‘Bio-inspired Microfluidics’

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Invited Seminar Presented at the NBMC Workshop;

‘Blood, Sweat and Tears’

Lockheed Martin, Arlington, Virginia

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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


Ligand (and variations of) used in many clinical analysers for blood Na⁺ profiling
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.
Dermot Diamond
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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 instantaneously 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
Glucose Sensors

Accuracy in use depends on;
• Very reproducible manufacturing with stable, reliable materials
• Testing of representative sub-populations of sensors
• Single shot use model

Abbott Diabetes (Ireland) manufactures 100,000’s of electrodes per week using high volume printing to deposit highly accurate amounts of materials in precise locations; (carbon tracks and substrate layer, glucose oxidase enzyme layer, mediator layer..)
Microfluidics – Evolution....

Engineering Inspired  →  BioInspired
But not everything is integrated.....
But not everything is integrated.....

- Many components are located off-chip
- Detectors, pumps, valves....
- Hard Materials

- Fluidic Interconnects can get very messy
- Most of the ‘Chip’ has no function

Photoswitchable Actuators

Merocyanine Spiropyran -

UV
VIS, Δ

Absorbance (ABS)

Off (spirogyran)  On (merocyanine)

Absorbance (ABS)

NM

400 450 500 550 600 650
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

Hydrophobic

Hydrated Polymer Chains

Loss of bound water

-> polymer collapse
Integrated Soft Gel Photovalves
Photo-actuator polymers as microvalves in microfluidic systems

Optimisation of valve dimensions

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

1.6 mm mask


Functional Organic Materials and Devices, Department of Chemical Engineering and Chemistry, and Institute for Complex Molecular Systems, Eindhoven University of Technology

INSIGHT Centre for Data Analytics, National Center of Sensor Research, Dublin City University, Dublin 9, Ireland
Flexible creation of µ-dimensioned features in flow channels using in-situ photo-polymerisation

Ntf2 pillars speed x3

DCA lines speed x4

With Dr Peer Fischer, Fraunhofer-Institut für Physikalische Messtechnik (IPM), Freiburg
Photocontrol of Assembly and Subsequent Switching of Surface Features

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

![Chemical structures of SPA and NIPAAm with crosslinker concentrations.]

High crosslink density

Low crosslink density

Light source

\( \lambda = 455 \text{ nm} \)

![3D images of surface topographies before and after light exposure.]

\[ \text{SPA, 1 mol\%} \]

\[ \text{NIPAAm, 91-92 mol\%} \]

\[ \text{acrylic acid, 5 mol\%} \]

\[ \text{MBIS, 1-2 mol\%} \]

\[ \text{Darocur 1173, 1 mol\%} \]

![Graphs showing surface height changes with light exposure.]

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Self-Maintenance: Immune Response
Activate the Channel Walls…
Switchable Binding and Release
ROMP Chemistry – thick SP polymer ‘brush’ films

Switchable Uptake and Release – ‘Post Column’ Detection

Co^{2+} + PAR → PAR-Co^{2+}

410 nm

510 nm
Self Aware Fluidics…
Chemotaxis – Autonomous Movement to a Plume Source with IL Droplets

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

Electronic structure calculations and physicochemical experiments quantify the competitive liquid ion association and probe stabilisation effects for nitrobenzospiropyran in phosphonium-based ionic liquids, D. Thompson et al., Physical Chemistry Chemical Physics, 2011, 13, 6156-6168.
Electrochemical Generation of Cl⁻ gradients on demand…
2D Rigid to 3D Flexible Microfluidics??
Background

Stereolithography

- Single photon absorption
- 2D patterns

Two-photon polymerisation

- Two photon absorption
- 3D structures
Background

http://www.nanoscribe.de/
The Exciting Potential of Stimuli-responsive Materials and Biomimetic Microfluidics
Larisa Florea¹, Vincenzo Curto², Alexander J. Thompson², Guang-Zhong Yang², and Dermot Diamond¹*
¹Insight Centre for Data Analytics, NCSR, Dublin City University
²The Hamlyn Centre for Robotic Surgery, Imperial College London, London, SW7 2AZ
Submitted to Euronanoforum, Riga, Latvia, June 2015

Creating 3D soft gel structures with a line resolution of ca. 200 nm
‘Daisy’ – Micro/Nano Scaled Porous Structure
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!

• Integrate flexible electronics, fluidics, photonics

Develop disruptive ‘revolutionary’ solutions
In parallel to ‘evolutionary’ improvements
Thanks to:

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nbmc, FlexTech, semi