Microfluidic Platforms with Bioinspired Functionalities: New Concepts for Future Devices

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INSIGHT Centre for Data Analytics, National Centre for Sensor Research, School of Chemical Sciences, Dublin City University

SelectBIO "Lab-on-a-Chip & Microfluidics Europe 2019 Congress"
de Doelen Conference Center,
Rotterdam, The Netherlands
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THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION
HORIZON 2020
HoliFAB

Jean Louis Viovy (Fluigent-Curie), Mark Bowkett (TE Laboratories), Laurent Malaquin (LAAS-CNRS)

The Insight Centre for Data Analytics

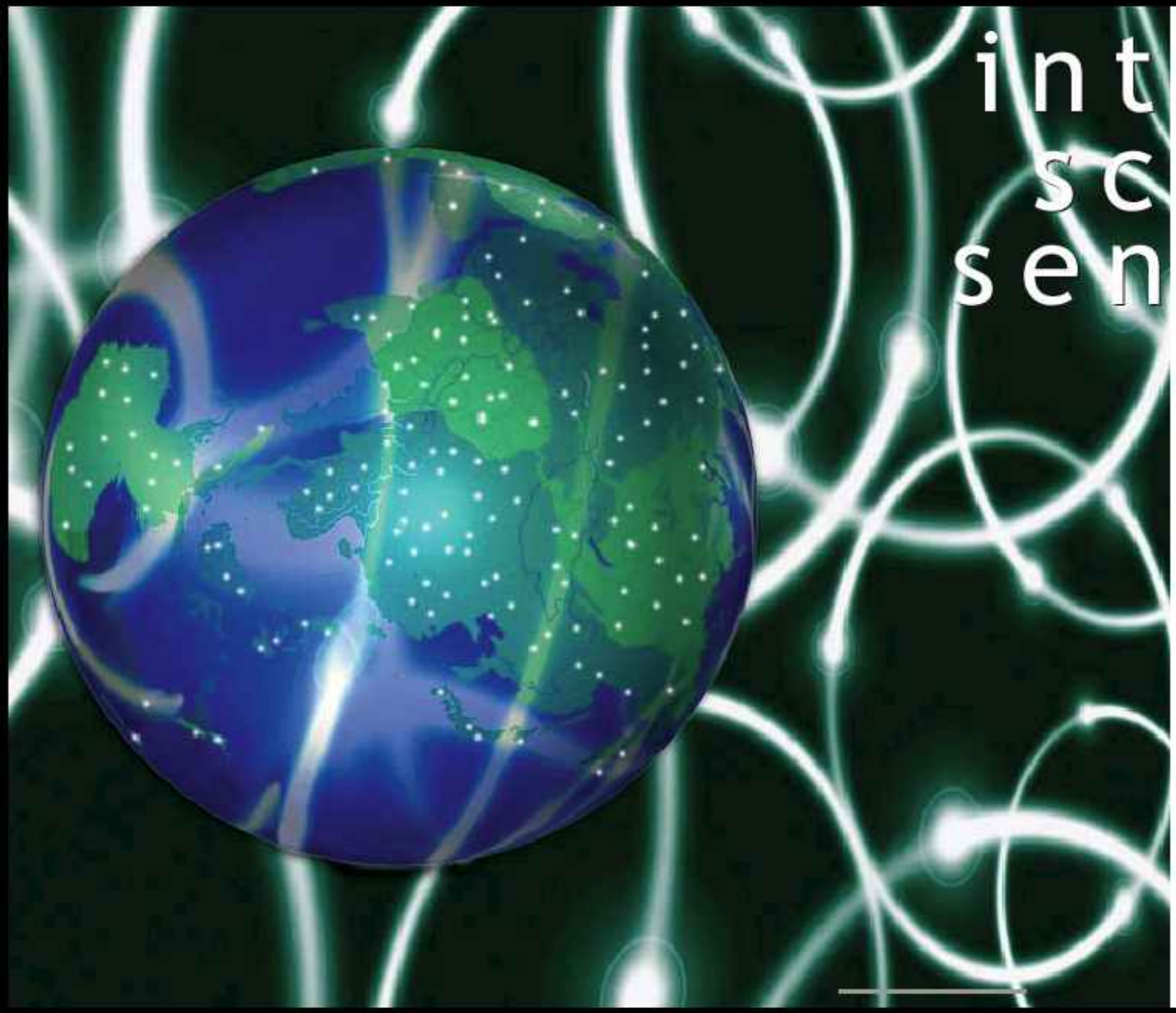
Insight is one of the biggest data analytics centres in Europe. It undertakes high-impact research, seeks to derive value from Big Data and provides innovative technology solutions for industry and society by enabling better decision-making.

With **€88 million (ca.50% Industry)** in funding, Insight has 400 researchers across areas such as connected health, decision analytics, social media analytics, smart cities and the semantic web.

http://www.sfi.ie/sfi-research-centres/insight/

2nd Phase funding approved (ca. €50 million SFI) commencing autumn 2019

Keynote Article: Anal. Chem., 76 (2004) 278A-286A



internet scale sensing

Dermot Diamond
Dublin City University
(Ireland)

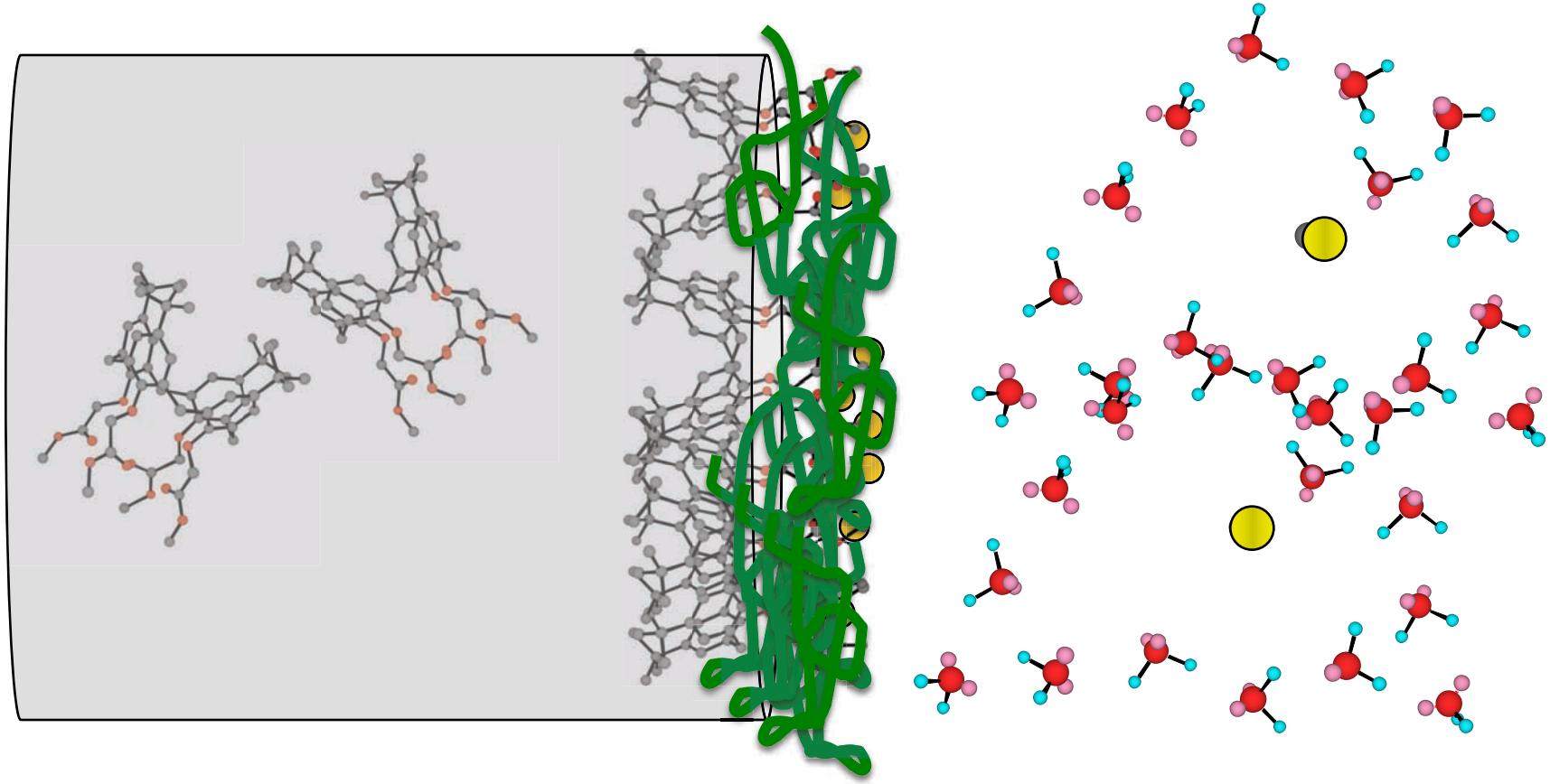
Incredible advances in digital communications and computer power have profoundly changed our lives. One chemist shares his vision of the role of analytical science in the next communications revolution.

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

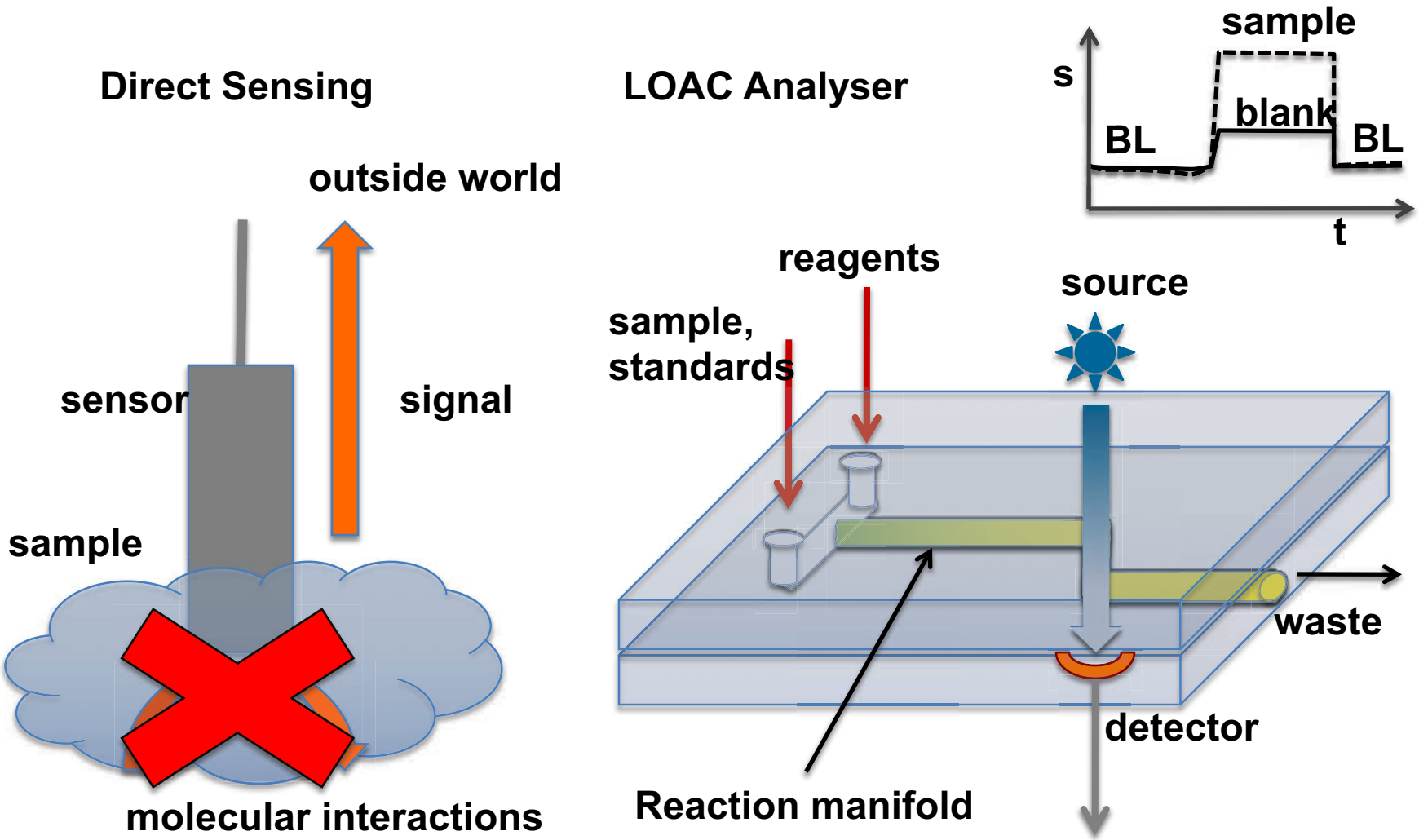
Ron Ambrosio & Alex Morrow, IBM TJ Watson

Control of membrane interfacial exchange & binding processes

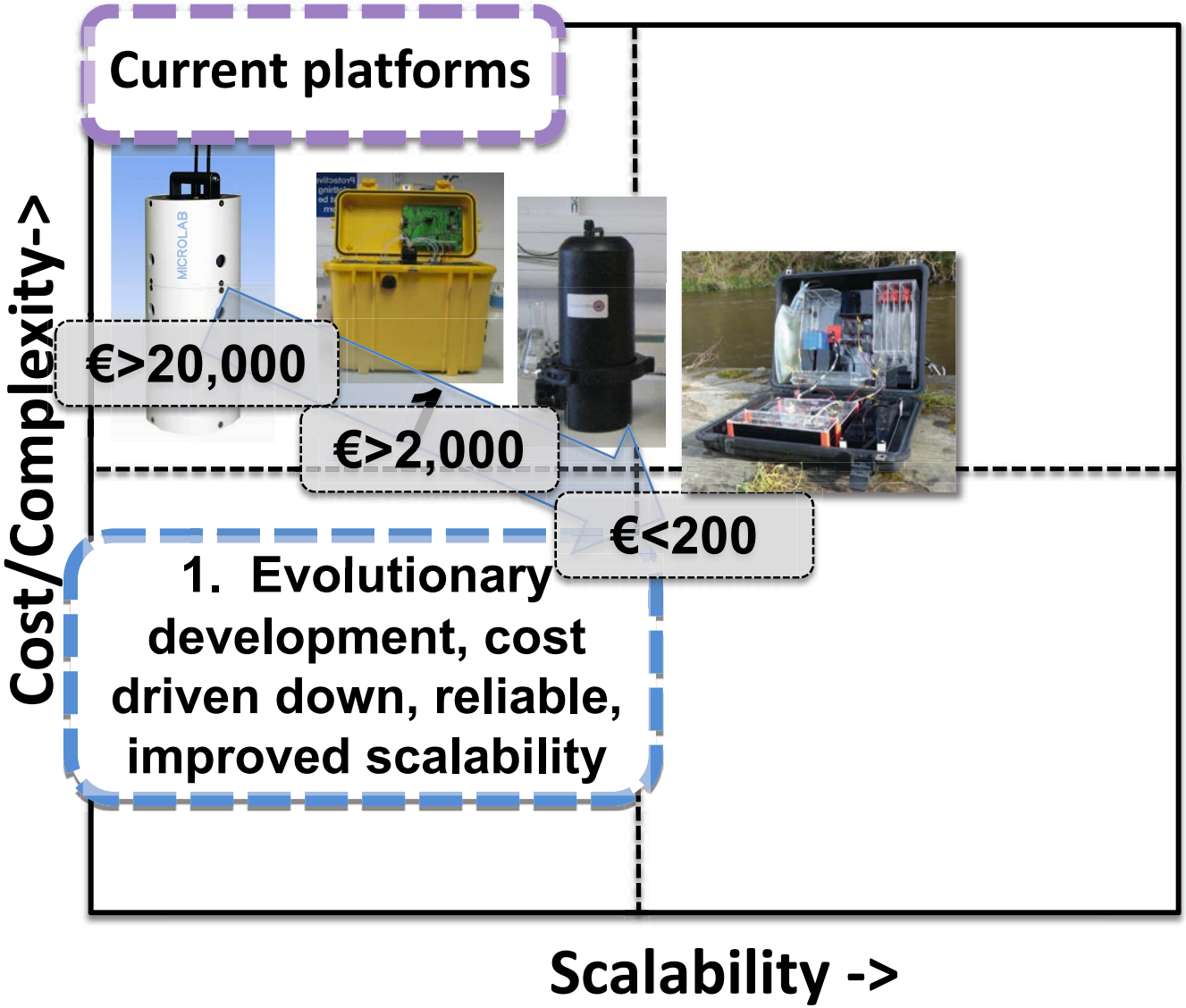


Remote, autonomous chemical sensing is a tricky business!

