Novel Optical Sensing System Based on Wireless Paired Emitter Detector Diode Device for Lab-on-a-Disc Water Quality Analysis

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ATWARM

Presentation Outline

- **Water quality analysis**
- Optical sensing device for Lab-on-a-Disc
- On chip measurements:
  - pH
  - turbidity
- **Ionogel microvalves**
- Materials and optical setup
- Valve actuation behaviour
- Conclusions

Introduction: Water Quality

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- Attention to proper water quality in an undeniable necessity in the developing world.
  - detect trends in water quality over time [1]
  - identify specific existing or emerging water quality problems
  - determine the effectiveness of watershed restoration

- Principal factors taken into consideration when determining water quality:
  - physical: **turbidity,** temperature, salinity
  - chemical: **pH,** nutrients, heavy metals, dissolved oxygen, electrical conductivity
  - biological: microorganizams, biologically active contaminats

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[1] J. Goldman, Distributed Sensing Systems for Water Quality Assessment and Management, 2007.

Water Sensors

- Traditionally: discrete sampling methods followed by laboratory analysis.
- Current norm: manual grab sampling 3 or 4 times a year.
- Low stability of natural water samples during long-term storage.[2]
- Expensive, time consuming and do not provide the high resolution data.

→ **Solution:**

- Simple: **Measure more often in more locations**

Why is this not happening?

[2] G. Hanraham, J. Environ. Monit. 6, 2004, 657.

Water Sensors

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+ portable
+ cheap

- single probe
- no data saving

+ hand-held device
+ multiprobe

- $$$

[3] A. Gollamudi, Water Quality Monitoring: Samling and Instruments, CARIWIN Advanced Course, 2007.

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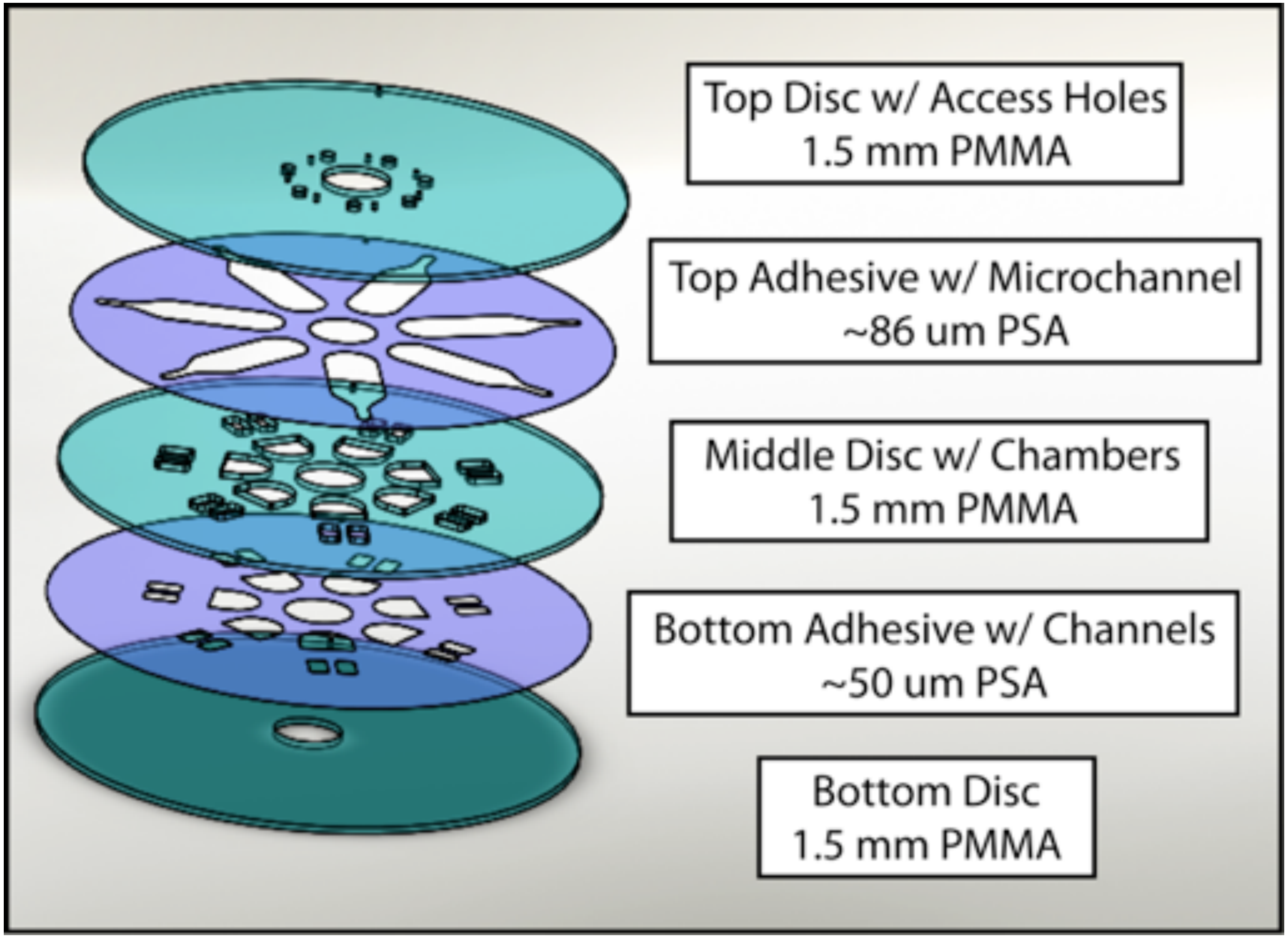
Our Sensor: Lab-on-a-Disc

WHY CENTRIFUGAL DISC (CD)?

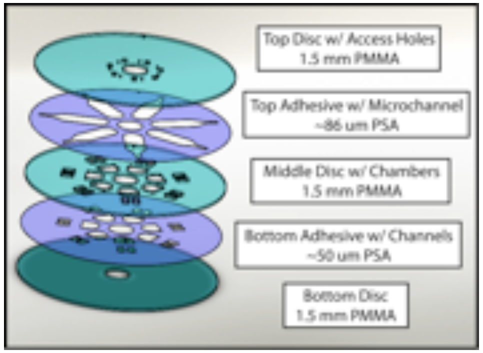
- Elimination of large power supplies and external pump.[4]
- Provides forces across the entire length of a fluid element.
- Several individual systems can be placed on a single CD.
- Design for multi-parameter water analysis.
- Contains large chambers with several sub-compartments for various functions.

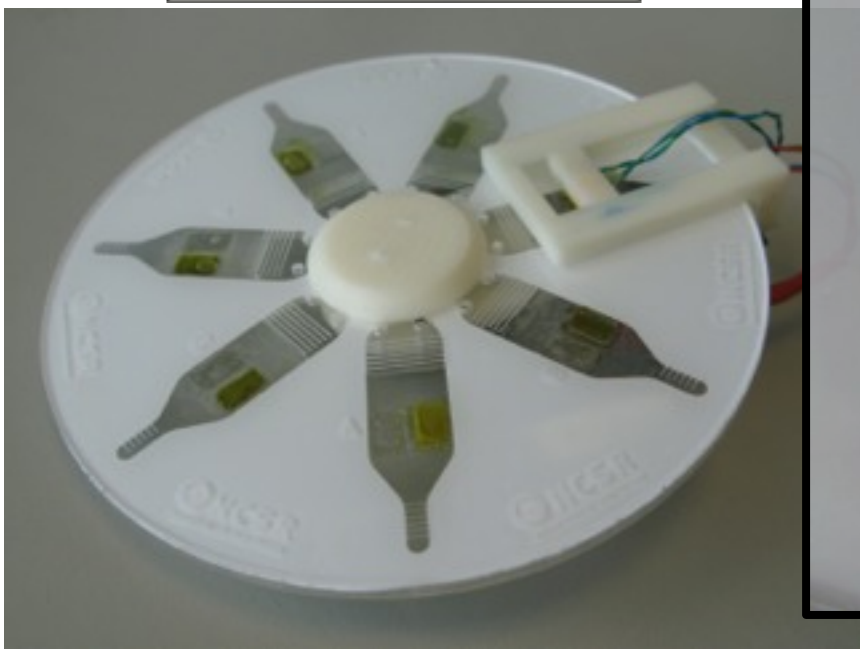
[4] J. Siegrist et. al., Lab Chip 10, 2010, 363.

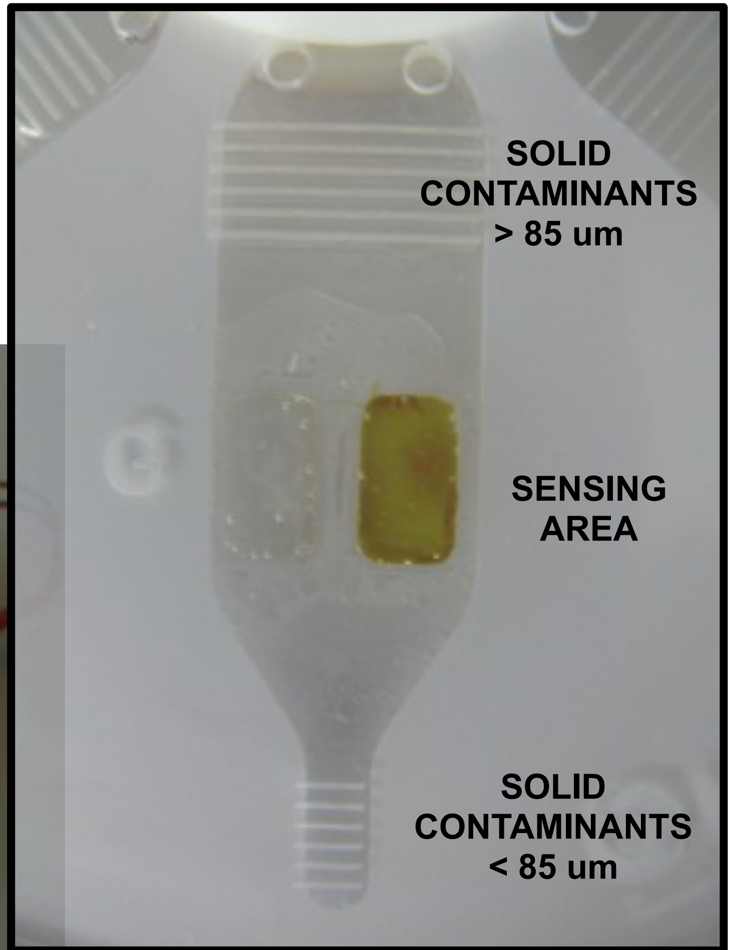
Our Sensor: Lab-on-a-Disc



Our Sensor: Lab-on-a-Disc

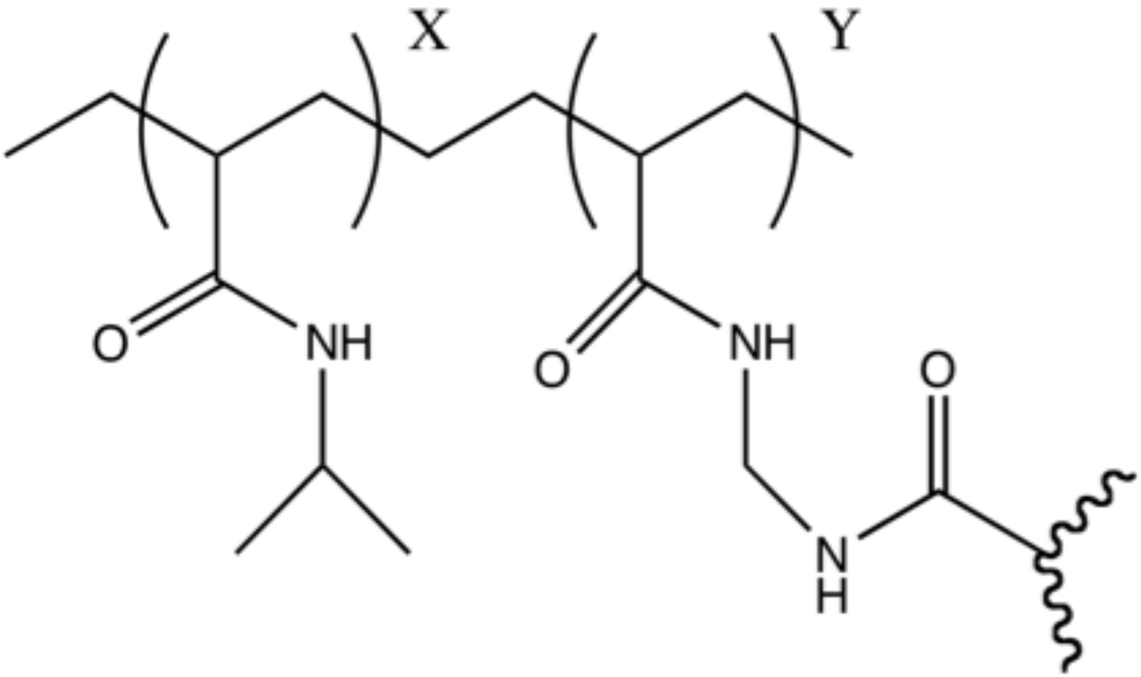






Our Sensor: Materials

A)

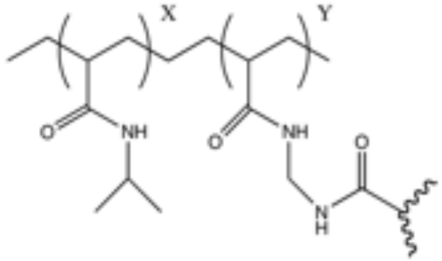


poly(*N*-isopropyl-acrylamide) and *N,N*-methylene-bis(acrylamide) cross- linked polymer 100 (x):5 (y)

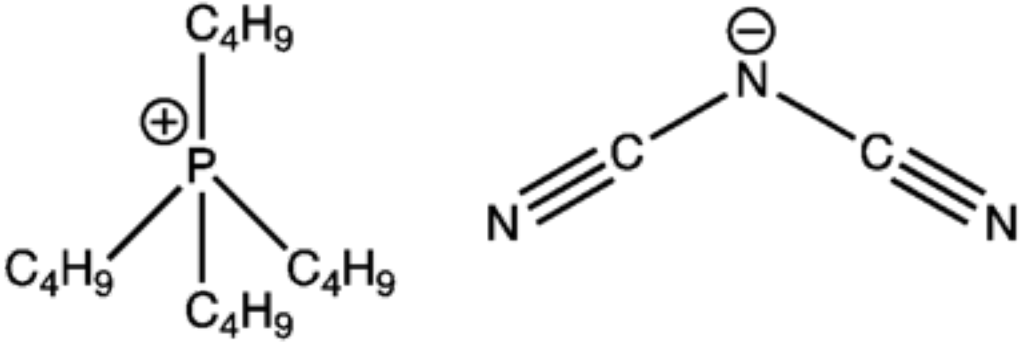
[5] G. Vansyut, Plan hys and Biochem 41, 2003, 27.

