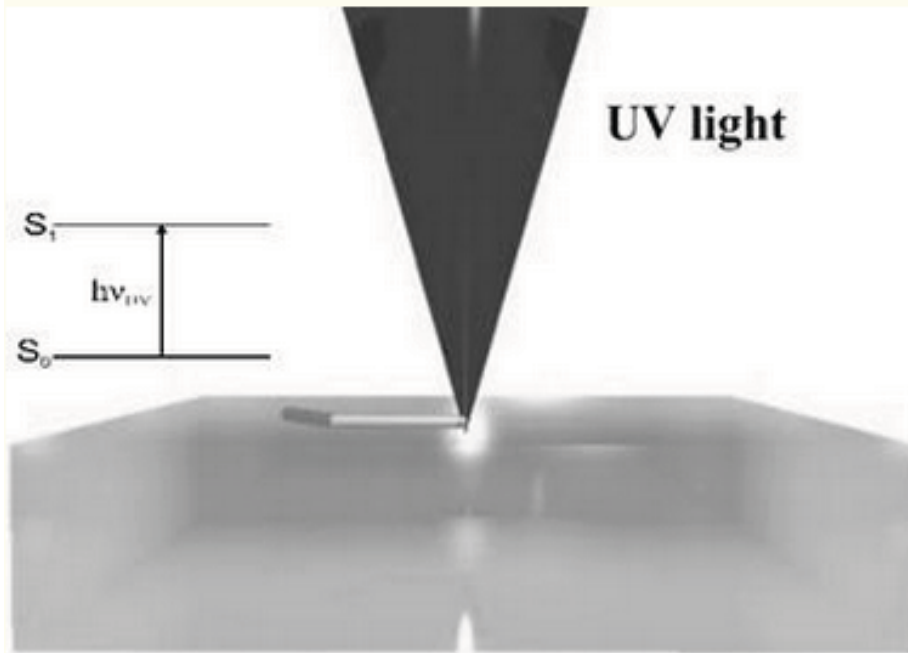
Trihexyl(tetradecyl)phosphonium chloride ( $[\text{P}_{6,6,6,14}][\text{Cl}]$ ) droplets with a small amount of 1-(methylamino)anthraquinone red dye for visualization. The droplets spontaneously follow the gradient of the  $\text{Cl}^-$  ion which is created using a polyacrylamide gel pad soaked in  $10^{-2}$  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.*