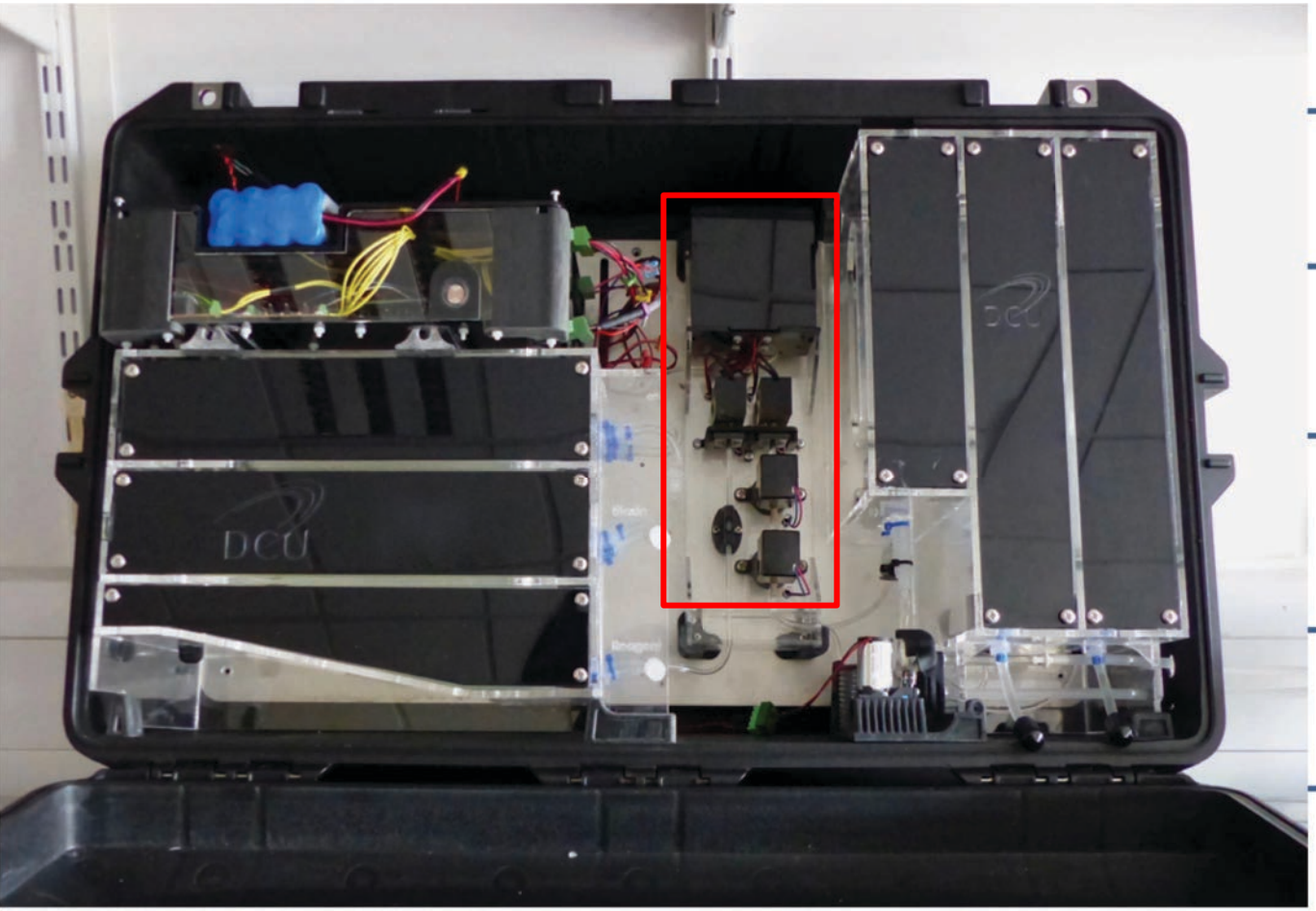
Direct Sensing vs. Reagent Based LOAC/ufluidics



Achieving Scale-up

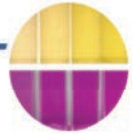


Current System – Autonomous Water Quality Monitoring




Rapid Prototyping


Microfluidics


Colorimetric Chemistries

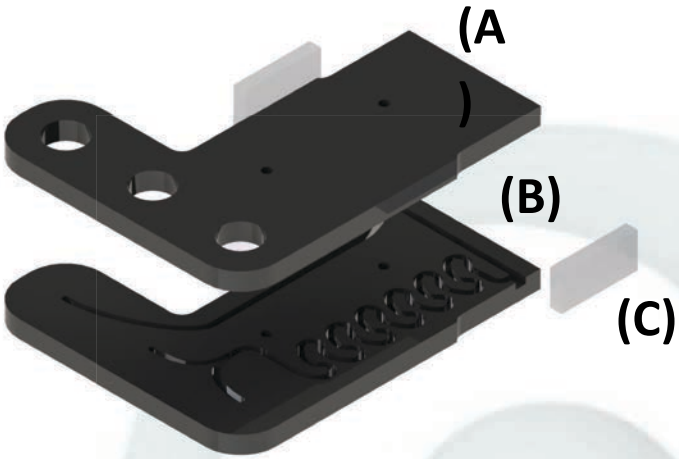

Optical Detection

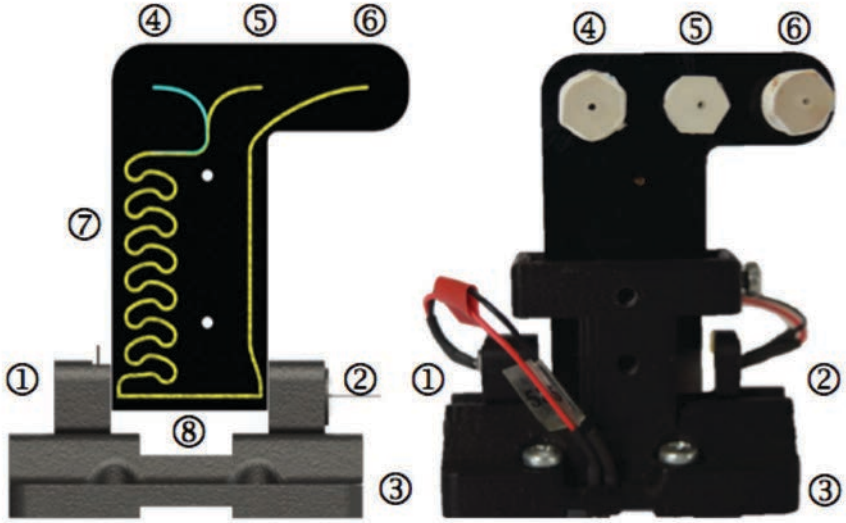

Electronics

Nutrient Platform: Microfluidics

Microfluidics

- 2 Layer PMMA Microfluidic Chip (A,B), Optical Windows (C)
- Manufactured using Precision Micro Milling
- Bonded using Heat and Pressure at transition temperatures
- Mixing Channels Induces chaotic advection
- 3D Printed Alignment Rail for Kinematic Stability

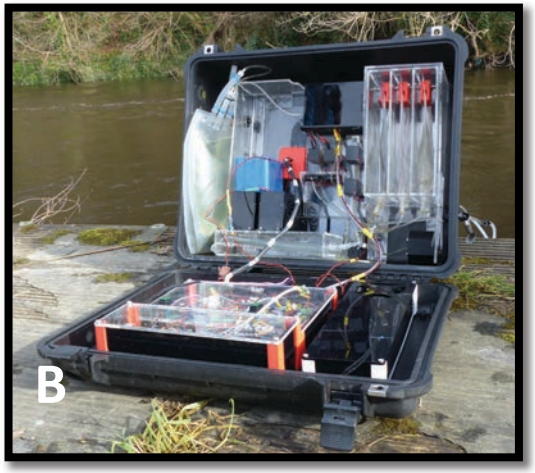




①. Photodiode
②. UV-LED
③. 3D Printed Mount and Rail
④. Sample Inlet
⑤. Reagent Inlet
⑥. Outlet
⑦. Serpentine Mixing Channel
⑧. Optical Detection Channel

River Liffey Deployment, Palmerstown, Dublin

- Sensor deployed on the River Liffey for 28 days (21/02/2018 – 19/03/2018)
- Measurements of Phosphate (PO_4^{3-}) detected every 3 hours
- Environmental Temperature, Rainfall and Water level recorded



Beast from the East: Status Red snow alert in place until Friday

Varadkar says people 'should not venture out of doors' while the red level warning is in place

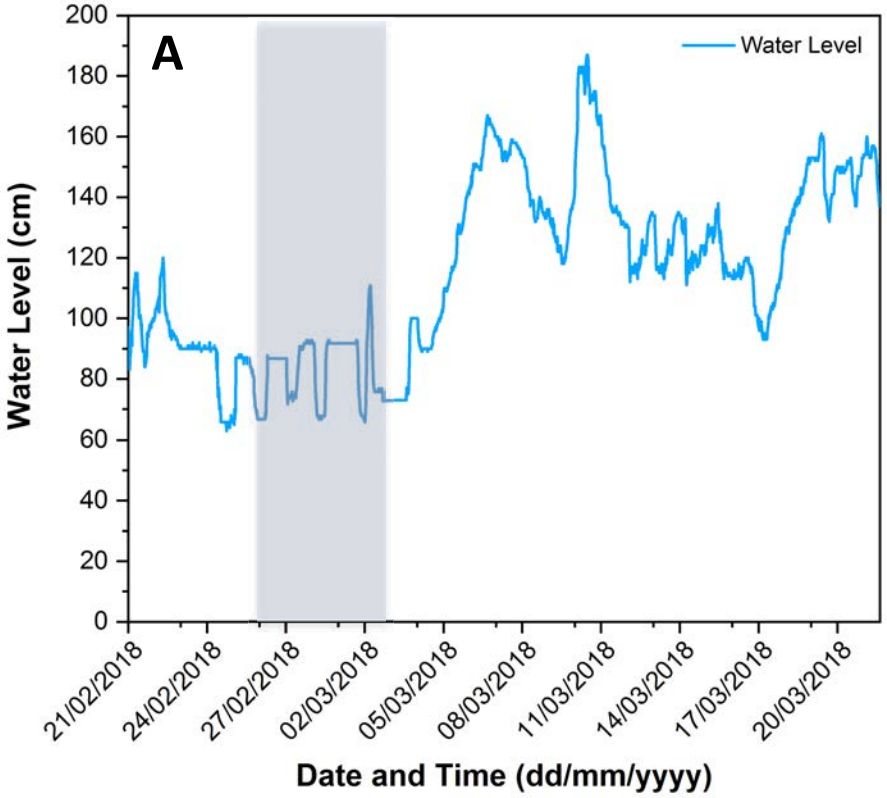
Wed, Feb 28, 2018, 06:29 | Updated: Wed, Feb 28, 2018, 21:05

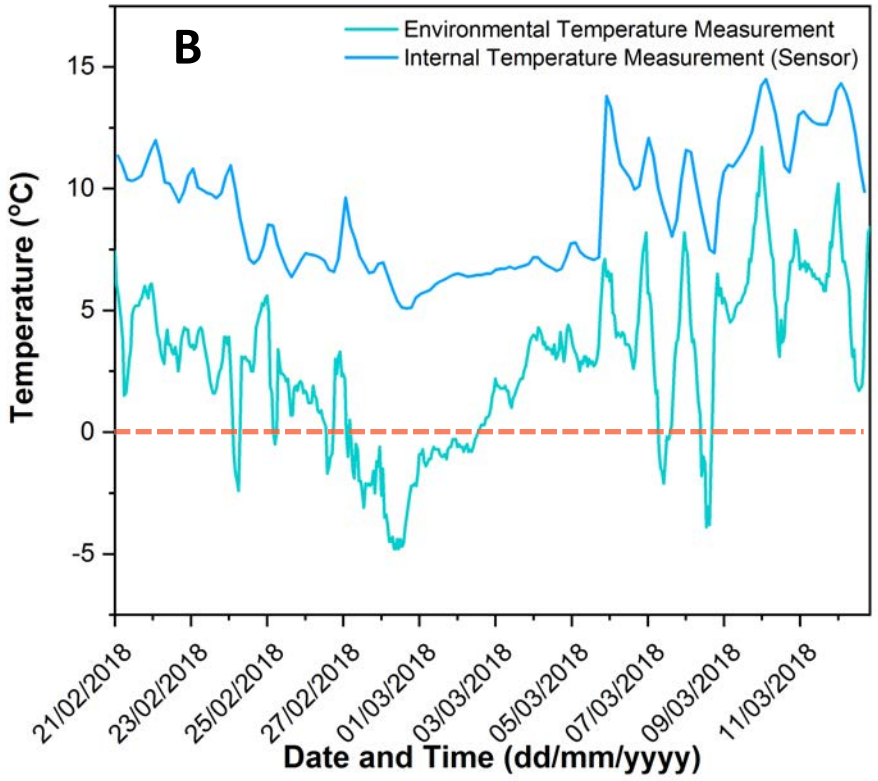
D

A. Deployment Location
B. Sensor Deployed
C. Sensor Deployed by depth gauge
D. Temperatures reach -4.5°C

https://www.irishtimes.com/news/environment/beast-from-the-east-status-red-snow-alert-in-place-until-friday-1.3408511