Our Sensor: Materials

A)



B)



ionic liquid: tetrabutylphosphonium dicyano-amide $[P_{4,4,4,4}][dca]$

- ionic liquids (ILs) are low melting point salts (<100^{o}C) that represent a new class of non-aqueous but polar solvents.
- Composed of ions: cations and anions.
- Designer solvents' as their properties can be adjusted to suit the requirements of a particular process.

[5] G. Vansyut, Plan hys and Biochem 41, 2003, 27.

Our Sensor: Materials

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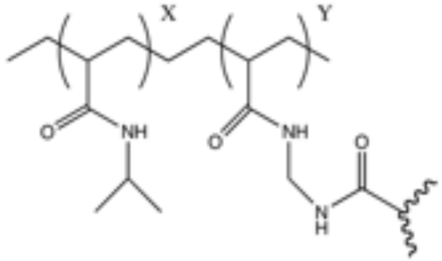
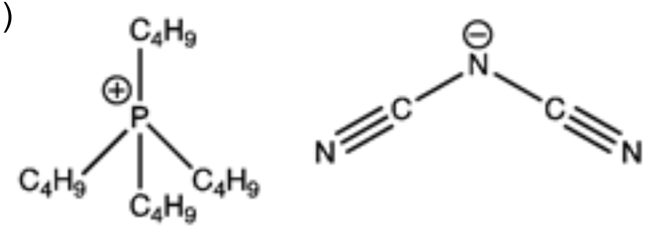
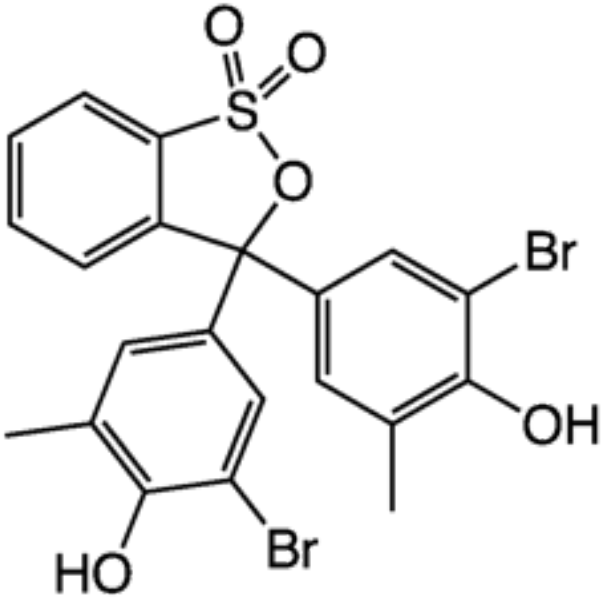
A)



B)



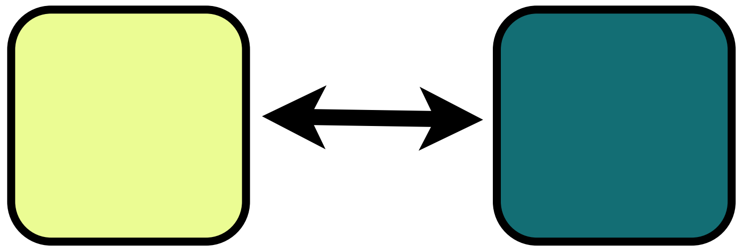
C)



In Ionogels

Acidic environment

Basic environment



Bromocresol Purple pH dye (pKa=6.3)

[5] G. Vansyut, Plan hys and Biochem 41, 2003, 27.

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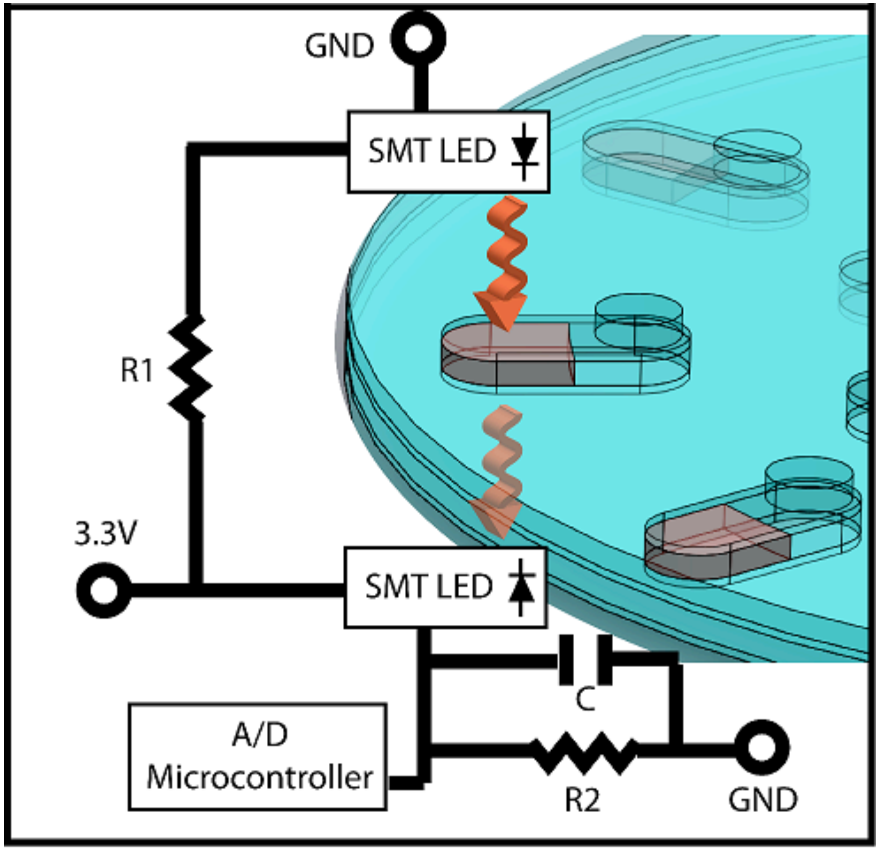
Tuesday 18 October 11

Our Sensor: Wireless Paired Emitter Detector Diode Device



- Excellent sensitivity and signal-to-noise ratio [6]
- Low power consumption
- Increasing spectral range coverage
- Intensity and efficiency
- Low cost
- Small size
- Ease of fabrication
- Simplicity
- AND adjusts ideally to the system based on centrifugal Lab-on-a-disc!

[6] M. O'Toole, R. Shepherd, G.G. Wallace, D. Diamond, Anal. Chim. Acta, 652, 2009, 308.

Our Sensor: Wireless Paired Emitter Detector Diode Device

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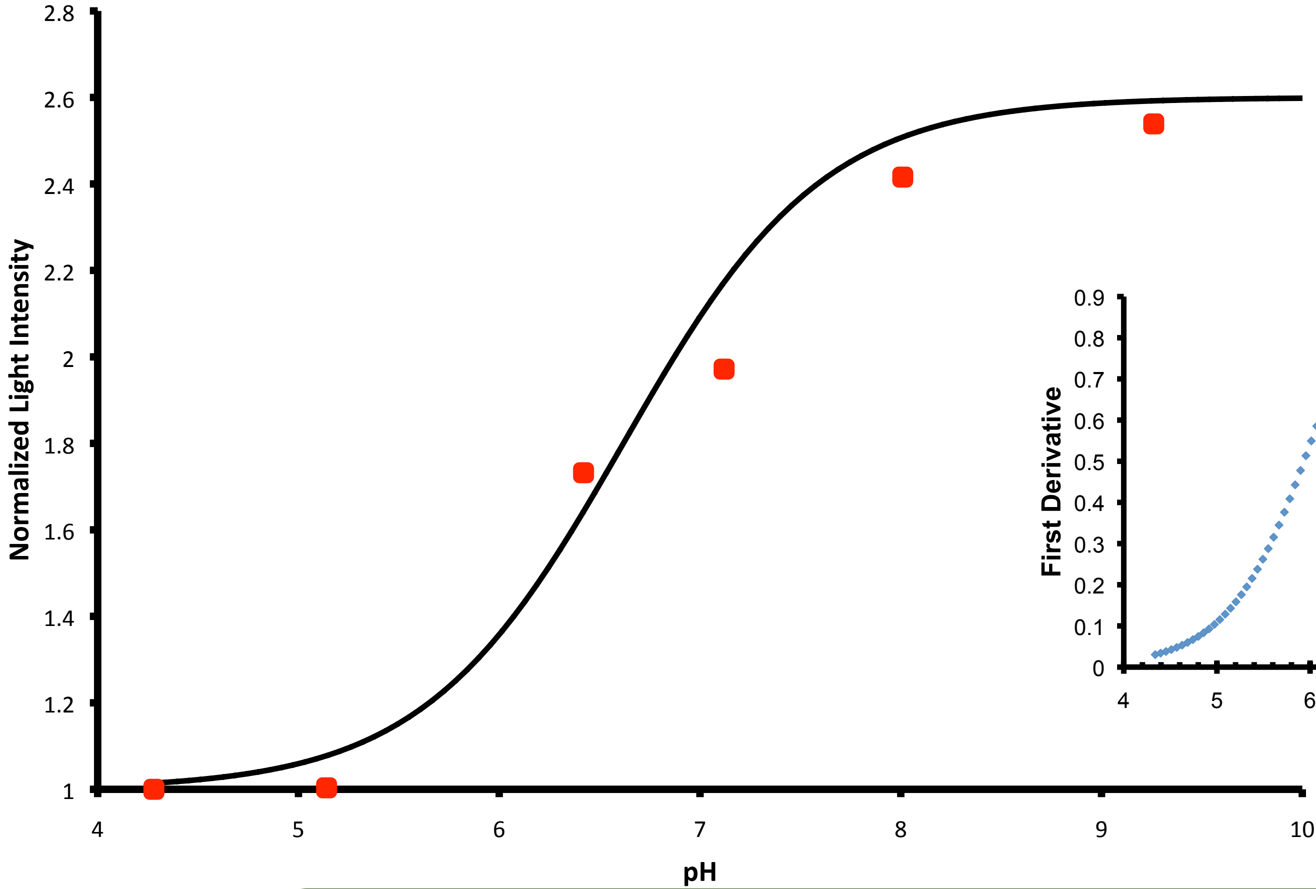
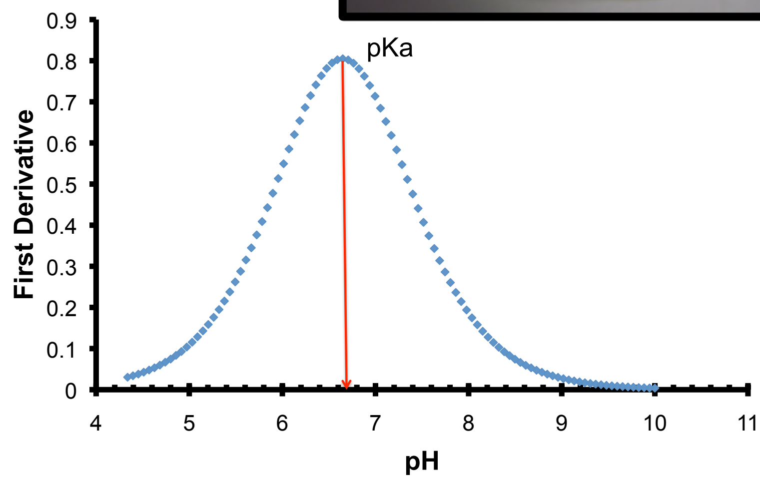
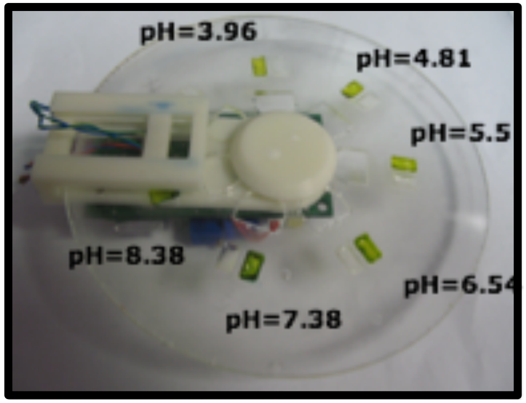
Calibration of the sensor







Ionogel pKa = 6.6 **Bromocresol Purple pKa = 6.3**

On-Chip Water Analysis: Sampling

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Aquatic Environment

River Pollution Case Study

Summary Report on pollution of the Tolka River near Clonee, Co. Dublin
Date of Offence: July, 2005

Members of local angling groups reported a poor quality discharge of effluent (and an associated fish kill) on the Tolka River to the ERFB in mid July 2005. On arrival at the reported discharge location and on visual inspection in the vicinity of the implicated surface water discharge point, it was noted that there was no discharge coming from the pipe. However significant 'chemical burning' of bank-side vegetation around the discharge pipe, a discolouration of the river bed and a general absence of in-stream aquatic flora and fauna downstream of the discharge point were noted. Live fish (juvenile stickleback) and invertebrates were observed approximately 5 metres upstream of the discharge point but were absent downstream of this location. An ammonia-like odour was present in this area. There was no other apparent discharge above or below this point in this area.