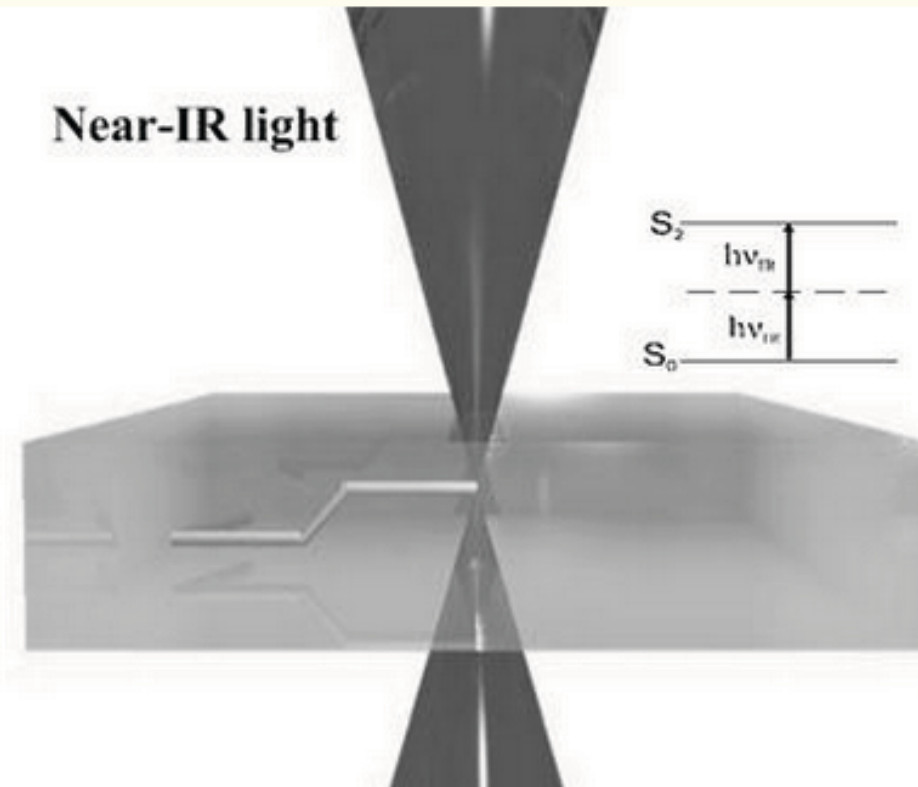
# Background

## Stereolithography



- Single photon absorption
- 2D patterns

## Two-photon polymerisation

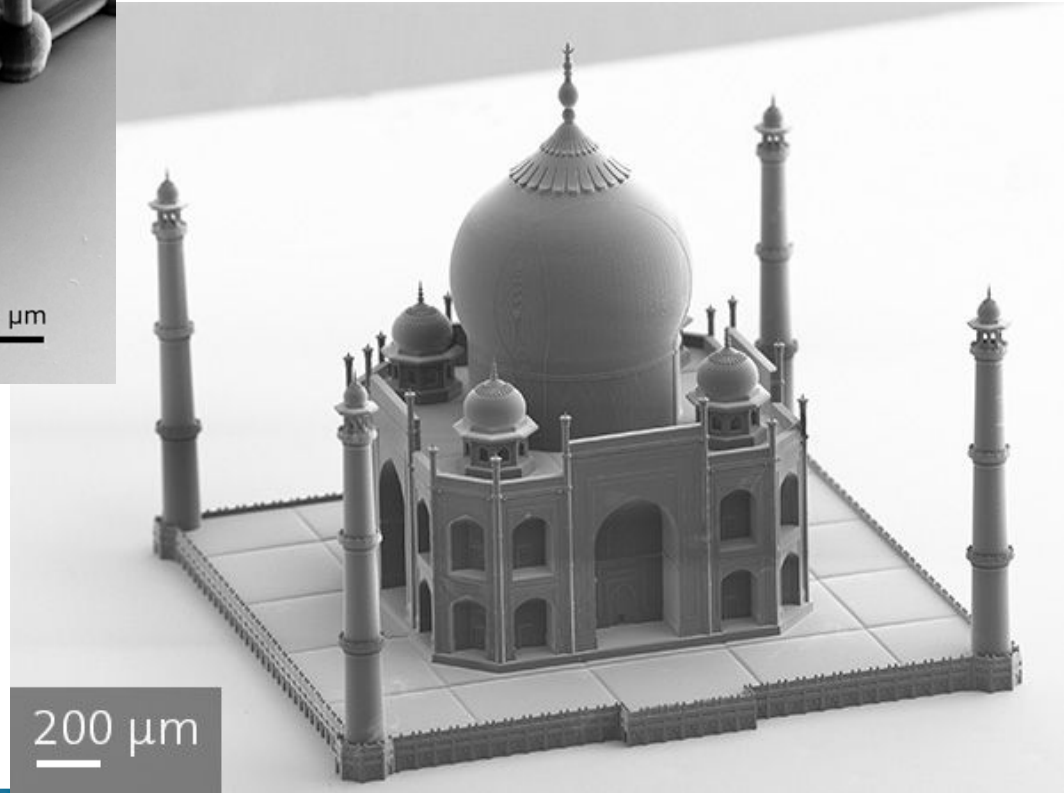
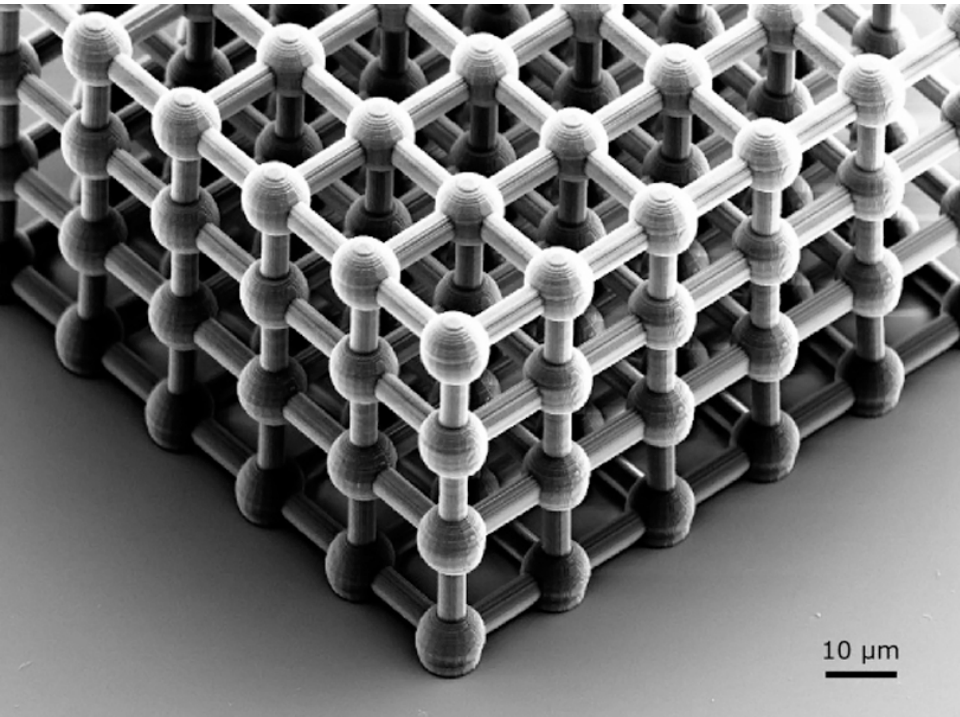