River Liffey Deployment, Palmerstown, Dublin

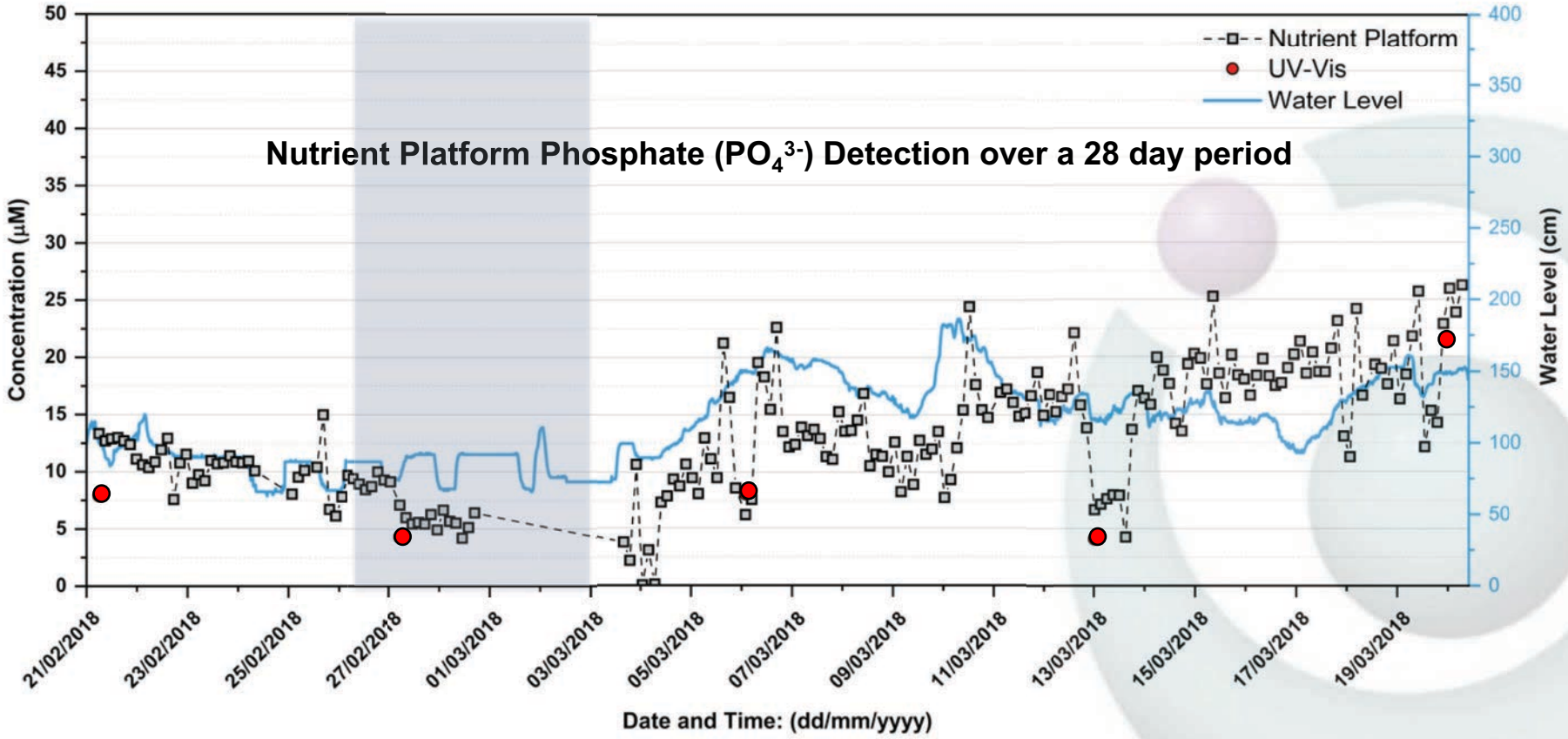




A. Water levels controlled by Leixlip Dam. Increasing water levels from the 5th Mar due to snow melt.

B. External vs Internal Temperature
External lows of -4.5°C.
Internal lows of 5°C.

River Liffey Deployment, Palmerstown, Dublin



636 measurements over 28 days recorded

From Multi-Part to Single Part Fluidic Chips

7 Parts : 3 days
~€50/chip

3 Parts : 1 day

1 Part : 1 hour
~€1/chip

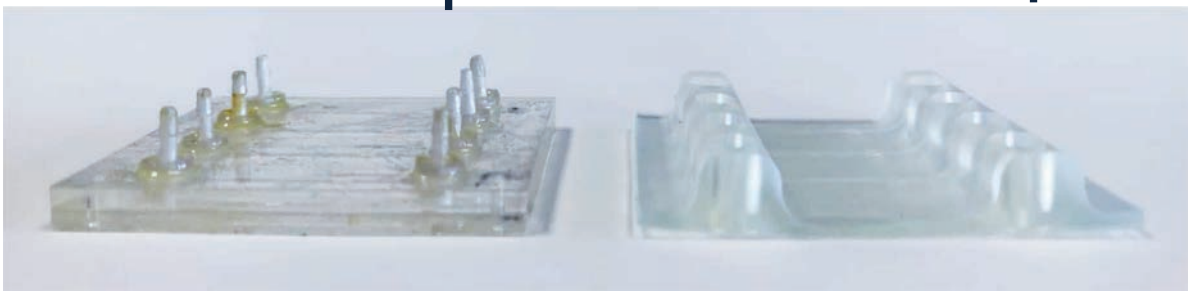
With Laurent Malaquin (LAAS-CNRS)

Impact of 3d Printing

Minimum thickness

- Assembled chip 4.25 mm
- 3D Printed Chip 1.58 mm

Assembled Chip **Printed Chip**



Advantages:

- No Assembly
- No Bonding necessary
- Integrated barbs (1/16”)
- Chip thickness reduced by 63%
- Automated manufacturing

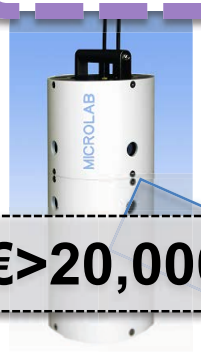
Rendered Chip

Printed Chip

See Poster – McCaul et al. “3D Printed Chips for Environmental Applications

Achieving Scale-up

Current platforms



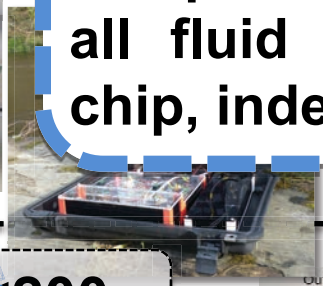
€>20,000

€>2,000

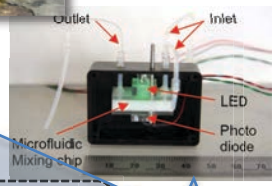
1

1. Evolutionary development, cost driven down, reliable, improved scalability

2. Revolutionary breakthroughs in materials science; hidden complexity, biomimetic platforms, all fluid handling integrated on chip, indefinitely self-sustaining



€<200



2

€<20

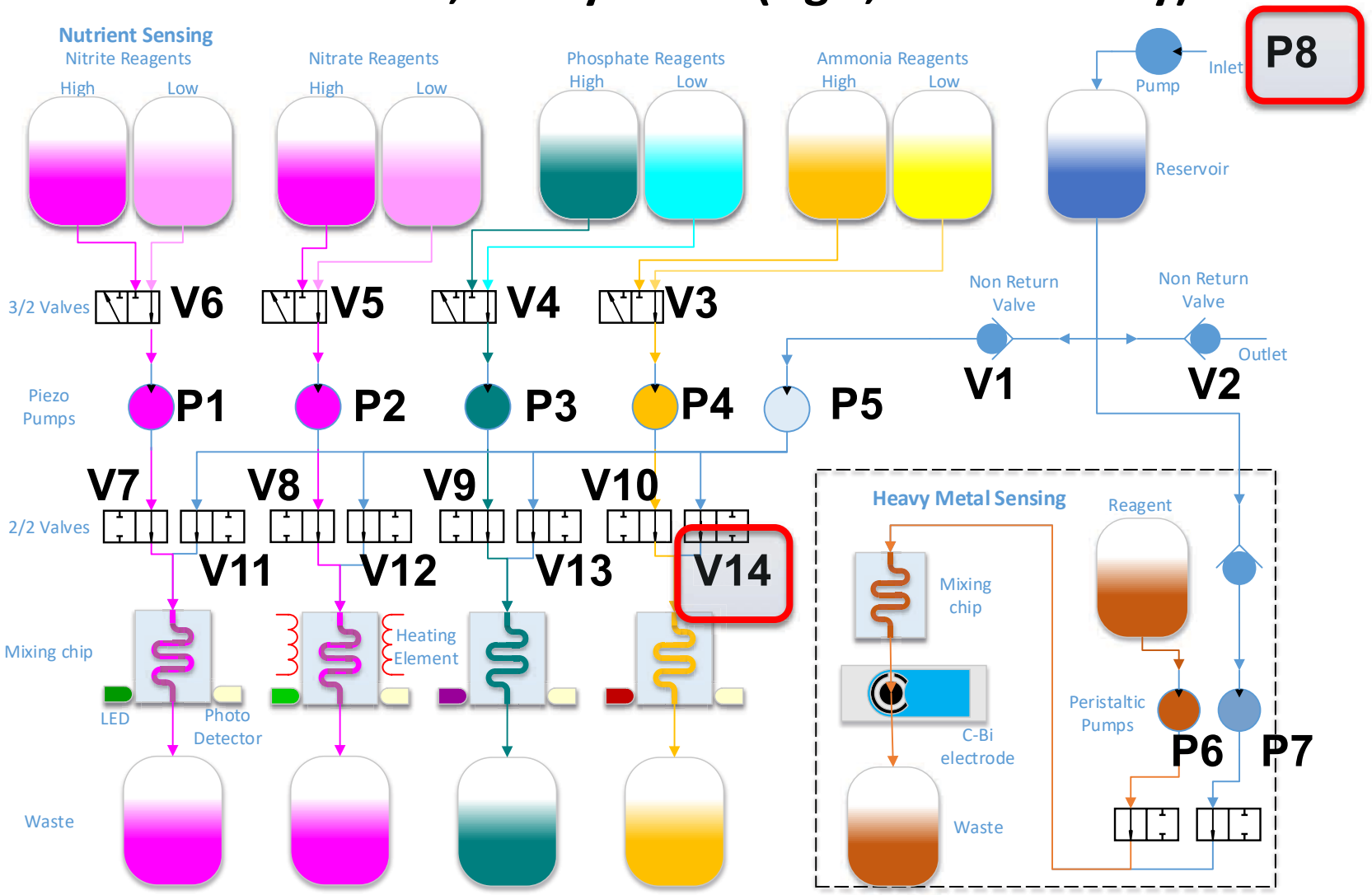
€<2

Massively scaled deployments of the future?

Cost/Complexity->

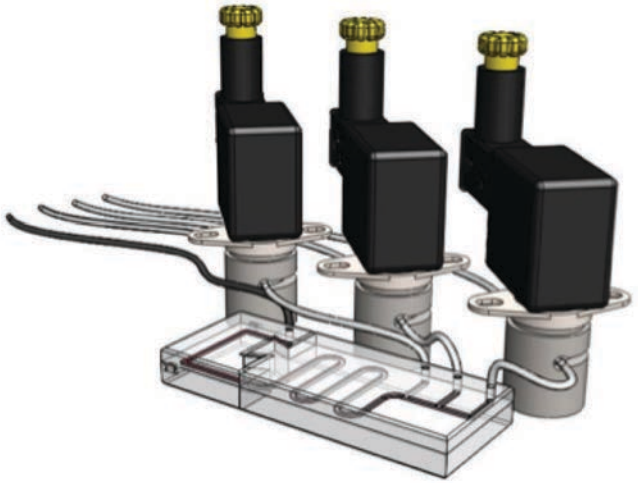
Scalability ->

Fluidic Schematic: Multi-Analyte - Nitrite, nitrate, phosphate, ammonia, heavy metal (Hg^{2+}, voltammetry)



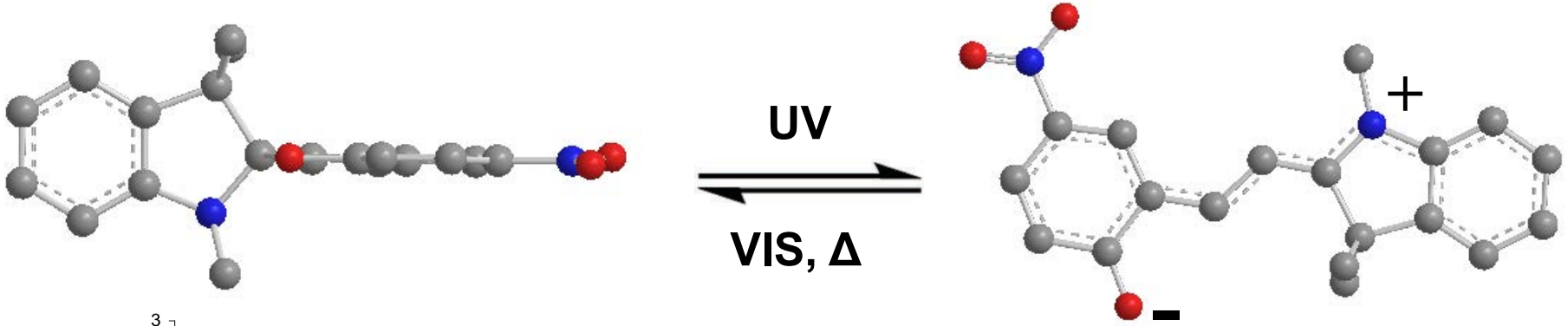
How to advance fluid handling in LOC platforms: re-invent valves (and pumps)!

