Water sensor system utilising organic electronic transducers

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Introduction to CDT

- CDT is a spin-out Company from the Cavendish Laboratory, University of Cambridge (1992)
  - To develop solution processable Polymer Organic Light Emitting Diode technology (P-OLEDs) for Displays (TV’s) and Lighting

- Since 2007, CDT has been part of Sumitomo Chemical Company Group (SCC)
  - CDT is a Research and Development subsidiary of Sumitomo Chemical.
  - 100-strong interdisciplinary team with strong expertise in physics, chemistry, materials and life sciences
  - Supported by state of the art chemistry laboratories, cleanrooms, analysis laboratories and device prototyping capabilities

- Developing a wide range of technologies for SCC including plastic electronics based low cost printed displays, printable photodetectors and biosensors.
Biosensors and their Applications
Biosensors

Elements of a Biosensor

Samples
- Cell Cultures
- Human Samples (Blood, Urine, Saliva)
- Food Samples
- Environmental Samples (Air, Water, Soil, Vegetation)

Transducers
- a) Bioreceptor(s)
- b) Electrical Interface(s)
- Nucleic Acids
- Cells
- Antibodies
- Enzymes
- Nanowire Array
- Nanoparticles
- Electrodes

Electronic System
- c) Signal Amplifier
- d) Signal Processor
- e) Display

Dorothee Grieshaber - Open access journal article, Wikipedia
Biosensors – Wide range of applications

- Cancer diagnostics
- Cardiac panel
- Liver function
- Thyroid
- Blood electrolytes

- Nutrient monitoring
- Pathogen/fungi detection
- Plant stress
- Animal health

- Heavy metals and toxins in water
- Vector borne disease
- Cleaning validation
- Bacterial swabs
- Residual pesticide

- Clinical trials
- Manufacturing control
- Process monitoring
- Fermentation
- Drug discovery research

- Quality assurance
- Validation
- Decay
- Pathogen identification
- Safety / Residuals

- Airborne bacteria
- Viral agents
- Toxins
- Explosives

- Safety / Residuals

- Food

- Medical

- Agriculture

- Environment

- Bio-Defence

- Biotech/Pharma
Portable Biosensors

Lab based equipment
- expensive
- centralised labs
- results can take days to weeks
- Expert operated

Vs

Portable
- inexpensive
- suitable for doctors office, farmers field
- instant results
- low expertise

- Rapidly growing market
  - Medical segment growing to $18.5B by 2020
- Drivers for growth
  - Distributed vs. centralised testing → Point of Care diagnostics
  - Faster turn-around
- Quantification and integration with electronic record desired for portable biosensors

Sources: Trimark, Sensormag, Clinical Laboratory News

Portable biosensors market revenue, $B

2013 2015 2020

1.9 2.2 3.3
10.9 12.6 18.5

Security and biodefense
Process industries
Research labs
Agriculture and environment
Medical

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Portable Biosensors – example applications

**Medical**
- Cancer diagnostics
- Cardiac panel
- Liver function
- Thyroid
- Blood gases and electrolytes

**Agriculture**
- Nutrient monitoring
- Pathogen/fungi detection
- Plant stress
- Residual pesticide/herbicide
- Animal health and husbandry

**Environment & Environmental Health**
- Heavy metal contamination
- Water test panel
- Vector borne disease identification
- Cleaning validation and bacterial swabs
- Food Safety and validation
Printed Electronics Optical Biosensors
Printed Electronics Biosensors

- Organic Electronic components as optical reader for biosensor
- Integration with lateral flow or micro-fluidic device
  - Disposable, single use quantitative biosensor

- Cost effective printable multi-channel system for multiplexed assays
  - Multi-biomarker panels
  - Extended dynamic range
  - Redundancy and repeats

- Thin, light-weight elements with planar emitters and detectors have potential for low coefficient of variation
  - Proximity integration of optical & fluidic elements
  - Reduced alignment errors
  - Area average over test & control lines

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Fluorescence Mode Optical Biosensors

Labelled Biosensor

Bio-molecules labelled with Fluorescent markers

Switching Labelled Biosensor

Organic LED (light source)

