NCSR
National Centre for Sensor Research

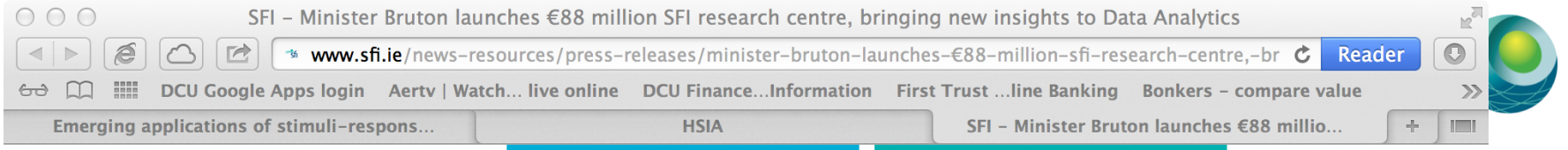
Insight

'Functional Materials, Implants, Wearables and The Connected Society'

Prof. Dermot Diamond
Director National Centre for Sensor Research
Funded Investigator, INSIGHT Centre for Data Analytics
Dublin City University

Presented at

Boston Scientific Euro Global Technology Expo
Galway, 9th September 2014



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

Insight Centre for Data Analytics

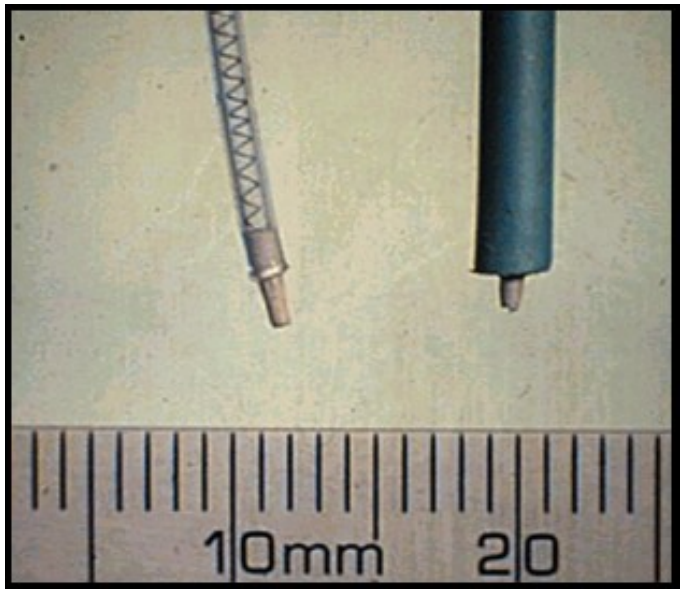
- **Biggest single research investment ever by Science Foundation**
- **Biggest coordinated research programme in the history of the state**
- **Focus is on 'big data' related to health informatics and pHealth**

- Insight, the Centre for Data Analytics, will position Ireland at the heart of global Data Analytics research
- The largest investment in a single research centre in the history of the state
- Uniting 4 universities, 30 industry partners, and 200 researchers in one multi-location research centre
- Creating 300 direct jobs through 12 funded spin outs, as well as creating indirectly thousands of other job opp...

Research and Innovation, Mr Sean Sherlock T.D. today officially launched Insight, a new **Science Foundation Ireland** (SFI) Research Centre for Data Analytics. In a joint initiative between DCU, NUI Galway, UCC and UCD, ... Education institutions, with 30 industry partners, to position Ireland at the heart of global data analytics research.

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.

Blood Analysis; In-Vo Sensing



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

Dr. David Band, St Thomas's Hospital London

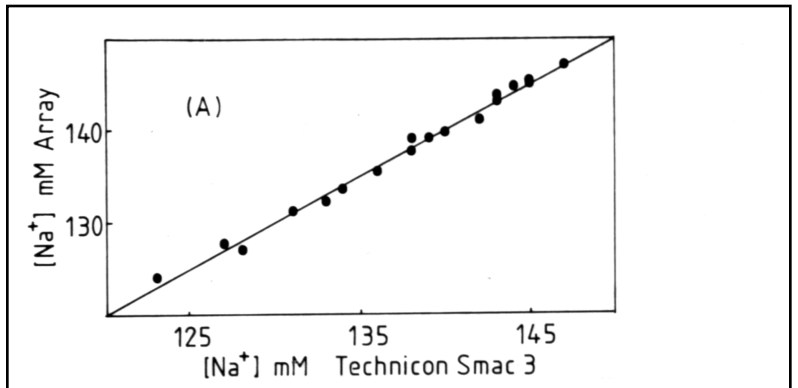
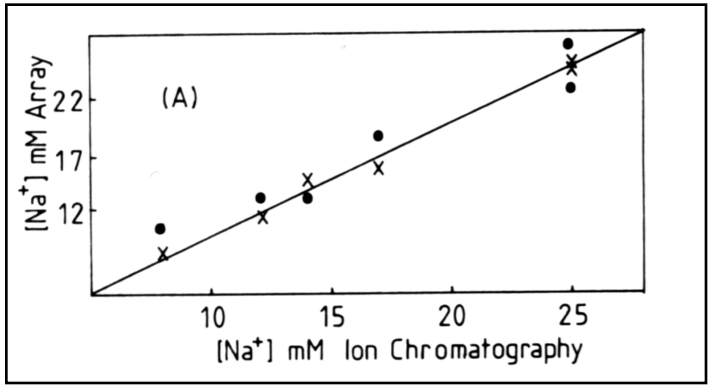


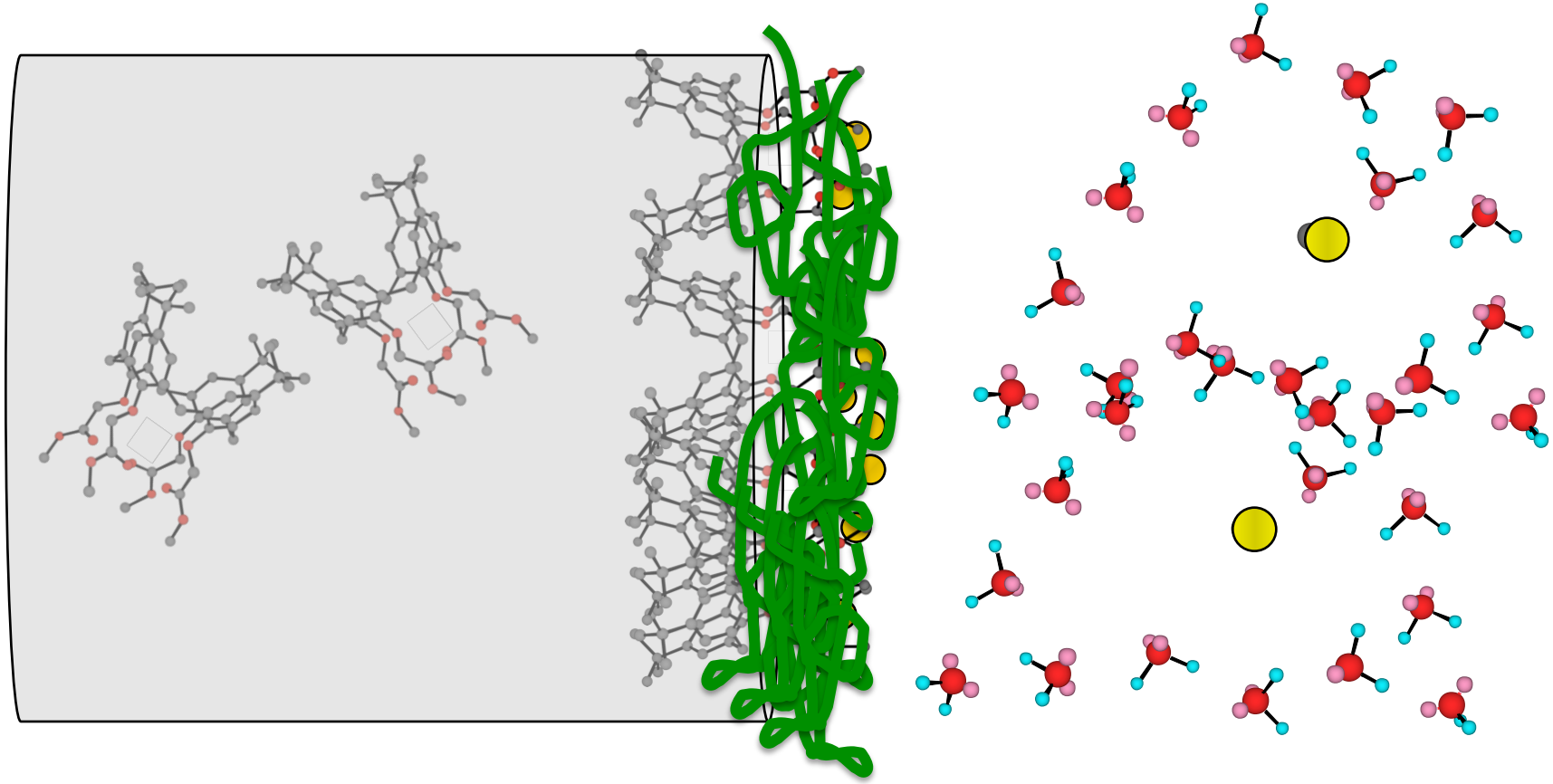
Fig. 3. Comparison of plasma sodium analysis using the array-FIA approach with a SMAC analyser. Good correlation without bias is obtained [5].



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

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

Control of membrane interfacial exchange & binding processes



Remote, autonomous in-vivo chemical sensing is a tricky business!