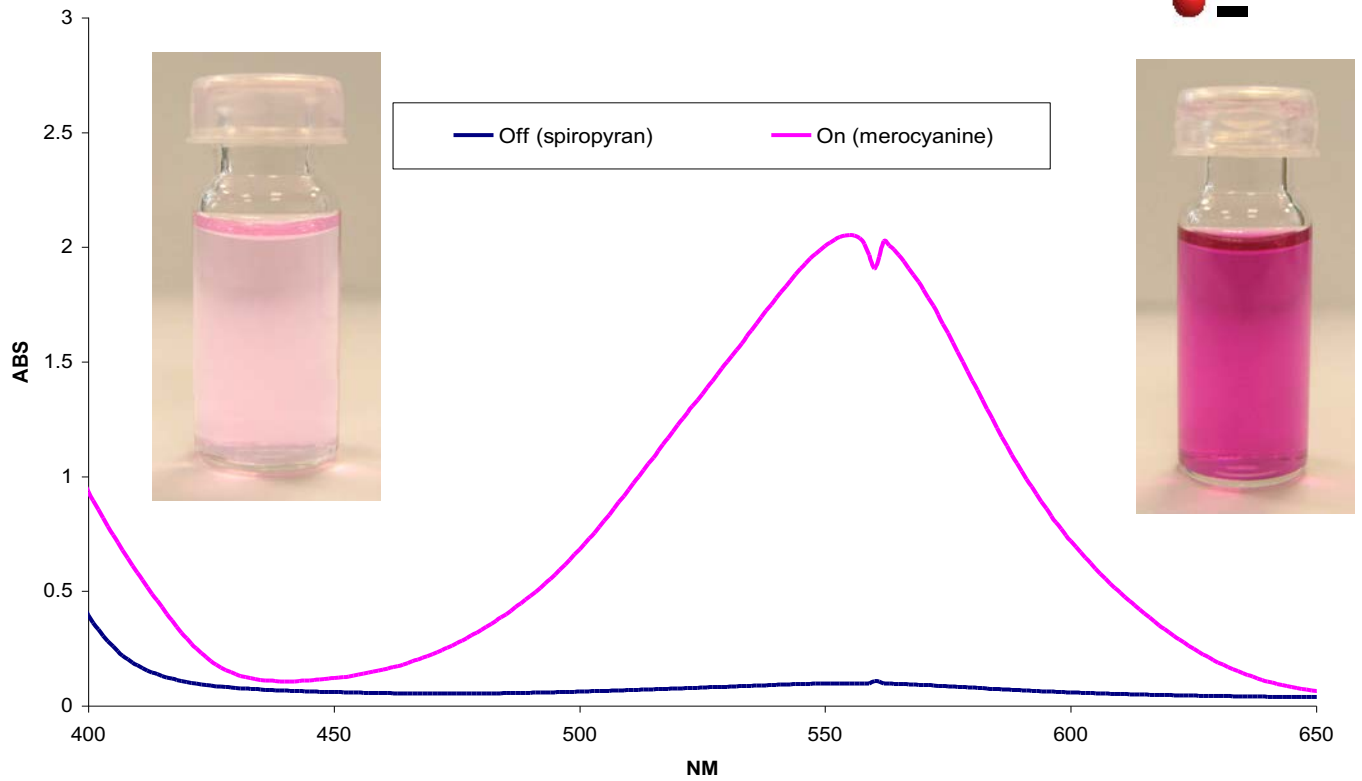
- **Conventional valves cannot be easily scaled down - Located off chip: fluidic interconnects required**
  - Complex fabrication
  - Increased dead volume
  - Mixing effects
- **Based on solenoid action**
  - Large power demand
  - Expensive



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

Photoswitchable Soft Actuators

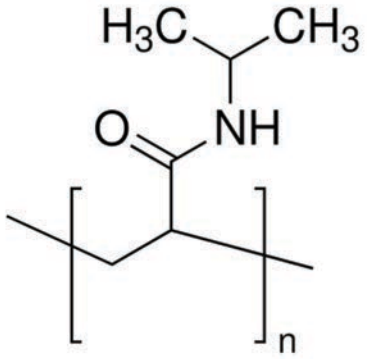




Poly(*N*-isopropylacrylamide)

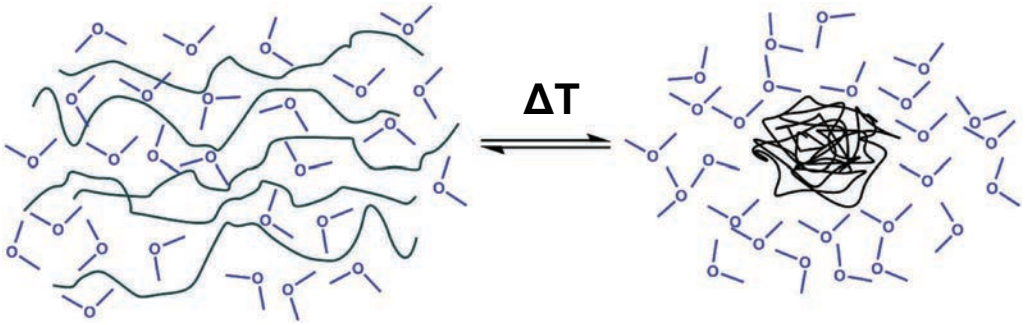
- pNIPAAM exhibits inverse solubility upon heating
- This is referred to as the LCST (Lower Critical Solution Temperature)
- Typically this temperature lies between 30-35^{o}C, but the exact temperature is a function of the (macro)molecular microstructure
- Upon reaching the LCST the polymer undergoes a dramatic volume change, as the hydrated polymer chains collapse to a globular structure, expelling the bound water in the process

pNIPAAM



Hydrophilic

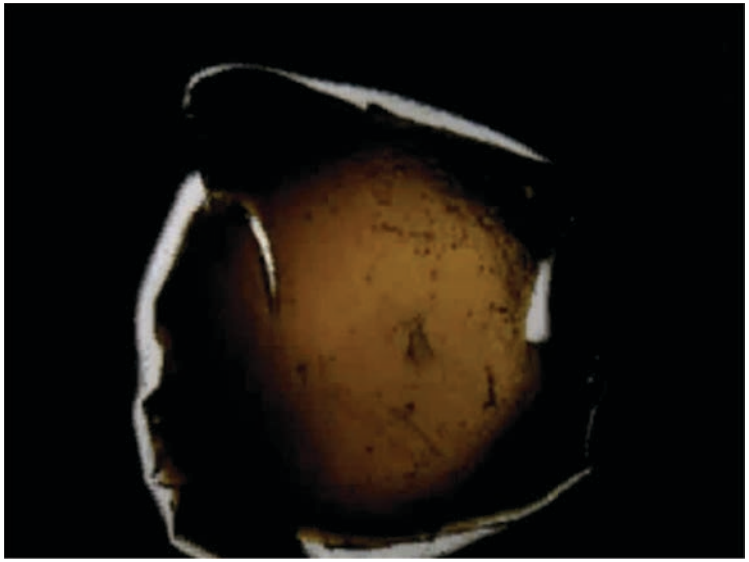
Hydrophobic

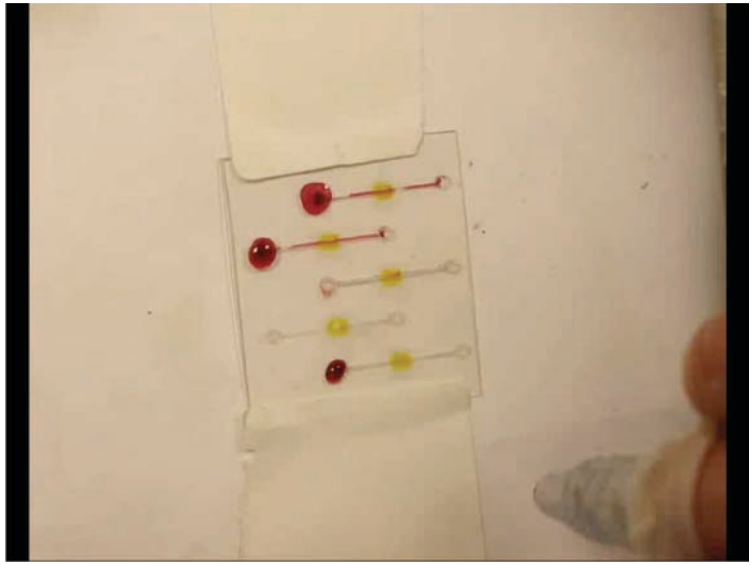


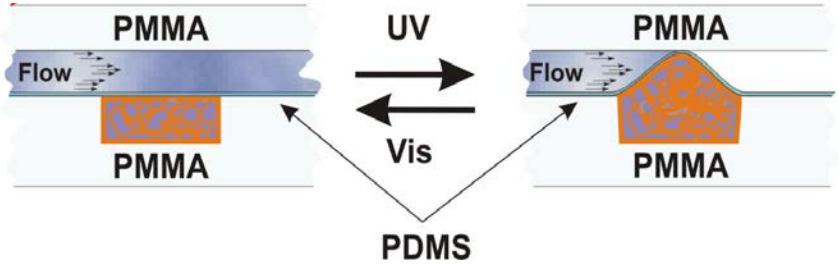
Hydrated Polymer Chains

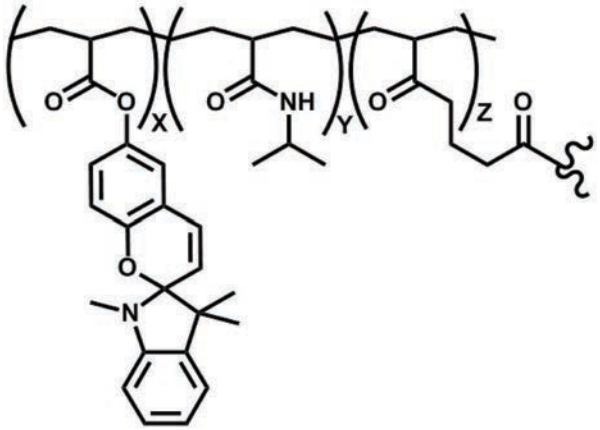
Loss of bound water -> polymer collapse

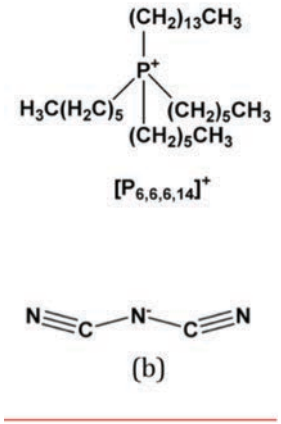
Photo-actuator polymers as microvalves in microfluidic systems











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.

Experimental set up for PID Control

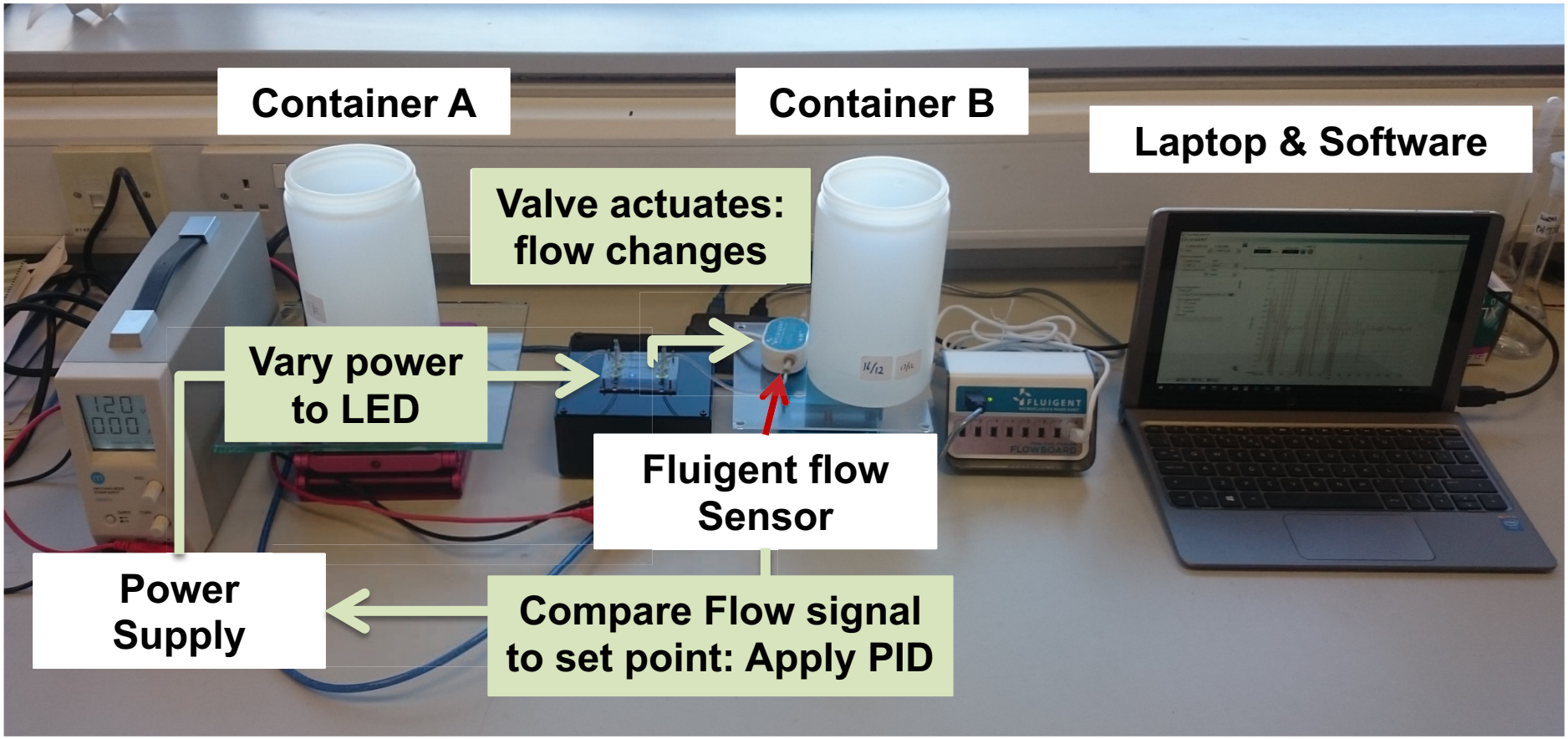
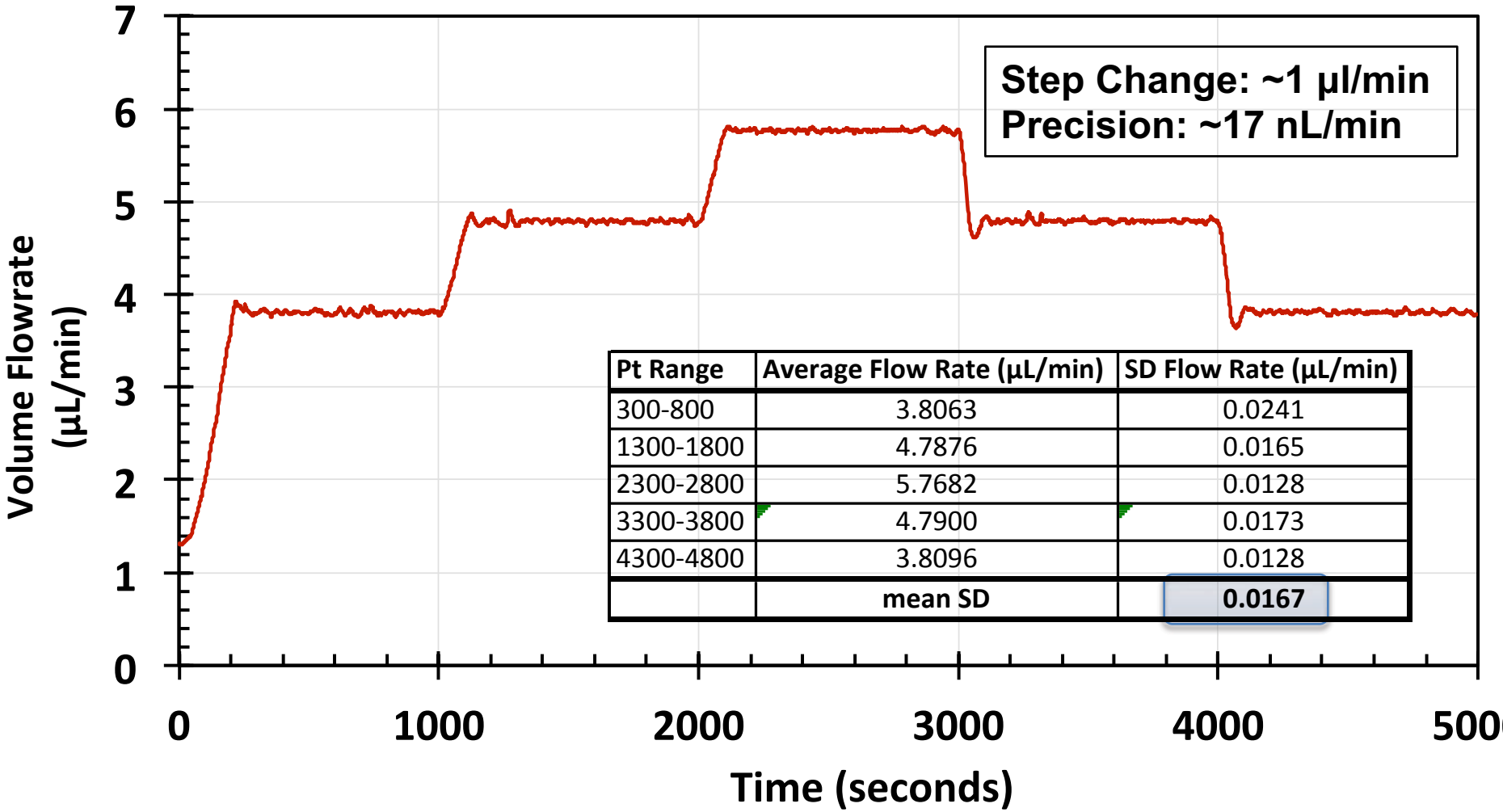


