

Optical enhancement strategies on centrifugal microfluidic water sensors for detection of phosphate

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Background

Phosphorous is one of the principle elements contributing to eutrophication[1] in coastal, marine and fresh water. This study aim to develop new technologies that can enabled near real-time, rapid, reliable and robust analysis of water nutrient levels, such as phosphate, in water systems.

Herein, describes an enhancement study of a previously demonstrated lab-on-a-disc (LOAD) centrifugal microfluidic device for the detection of phosphate in freshwater. The LOAD device utilizes a microfluidic sample processing to enable high precision metering and reagent mixing, followed by colorimetric analysis (at 880 nm) of the resultant complex. A customisable and complementary, in-house analysis system was also developed to enhance user interaction and enable rapid analysis. This analysis system delivers both disc centrifugation and automated colourimetric detection of the LOAD device, with recording of data transmitted via PC interface. The aim of this study is to maintain the same level of sensitivity of the current[2] system with a reduced pathlength. The limit of detection (LOD) and limit of quantification (LOQ) for this new revised system are as follows: The blackened chip obtained the best sensitivity with an LOD and LOQ of 6 and 19 $\mu\text{g L}^{-1}$ respectively.

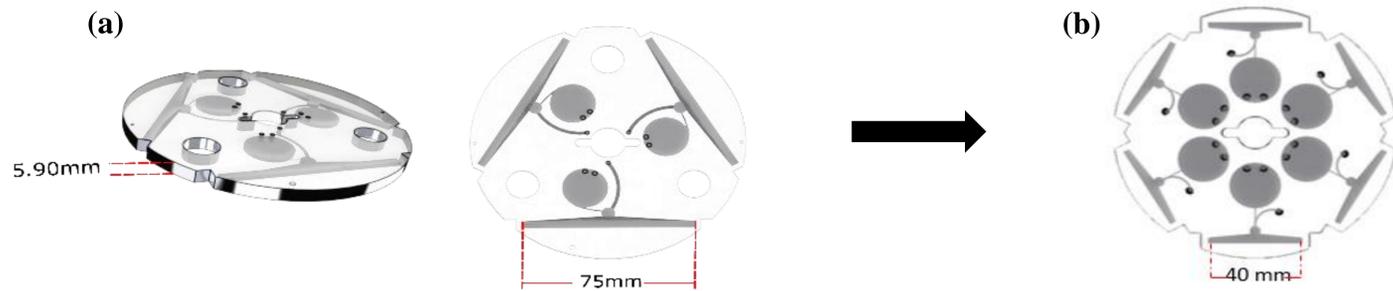


Figure 1 (a) 3 analyte microfluidic disc and (b) new proposed design for the six-analyte disc, with a shorter pathlength of 40mm.

The Vision

The aim of this work was to optimise the phosphate sensor such that six measurement reservoirs can be incorporated on a single disc. The current prototype system[1] is a handheld device that allows for three measurements to be taken per disc. To facilitate the increased number of tests on the disc, modifications are carried out on a shortened pathlength to maintain the same sensitivity achieved by the original 3-analyte disc design.

Optical enhancement techniques were carried out within the detection channel to increase the signal that is delivered to the detector. The main techniques discussed in this work are blackening the chip and manual roughening the chip channel using different grades of sandpaper.

The new LOAD device aims to overcome the limitations of the previous prototype by incorporating optical enhancement techniques within the detection channel of the disc to ensure that the same sensitivity is being maintained. The width of the detection channel has been increased to facilitate an increase in volume of liquid enclosed within the test chips, this also aims to help maintain the sensitivity obtained by the current prototype system.

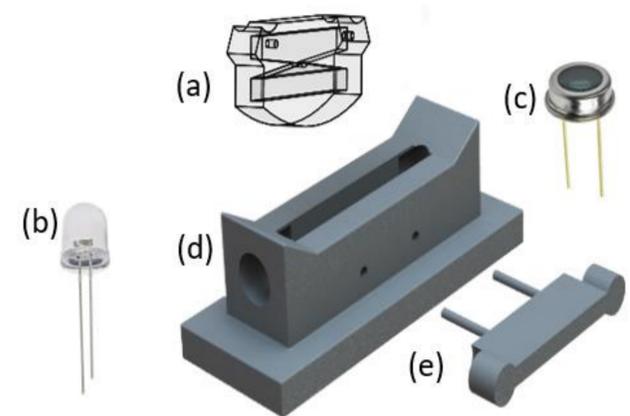


Figure 2 This image displays the test bench set up that was used to carry out all experiments on the modified detection channels within the microfluidic chips. (a) microfluidic test chip, (b) LED, (c) PD, (d) 3D printed test bench and (e) alignment pins.

Optical Enhancement Techniques

Surface modifications were tested within the detection channel of the microfluidic chips to enhance their optical performance, these included matt black paint and roughening of the microfluidic test chips manually with different grades of sand paper. The blackened test chips acted as a barrier and inhibited external light from getting into the detection channel. External light is also referred to as stray light, this is the action of light being detected that is not from the intended source. The black coating was tested to investigate the reduction of this stray light therefore, decreasing the amount of noise in the system.