- Two photon absorption
- 3D structures





# Background

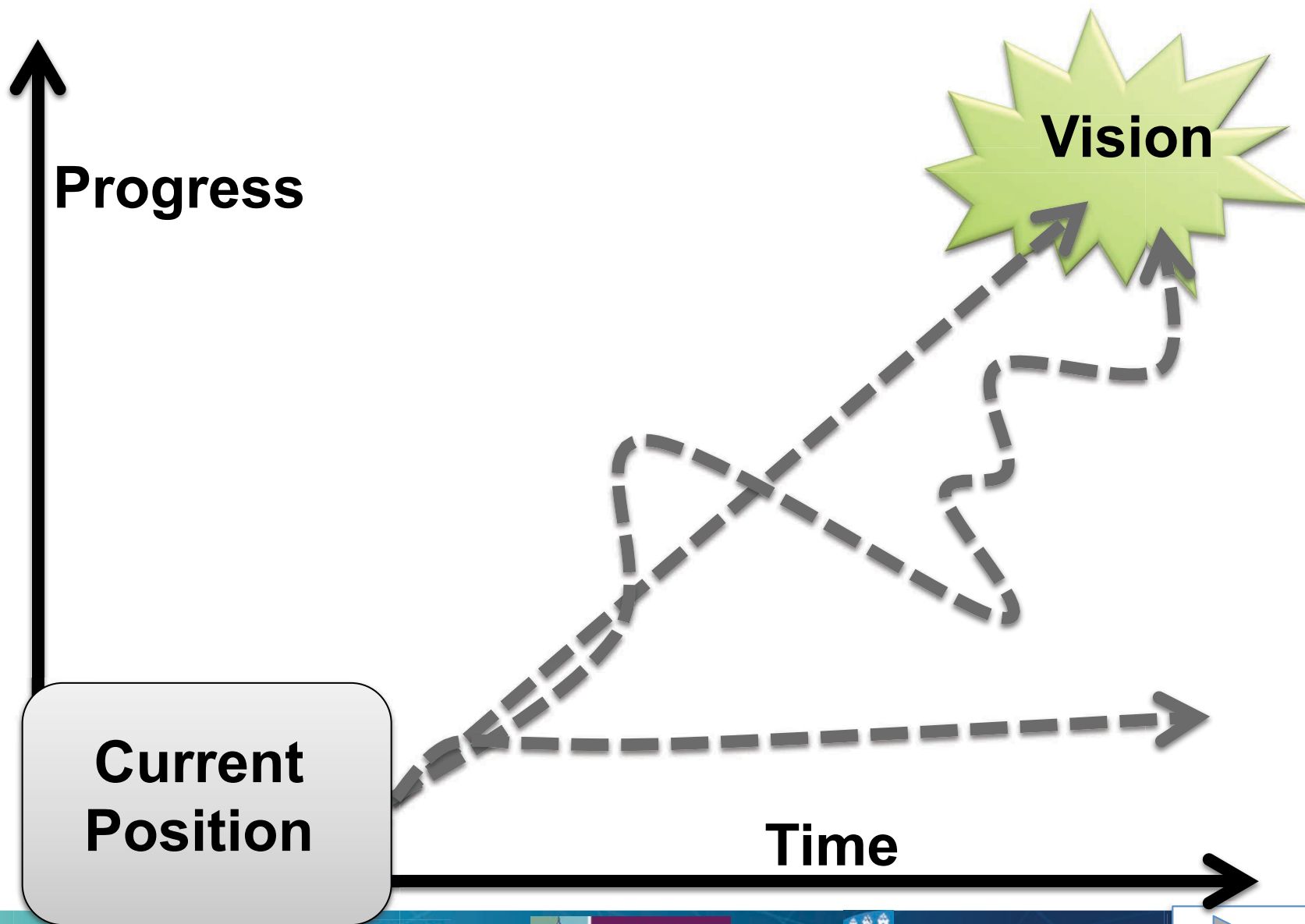


<http://www.nanoscribe.de/>



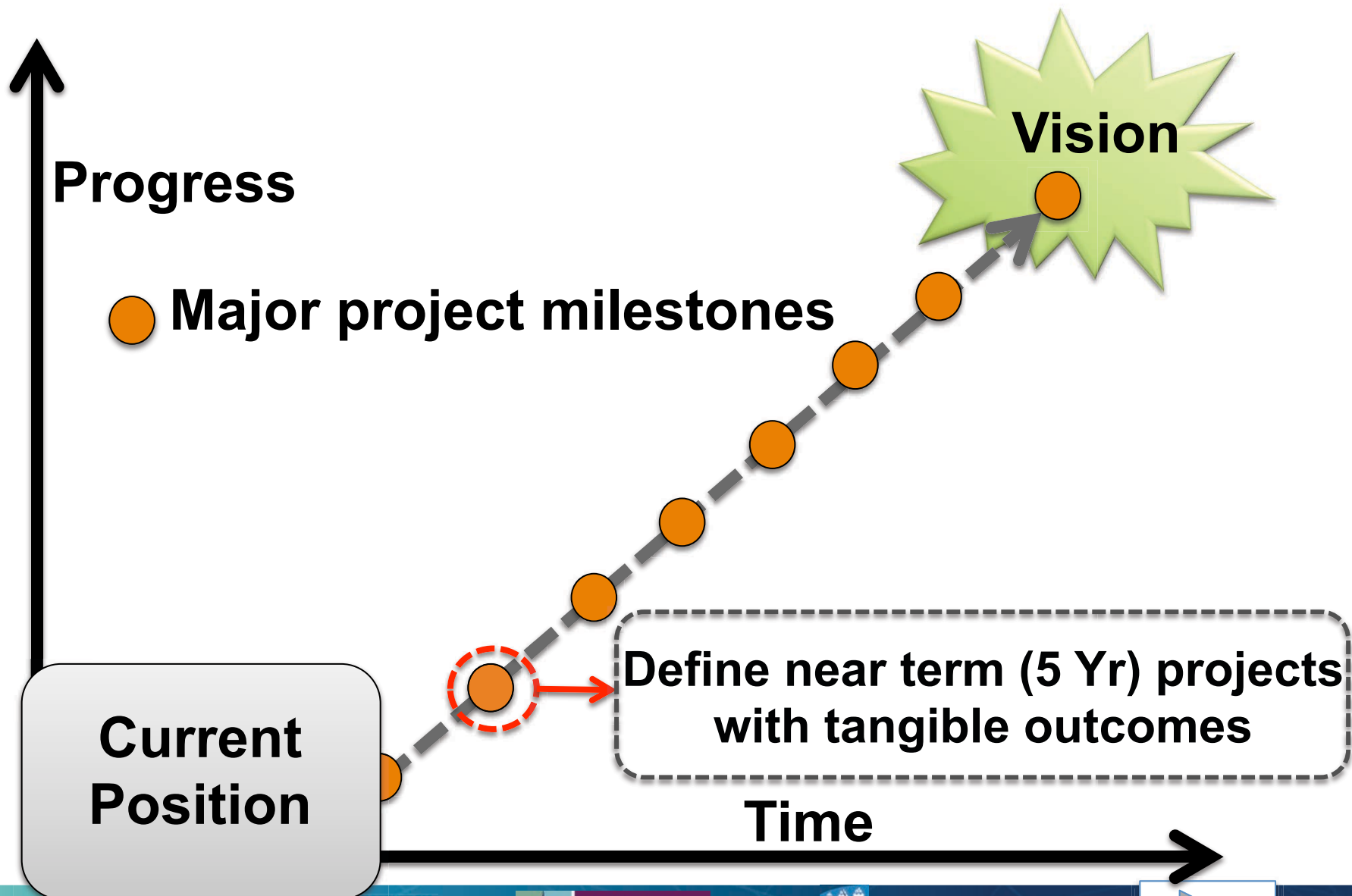


# Roadmap?





# Roadmap?





# Near Term Goals (5Years)

## Outside: On-Body

**Smart  
Bandages**

**Sensorised  
Contact Lens**

**On-Skin wearable  
platforms  
patches/watches**

**Sensorised  
Splints/  
dentures**

**Smart Textiles/  
Clothing**

## Inside: Implants/In-vivo

**Smart Stents**

**Self-Aware  
Transplant  
Joints**

**3D Tissue  
Platforms and  
Implants**

**Post-Operative  
IC (days)**

**Medium term  
Convalescence  
(weeks)**





# Convergence of Materials, Fabrication & Characterisation

**Basic**

**Applied**

## Materials Science

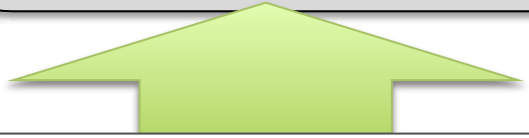
- Biomaterials & Materials chemistry
  - Chem/bio-recognition
  - Transduction/signalling
  - Chem/bio-polymers
- Rapid prototyping & fab
- Materials characterisation
  - Spectroscopies
  - Electrochemistry
  - Separations?
  - Imaging and microscopies
- (Bio)Microfluidics

## Prototype devices & platforms

- Incorporating bioinspired functionalities, biomimetic characteristics
- Self-aware, self-healing/repair, self-replicating..
- Capable of self- or externally controlled movement