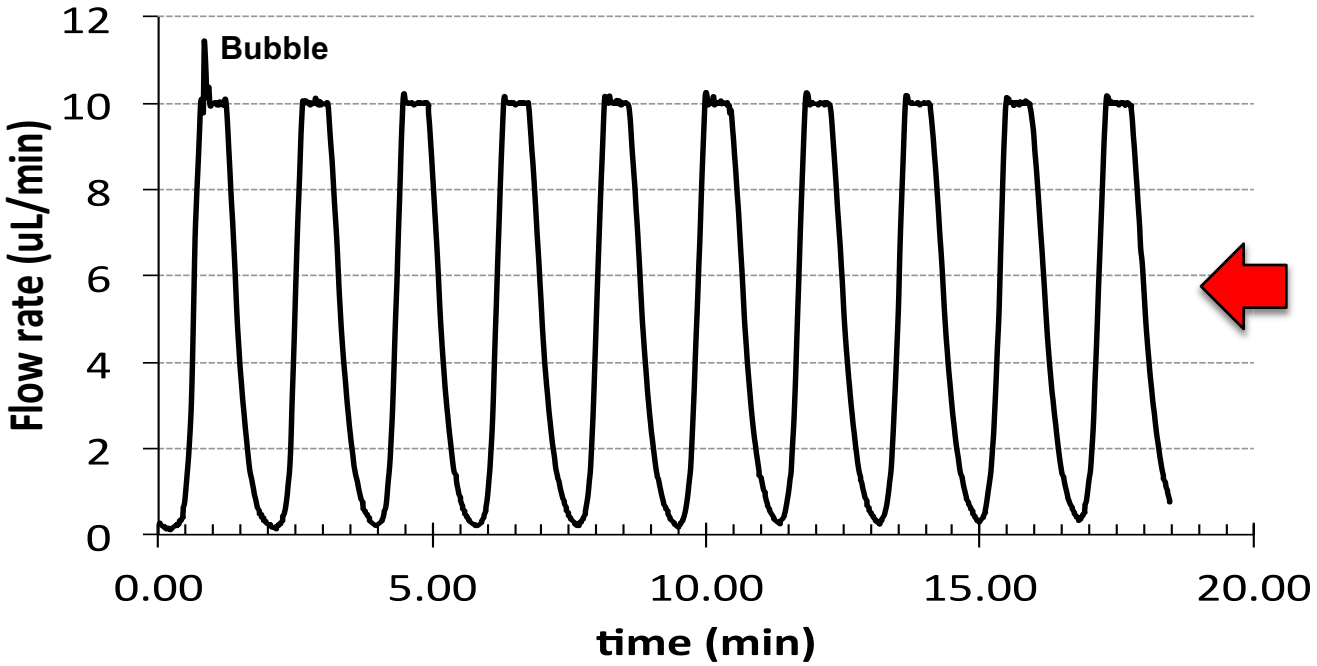
Photo-Controlled Flow Rate



Pt Range	Average Flow Rate (µL/min)	SD Flow Rate (µL/min)
300-800	3.8063	0.0241
1300-1800	4.7876	0.0165
2300-2800	5.7682	0.0128
3300-3800	4.7900	0.0173
4300-4800	3.8096	0.0128
	mean SD	**0.0167**

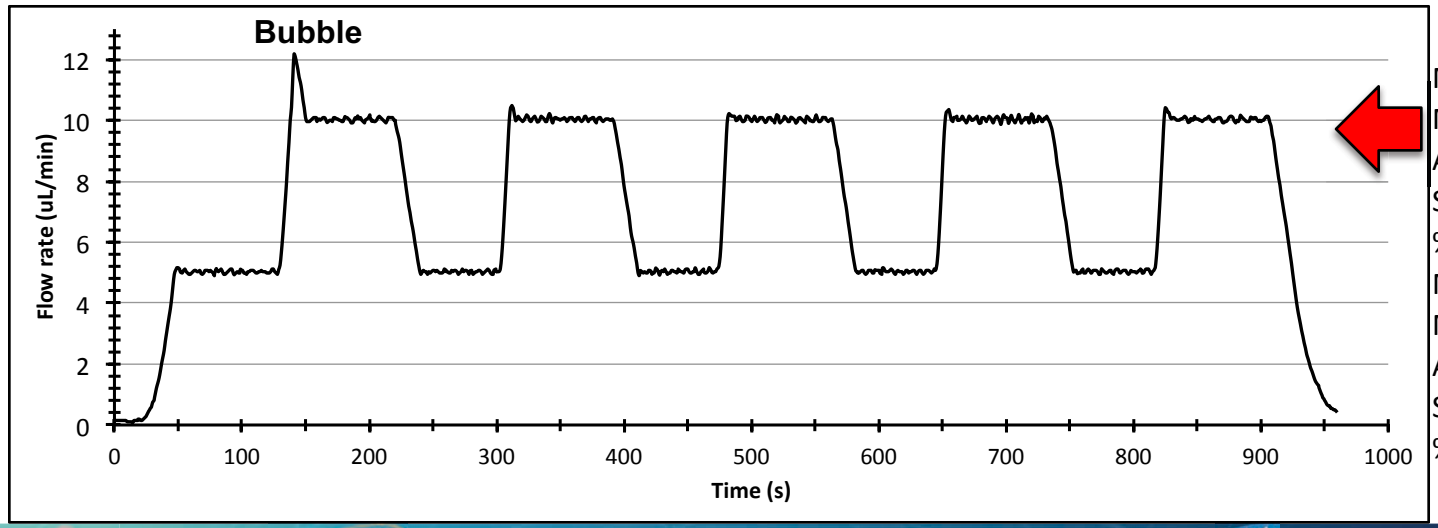
C. Delaney, P. McCluskey, S. Coleman, J. Whyte, N. Kent, D. Diamond, Precision control of flow rate in microfluidic channels using photoresponsive soft polymer actuators, LAB ON A CHIP. 17 (2017) 2013–2021. doi:10.1039/c7lc00368d.

Some figures of merit



Switching 0.0-10.0 µL/min
n= 15 points sampled behind the initial small overshoot

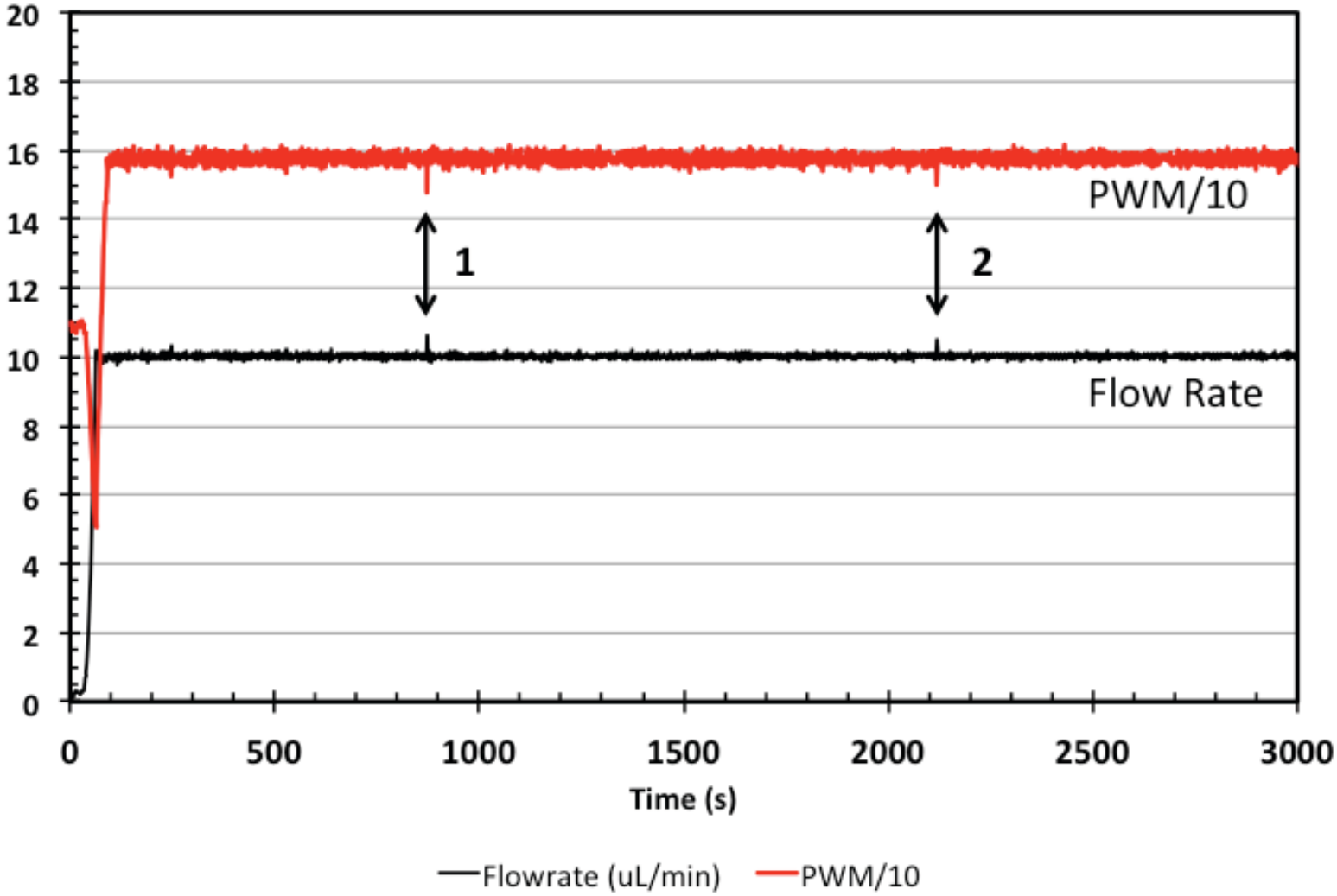
Averages (n=10)	
mean	10.0028
Mean SD	0.0323
Error Mean	0.0028
%RSD	0.3235
%RE mean	0.0279



Switching 5.0-10.0 µL/min
n= 30 points sampled

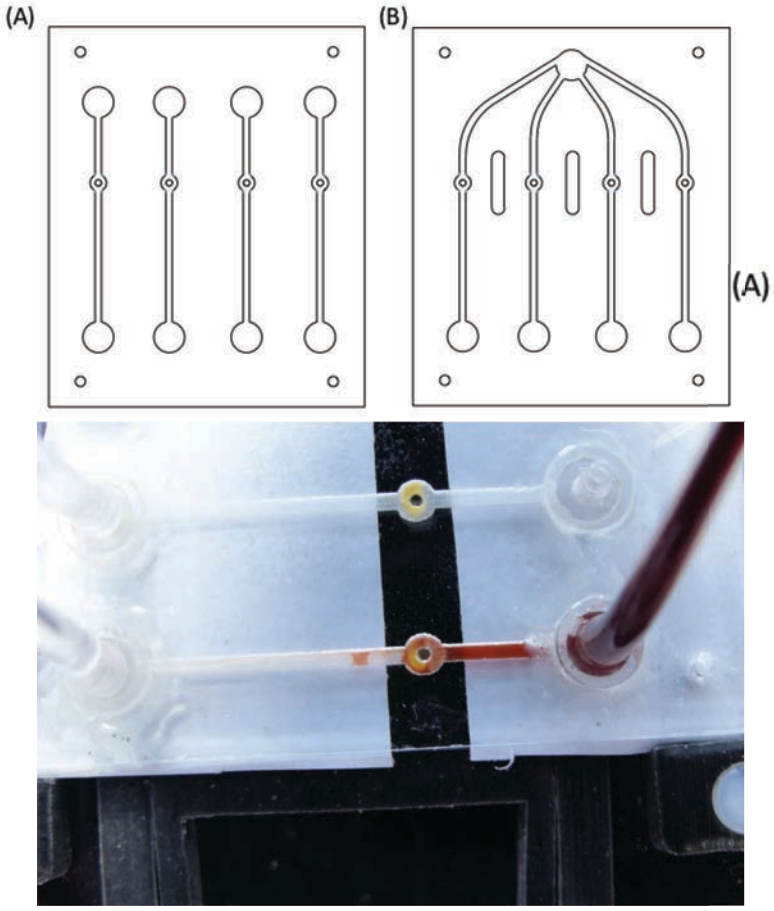
Mean %RE (5=true)	0.780
Mean %RE (5.039=true)	0.098
Average of mean	5.039
SD Mean	0.006
%RSD	0.120
Mean %RE (10=true)	0.372
Mean %RE (10.037=true)	0.102
Average of mean	10.037
SD Mean	0.012
%RSD	0.124

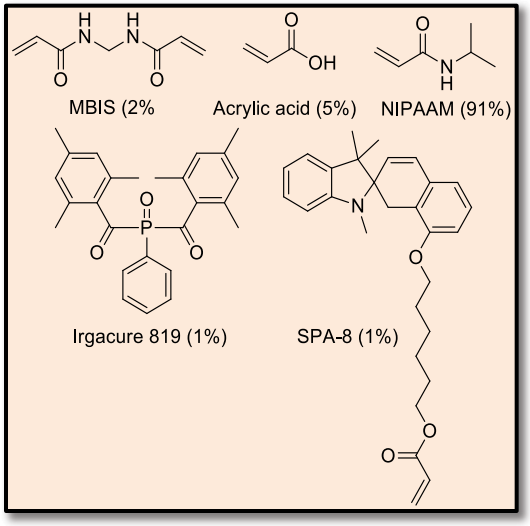
Power Supply to LED



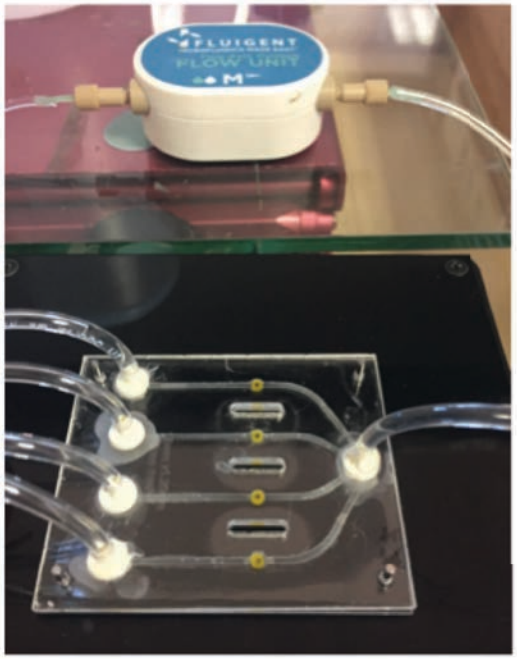
Over a period of 50 min constant maintenance of 10 µL/min flow rate there is no discernable change in LED power ➔ diagnostic information