Blue Colour Filter

Red Colour Filter

Organic Photo-Detector
Elements of Printed Electronics Optical Sensor

- Organic light-emitting diode (OLED): source of excitation light
- Short pass filter: reduces width of excitation light, reducing leakage through sensor
- Sample cell (eg Microfluidics or lateral flow membrane): controls mixing of reagents and provides measurement area for fluorescent indicator
- Long pass filter: selectively allows fluorescence from assay to pass while blocking background excitation light
- Organic photodiode (OPD): collects and transduces fluorescence from assay into an electronic signal (current or voltage)
OLED and OPD

Blue OLED emission

Normalised Intensity

Wavelength (nm)

OPD EQE

EQE (%)

wavelength (nm)
Solution deposited filters

- Filters formed from printable ink onto plastic substrates
- Solution cast or screen printed to give thick, high optical density filters
- With filtered OLED, there is no overlap between OLED emission and transmission band of high pass filter
Printed Electronics Ion Sensors
Optical Fluorescence Ion Sensors

- Switching fluorescent indicator used
- Different indicator for each ion
- Ca, K, Na channels demonstrated
- Aqueous ion solutions for calibration files
Mixed Ion Solutions

- 3 different solutions with different concentrations of 3 ions
- Sensor response shows *unique pattern* for each solution of mixed ions
- Array analysis can allow quantification of the ion concentrations
Application relevant levels for Ion Panel

- Confirmed affinity of indicator determines concentration range detectable
- Indicators with appropriate affinity can be selected for specific applications

![Graph showing concentration levels for Ca^+ and Na^+ ions with high and lower affinity, and concentration levels for K^+ ions demonstrating measurement in hydroponics solution and blood.](chart.png)
Ion Sensor System Demonstrator
OLED/OPD for 4-Channel Micro-fluidic

- Fluidic chip developed
  1. Single entry port
  2. Control channel
  3. Ion channel (Ca, Na, K)

- Fast even filling of channels
- No intermixing
- Fast and uniform reaction between sample and ion indicators
4-Channel Micro-fluidic

- OLED and OPD multi-element illumination and detection devices made
- Design accurately couples OLED to OPD via each channel
Electronics Interface

- OLED drivers
- OPD read-out electronics
- Micro-controller

Cartridge assembled with: OLED/filter/fluidic chip/filter/OPD
Identification of test ion solution

< 5 minute assay

High Potassium detected,

Test Solution
2mM NaCl
20mM KCl
Protein Sensing & other biomarkers
Fluorescence-based immunoassay

- Glass
- Capture antibody
- Antigen
- Reporter antibody (enzyme-tagged)

Enzyme amplification provides enhanced fluorescent signal
**Model Protein - CRP**

**C-Reactive Protein - CRP**
- C-reactive protein is a protein found in blood plasma
- The levels rise in response to inflammation, sepsis, cardiac stress

**Test methodology**
- Fluorescence using OLED as source and OPD as detector
- Flow-cell used as model for micro-fluidic channel

- Limit of detection demonstrated
  - 300pg/ml = ~ 10 pM
- Aqueous buffer matrix and Horse Serum has been demonstrated
Detection of biomarkers demonstrated

<table>
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<tr>
<th>Biomarker Class</th>
<th>Ions</th>
<th>Small molecules</th>
<th>Proteins</th>
<th>DNA/RNA</th>
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<td>Biomarker</td>
<td>Fluorescence</td>
<td>Fluorescence</td>
<td>Fluorescence</td>
<td>Organic Transistor</td>
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<tr>
<td>Limit of Detection</td>
<td>Na, K, Nitrate/Nitrite</td>
<td>&lt;10 µg/ml</td>
<td>&lt;10 µg/ml</td>
<td>DNA</td>
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<td></td>
<td>Ca</td>
<td>Glucose</td>
<td>C-reactive Protein</td>
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<td>0.4-60 µg/ml</td>
<td>&lt;10 µg/ml</td>
<td>300 pg/ml</td>
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Summary

- Demonstrated Printed electronics based biosensors based on optical fluorescence
  - OLED Light source
  - Organic Photo-detector
  - Printable filter-set

- Multi-channel ion demonstrator integrating fluidic sample handling and OLED/OPD transducers

- Protein sensing also demonstrated using labelled antibodies

- Enzymatic assays for bio-molecules also compatible with OLED/OPD sensors

If you are interested in working with CDT to co-develop biosensors to address a specific application, please visit the CDT Booth in the LOPE-C Exhibition to discuss how we might collaborate (Hall B0 stand 306)