Artificial Pancreas

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

Used a Technicon segmented flow colorimetric glucose analyser

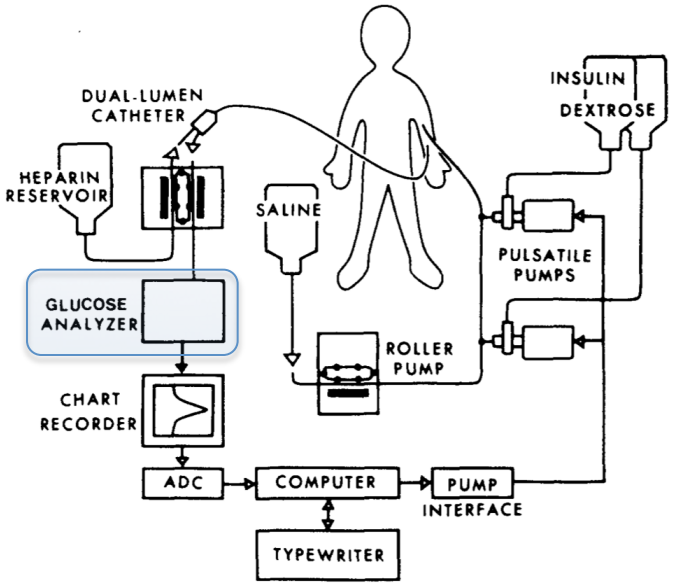
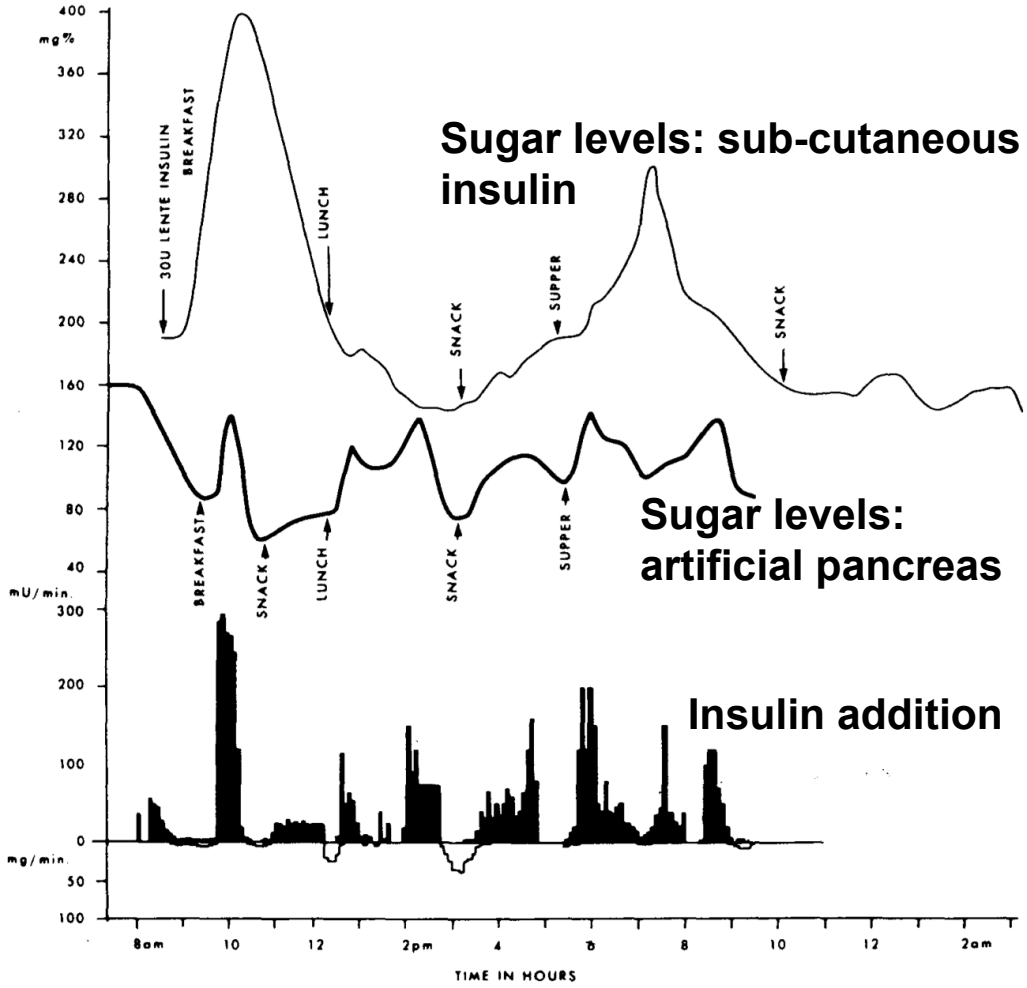


FIG. 1. Schematic diagram of apparatus used for monitoring and automatic regulation of blood sugar.



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)

Freestyle Navigator

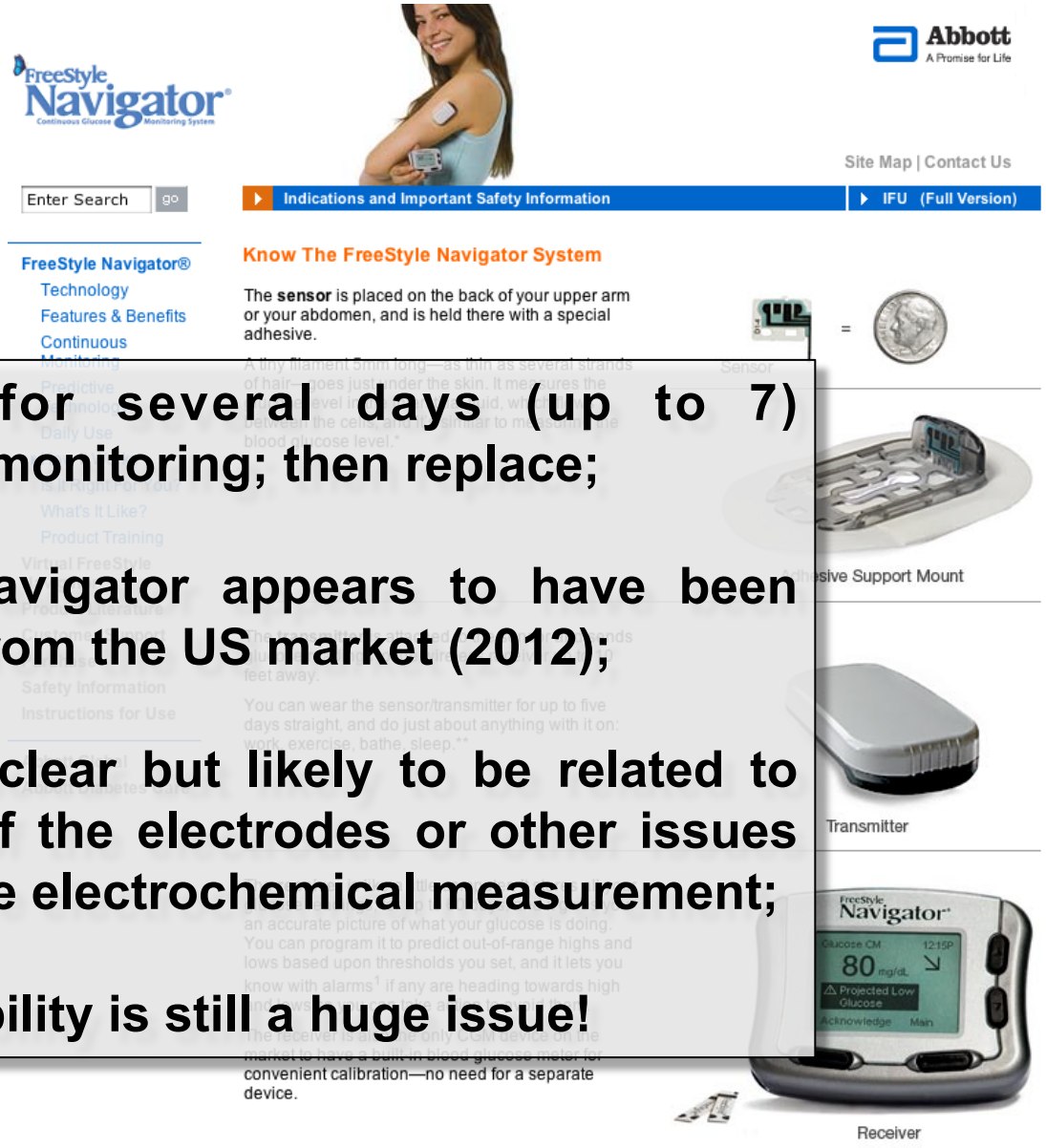
- Combines microfluidics with a micro-dimensioned filament sampling unit which is designed to minimise incidence of infection (therefore can be left in place for 5 days).
- Measures glucose in interstitial fluid (not blood). Diabetics have poor peripheral blood flow so therefore this is easier in advance.
- 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;

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

Reasons unclear but likely to be related to biofouling of the electrodes or other issues related to the electrochemical measurement;

Biocompatibility is still a huge issue!



So where are we?

- **The dominant model for success (outside specialised laboratories) in clinical applications for chemical sensors and biosensors is primarily based on 'single shot' or at best short-term use (hours, days), employing disposable devices.**
- **Long-term chemo/bio-sensor implants are still a long way off.**
  - Fundamental breakthroughs are required to make progress
- **In the meantime, on-body sensing (non- or minimally-invasive…..) offer opportunities.**

What sample do we go for?
blood, sweat, tears……..

Nike & Apple

Nike FuelBand Was the First Fitness Tracker to Fall, But It Won't Be the Last

1.9k SHARES | Share on Facebook | Share on Twitter | WHAT'S THIS?

BY PETE PACHAL

20 HOURS AGO

When Nike laid off big chunks of its FuelBand team on Friday, the future of fitness trackers was suddenly in question. Nike, after all, has one of the most active fitness communities in Nike+, and its FuelBand hardware received generally good reviews. Why run for the exit now?

However, Nike isn't leaving behind wearables *per se*; it's just not going to make any new hardware. The company said it will continue to support existing FuelBands, and its team will work to adapt the software for more platforms. Given Nike's close ties to Apple, this only fuels speculation about an upcoming release of the long-rumored Apple wearable — the iWatch.

Nike Layoffs Add Fuel to Apple iWatch Rumors

ADARIO STRANGE / 3 days ago

Layoffs at Nike's FuelBand unit took many by surprise when the news broke Friday, a move that has further fueled speculation that Apple may be working with the sports-apparel maker to develop an iWatch. A CNET report described the first rumblings of ...

2.7K SHARES

Report: iWatch to Get LG-Made Flexible Display

SAMANTHA MURPHY KELLY / Apr 15, 2014

The much-anticipated Apple iWatch may come with a flexible display manufactured by LG, a new report suggests.

6.7K SHARES

Pebble Sold 400,000 Smartwatches in 2013

APPADVICE / Mar 21, 2014

Pebble is definitely proving the smartwatch market is growing. The company sold 400,000 devices last year, snagging somewhere around $60 million in revenue. And in 2014, the company is well on track to double that revenue number. Talking with Fortune...