Multiplexing: Valve Arrays

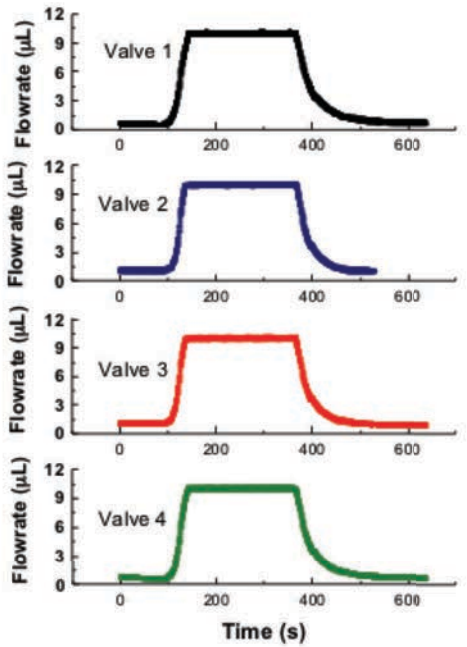




(A)



(B)



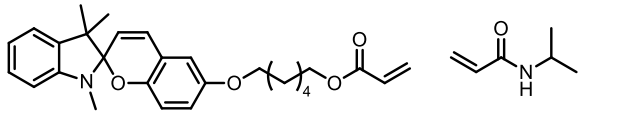
Photocontrol of Assembly and Subsequent Switching of Surface Features

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

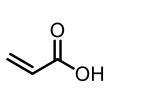
Jelle E. Stumpel,[†] Bartosz Ziółkowski,[‡] Larisa Florea,[‡] Dermot Diamond,[‡] Dirk J. Broer,*[,†,§] and Albertus P. H. J. Schenning*[,†,§]



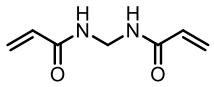
SPA, 1 mol%

NIPAAM, 91-92 mol%

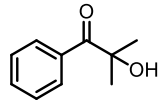
a)



acrylic acid, 5 mol%

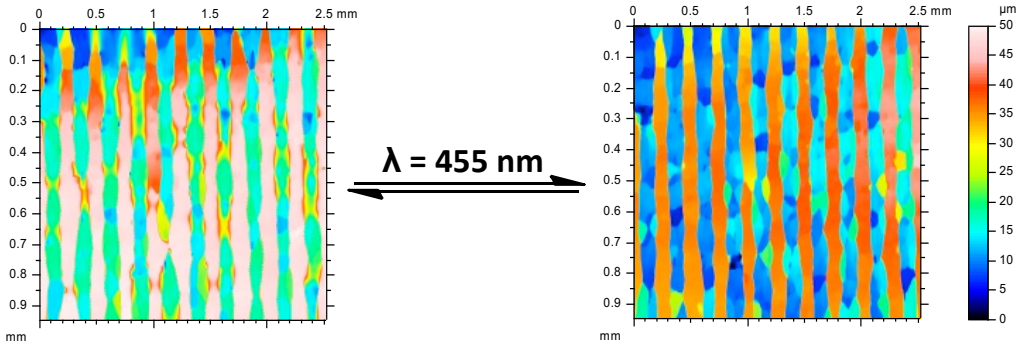


MBIS, 1-2 mol%

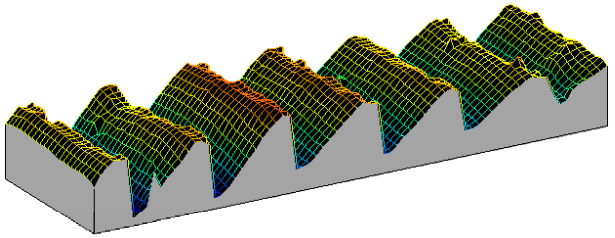


Darocur 1173, 1 mol%

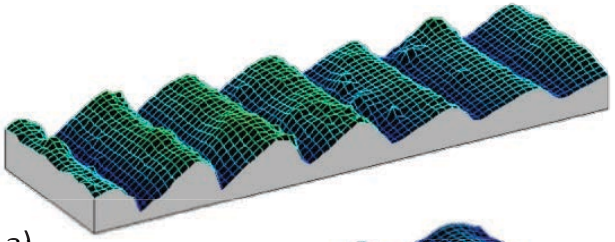
b)



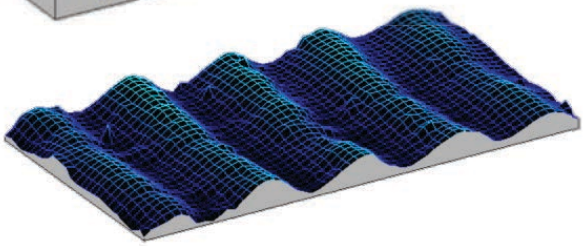
a)



b)

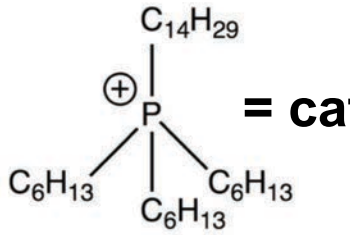


a)

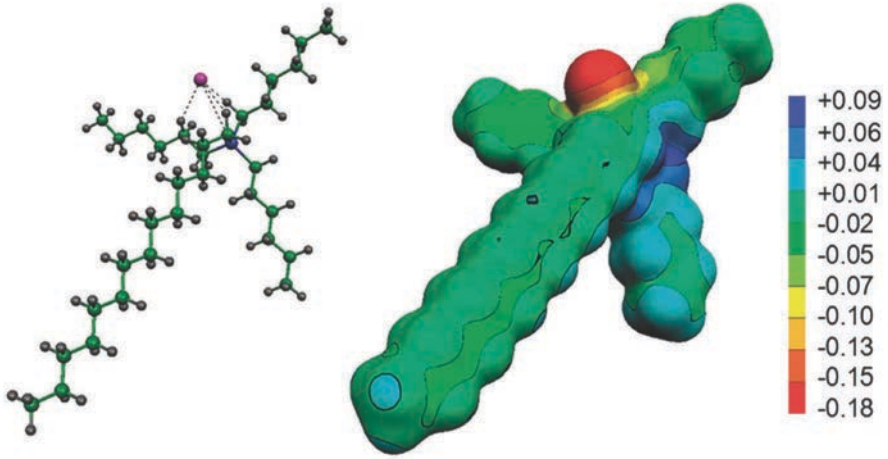


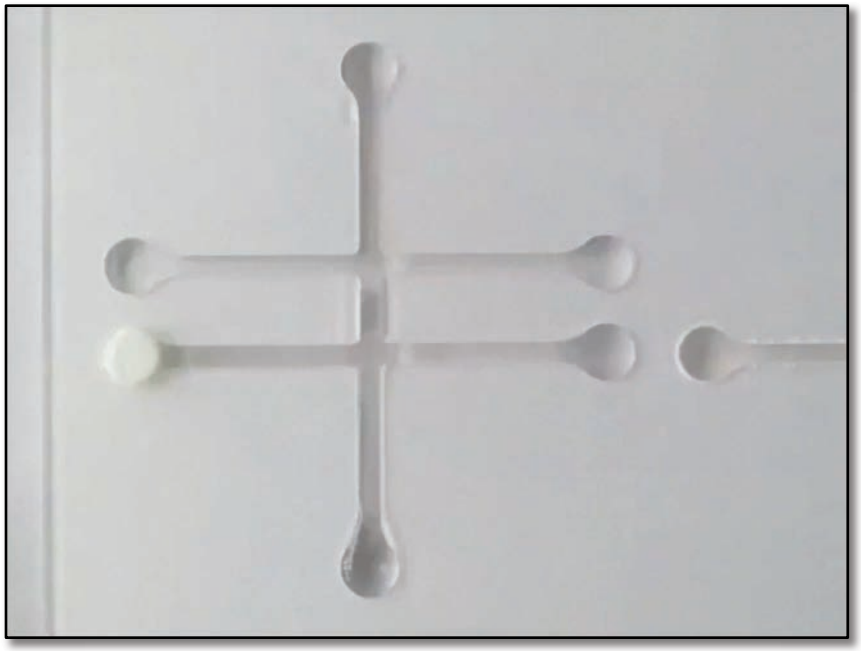
b)

Chemotactic IL Droplets



= cationic surfactant



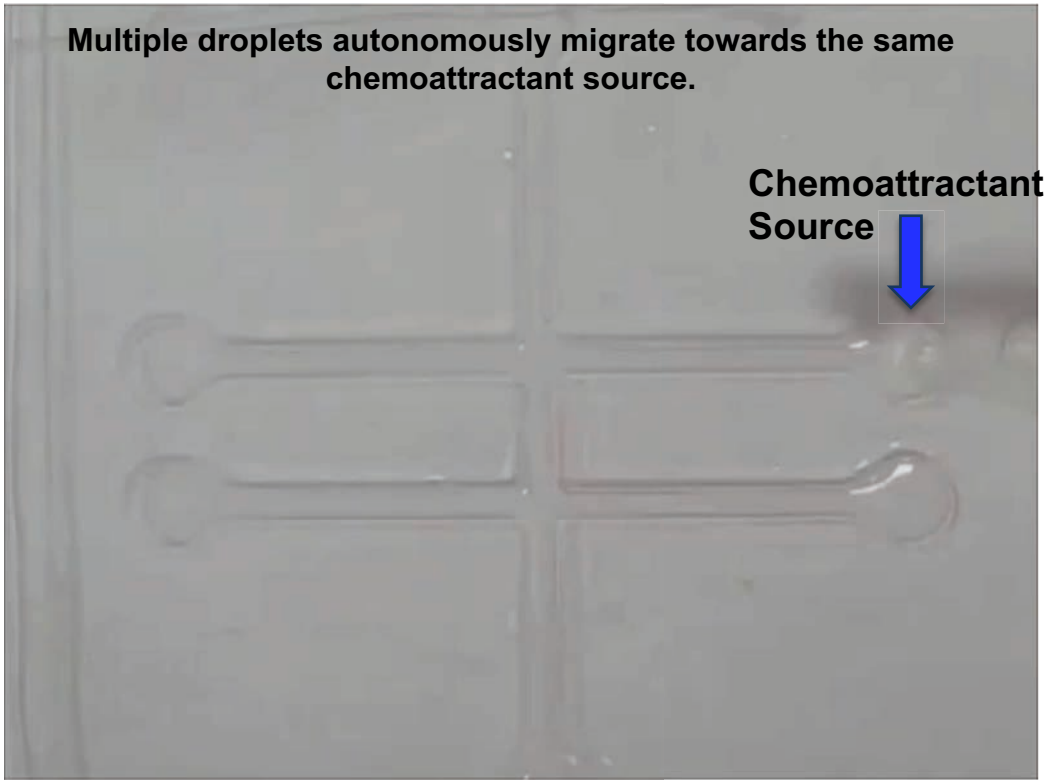


Trihexyl(tetradecyl)phosphonium chloride ($[P_{6,6,6,14}][Cl]$) droplets with a small amount of 1-(methylamino)anthraquinone red dye for visualization. The droplets spontaneously follow the gradient of the Cl^- ion which is created using a polyacrylamide gel pad soaked in 10^{-2} M HCl; A small amount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

From 2D to 3D Movement

2D Movement



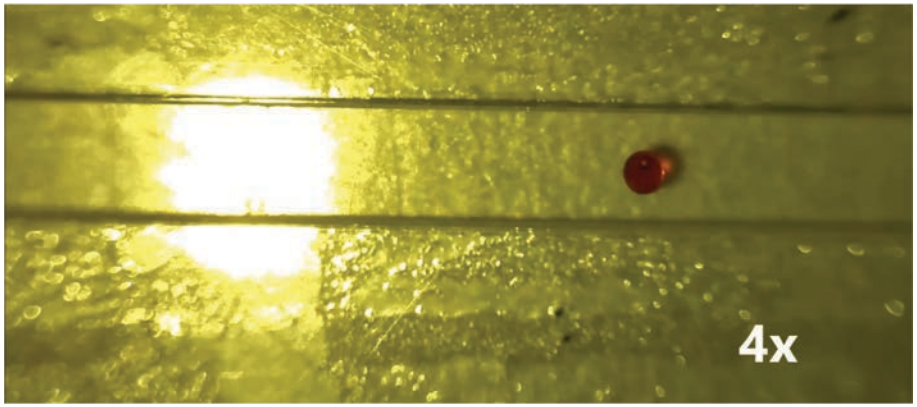
L. Florea et al. Chem. Comm. 51 (2015) 2342.

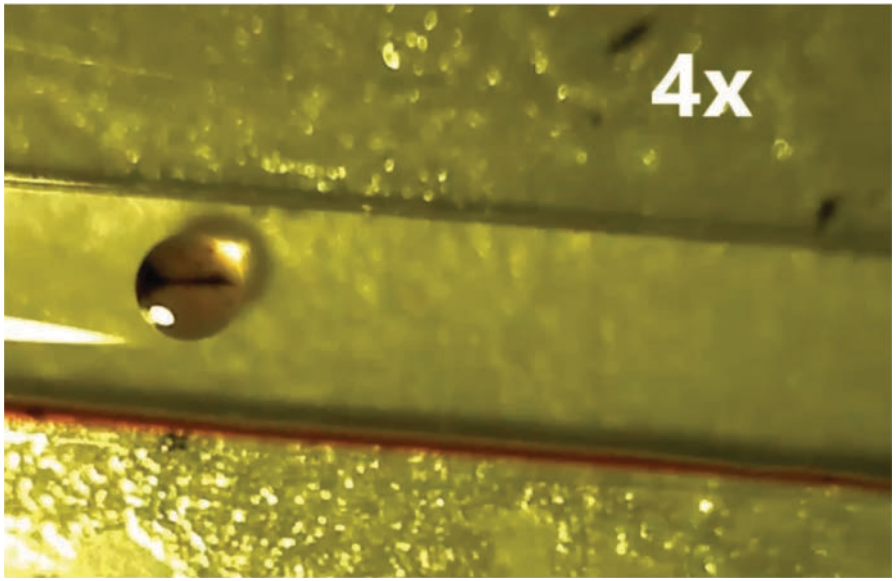
L. Florea et al. Sens. Actuators B 239 (2017) 1069.