Tolka River, Dublin, Ireland

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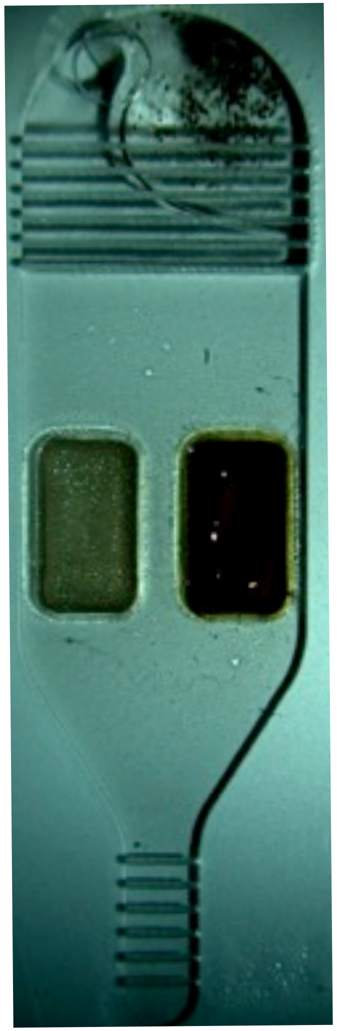
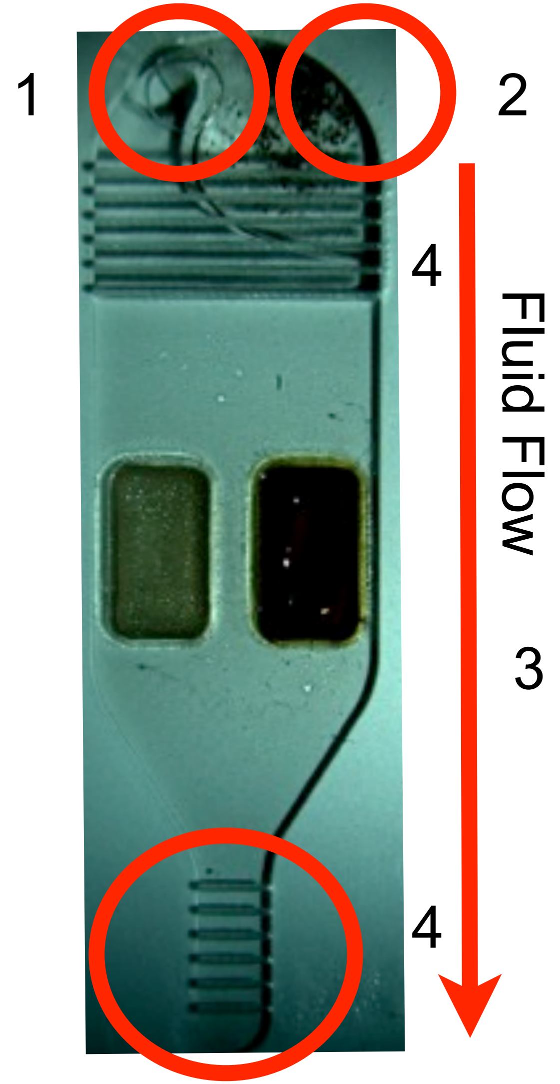
On-Chip Water Analysis: Sample Loading during rotation



On-Chip Water Analysis: Sample Loading during rotation



1: Inlet for loading 100 ul of sample
2: Air release
3: Centrifugation at 1500 rpm
4: Solid contaminants

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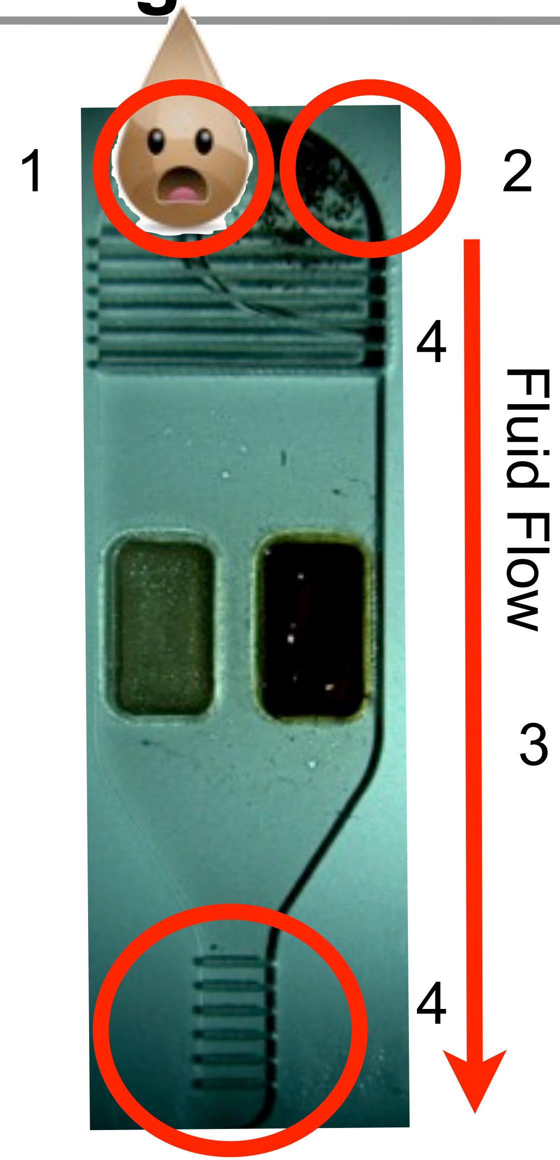
On-Chip Water Analysis: Sample Loading during rotation



1: Inlet for loading 100 ul of sample
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On-Chip Water Analysis: Sample Loading during rotation

1: Inlet for loading 100 ul of sample
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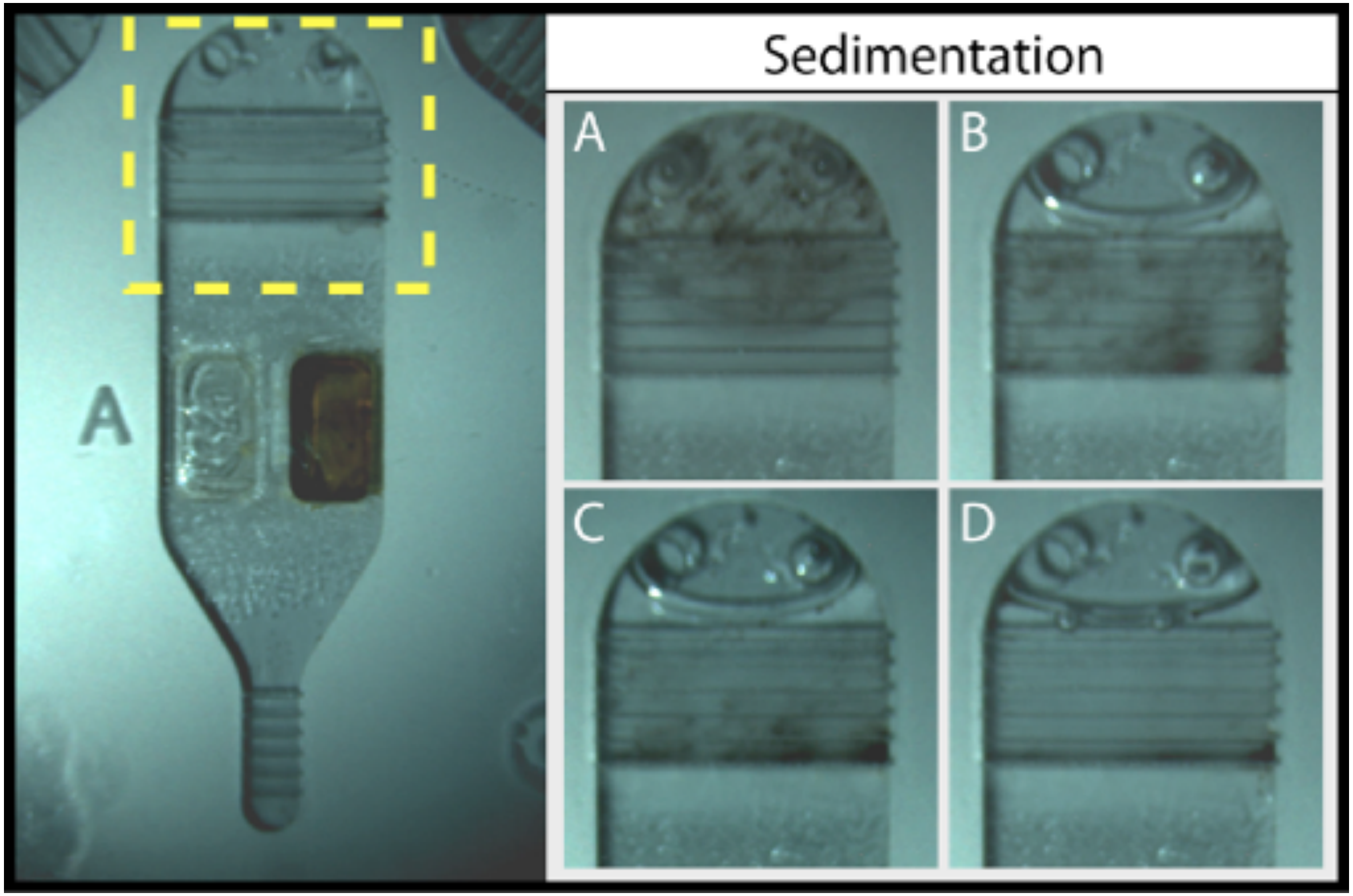
On-Chip Water Analysis: Sample Loading during rotation



CD-chip during centrifugation at 1500 rpm.

On-Chip Water Analysis: pH

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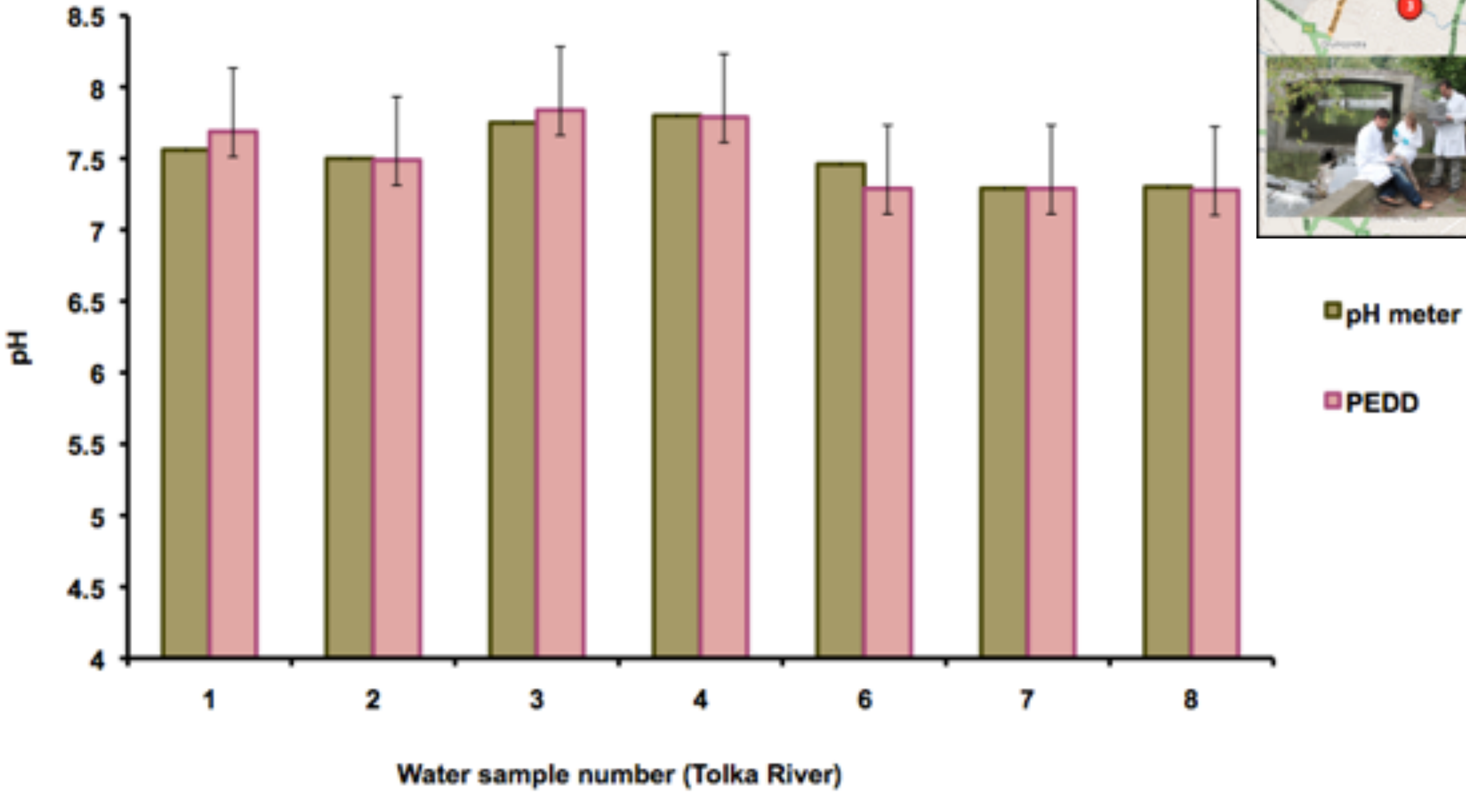
Water pH analysis using a commercially available pH-meter and the PEDD lab-on-a-disc device (error n=3)



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[7] M. Czugala, R. Gorkin, T. Phelan, J. Ducree, D. Diamond, F. Benito-Lopez, MicroTAs, October 2-6 2011, Seattle, USA. (TALK)