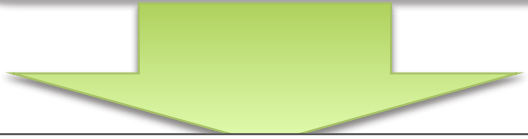
## Applications

- Personal Health
  - Wearables/on-body devices – minimally or non-invasive
  - (micro) robotics and micro surgical tools
  - Implantable sensors for in-situ, real-time monitoring
  - Imaging and spatially resolved data for tissue mapping and location verification



**Fundamental/Futuristic Concepts & Thinking**

**IMPACT**



**Industry links, Research networks, community engagement**

# 'STEP': Shared access to major facilities and equipment

- Open to internal and external users
- Transparent cost
- Generate new revenue streams
- Trained user base
- Maintenance

Research and Innovation

- Key R&I Areas
- Facts & Figures
- R&I Strategy
- Collaborate with DCU
- News & Events
- Research by Faculty
- Research by Institute/Centre
- Research Infrastructure
- Graduate Research
- International
- Research Support
- Technology Transfer
- Contact

## Research Infrastructure Network at DCU

Please continue to the [Access](#) page if you would like to access a facility, use a particular piece of equipment or request training on an instrument

### MICROSCOPY & SPECTROSCOPY CORE FACILITY

- Optical Microscopy Labs
- Super Resolution Microscopy Lab
- Electron Microscopy Labs
- Spectroscopy Labs (*under construction*)

