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The Development of Optical Chemical Sensors using Inkjet Printing

key parameters include accuracy, reproducibility and cost

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Objective

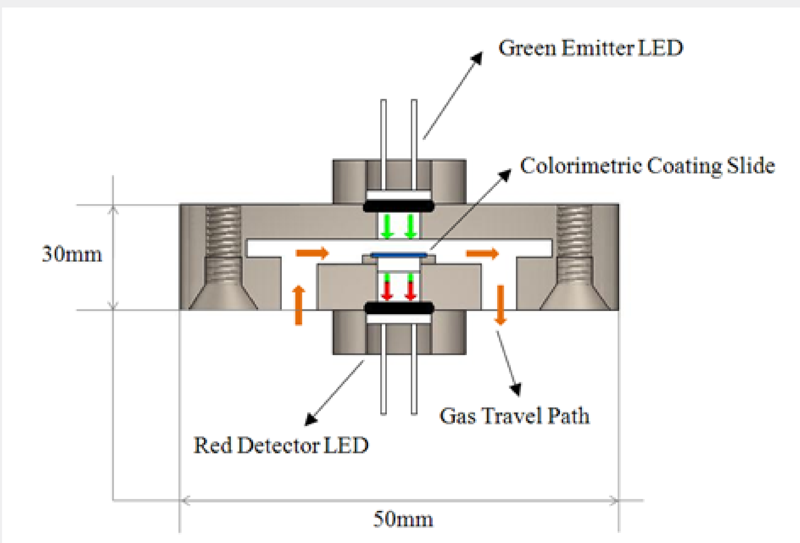
The optical sensor industry is forseen to become a $4 billion market worldwide within 10 years [1]. This projected figure suggests the incorporation of wireless sensor networks into our daily lives. In order to achieve this, many hardware requirements have already been met, with many of the world's top university involved in wireless "mote" development. The objective of this study is to prove that inkjet printed sensors will be compatible with these motes in terms of both accuracy and more importantly reproducibility.

Background

The sensing setup is based on the paired emitter detector diode (PEDD) light capture system. This system is coupled with a colorimetric chemical sensitive coating. The coating modulates penetrating light, providing an indirect chemical concentration measurement. There is potential for these sensors to be coupled with wireless "motes" to create wireless sensor networks. However, although the production cost is minimal, expensive manual calibrations are inhibiting such deployment potential. This study investigates the reproducibility of inkjet printed chemical sensors. It is hoped that sensors could be be characterised in batches through a single calibration.

Experimental Setup

In order to test the reproducibility of the inkjet printed optical sensors, a 10 point calibration was carried out. The calibration was implemented over the range from 0.1 mg/L to 1 mg/L acetic acid in air. The tests were carried out on optical slides, in a purpose built flowcell shown below.



Future Work

- **Deployment:** With the limit of detection of these sensors proven to be 13 ppb [2] and inkjet printing proven to create reproducible sensors, a logical step would be a lab deployment of multiple inkjet printed sensors.
- **New Dyes :** The Development of new dyes will lead to sensing of a wider pH range and potentially other compounds.