On-Chip Water Analysis: pH

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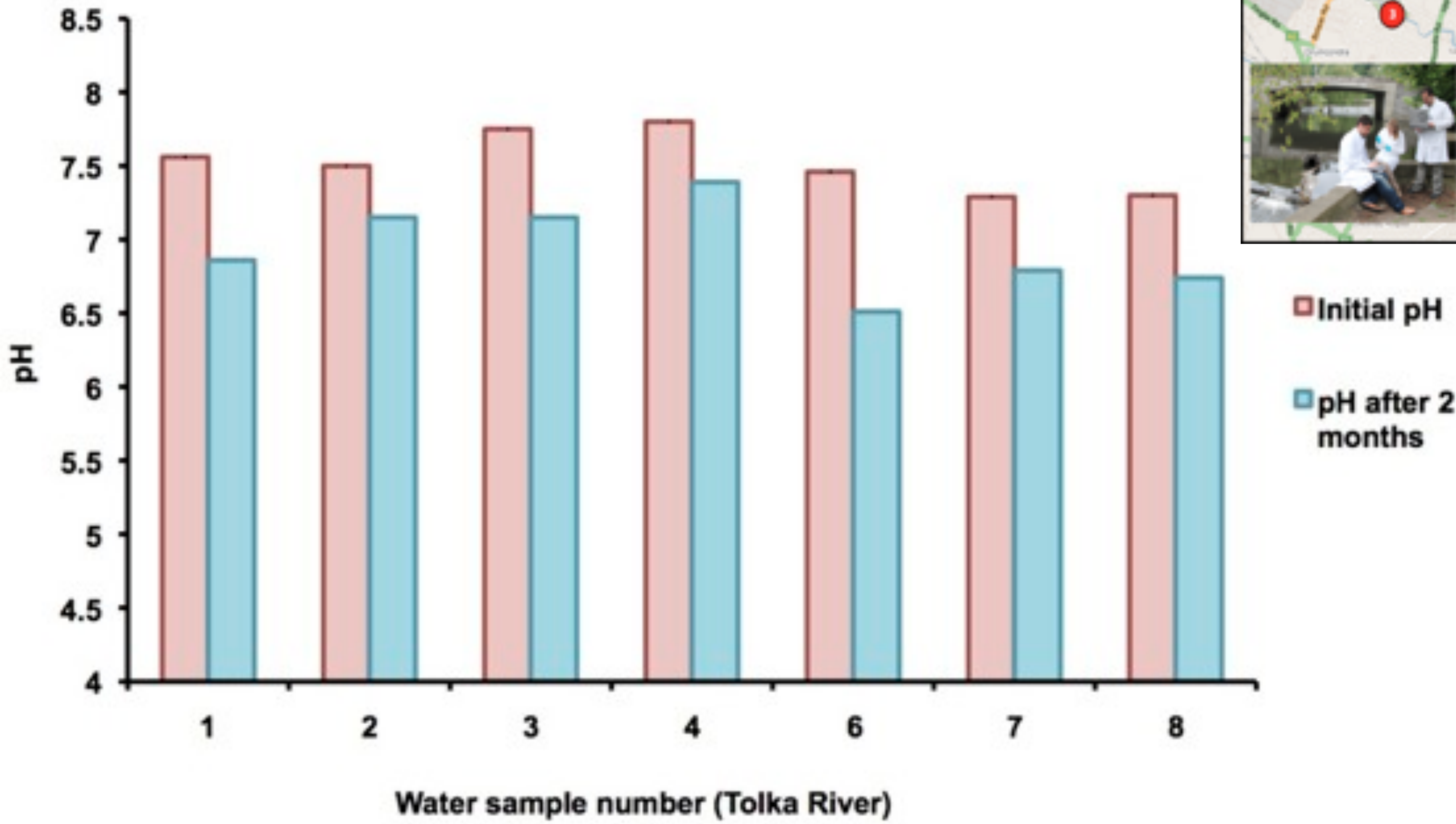
Water pH analysis using a commercially available pH-meter



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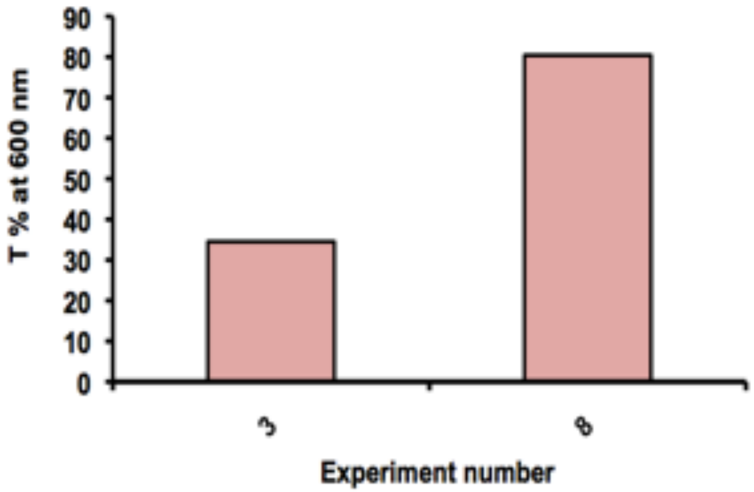
[7] M. Czugala, R. Gorkin, T. Phelan, J. Ducree, D. Diamond, F. Benito-Lopez, MicroTAs, October 2-6 2011, Seattle, USA. (TALK)

On-Chip Water Analysis: Turbidity

Filtering



UV-VIS spectrometer (transmittance)

CONTAMINATED SAMPLE (No. 3)

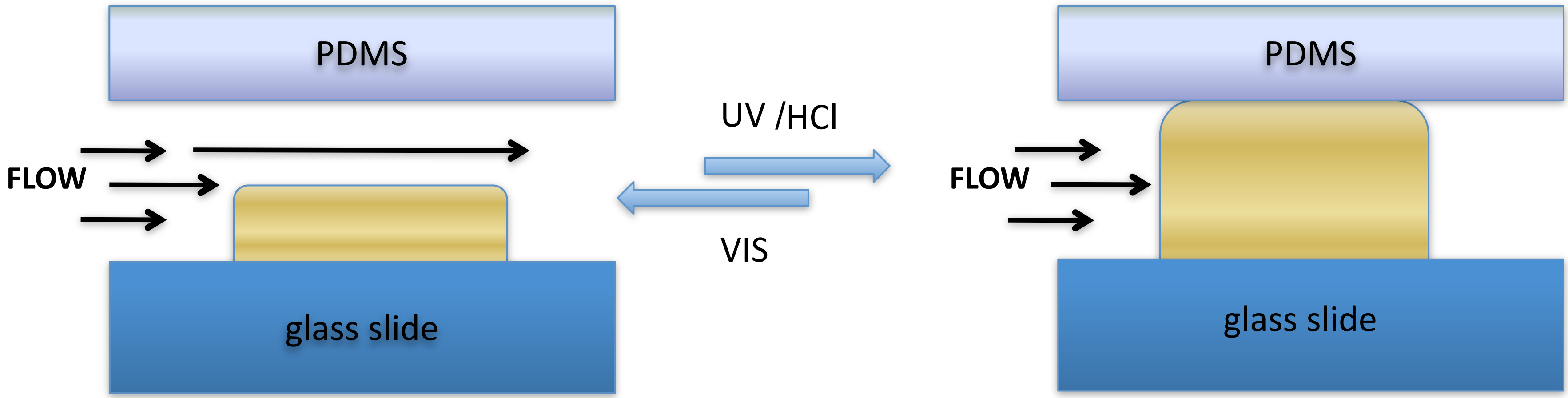
CD: pH 7.83
Meter: pH 7.75

CLEAN SAMPLE (No. 8)

CD: pH 7.27
Meter: pH 7.3

Ionogel Microvalves

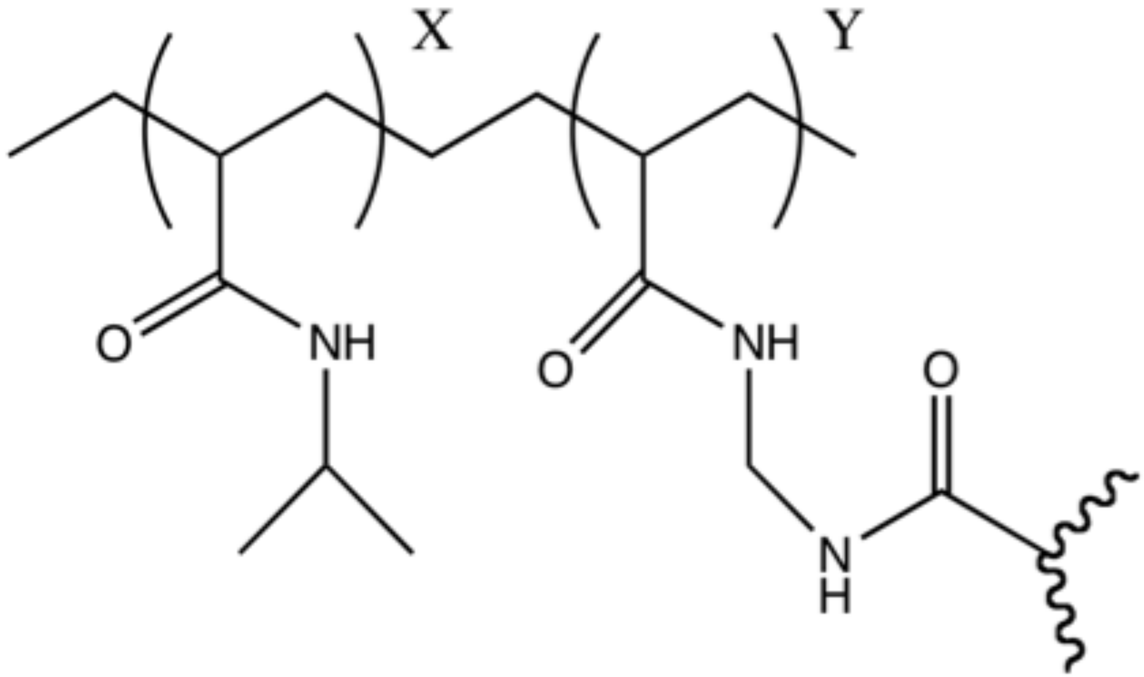
- Photoswitchable materials - the use of non-contact, non invasive stimuli.
- Ionogels containing spiropyran moieties with photochromism properties.
- Protonated spiropyran ionogels exhibit a drastic swelling effect.
- Shrinking process of the ionogels happen upon white light irradiation.



[8] M. Czugala, B. Ziolkowski, R. Byrne, D. Diamond, F. Benito-Lopez, SPIE-2011, Nanoscience + Engineering, 21 - 25 August, 2011, San Diego, USA.

Photoswitchable Materials

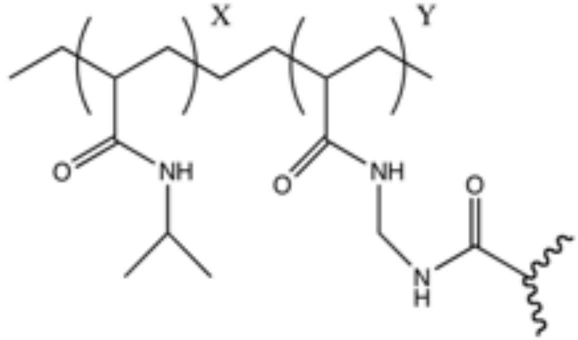
A)



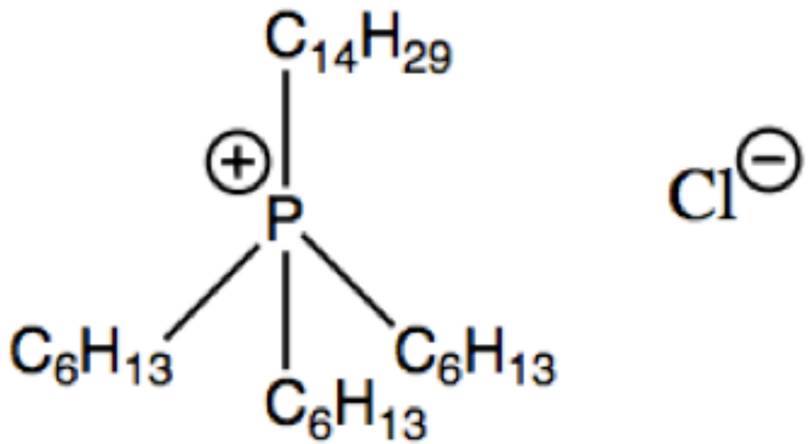
poly(*N*-isopropyl-acrylamide) and *N,N*-methylene-bis(acrylamide) cross- linked polymer 100 (x):5 (y)

Photoswitchable Materials

A)



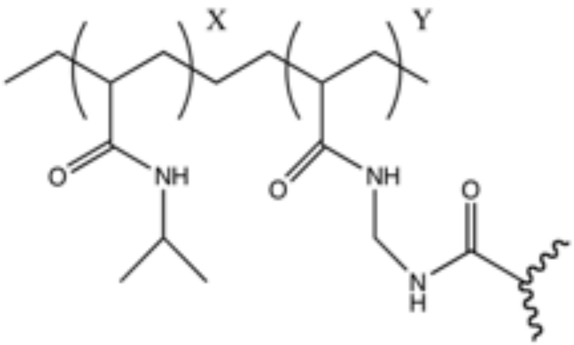
B)



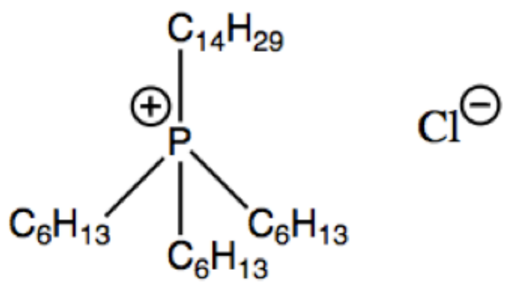
ionic liquid: trihexal-tetradecyl phosphonium chloride $[P_{6,6,6,14}][Cl]$

Photoswitchable Materials

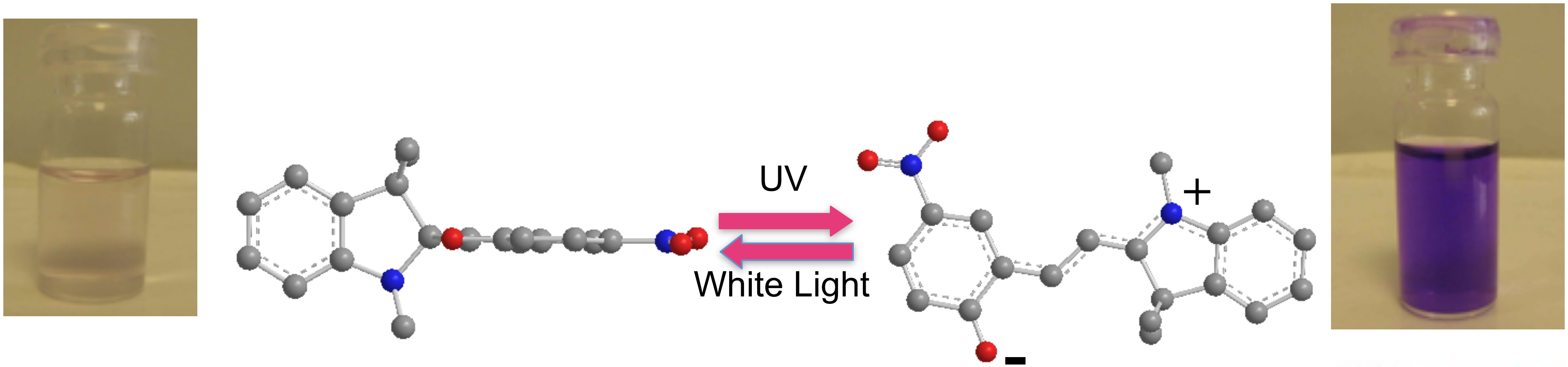
A)