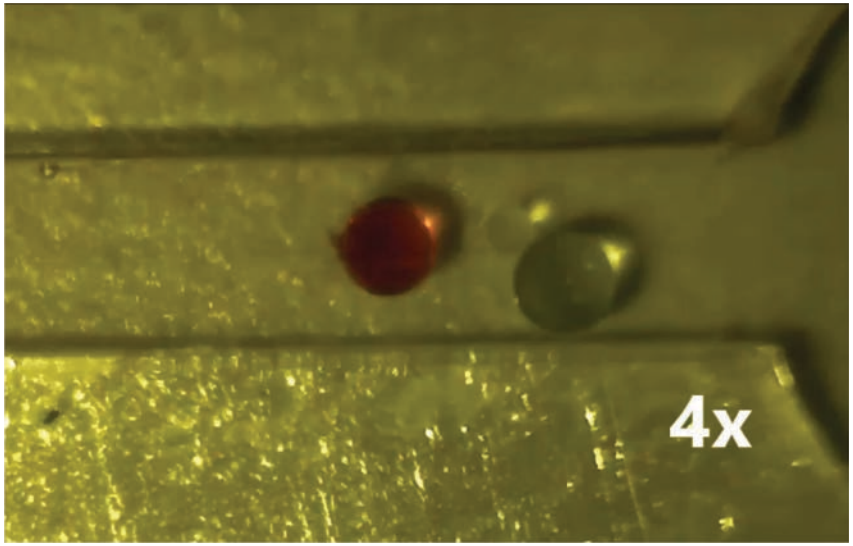
3D Movement

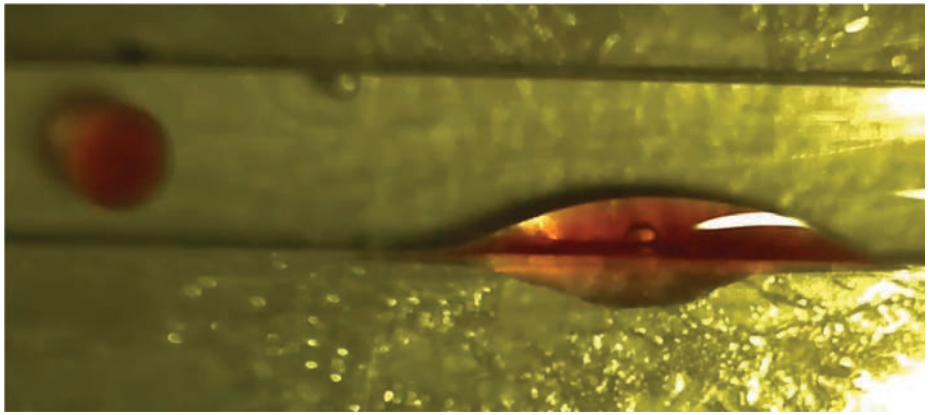
With David Officer, Adv Mater. 2018
doi: 10.1002/adma.201801821

Fun with Droplets and Dynamic Electro-Ionic Gradients



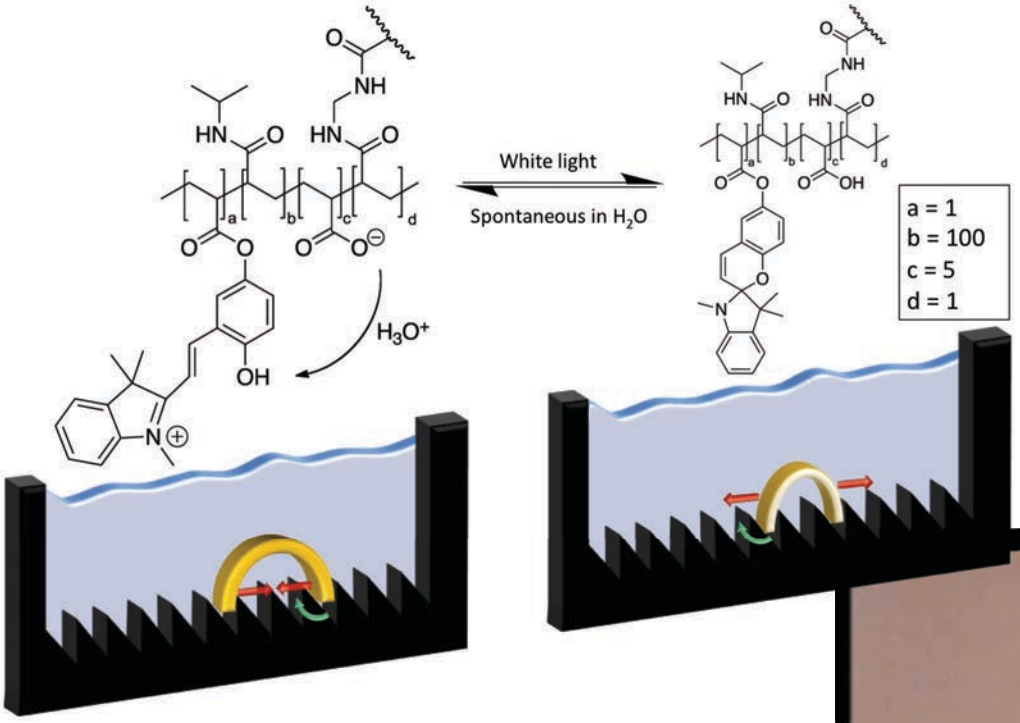




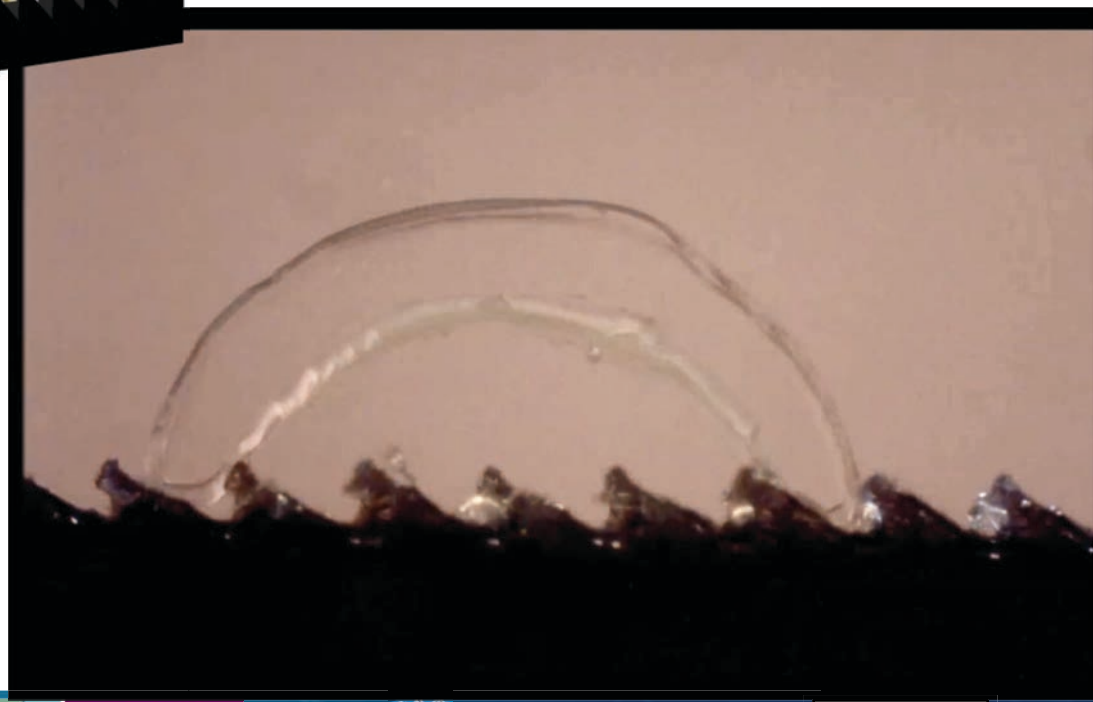


Joan Cabot, Brett Paull (UTAS), Larisa Florea

Photo-Responsive Soft Hydrogels



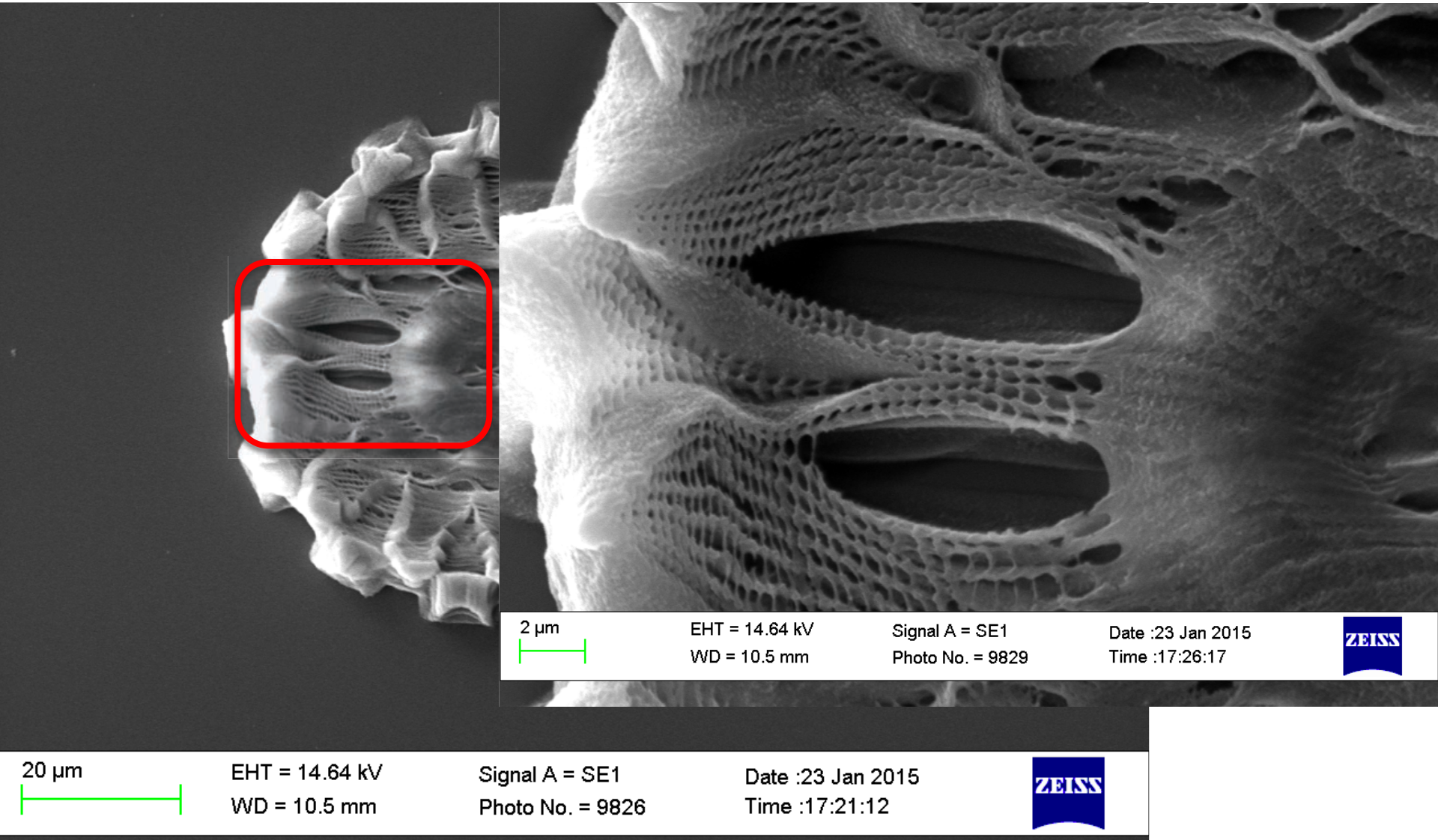
‘Walking towards the light’



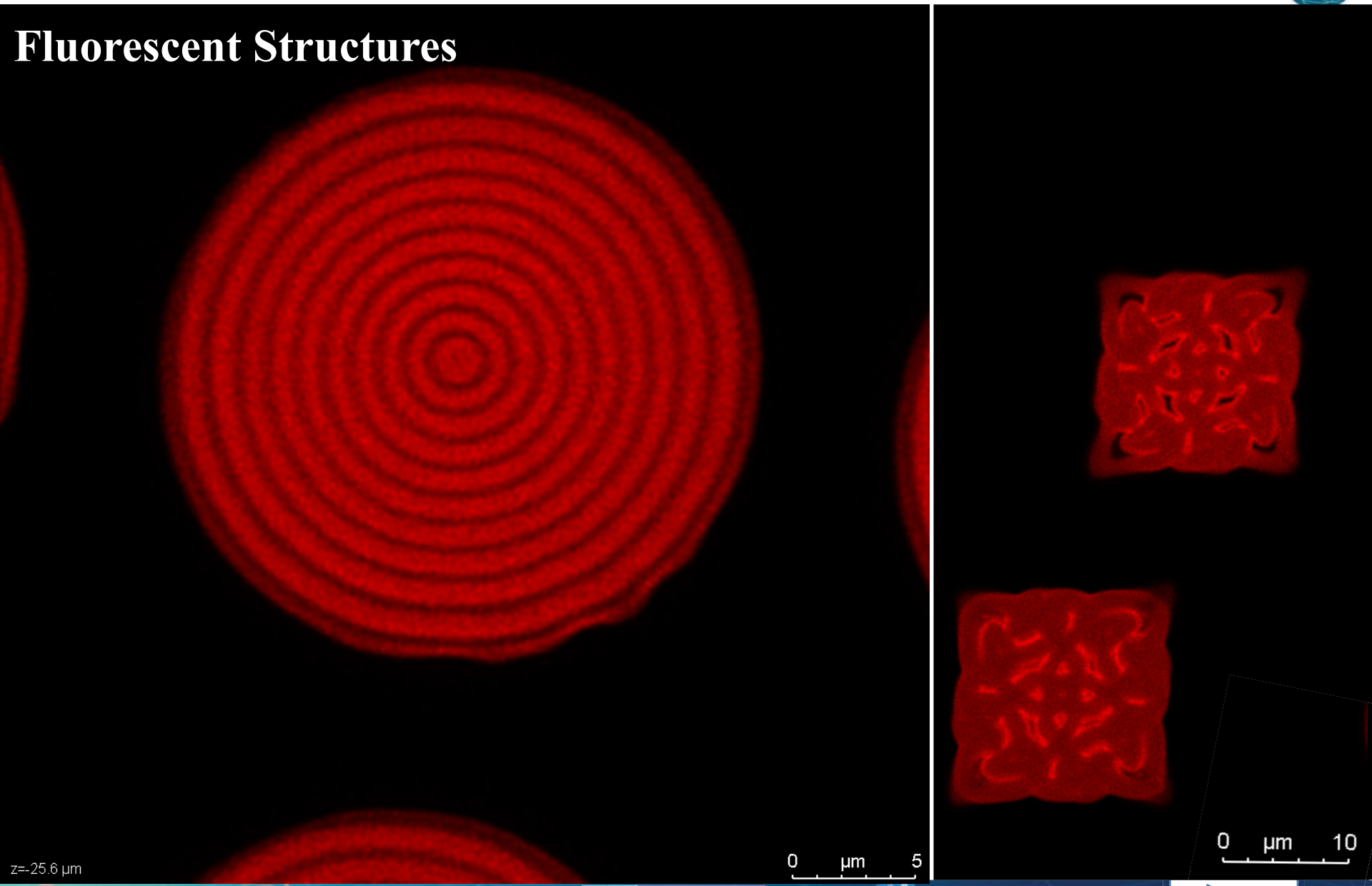
W. Francis et al. / Sensors and Actuators B 250 (2017) 608–616