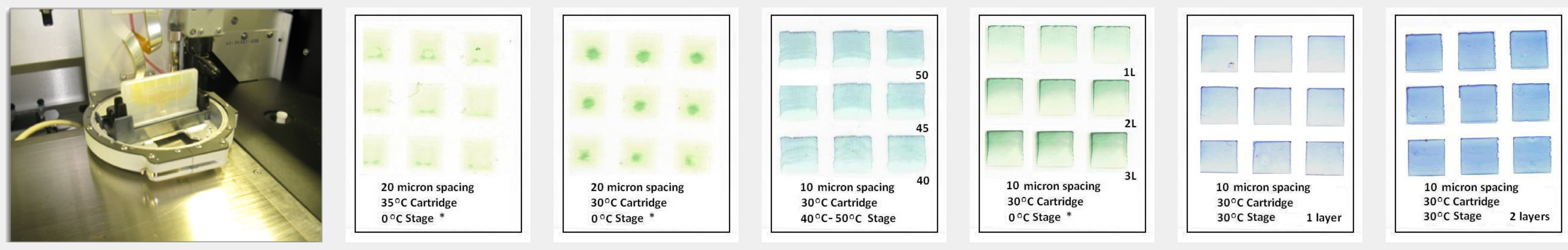
References

[1] J. Li, Y. Lu., Carbon Nanotube Based Chemical Sensors for Space and terrestrial Applications, *35 Years of Chemical Sensors- An Honorary Symposium Celebration*, 2009,(6).

[2] D. Orpen, C. Fay, S. Beirne, K.T. Lau, B. Corcoran, D. Diamond., The Optimisation of a Paired Emitter-Detector Diode Optical pH Sensing Device, *Sensors and Actuators B: Chemical*, 2010,*In Press*.

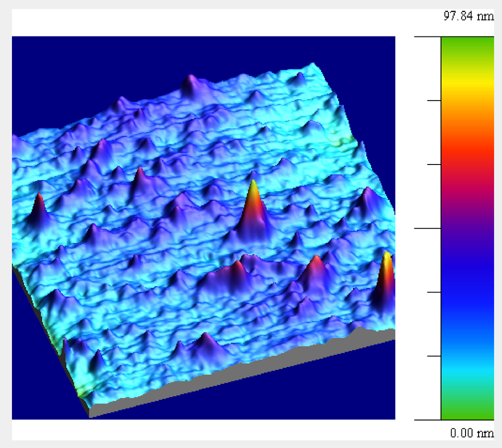
Print Optimisation

Inkjet printing requires delicate control of its variables in order to create homogenous films using novel inks. The butanol based ink, in this case, presented challenges in printing it effectively. A series of experiments were carried out in order to find the optimum deposition settings. Firstly, the ink had to be tailored to fit in the correct viscous range (13cP), and then the ink was substrate matched, in order to change a film which maintained its pH neutral state. Then the ideal printing parameters where found through single variable variation runs. Varying of stage temperature, cartridge temperature, excitation voltage and drop spacing resulted in very dissimilar films being created; where the reproducibility in the process can be lost. The following image sequence illustrates the timeline of the print optimisation.

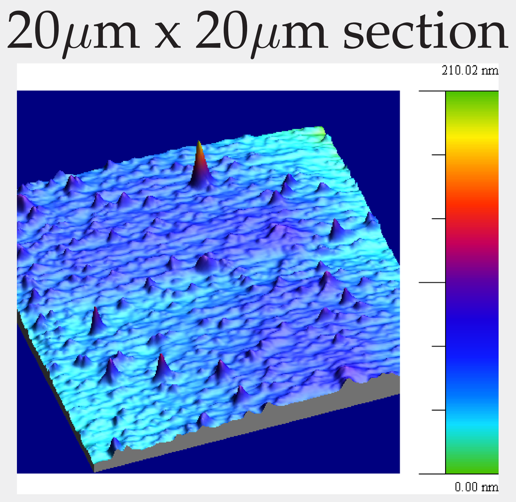


Thickness Measurements & AFM

- Multiple layer depositions led to redissolving of the solvent and heterogeneous films being created.
- Drop spacing was reduced to the minimum in order to deposit single layers of sufficient thickness. (5-7 μm).
- Thickness measurements showed agradient effect in films created, resulting from the evaporating solvent. Printing on both sides of the substrate in opposite directions was used to counter act this effect.
- Resulting films were analysed using atomic force microscopy. (Measured RMS values between 7-12 nm).
- These low RMS values suggested that they would work well as optical sensors and also highlight the uniformity in the films.