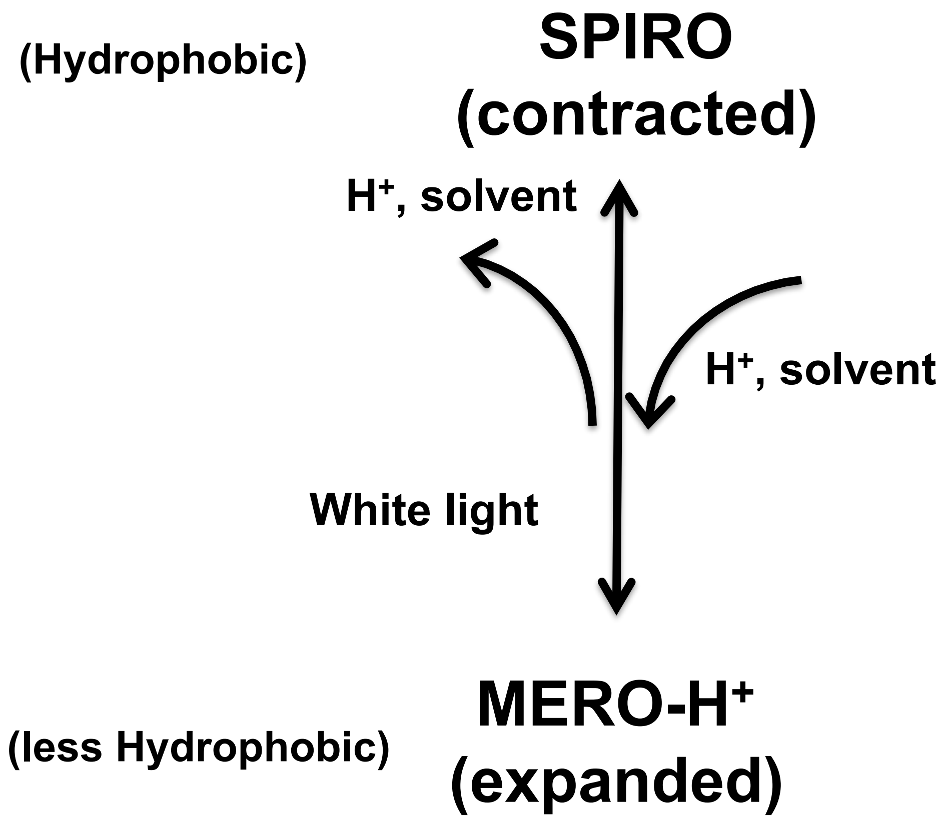
B)



C)

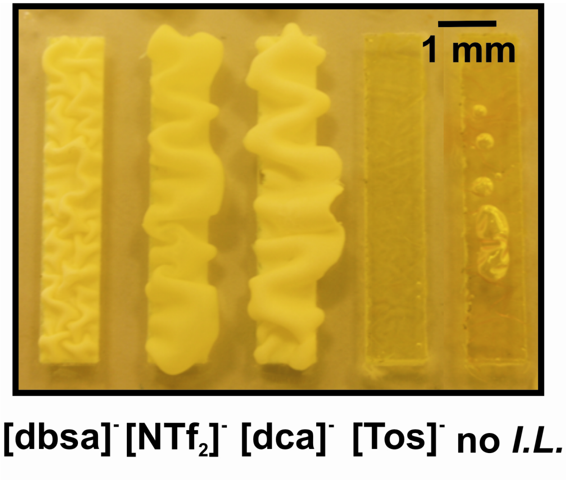


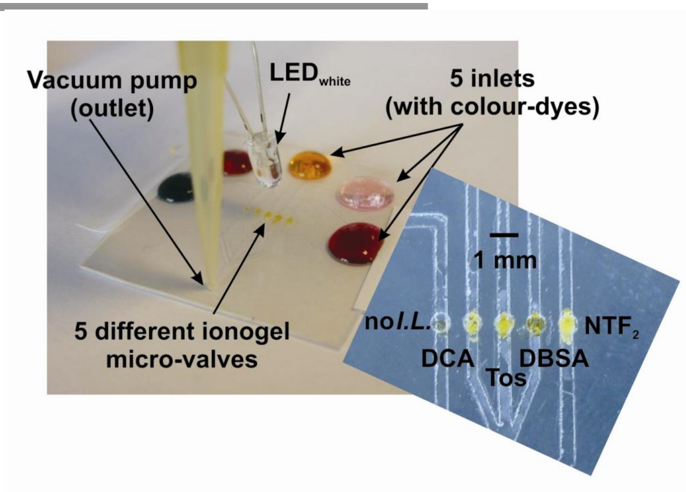
Photoswitchable Materials: Actuation Mechanism

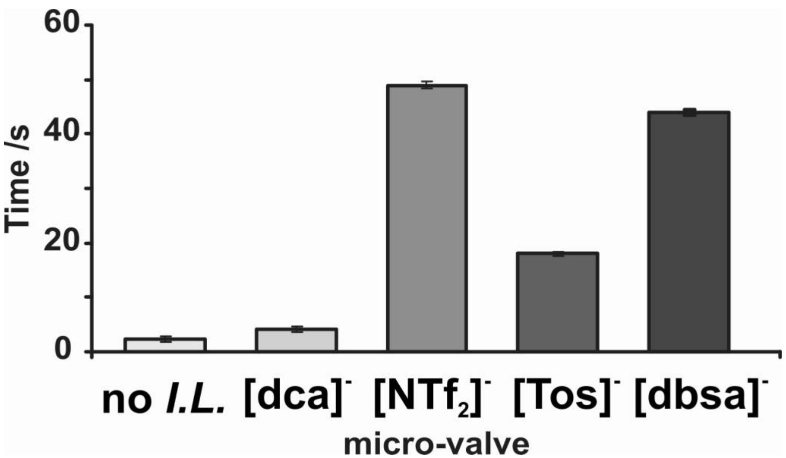


- OPTICALLY ACTUATE BETWEEN TWO DISTINCT ISOMERS
- CONTROL PHYSICO-CHEMICAL PROPERTIES OF SYSTEM
- NON-CONTACT SPATIAL CONTROL OF ACTUATION

Photoswitchable Microstructures

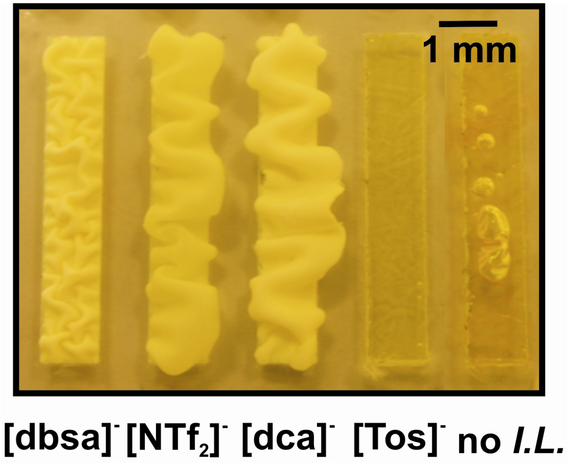


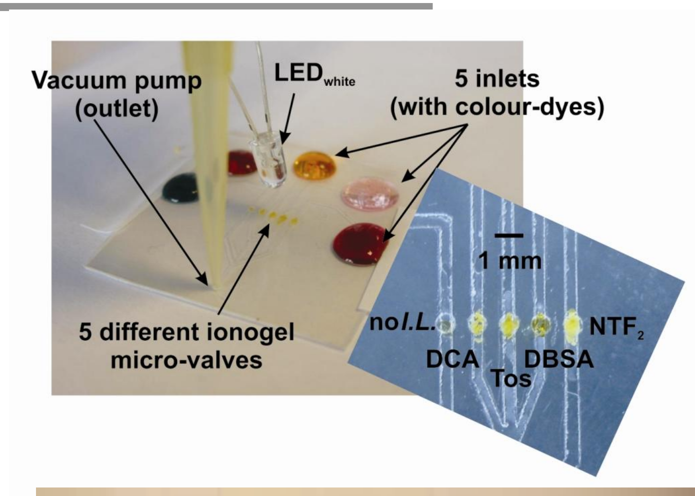


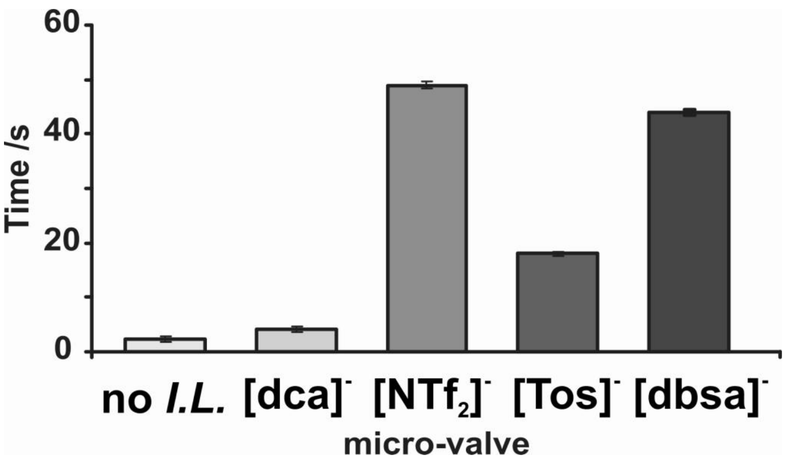


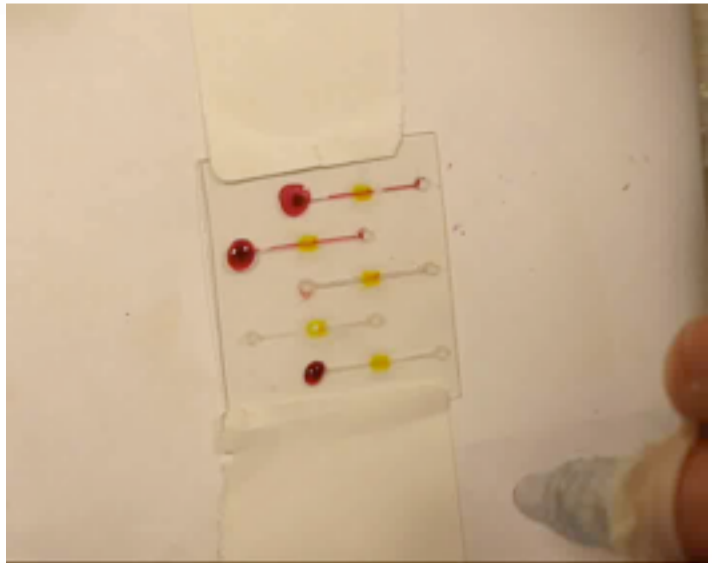
[9] F. Benito-Lopez et. al., Lab Chip 10, 2010.

Photoswitchable Microstructures









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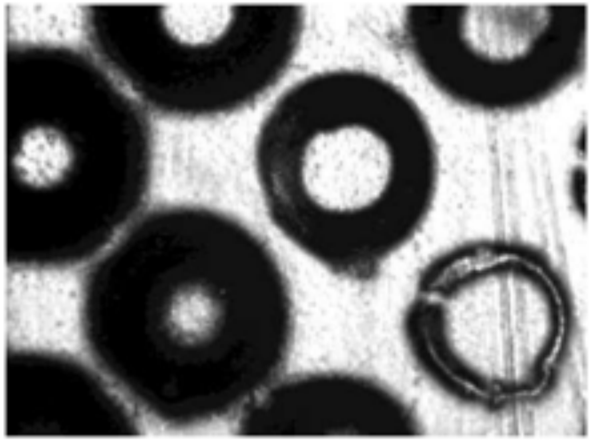
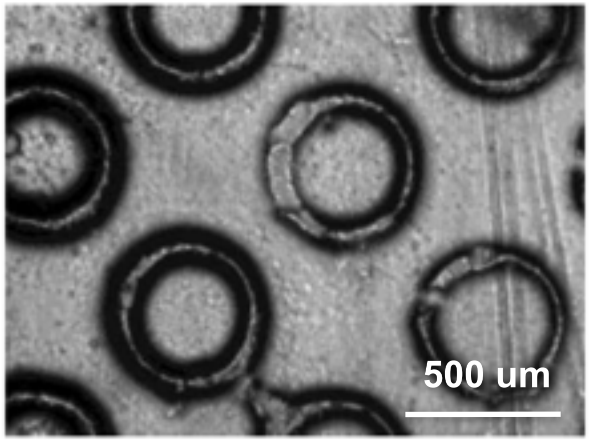
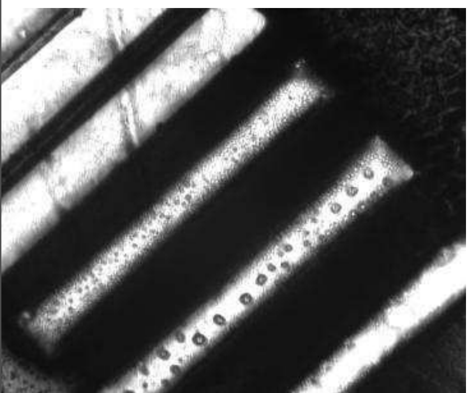
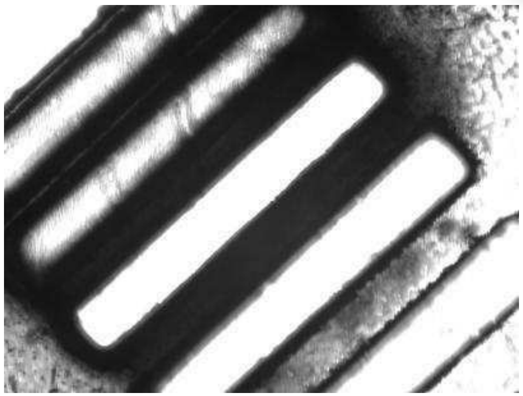