‘Daisy’ – Micro/Nano Scaled Porous Structure

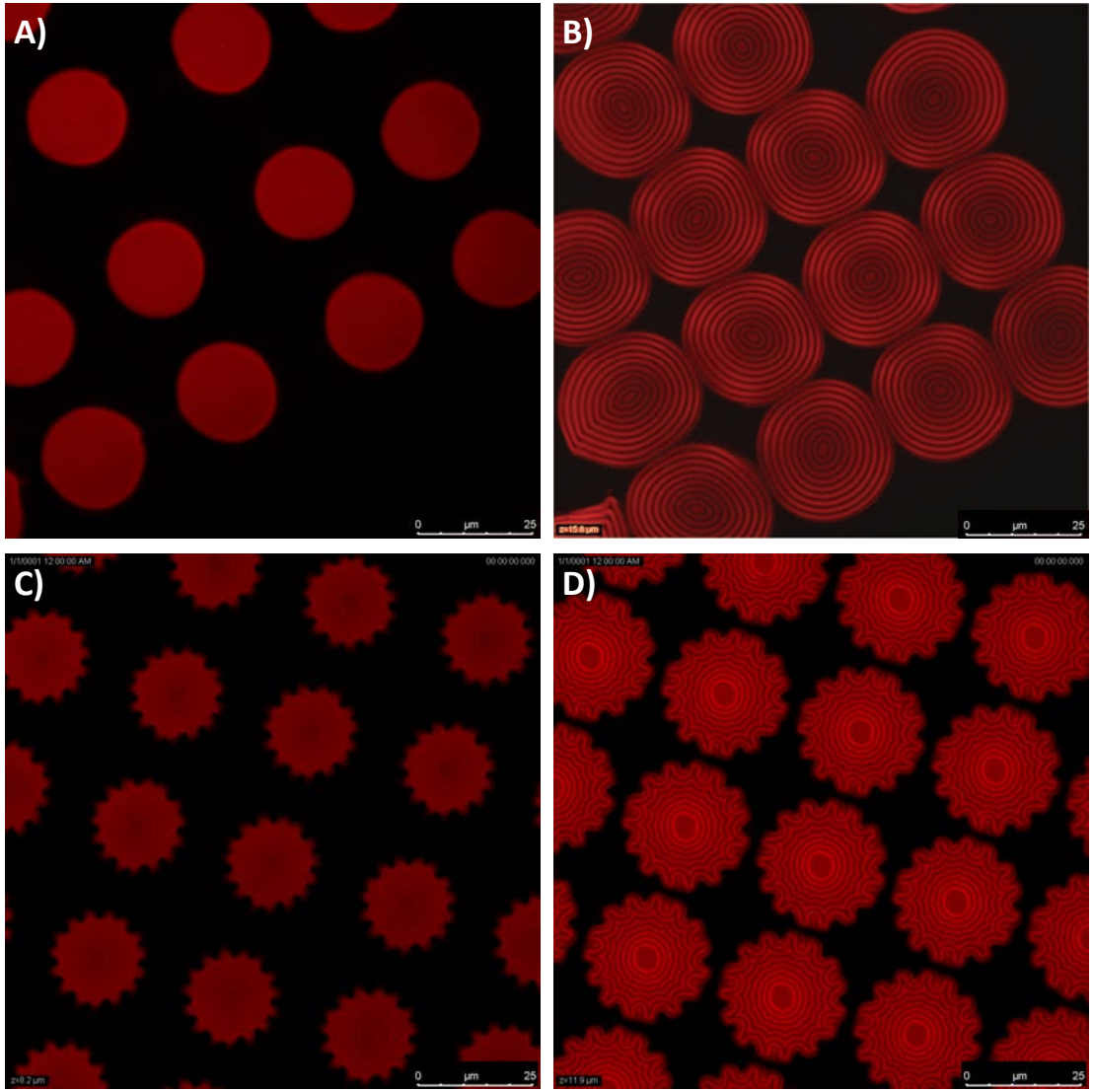
(with Guang Zhong Yang, Imperial College London)



Rhodamine labeled gels (STED Microscopy)



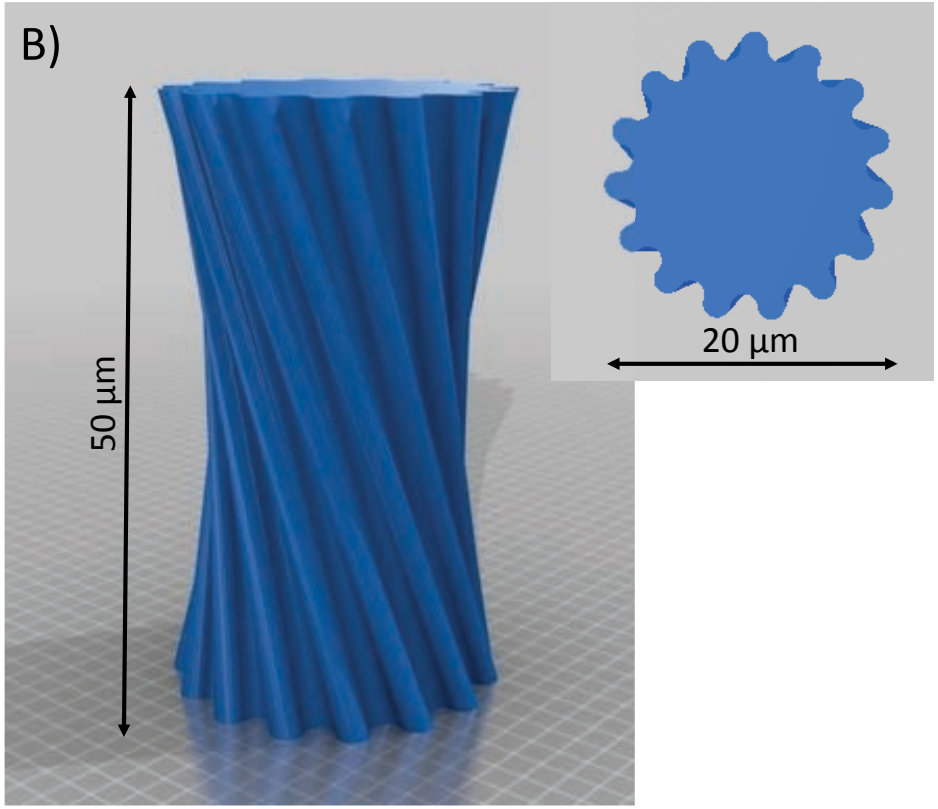
Endo-Skeleton Controlled Actuation

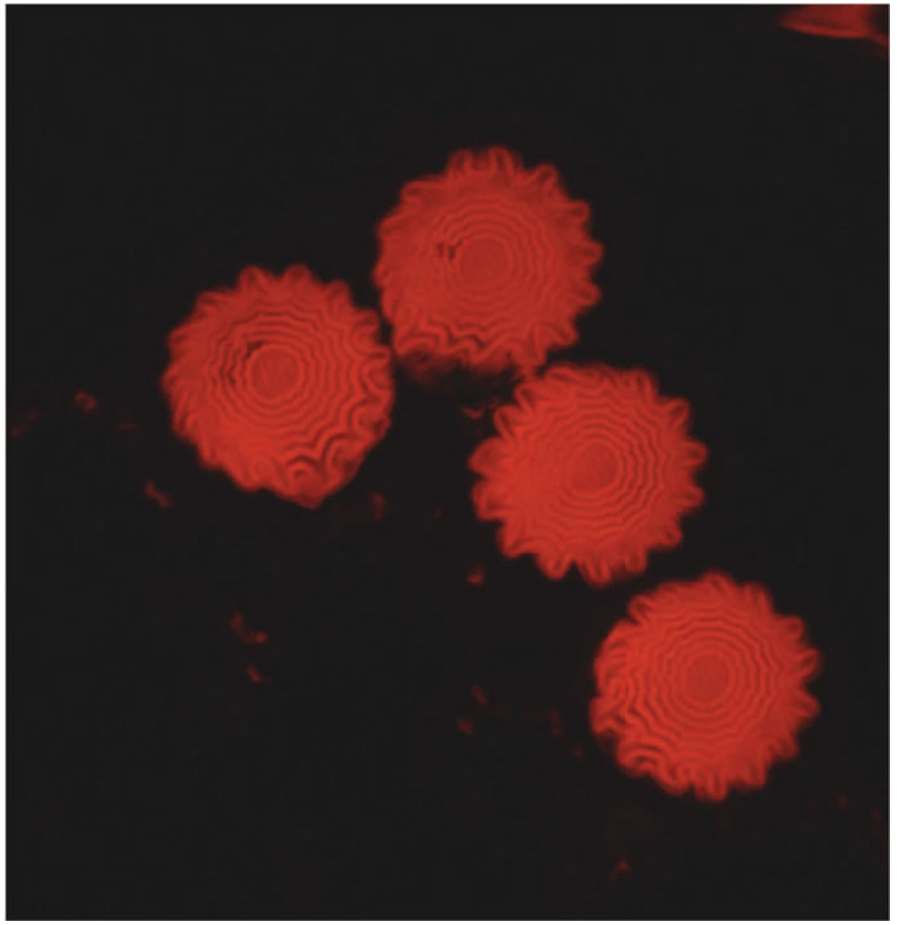


Microscope images of micro-scale pillar array fabricated in PIL hydrogels by 2-PP showing the collapsed pillars before hydration (left) and after hydration (middle and right). The concentric contour slicing pattern used to create the microstructure is visible in the swollen hydrated structures and are very clear in the high resolution STED image (right) of rodamine modified hydrogels. The hydration process is fully reversible and shows shape-memory behaviour.

See Tudor, C. Delaney, H. Zhang, A.J. Thompson, V.F. Curto, G.-Z. Yang, M.J. Higgins, D. Diamond, L. Florea, Fabrication of soft, stimulus-responsive structures with sub-micron resolution via two-photon polymerization of poly(ionic liquid)s, **Materials Today. 21 (2018) 807–816. doi:10.1016/j.mattod.2018.07.017.**

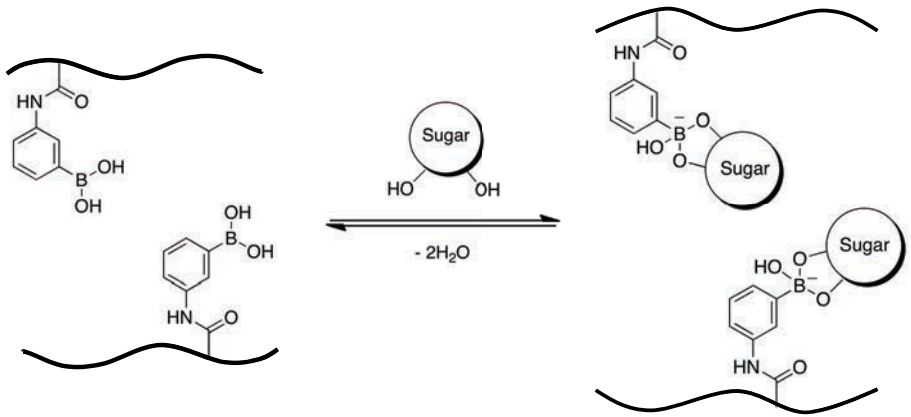
Twisting Motion from Spiral Ratchet Structure

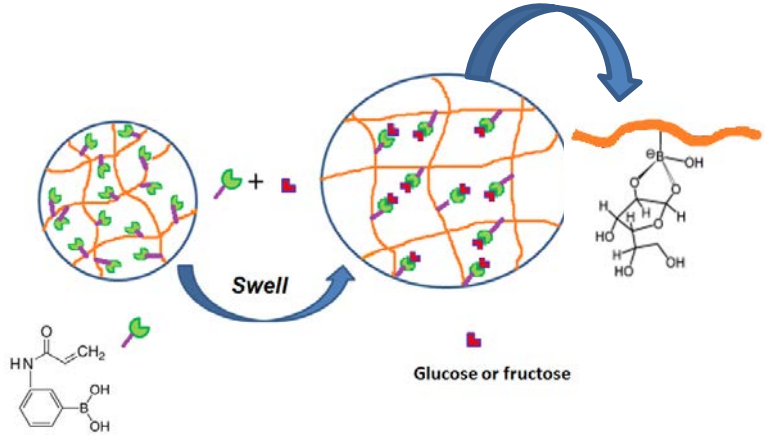




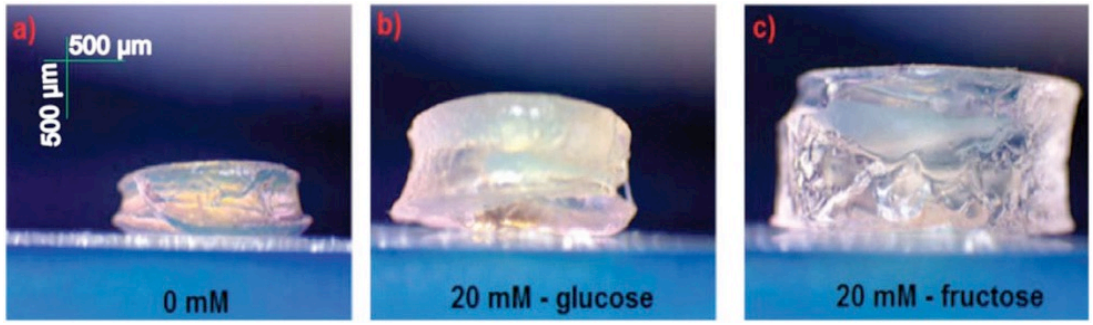
Materials Today. 21 (2018) 807–816. doi:10.1016/j.mattod.2018.07.017.

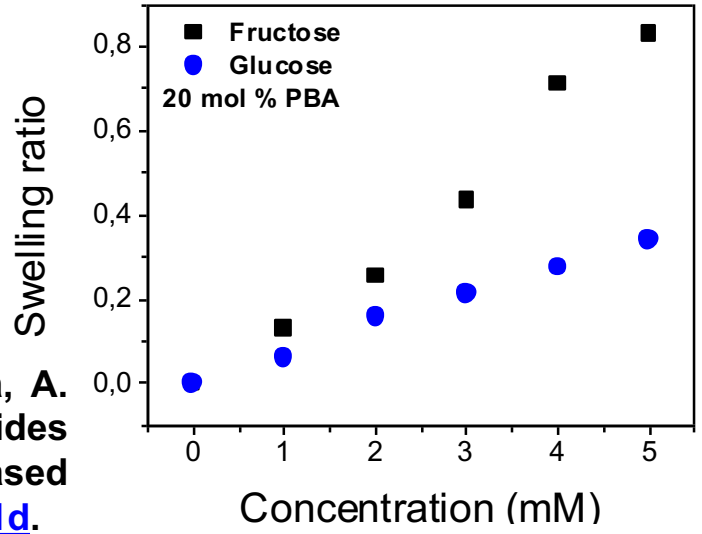
Sugar-Responsive Soft Hydrogels





Acrylamide-*co*-PBA Polymer





C.M. Daikuzono, C. Delaney, H. Tesfay, L. Florea, O.N. Oliveira, A. Morrin, D. Diamond, Impedance spectroscopy for monosaccharides detection using responsive hydrogel modified paper-based electrodes, Analyst. 142 (2017) 1133–1139. doi:10.1039/c6an02571d.

Merging of Materials, Devices and Data

Data and Information; IOT

Devices and Platforms

MATERIALS

Physics Chemistry Biology Engineering
(photonics, electronics, fluidics, 4D materials)

Thanks to…..

- NCSR, SCS, DCU
- Science Foundation Ireland & INSIGHT Centre
- Enterprise Ireland
- Research Partners – academic and industry
- EU Projects: Holifab Project

Jean Louis Viovy (Fluigent) , Mark Bowkett (TE Laboratories), Laurent Malaquin (LAAS)

HoliFAB

sfi DCU UCC OÉ Gaillimh NUI Galway UCD DUBLIN

Thanks for the invitation!

HoliFAB