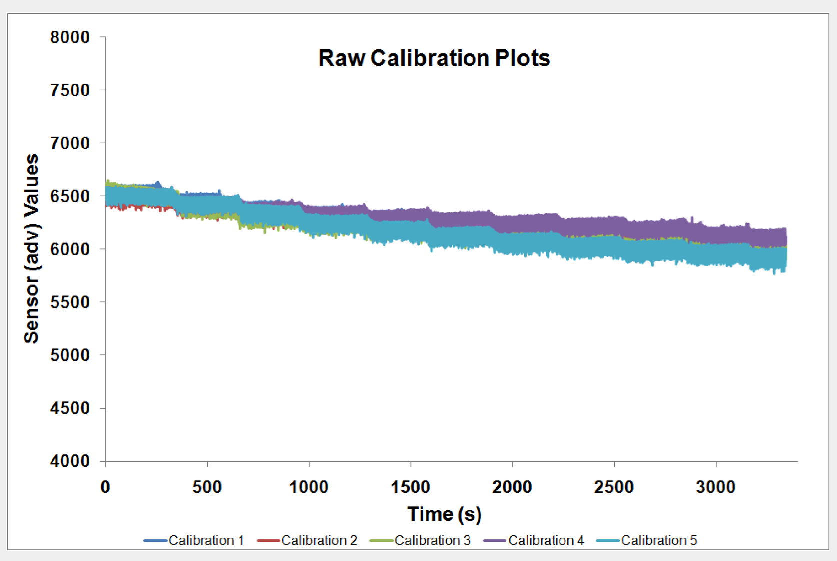
20μm x 20μm section

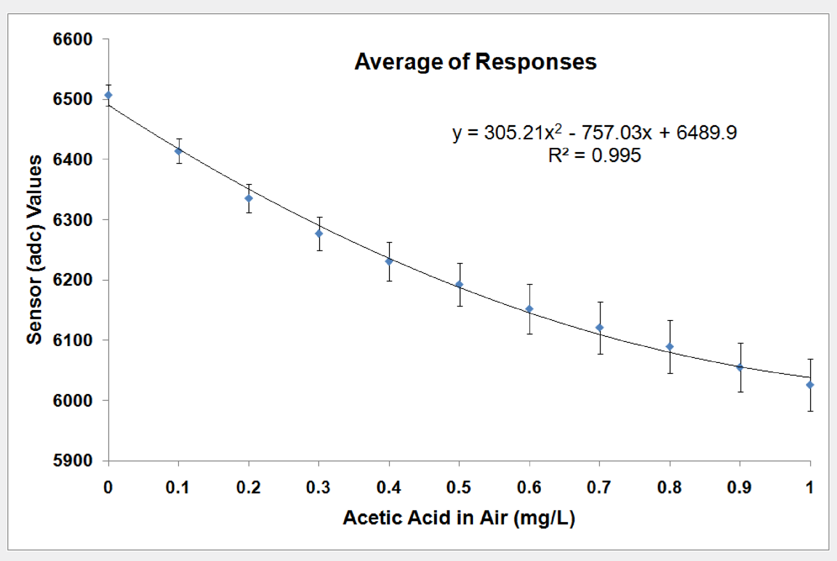


80μm x 80μm section

Reproducibility Results

Although thickness and AFM results have suggested high reproducibility within the process, the key goal was to create films that operated as identical chemical sensors. A 10 point calibration was carried out with five separate slides printed in the same batch. Results were normalised and a calibration curve developed. The raw data can be seen on the left hand figure. The right hand figure contains the averaged response to each injection from each of the five slides, as well as error bars representing the standard deviation of the responses to the calibration.





Conclusions

- Inkjet printing of chemical sensors has been successfully achieved.
- Layers operate similarly over the range of 0.1 mg/L to 0.3 mg/L acetic acid in air.
- The maximum RSD between the 5 sensors over the entire calibration was shown to be 1.4 %.
- Wet layers disolving into dry layers inhibited reproducible multiple layer deposition.
- However, this study proves that the process is ideal for the creation of thin film, trace sensors.

Acknowledgements

The authors wish to acknowledge the contribution from the many personnel worked on the PEDD chemical sensing technique. This work is supported by Science Foundation Ireland under grant 07/CE/I1147.