thickness: 150 um → 84 um



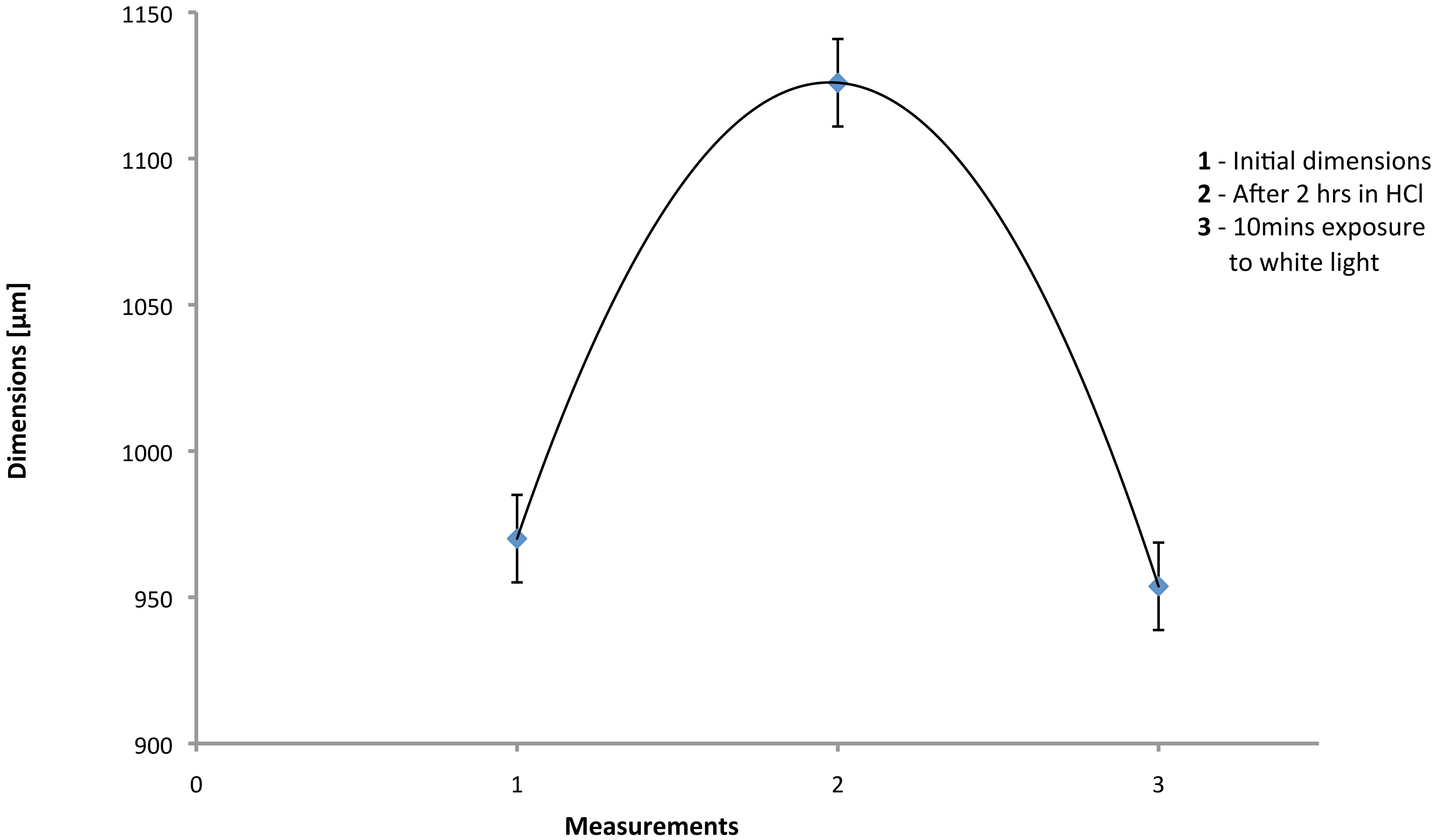


smallest line:
75 um → 45 um

biggest line:
250 um → 170 um

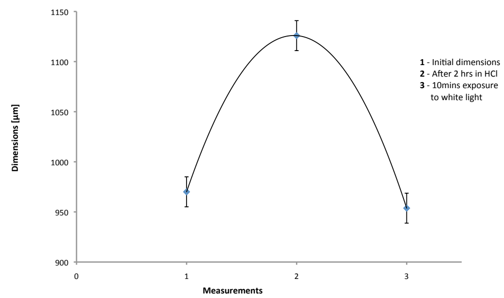
[10] B. Candice, A Two-Chromophore photolithography photopolymerization, IPM Fraunhofer, 2010.

Expanding and Shrinking Process

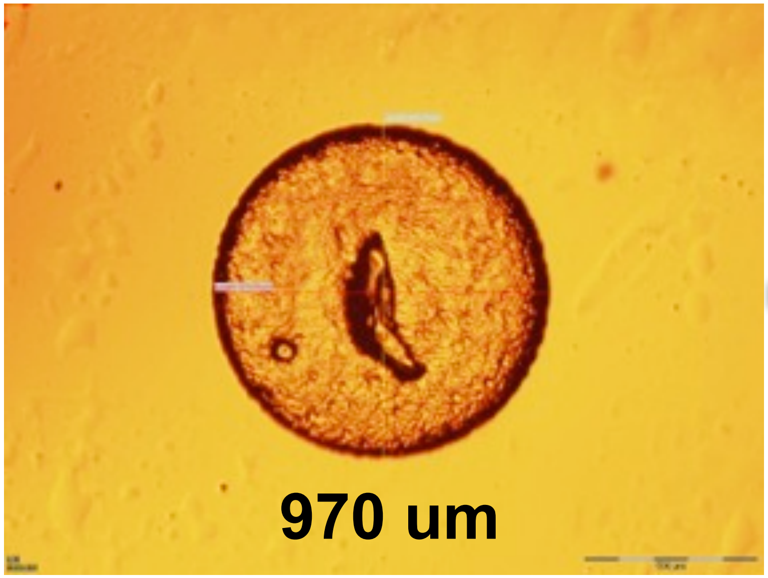


Expanding and Shrinking Process

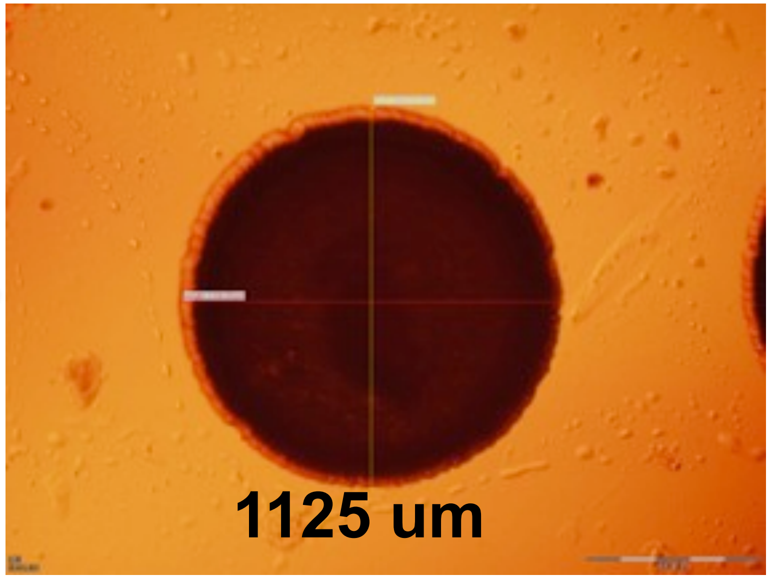
Expanding



- Using Microscope

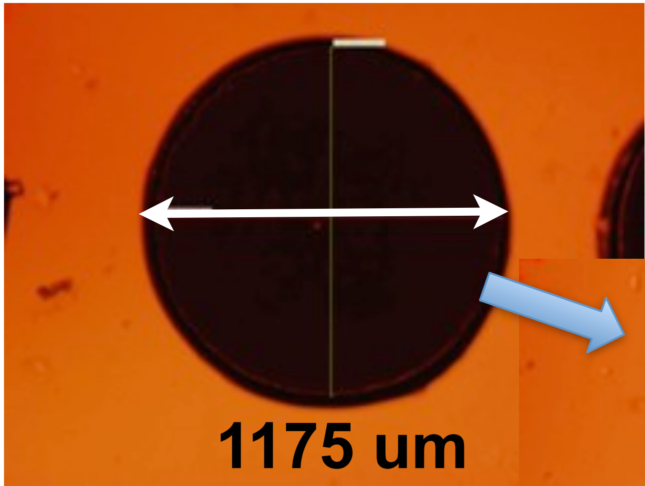


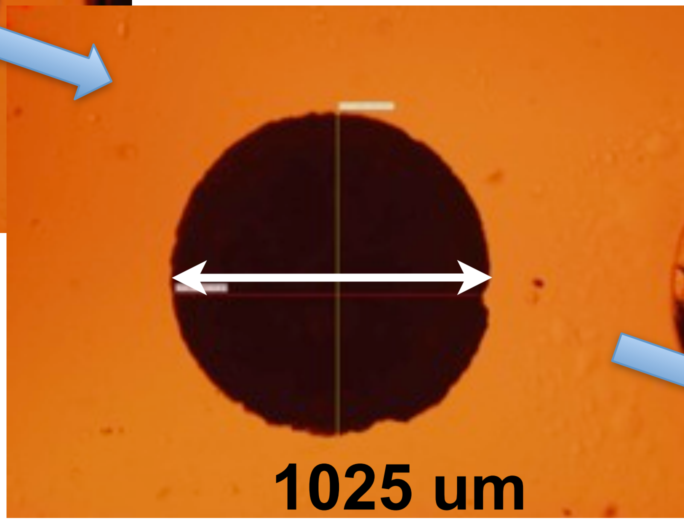
1mM HCl



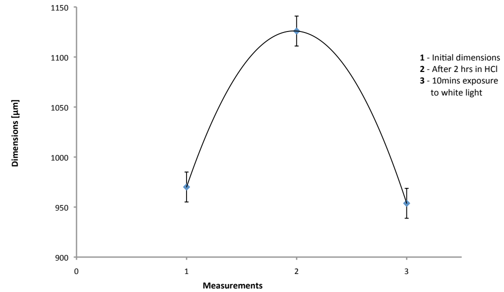
Expanding and Shrinking Process

Shrinking

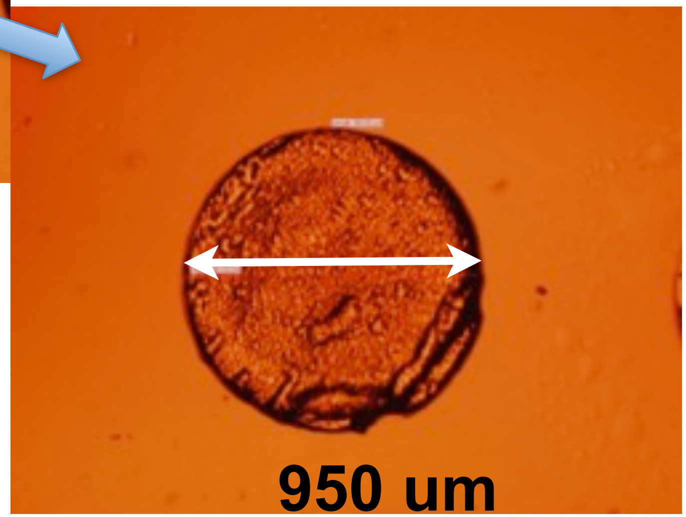




White light – 3mins **87,2 %**



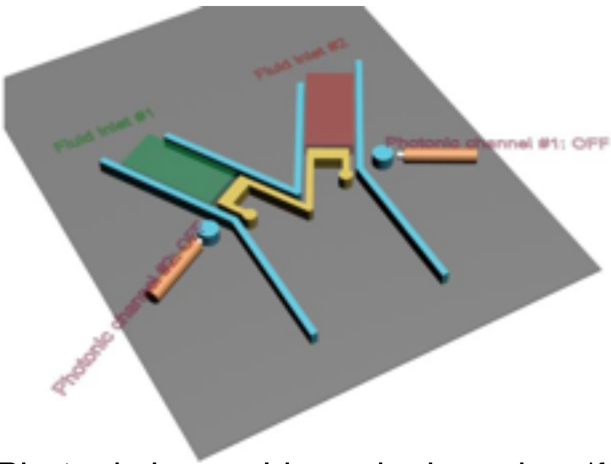
White Light - 10mins **80,8 %**



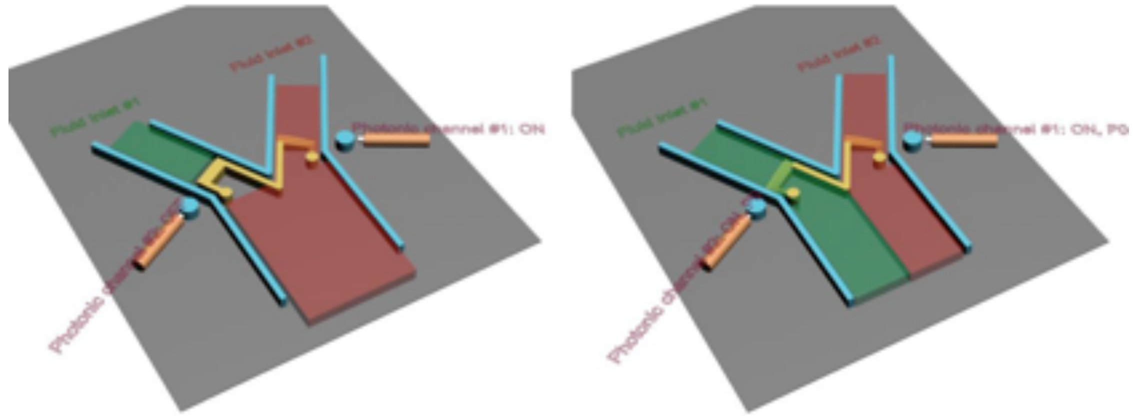
10 mins → ±20 % difference

Photonically controlled actuators in micro- and nano-fluidics

Photonic ionogel-based tunable micromixer

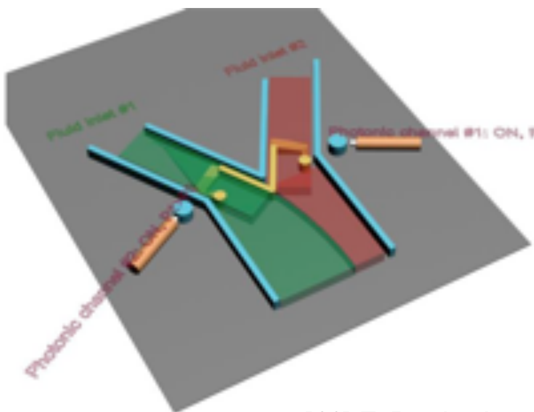


Photonic ionogel-based micromixer [11]



(a) (b)

(a) Actuation on the photonic channel #1
(b) Actuation on both photonic channels with identical optical power P0



Actuation on both photonic channels with different optical power (channel 1, P0: channel 2, P1>P0).