4.6K SHARES

Apple's Jony Ive on Design Theft, the Joy of Ignorance and the iWatch

ADARIO STRANGE / Mar 17, 2014

In a rare and wide-ranging interview, Apple's design chief Jony Ive offers a few new insights into one of the most secretive technology companies on the planet -- and explained why he, like his late mentor Steve Jobs, takes it personally when other c...

Intel Buys Wearables Company Basis Science

TODD WASSERMAN / Mar 25, 2014

Intel on Tuesday announced it has purchased Basis Science, the company behind the Basis Band health tracker. Terms of the deal were not disclosed, but TechCrunch reported earlier this month that Intel was paying around $100 million for the company. F...

Apple Prepping Sensors That Predict Heart Attacks, Report Says

ADARIO STRANGE / Feb 16, 2014

We now know that Apple held closed-door talks with Tesla, a meeting of two innovative companies that hints at a number of possibilities. But buried in that same report from the San Francisco Chronicle is the news that Apple may also be preparing to r...

5.6K SHARES

Apple Continues Hiring Spree to Develop iWatch

SAMANTHA MURPHY KELLY / Feb 13, 2014

Apple is still making hires to work on its much-anticipated iWatch.

1.9K SHARES

Apple, iWatch & Health Monitoring

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Apple hiring medical device staff, shares break $600 mark

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Apple Inc CEO Tim Cook

UPDATED 06 MAY 2014 10:50 PM

Apple is building a team of senior medical technology executives, raising hackles in the biotechnology community and offering a hint of what the iPhone maker may be planning for its widely expected iWatch and other wearable technology.

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.

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.** The working electrode can have at least one dimension less than 25 micrometers. The reference electrode can have an area at least five times greater than an area of the working electrode. A portion of the polymeric material can surround the working electrode and the reference electrode such that an electrical current conveyed between the working electrode and the reference electrode is passed through the at least partially surrounding portion of the transparent polymeric material.

Google Smart Contact Lenses Move Closer to Reality

8.6k SHARES | Share on Facebook | Share on Twitter | WHAT'S THIS?

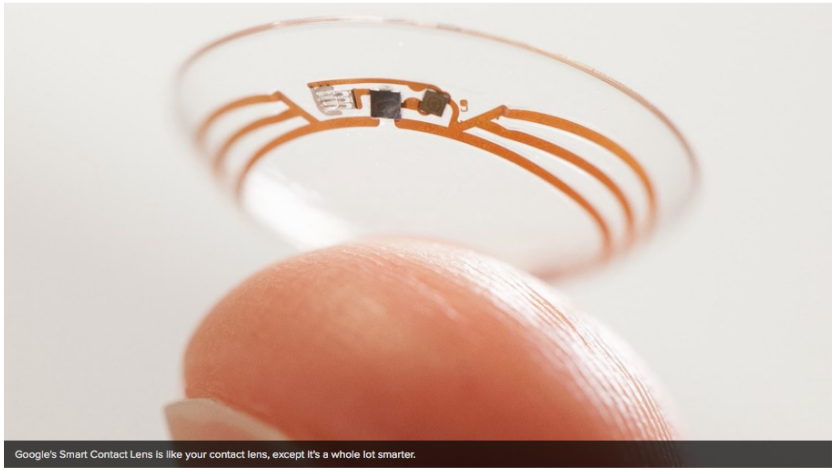


IMAGE: GOOGLE

BY LANCE ULANOFF

1 DAY AGO

Google's plan to bring smart contact lenses to diabetes sufferers inched closer to reality as the company secured two patents last week for the cutting edge, biometric sensor technology.

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.

SEE ALSO: 7 Incognito Wearables You'd Never Guess Were Gadgets

According to the patent:

> "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 contact lens with one or more sensors that can measure one or more of these components provides a convenient, non-invasive platform to diagnose or monitor health related problems. An example is a glucose sensing contact lens that can potentially be used for diabetic patients to monitor and control their blood glucose level.

Google's project is one of a number of in-eye wearable sensor technologies currently under

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

Google, Novartis to Develop Smart Contacts

The technologically advanced eyewear monitors blood sugar concentrations in diabetic patients.

By Bob Grant | July 17, 2014

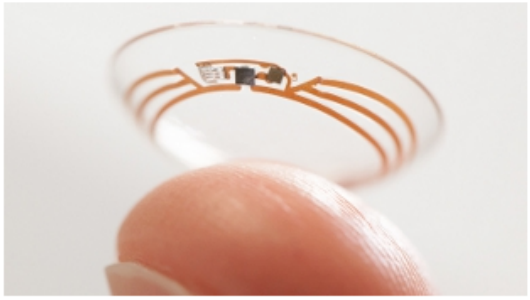


IMAGE FROM GOOGLE'S BLOG

Internet giant Google and pharmaceutical company Novartis are joining forces to develop a high-tech contact lens that will be able to monitor blood sugar levels in people with diabetes, Novartis announced in a statement released Tuesday (July 15).

Google announced the creation of a prototype of the smart lens in January. "We're now testing a smart contact lens that's built to measure glucose levels in tears using a tiny wireless chip and miniaturized glucose sensor that are embedded between two layers of soft contact lens material," the company said in a January 16 post on its official blog. "We're testing prototypes that can generate a reading once per second."

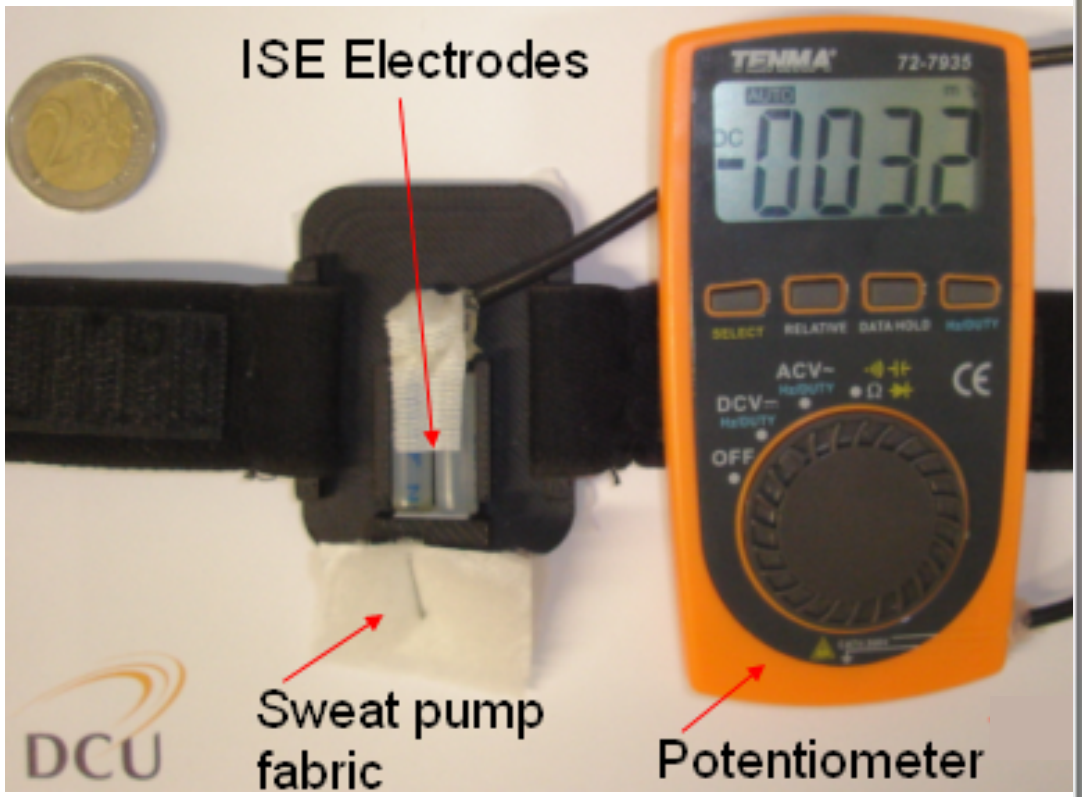
Six months later, Alcon, Novartis's eye care unit, has licensed the technology from Google(x), the research division within the Internet company that tackles global technological problems, with the goal of pushing the smart lens onto the market. "We are looking forward to working with Google to bring together their advanced technology and our extensive knowledge of biology to meet unmet medical needs," Novartis CEO Joseph Jimenez said in the statement. "This is a key step for us to go beyond the confines of traditional disease management, starting with the eye."

Blood glucose concentrations could be sent from tiny sensors via a super thin radio antenna in the contact lenses to a doctor's or a wearer's computer or smart phone to alert them to dangerously rising or falling levels.

"If it is accurate and affordable, it could be an absolute game-changer," dietician and diabetes expert Jill Weisenberger told the *Los Angeles Times*. More than 29 million Americans have diabetes, according to the American Diabetes Association.

Jimenez declined to tell *The New York Times* the financial terms of the deal, nor did he give an estimate for what the lenses might cost.

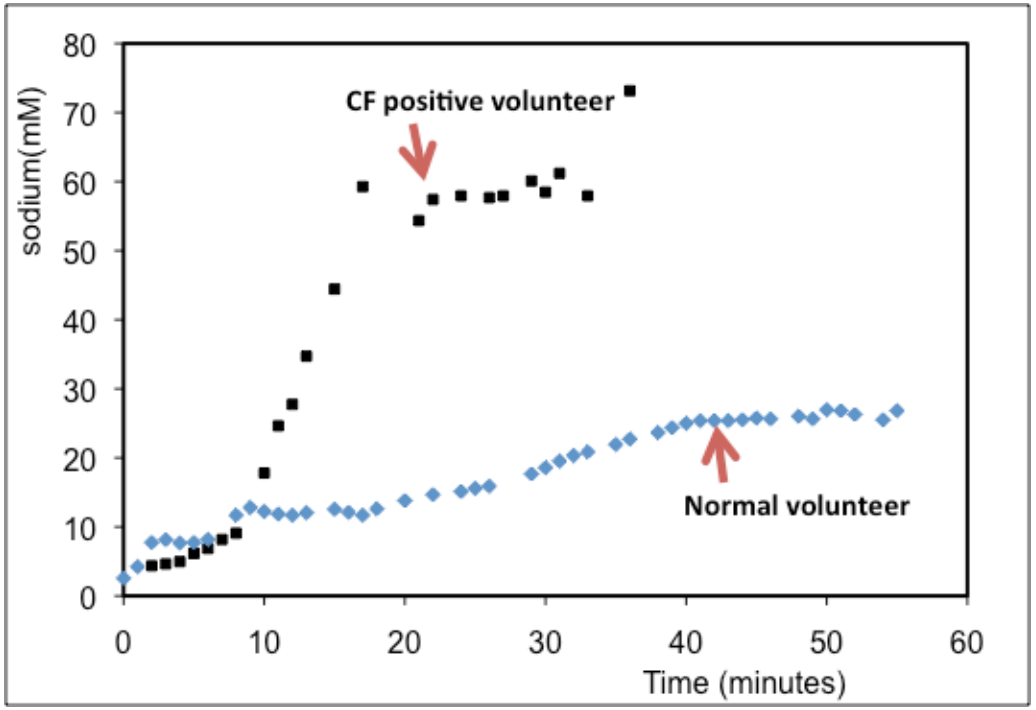
Na^+ sensor: Sodium Sensor Belt (SSB)



Schazmann, B., et al., Analytical Methods, 2010, 2(4): p. 342-348.