### MATERIALS & SURFACES ANALYTICAL CORE FACILITY

(web pages under construction)

- Chemical Analysis / Chromatography Lab (*under construction*)
- Mass Spectrometry (*under construction*)
- Material Properties Analysis (*under construction*)
- Surface Profiling (*under construction*)
- Surface Properties - Analysis (*under construction*)

### MATERIAL PROCESSING CORE FACILITY

- 3D Printing Labs
- Micro/Nano Fabrication Labs
- Screen Printing Lab
- Plasma Etch & Thinfilm Deposition Labs (*under construction*)

### BIOLOGICAL CHARACTERISATION CORE FACILITIES

- Antibody Characterisation Labs

### ENHANCED SPECIFICATION LABS

- Cleanrooms and Clean Air Labs
- NRF Chemical Synthesis Labs
- Biological Resource Unit

### e-INFRASTRUCTURE & SCIENTIFIC COLLECTIONS

ICHEC





# 'STEP' 3D Printing Suite



## Research and Innovation

### Research and Innovation

Key R&I Areas

Facts & Figures

R&I Strategy

Collaborate with DCU

News & Events

Research by Faculty

Research by Institute/Centre

Research Infrastructure

Graduate Research

International

Research Support

Technology Transfer

Contact

## 3D PRINTING FACILITIES

DCU's 3D printing facility contains a suite of printers that can print using a broad range of materials, have a range of printing techniques and can also print to low micron resolution.