[11] F. Benito-Lopez, M. Czugala, Project proposal: Novel Functional Materials Based on Ionic Liquids (Ionogels) as Photonically Controlled actuators in Micro- and Nano-fluidics, 2010.

Fabrication

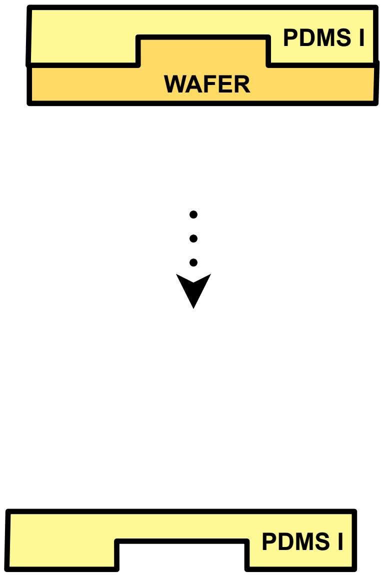
I MICROCHANNELS

II MICROVALVES

Fabrication

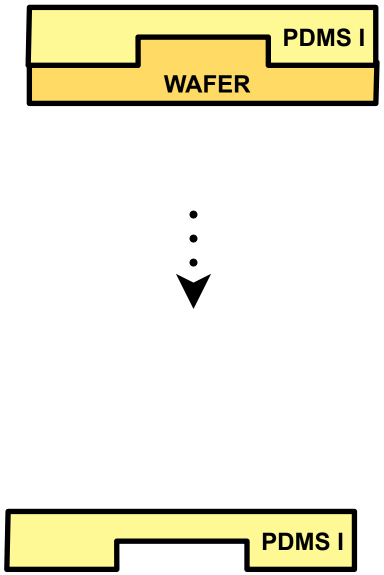
I MICROCHANNELS

II MICROVALVES



Fabrication

I MICROCHANNELS



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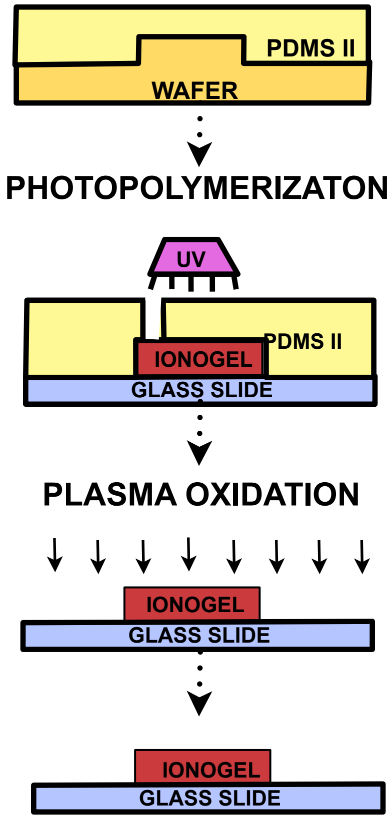
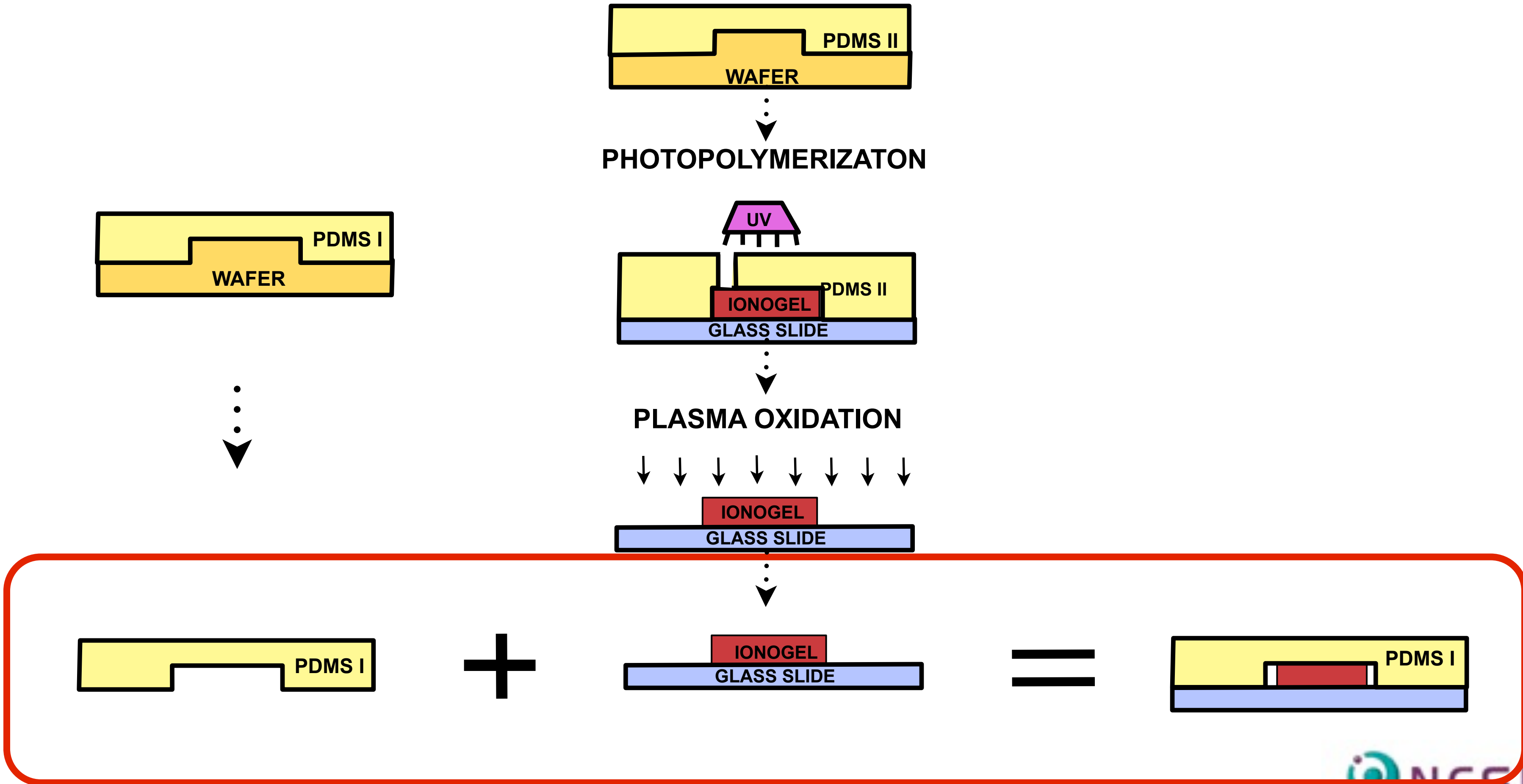


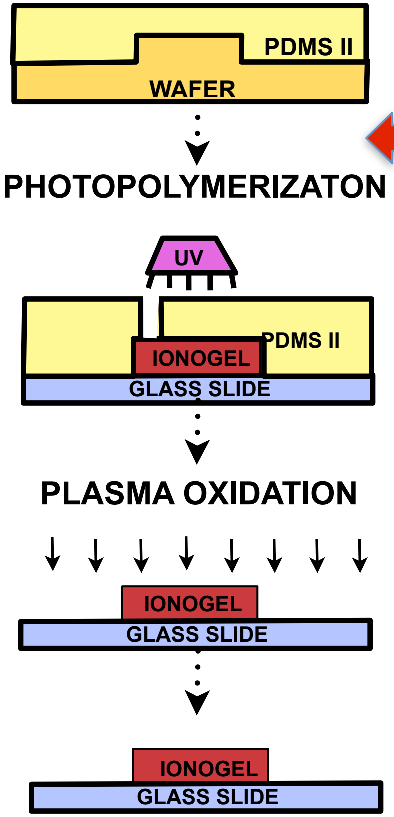
Fabrication

I MICROCHANNELS

II MICROVALVES

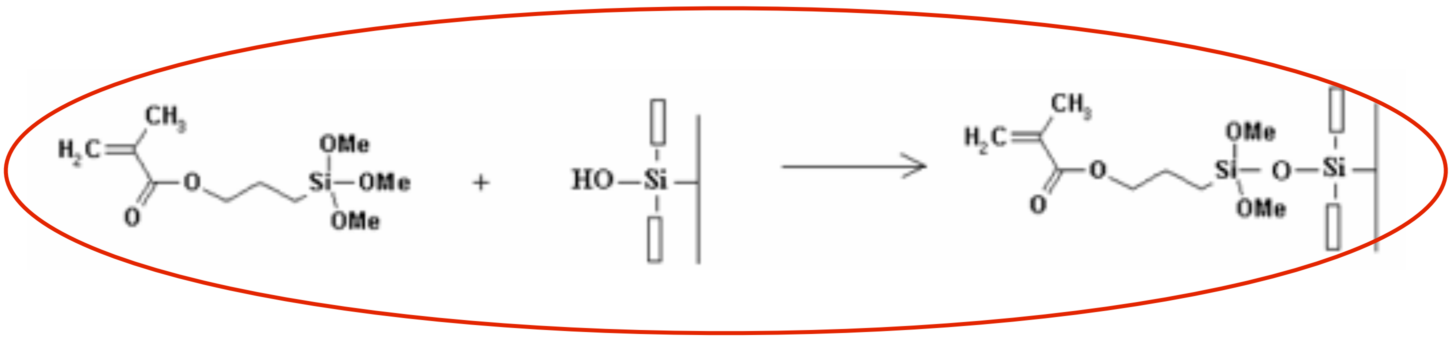


Surface modification of glass substrate



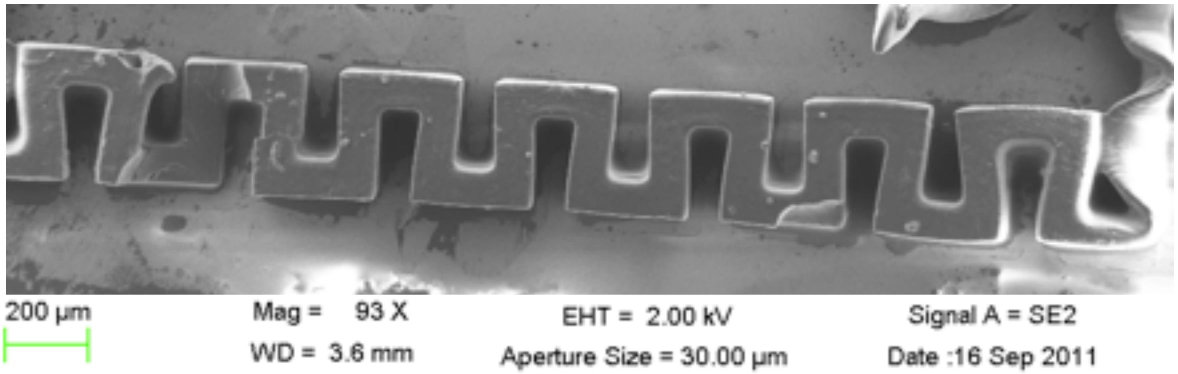
SILANISATION

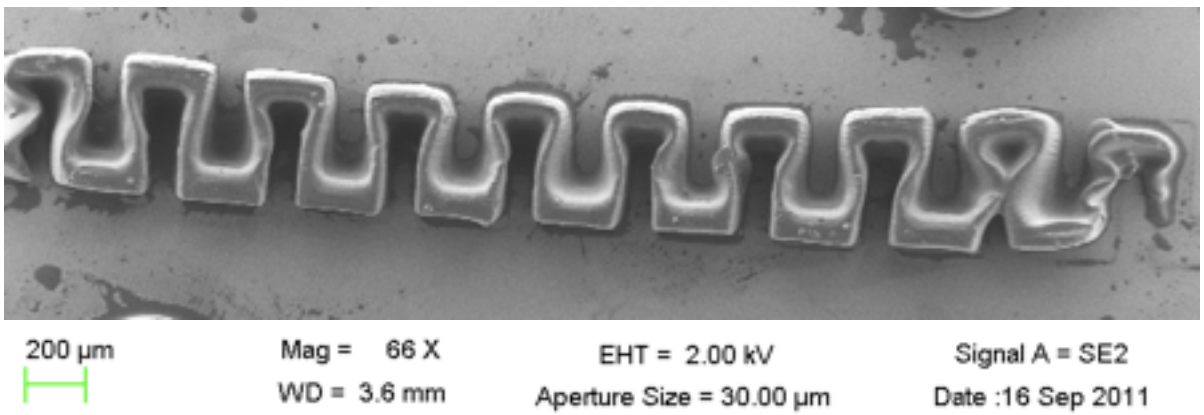
- dipping in 1M NaOH solution - 30 minutes,
- dipping in water solution of silane agent - 30 minutes: **(3- (Trimethoxysilylpropylmethacrylate)**



[8] B. Candice, A Two-Chromophore photolithography photopolymerization, IPM Fraunhofer, 2010