Na^+ monitoring in sweat using wearable sensor

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

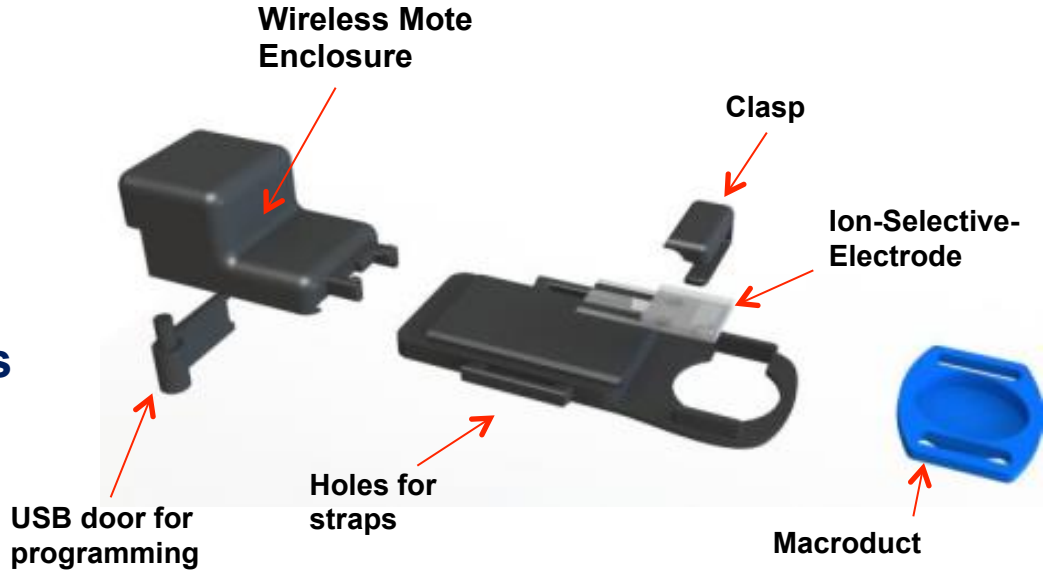


- **Diagnostic CF threshold >60mM [Na^+] reached**
- **Issue with initial delay**
  - arises from inherent delay in onset of sweating
  - contribution from device 'dead-volume'

Na^+ Monitoring in Sweat

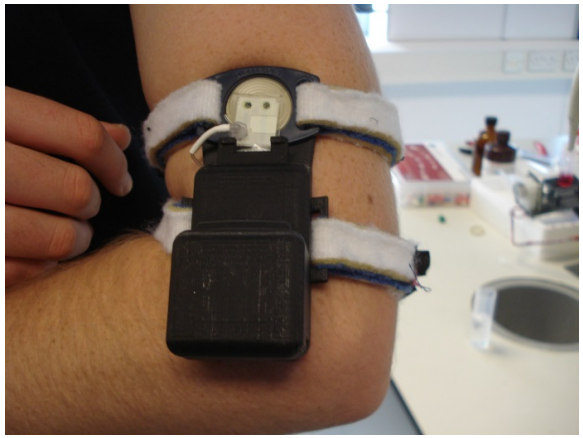
Real time monitoring of Sodium in Sweat through screen printed potentiometric strips:

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

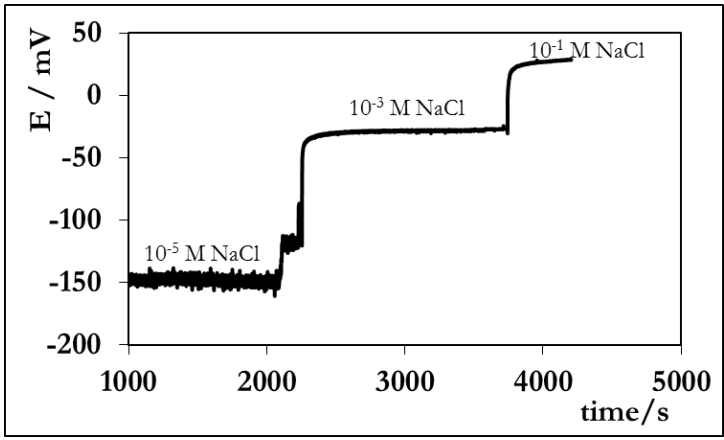


Macroduct sweat sampling unit (Wescor Corporation) Speed x4

Pilocarpine based sweat sampling

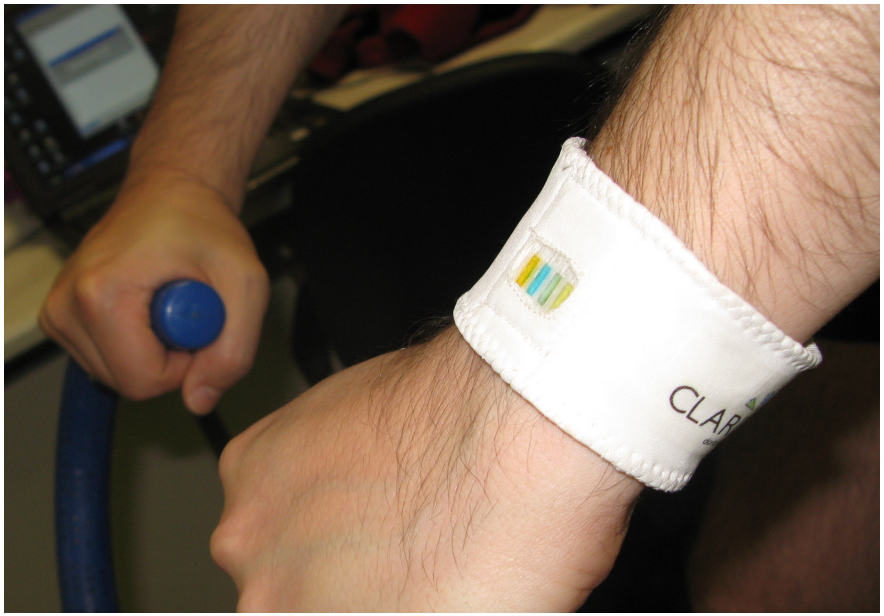


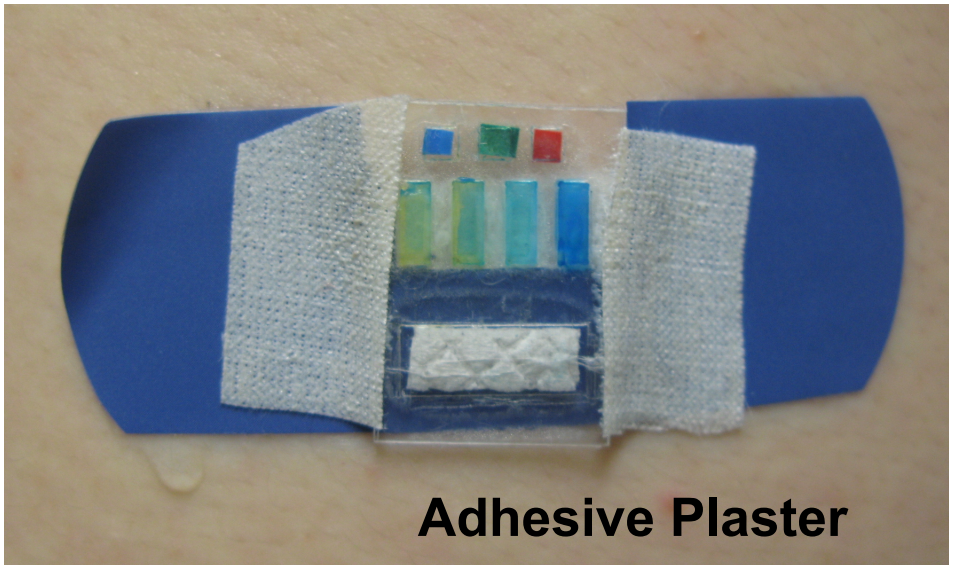
Exercise based sweat sampling

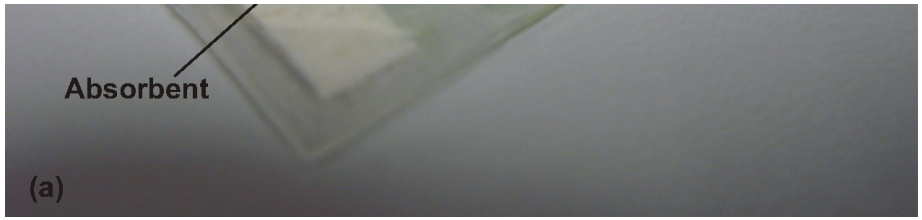


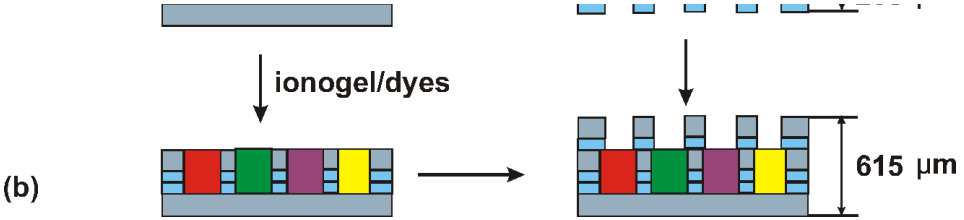
Sensor calibration

Microfluidic pH Sensor fabrication

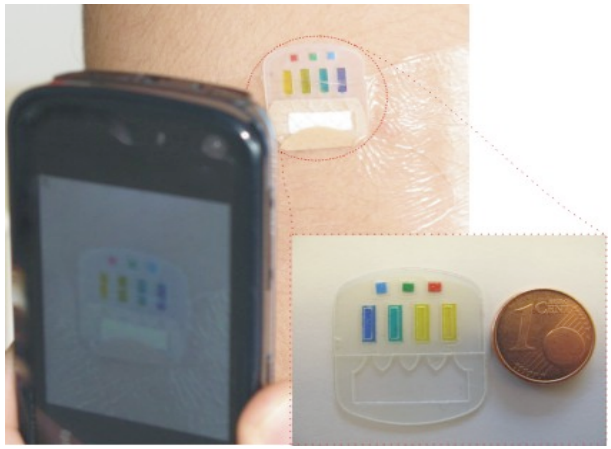




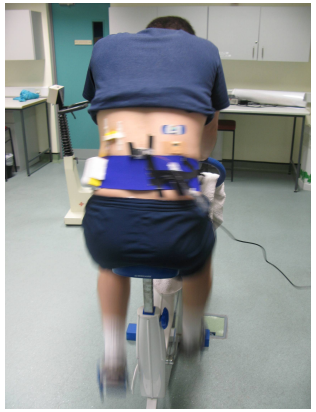




pH Monitoring via Smart Phone App



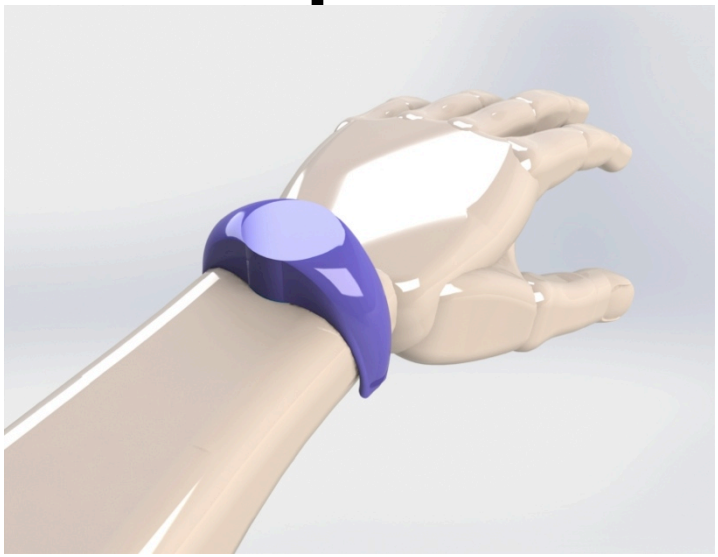
- COLOUR CHANGE VISIBLE BY EYE
- SMARTPHONE APP TO DETECT pH AUTOMATICALLY
- REAL TIME VIDEO ANALYSIS IS POSSIBLE

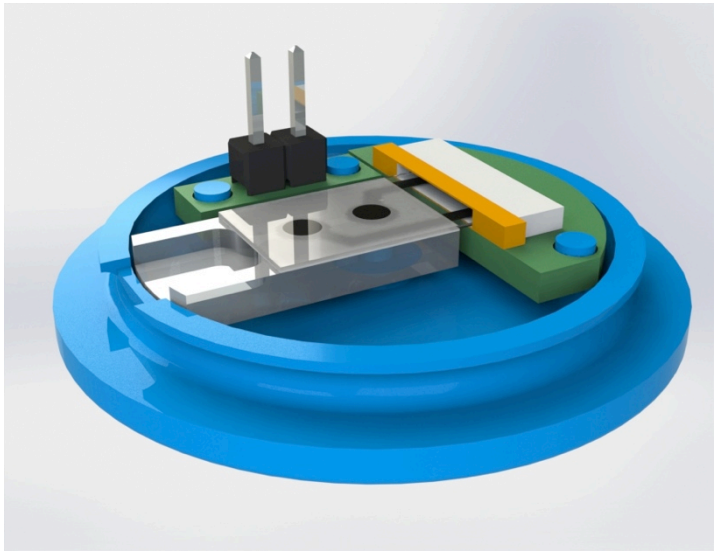


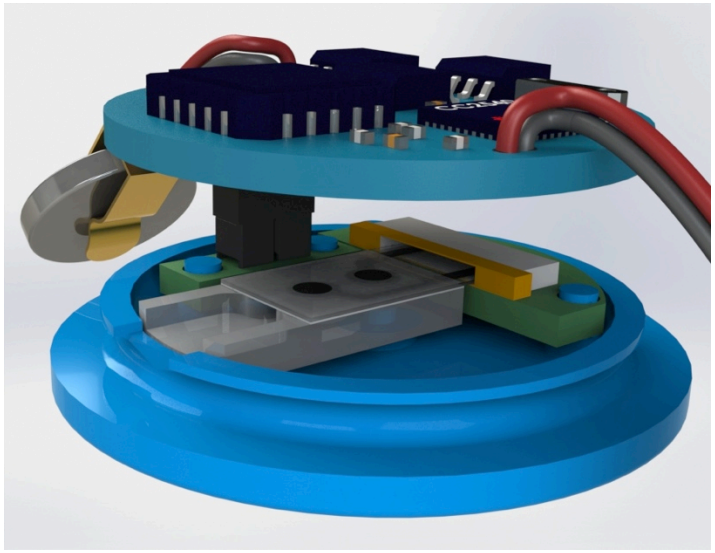
Time [min]	pH Meter	Dyes Prediction (pH)	% RE
20	6.38	5.89	7.68
30	5.8	5.56	4.14
40	5.67	5.67	0.00
50	5.95	5.63	5.38

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

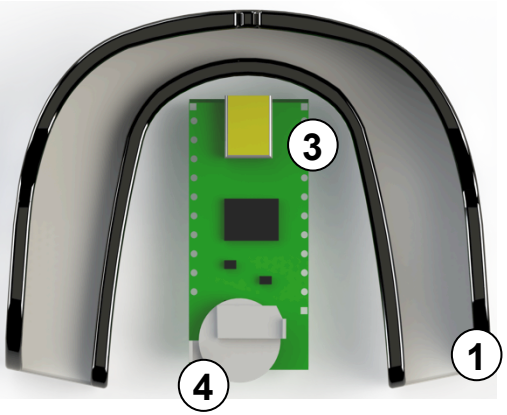
Next Generation: Watch Fluidic Sensor Concept