### Pricing:

Academic: €45 per hour  
Industry: €90 per hour

**NOTE:** Prices may vary depending on CAD modifications, material costs and technical intervention required. Quotations can be provided for all jobs.

### Contact:

Technical: lorcan.kent@dcu.ie

### Instruments:

#### Stratasys Objet260 Connex 1

The Objet260 Connex1 allows us build three-material models as large as 255 x 252 x 200 mm.

The instrument has 16-micron layer accuracy and 14 photopolymers to simulate a range of material properties.

The Objet260 Connex1 offers 14 base materials including:

- Rigid Opaque (VeroWhitePlus, VeroBlackPlus, VeroGray and VeroBlue)
- Rubber-like (Tango family)
- Transparent (RGD720 & VeroClear)
- Simulated Polypropylene (Endur and Durus)
- Biocompatible (MED610)
- High Temperature (RGD525)



#### Stratasys Dimension SST 768



Stratasys Dimension 3D printer, capable of printing 3-dimensional fundamental structures, as well as highly-resolved pre-commercial prototype structures.

This printer has a large build envelope to print models up to 254 x 254 x 305 mm. It uses Stratasys' Fused Deposition Modeling (FDM) Technology to create models in ABSplus thermoplastic. It uses CAD STL files and with two layer resolution settings, 0.254mm or 0.330mm slices, we can build a part quickly for design verification, or choose the finer setting for higher quality surface detail. The system builds the parts by extruding a bead of ABS plastic through an extrusion head, producing high quality parts that are ready to use immediately after completion.



#### Stratasys Dimension uPrint



The uPrint is a workhorse printer producing high quality parts as large as 203 x 152 x 152mm produced in 0.254mm slices. It uses soluble support material which means the finished parts are quickly cleaned with the built in wave wash system.



#### Smart 3D - Miicraft+ HR

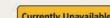


Miicraft+, SLA-based DLP pico 3D printer, offers resolution as high as 30 microns in the Z-axis and 56 microns in the XY-plane. Very good printer for smaller items printed in a short time frame

- X and Y resolutions: 25 micron (slow speed) and 40 microns (fast build speed)
- Z resolution: 30/50/100 microns with Miicraft Resin
- Build area: X = 25 mm, Y= 45mm, Z=180m
- Materials - Photocurable polymer resins – blue and transparent



#### Asiga - Freeform Pico Plus 27



The Freeform Pico is a 3D printing system which uses Asiga's Slide-And-Separate technology to achieve very low fabrication forces for an upside-down stereolithography system. This results in minimal support structures and very high accuracy. It can build at up to 12mm per hour at 25 micron slice resolution and 48mm per hour at 100 micron slice resolution

- X and Y resolutions: 27 micron
- Z resolution: 1 micron step size, approx 30 micron layer depth
- Light source: UV LED
- Build area: X = 35 mm, Y=21.8mm, Z=76m





# Time to re-think the game!!!



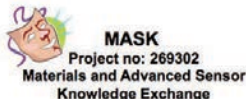
- **New materials with exciting characteristics and unsurpassed potential...**
- **Combine with emerging technologies and techniques for exquisite control of 3D morphology**
- **And greatly improved methods for characterisation of structure and activity**
- **Learn from nature – e.g. more sophisticated circulation systems for ‘self-aware’ sensing devices!**

**Henkel could play a leading role – unique core knowledge of polymer and materials chemistry**



# Thanks to.....

- Members of my research group
- NCSR, DCU
- Science Foundation Ireland & INSIGHT Centre
- Enterprise Ireland
- Research Partners – academic and industry
- EU Projects: NAPES, CommonSense, Aquawarn, MASK-IRSES, OrgBio





**Thanks for listening**