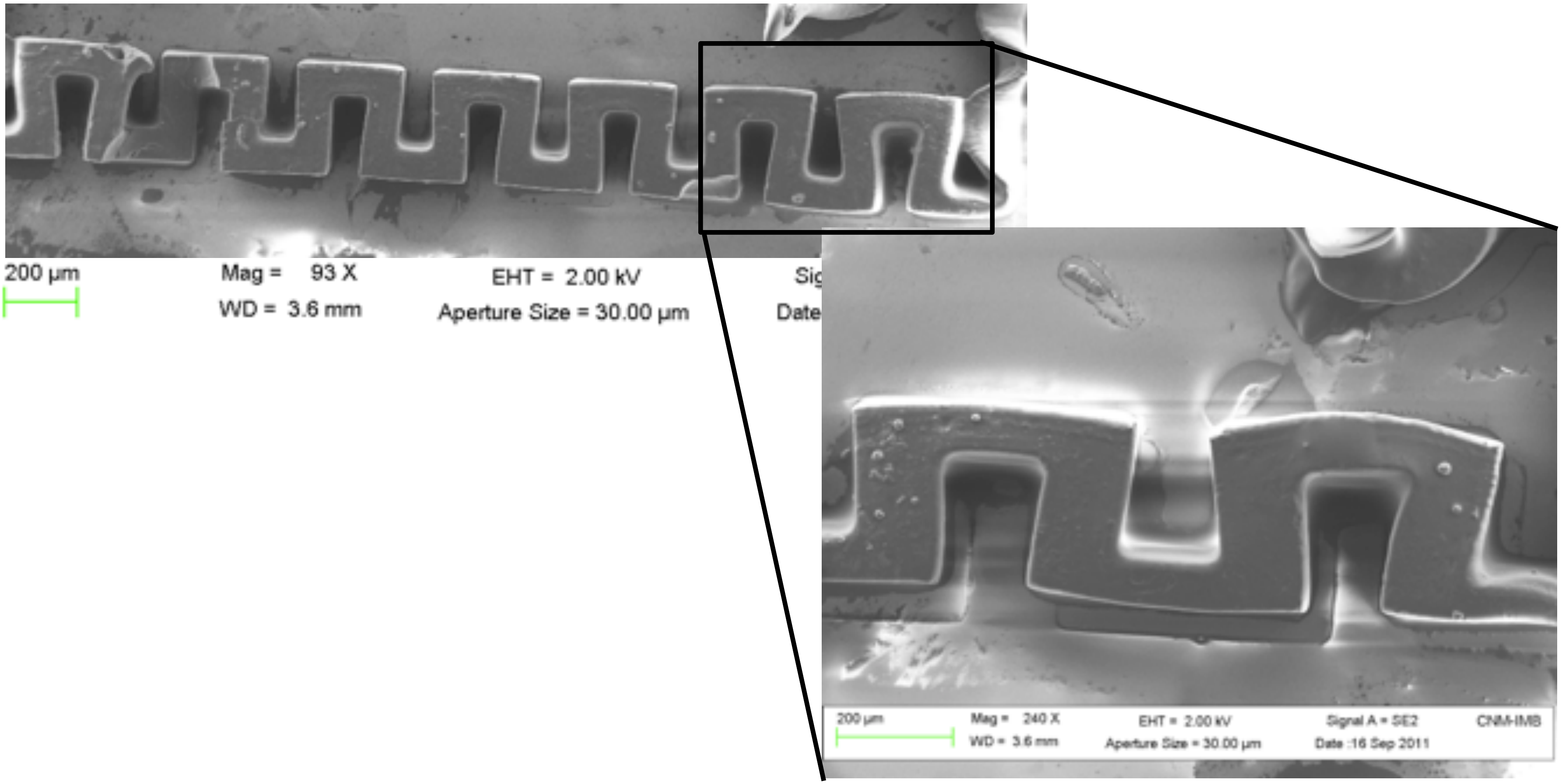
Ionogel microvalves: SEM Pictures





Ionogel microvalves: SEM Pictures

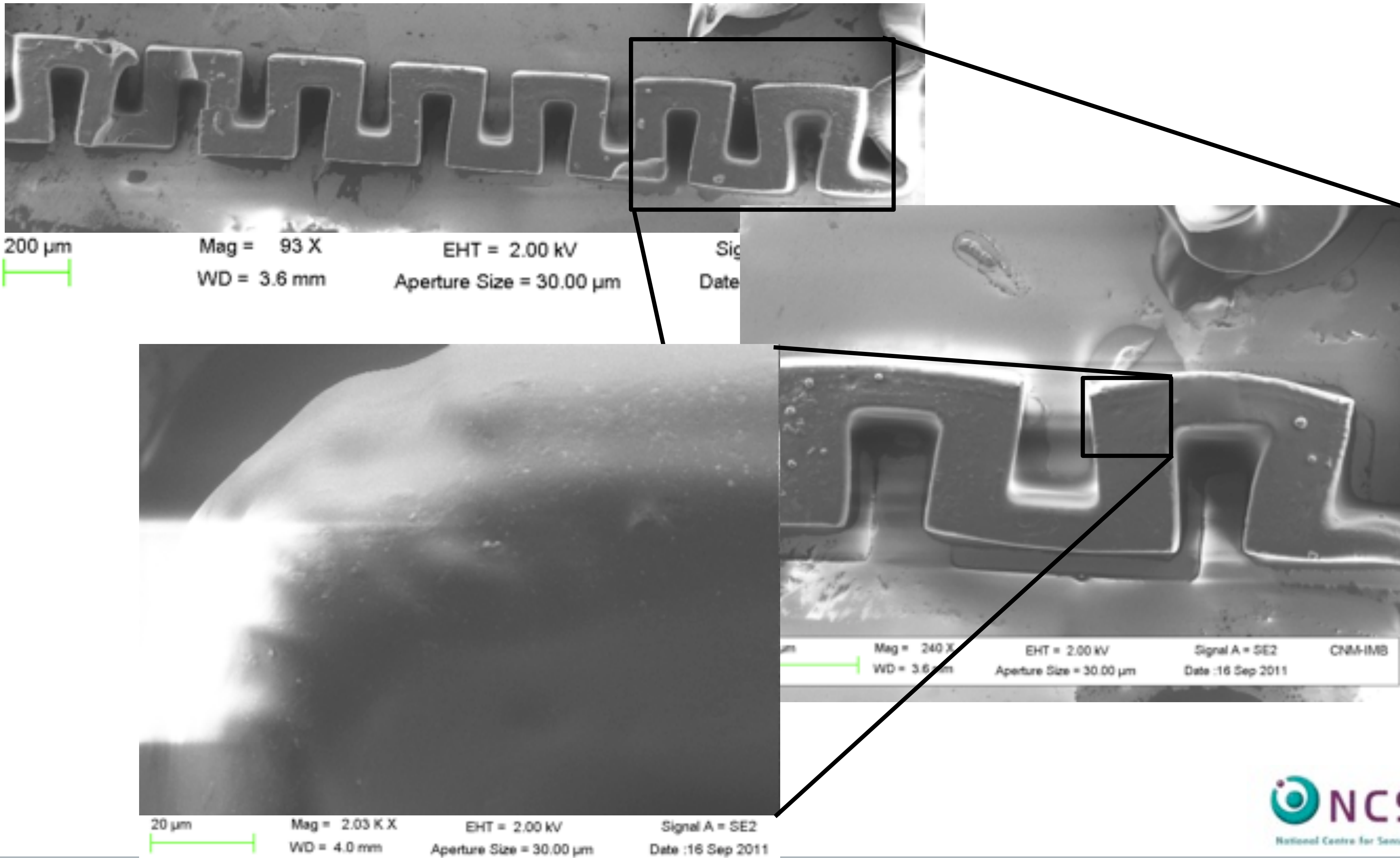
CLARITY
clarity-centre.org



NCSR
National Centre for Sensor Research

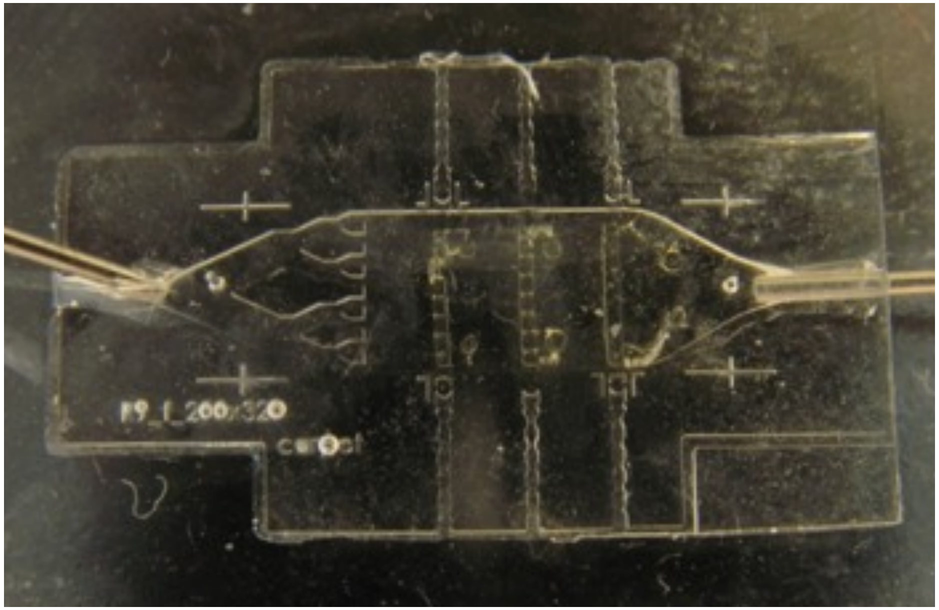
Ionogel microvalves: SEM Pictures

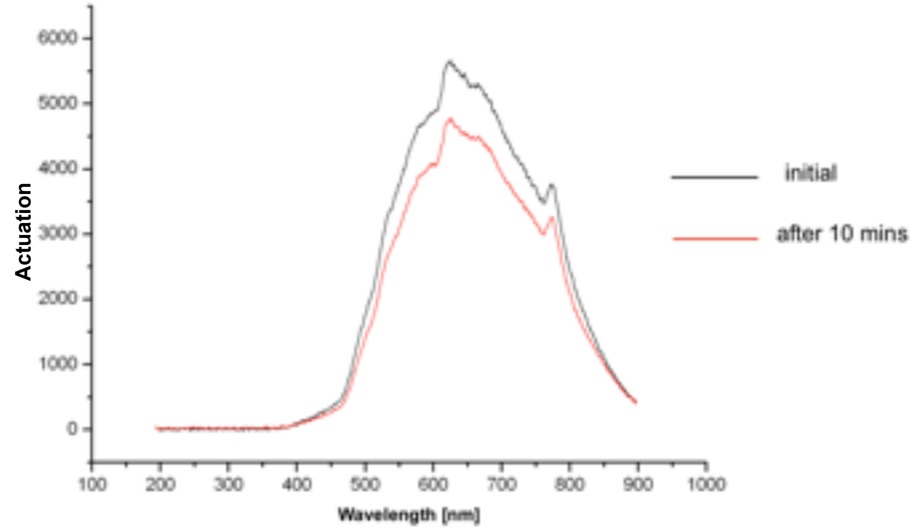
CLARITY
clarity-centre.org



NCSR
National Centre for Sensor Research

Fabricated Microreactor





Fabricated Microreactor

CLARITY
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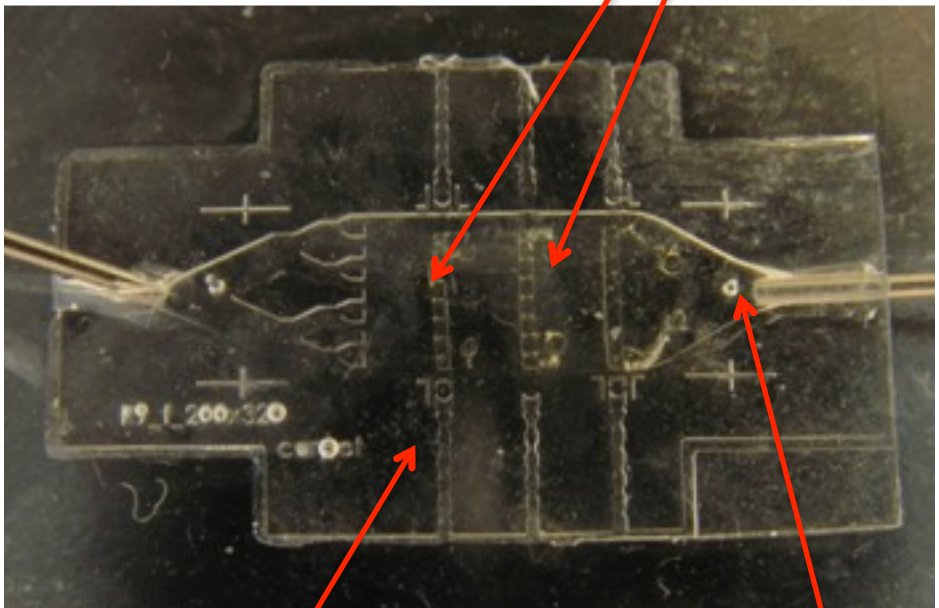
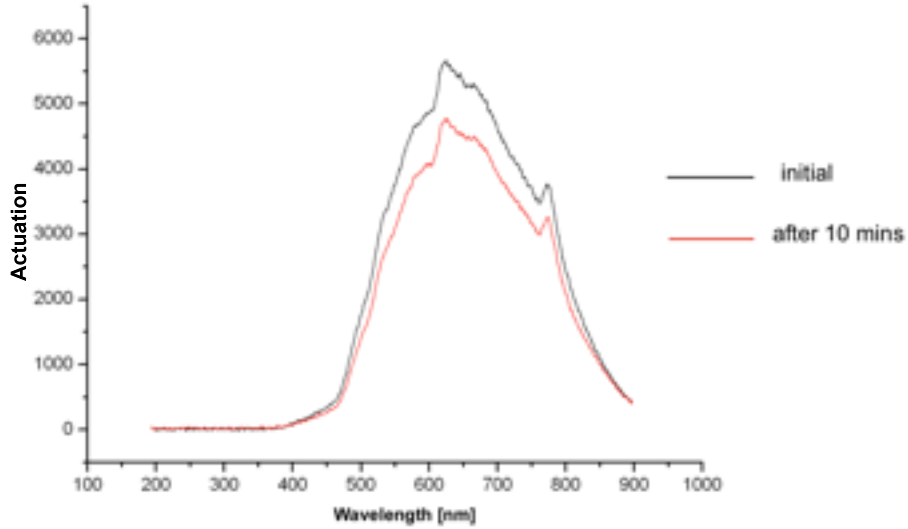
MICROVALVES



PHOTONIC CHANNELS

MICROCHANNEL



NCSR
National Centre for Sensor Research

Conclusions

Water Quality Sensor

- A novel optical sensing configuration for lab-on-a-disc water quality measurements applications has been developed

- The CD designed for multi-parameter water analysis allows not only for pH measurement, but also solid contamination.

- This device will be of special interest in samples with a relatively high level of solid contaminants that could interfere with optical analytical measurements.

Ionogel Microvalves

- Photoswitchable microvalves were successfully fabricated.

- Rapid and significant change in volume up to 20 %.

- Successful actuation by optical microfibres.

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Thank You for Your Attention!