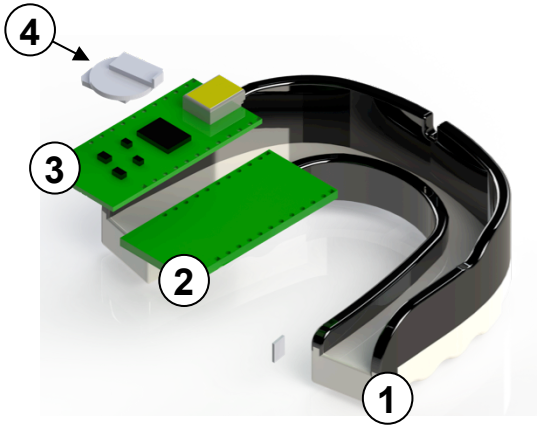




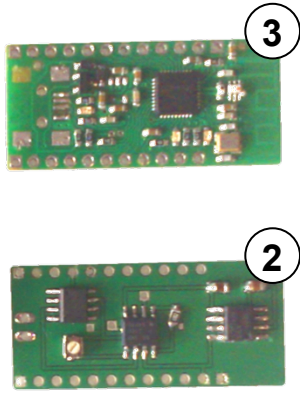
Smart Gumshield

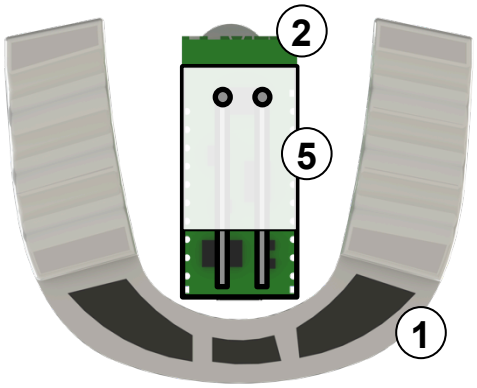


(a) Top View

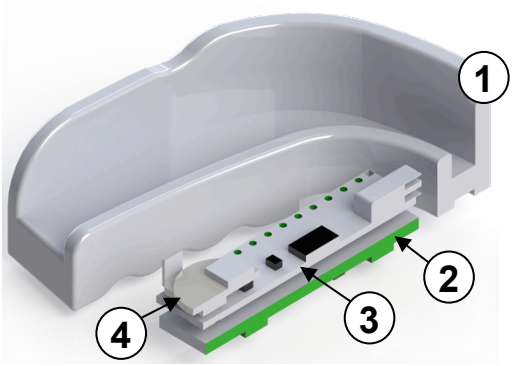


(b) Exploded View

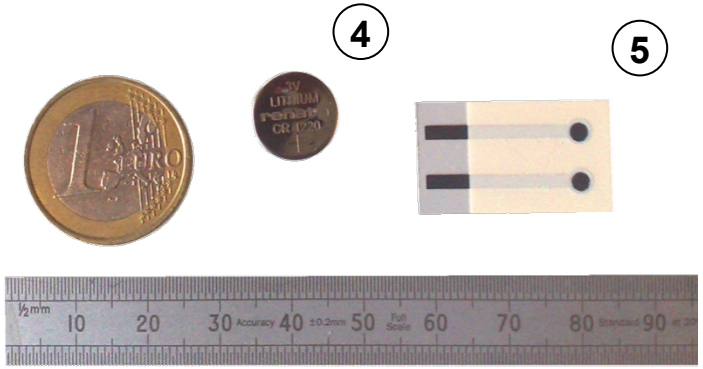




(c) Bottom View



(d) Assembled Sectional View



(e) Photo of components laid out

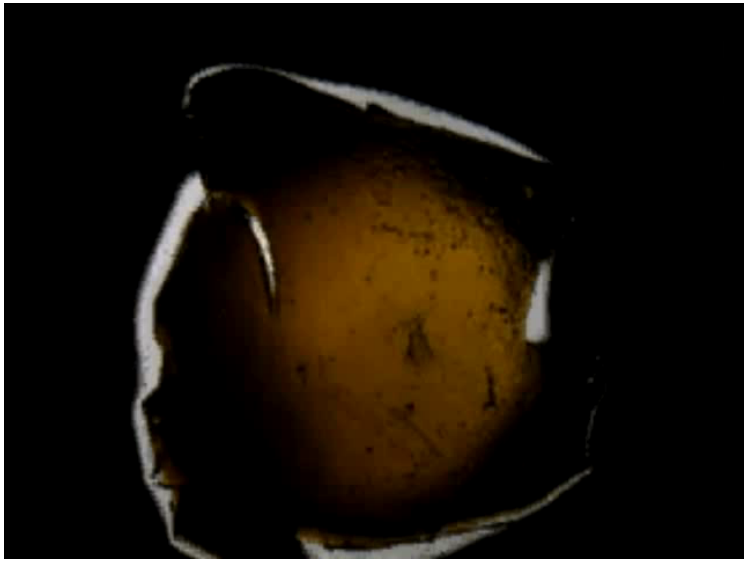
Contact lens for diabetics

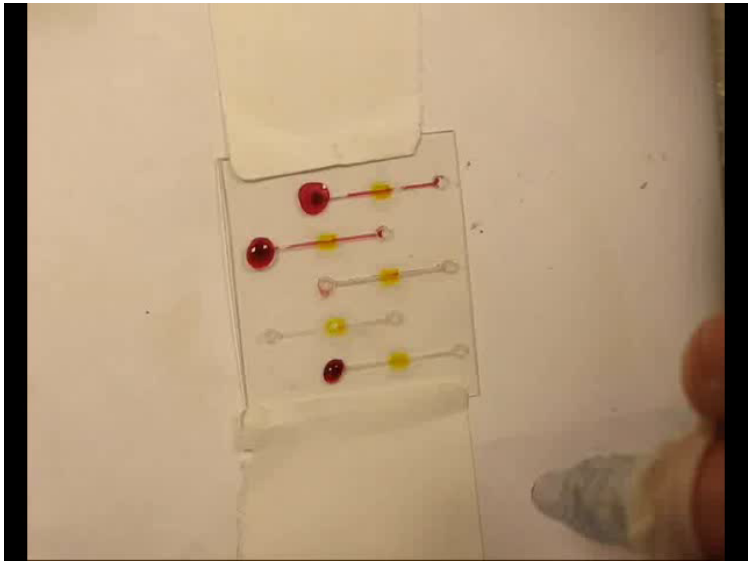
- **Optically responsive contact lenses for diabetes**
  - **Series of papers by Ramachandram Badugu, Joseph R.Lakowicz, and Chris D. Geddes; e.g.[1]**
  - **Jin Zhang of the University of Western Ontario[2].**

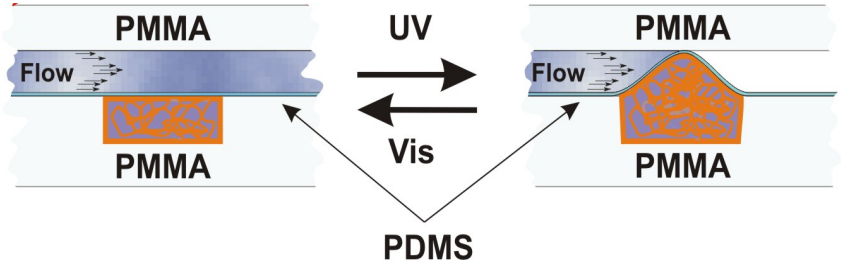
[1] Noninvasive continuous monitoring of physiological glucose using a monosaccharide-sensing contact lens, R. Badugu, J.R. Lakowicz, C.D. Geddes, Analytical Chemistry, 76 (2004) 610-618.

[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)

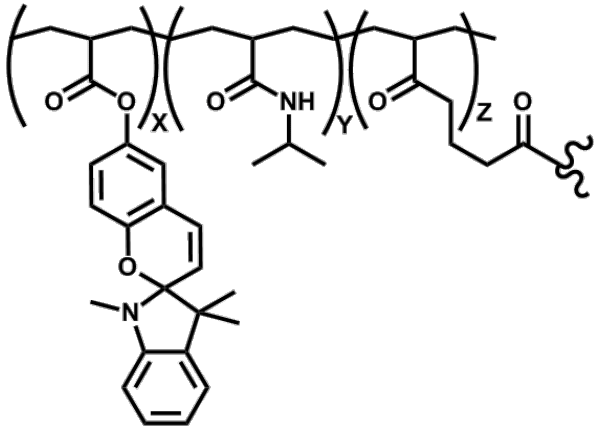
Photo-actuator polymers as microvalves in microfluidic systems

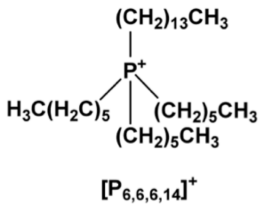


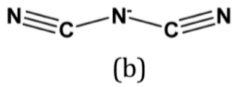




trihexyltetradecylphosphonium dicyanoamide $[P_{6,6,6,14}]^+[dca]^-$

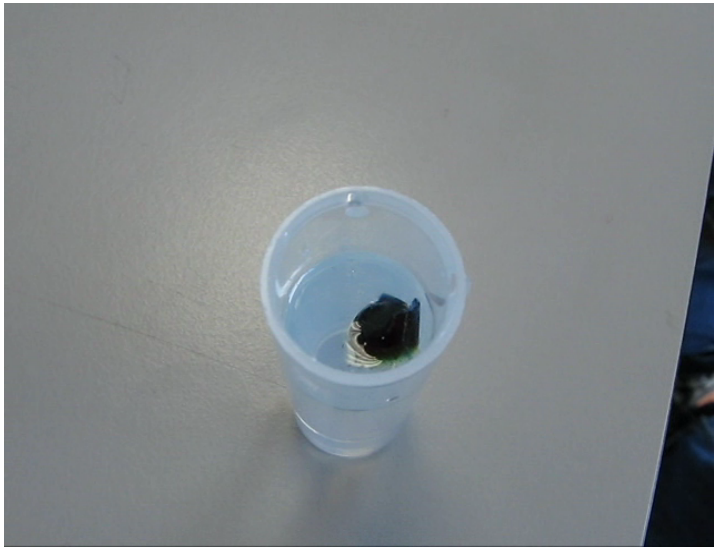






Ionogel-based light-actuated valves for controlling liquid flow in micro-fluidic manifolds, Fernando Benito-Lopez, Robert Byrne, Ana Maria Raduta, Nihal Engin Vrana, Garrett McGuinness, Dermot Diamond, Lab Chip, 10 (2010) 195-201.

Biomimetic low-power soft pump



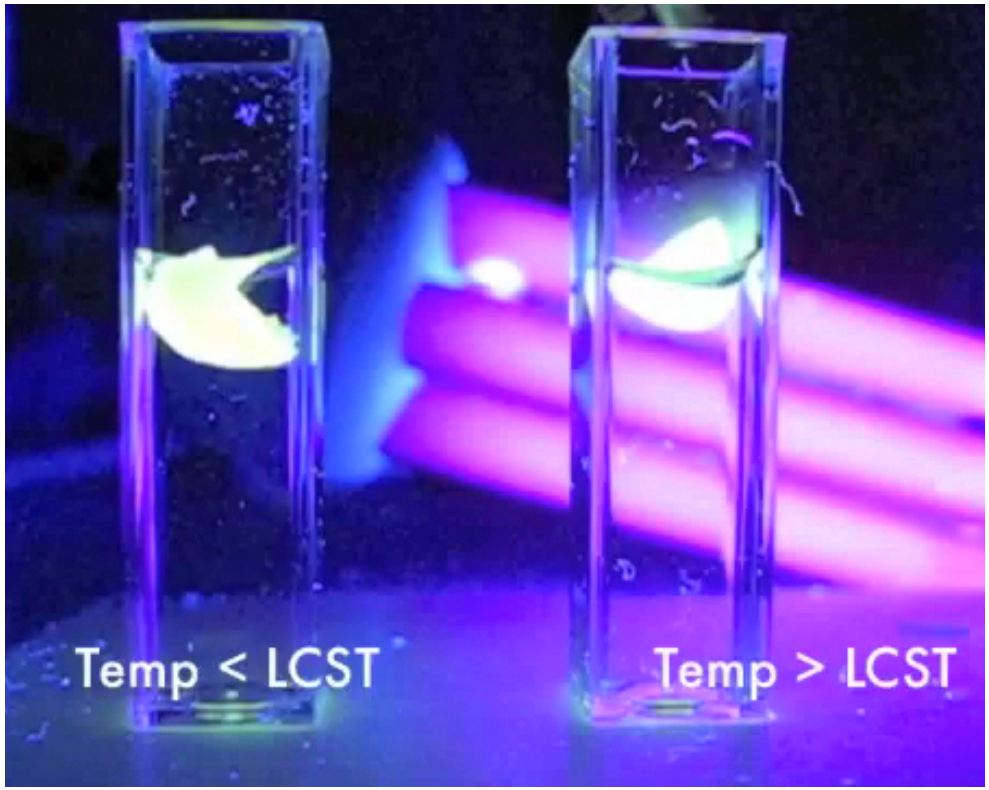
Low Power control of fluid movement in channels and on surfaces is possible using electrochemically switched actuators!

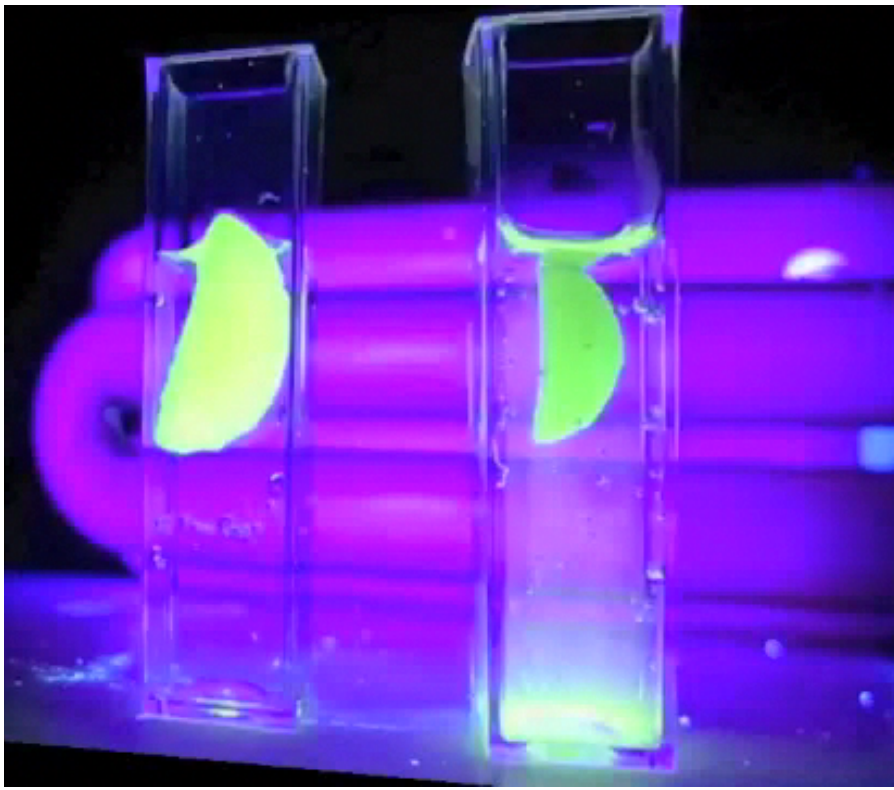
Internet-scale Sensing: Are Biomimetic Approaches the Answer?, Sonia Ramirez-Garcia and Dermot Diamond, Journal of Intelligent Material Systems and Structures, 18 (2) (2007) 159-164.

