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

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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

- 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: microorganisms, biologically active contaminants

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?

Water Sensors

- portable
- cheap
- single probe
- no data saving

+ hand-held device
+ multiprobe
- $$$

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.

Our Sensor: Lab-on-a-Disc

- Top Disc w/ Access Holes
  1.5 mm PMMA

- Top Adhesive w/ Microchannel
  ~86 um PSA

- Middle Disc w/ Chambers
  1.5 mm PMMA

- Bottom Adhesive w/ Channels
  ~50 um PSA

- Bottom Disc
  1.5 mm PMMA
Our Sensor: Lab-on-a-Disc

**SOLID CONTAMINANTS**

- > 85 um

**SENSING AREA**

- < 85 um
Our Sensor: Materials

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

Our Sensor: Materials

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

- Ionic liquids (ILs) are low melting point salts (<100°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.

Our Sensor: Materials

A) 

B) 

C) 

In Ionogels

Acidic environment

Basic environment

Bromocresol Purple pH dye (pKa=6.3)

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!

Our Sensor: Wireless Paired Emitter Detector Diode Device

- XBee RF Module
- Battery
- Arduino Fio microcontroller
- PEDD system
Calibration of the sensor

Ionogel $pK_a = 6.6$  Bromocresol Purple $pK_a = 6.3$
On-Chip Water Analysis: Sampling

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 EPA 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 discoloration 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
On-Chip Water Analysis: Sample Loading during rotation

![Image of a microfluidic device with sample loading during rotation.](image-url)
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
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
2: Air release
3: Centrifugation at 1500 rpm
4: Solid contaminants
On-Chip Water Analysis: Sample Loading during rotation

CD-chip during centrifugation at 1500 rpm.
On-Chip Water Analysis: pH

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

On-Chip Water Analysis: pH

Water pH analysis using a commercially available pH-meter

On-Chip Water Analysis: Turbidity

Filtering

CONTAMINATED SAMPLE (No. 3)

CLEAN SAMPLE (No. 8)

UV-VIS spectrometer (transmittance)

CD: pH 7.83
Meter: pH 7.75

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.

A)

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

A) ionic liquid: trihexadecyl-tetradecyl phosphonium chloride $[P_{6,6,6,14}][Cl]$
Photoswitchable Materials

A) [Chemical structure image]

B) [Chemical structure image]

C) [Chemical structure image]
Photoswitchable Materials: Actuation Mechanism

 SPIRO
(Hydrophobic)

(H contracted)

H^+, solvent

(less Hydrophobic)

MERO-H^+
(expanded)

White light

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

Photoswitchable Microstructures

Photoswitchable Microstructures

150 um  →  84 um

smallest line:  
75 um  →  45 um

biggest line:  
250 um  →  170 um

Expanding and Shrinking Process

Dimensions [µm]

Measurements

1 - Initial dimensions
2 - After 2 hrs in HCl
3 - 10 mins exposure to white light
Expanding and Shrinking Process

Expanding

- Using Microscope

![Expanding and Shrinking Process Image]

970 µm → 1125 µm using 1mM HCl
Expanding and Shrinking Process

**Shrinking**

White light – 3mins 87.2%

1175 um

10 mins ±20% difference

1025 um

950 um

White Light - 10mins 80.8%

Tuesday 18 October 11
Photonic ionogel-based tunable micromixer

(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).

Fabrication

I MICROCHANNELS

II MICROVALVES

PDMS I
WAFER
PDMS I
Fabrication

I MICROCHANNELS

II MICROVALVES

PDMS I

WAFER

PDMS II

WAFER

PHOTOPOLYMERIZATION

UV

PLASMA OXIDATION

IONOGEL

GLASS SLIDE

IONOGEL

GLASS SLIDE

IONOGEL

GLASS SLIDE
Surface modification of glass substrate

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

Ionogel microvalves: SEM Pictures
Ionogel microvalves: SEM Pictures
Ionogel microvalves: SEM Pictures
Fabricated Microreactor
Fabricated Microreactor

MICROVALVES

PHOTONIC CHANNELS

MICROCHANNEL

Actuation

Wavelength [nm]

initial

after 10 mins
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!