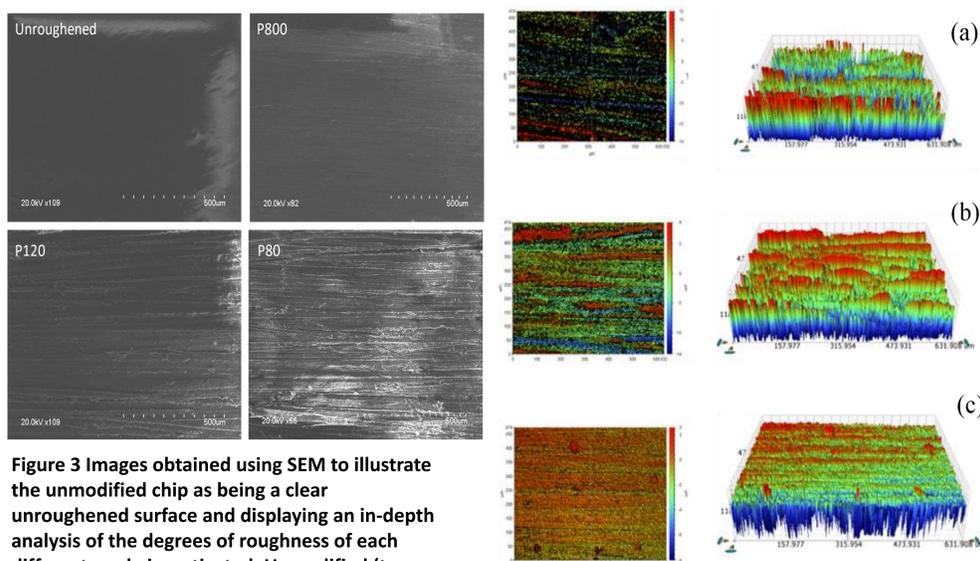


Figure 3 Images obtained using SEM to illustrate the unmodified chip as being a clear unroughened surface and displaying an in-depth analysis of the degrees of roughness of each different grade investigated. Unmodified (top left), P800 (top right), P120 (bottom).

Figure 4 Images taken on the Contour Profiler Instrument to investigate the effects of the different grades of sandpaper. (a) P80 (top), (b) P120 (middle) and P800 (bottom).

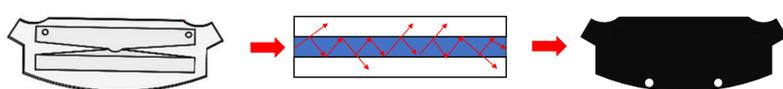


Figure 5 Schematic of internal light escaping and getting "lost" in the bulk material. And the proposed solution of blackening the chip.

Catchment Area of Interest



Figure 6 Sentinel 2 satellite image of the Burrishoole catchment, layered with GIS coordinate sampling data.

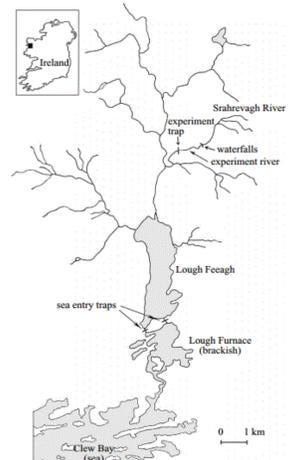


Figure 7 Burrishoole catchment, map conveying the complexity of the water system, both fresh and marine water mixing.[3]

Results And Conclusion

A method of decreasing detection channel length without a significant reduction in sensitivity has been developed by using optical enhancement techniques. The use of roughening and blackening the test chips shows a significant increase in sensitivity compared to the untreated chips. Achieving an LOD OF 6 $\mu\text{g L}^{-1}$ compared to that of the unmodified which obtained 15 $\mu\text{g L}^{-1}$ $\text{PO}_4\text{-P}$. The modification that achieved the best result was the blackened chip. Roughening of the detection channel showed an increase in sensitivity as the grade of roughness increased, hence conveying a correlation between roughness and sensitivity.

Table 1 Comparison of treated versus untreated test microfluidic chips.

Treated Chip	Values for LOD and LOQ	
	LOD ($\mu\text{g/L}^{-1}$)	LOQ ($\mu\text{g/L}^{-1}$)
Black	6.4	19.4
P80	12.8	38.4
P120	13.3	40.1
Unmodified	15.3	45.9
P800	18.5	55.5

[1] D. Verheyen *et al.*, "Dissolved phosphorus transport from soil to surface water in catchments with different land use."

[2] Duffy, G., Maguire, I., Heery, B. "PhosphaSense: A Fully Integrated, Portable Lab-on-a-Disc Device for Phosphate Determination in Water," Sensors and Actuators B: Chemical, 246, 2017, 1085-1091.

[3] <http://fisheye.ucc.ie/marine-institute-newport/burrishoole-catchment/>