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

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

Controlled Release – material, temperature and pH dependent

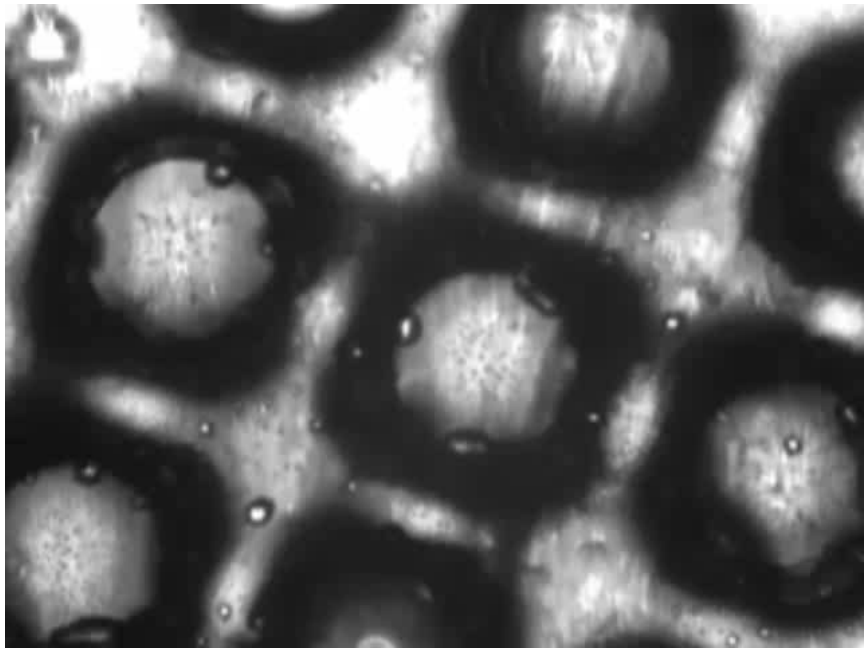




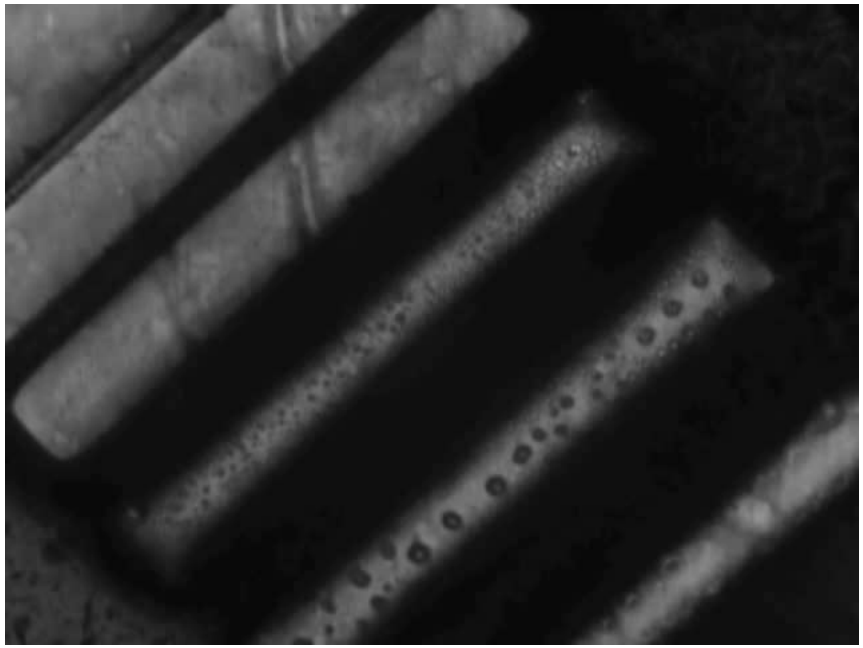
Hydrogel pH 4

Ionogel pH 7

Dynamic Structures for uFluidic Systems



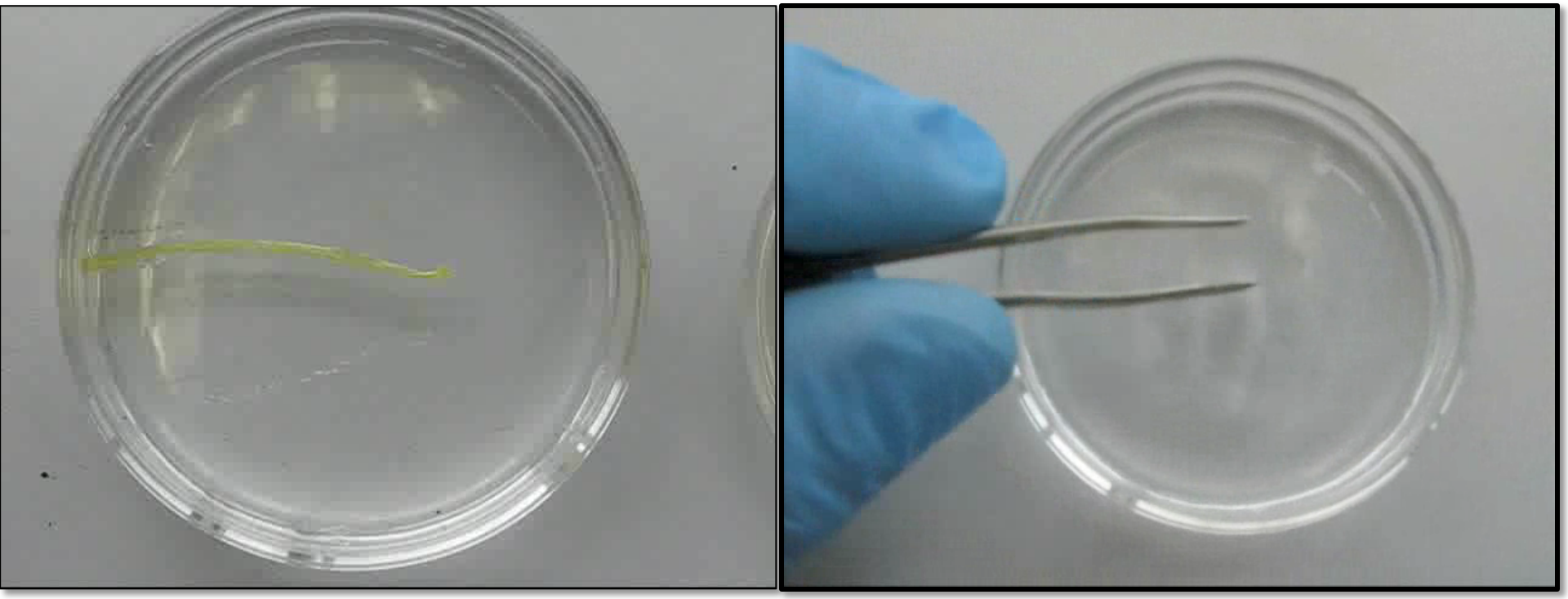
Ntf2 pillars speed x3



DCA lines speed x4

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

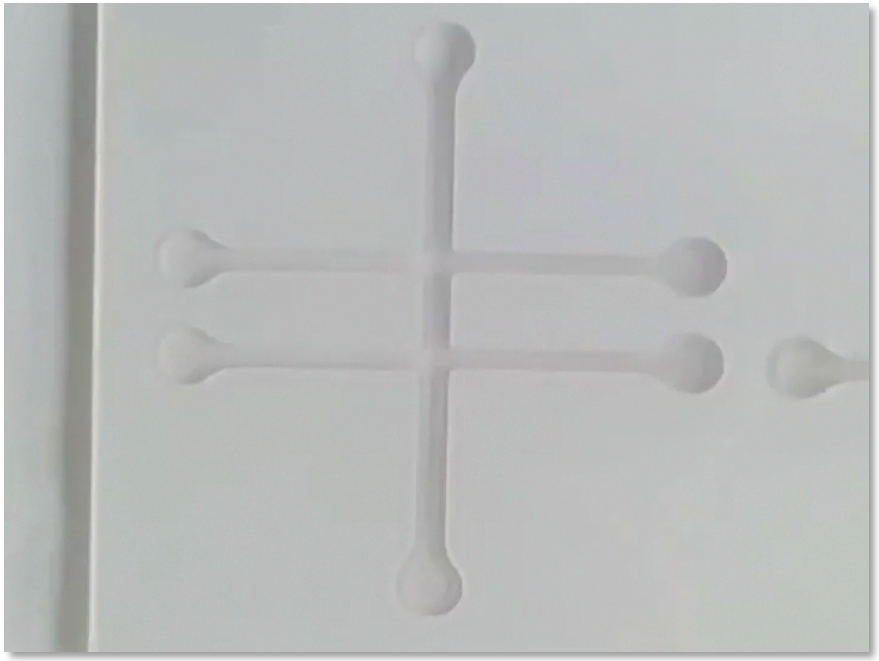
Mobile platforms with chemical actuation: No external power required

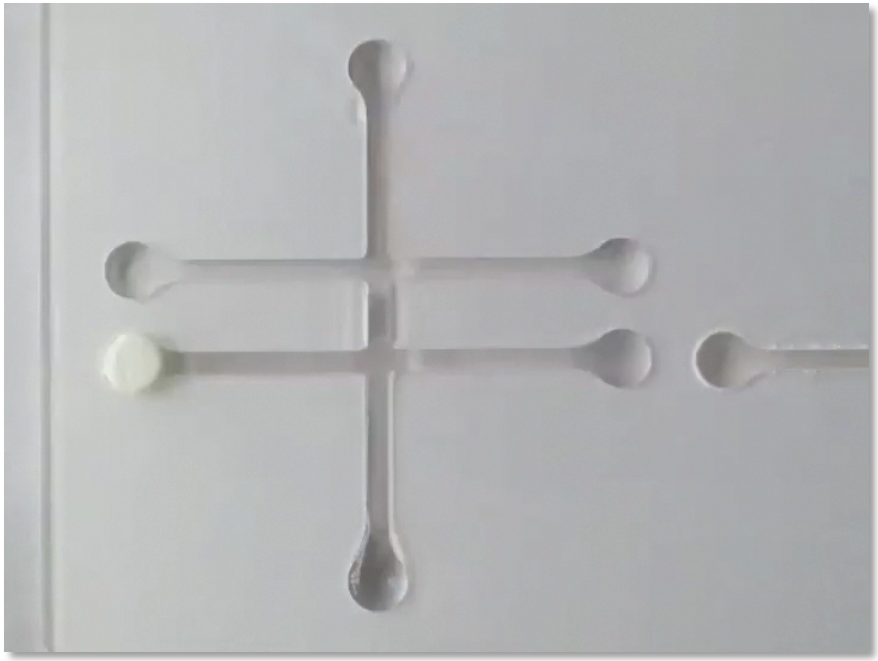


Based on solvent exchange within ionogel (water/ethanol)

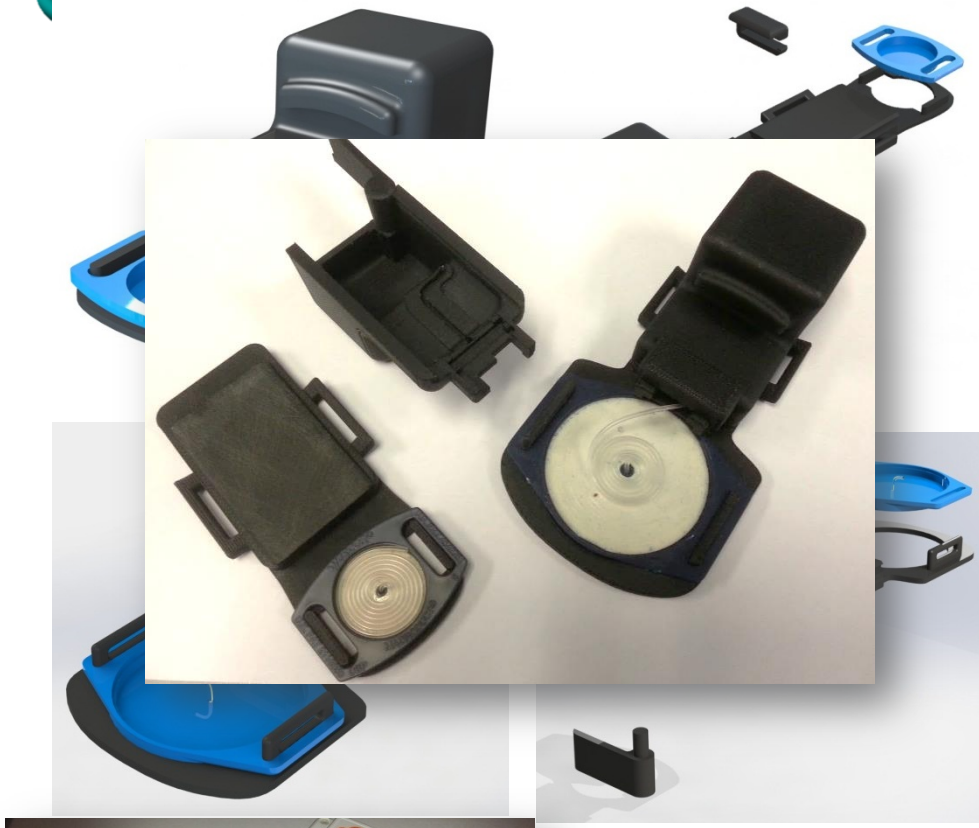
Robert Byrne and Fernando Lopez

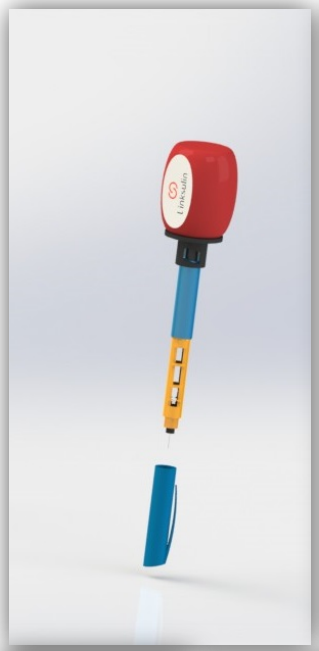
Chemotaxis





- Droplets spontaneously move along a chemical gradient to a particular location – typically the source of the stimulus/chemo-attractant species
- At the location, droplets can be programmed to release a molecular payload (e.g. due to a local pH or temperature difference) and report remotely on the status of the local environment





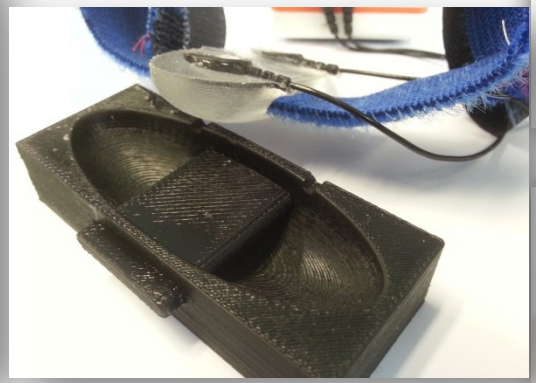
Linksulin

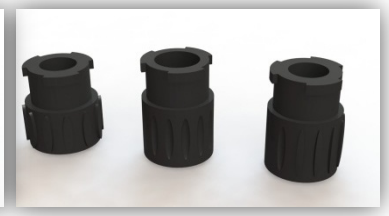
Linksulin

Linksulin

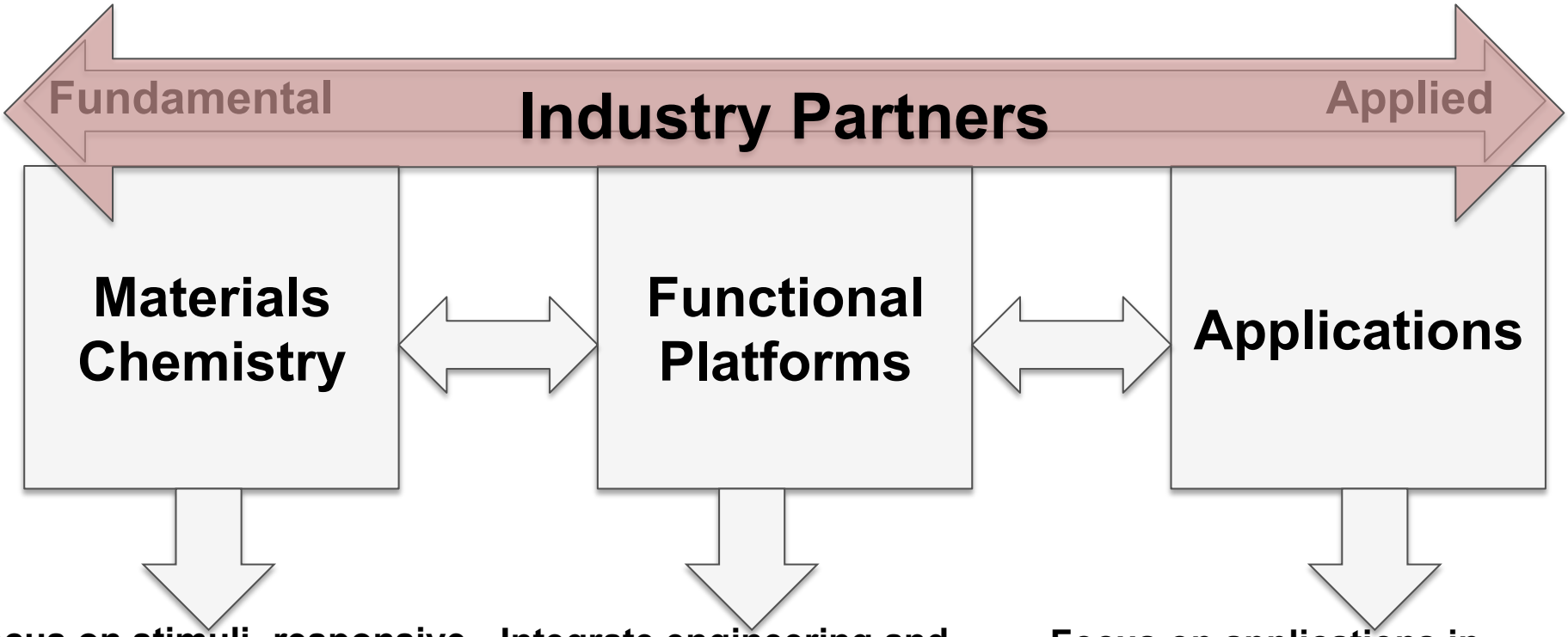
Linksulin

Linksulin

shimmer




Research Strategy



Focus on stimuli- responsive materials;

- Generate a signal = sensor
- Switchable properties
  - Colour
  - Hydrophobicity
  - Porosity
  - Binding/release
  - Swelling/shrinking
  - Location…..

Integrate engineering and science

- Rapid Prototyping focused on polymers e.g. 3D printing, laser ablation,
- Sensing Platforms
- Microfluidics - components like biomimetic pumps and valves
- Add functionality to existing platforms

Focus on applications in personal health and the Environment

- Interest in generating time series data (autonomous sensors)
- Wearable sensors or other minimally invasive approaches
- Monitoring of (bio)chemical parameters

Conclusions

- Our strategy is to create an integrated environment based on cutting edge technologies that allow us to control the placement and 3-D form of emerging multifunctional materials in highly precise locations
- Strongly linked with fundamental materials chemistry and materials biology research
- Integrated with suites of characterisation equipment; e.g. SEM, imaging microscopies, spectroscopies
- Strong links with key industry partners – multinational and indigenous SMEs/spin-outs
- Access to patient cohorts and test populations/real samples for device validation studies/clinical trials

Thanks to…..

Thanks for the invitation