

Design and Fabrication of a Multianalyte-Capable Optical Biosensor Using a Multiphysics Approach

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Abstract—An evanescent-wave biosensor was designed and fabricated using simple and robust microfabrication technology. The significance of the sensor is the design method, in which a multiphysics approach is used to draw from much broader field than is customary for these sensor types. The sensor uses a microscale SU-8 optical waveguide that is surface-altered with a custom chemical modification process, coupled with modified self-assembly of a fluorescent dye and enzyme. To interface the analyte with the waveguide surface, a multilayer PDMS fluidic mold is designed to fit over the waveguide. Interfacing of both optics and fluidics are achieved using specifically-designed couplings. The entire device has been successfully fabricated and assembled, with preliminary analyte response testing completed.

Keywords – Multiphysical, biosensor, design.

I. INTRODUCTION

THE design and development of cutting-edge microanalysis systems has consistently centered on elemental design, particularly towards characterization of single components. Generally, these studies are limited to one or two engineering fields, such as enzyme interaction with a simple electrical system in the case of an amperometric oxygen biosensor. Use of more complex physical systems can lead to much more capable systems, provided the designer is willing to deal with the possible interactions. For example, an optical chemical sensing system can be combined with an enzymatic system to produce a very flexible biosensor. However, the convolution of design interactions can easily produce unintended difficulties in fabrication, packaging and operation of an integrated system. For a microanalysis system design to be practical, regardless of the application, all elements of the fabrication, testing and final use must be considered at the design outset. The purpose of this study is to examine the interactions of a biochemical sensing system designed using this philosophy to better understand the design implications from conceptual stages to final implementation.

II. METHODOLOGY

The optical waveguide is composed of a 130 μm x 130 μm SU-8 strip waveguide fabricated on a glass substrate, with integrated packaging to 125 μm silica fibers. The choice of waveguide materials was important in the initial design stages, as the surface properties of the waveguide affected the dye/enzyme immobilization process, and ultimately required the development of an entirely new SU-8 surface modification process. The waveguide was modified using sulfuric acid to render the surface negatively charged at

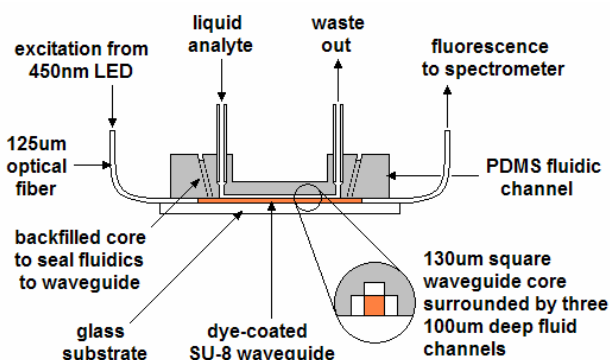


Fig. 1. Diagram of assembled SU-8 waveguide sensor. The unusual cross-sectional area of the fluidic channel was created to limit the analyte exposure to the waveguide surfaces, allowing only 1-dimensional analyte diffusion to the immobilized dye/enzyme.

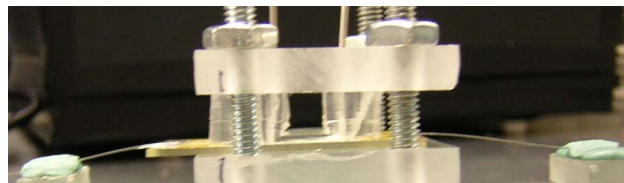


Fig. 2. Photograph of assembled sensor. The excitation and emission optical fibers can be seen entering and exiting the device. The PDMS above the fluid channel (also shown in Figure 1) was thinned to allow rapid diffusion of oxygen to the fluid and waveguide surface.

neutral pH and capable of supporting electrostatic layer-by-layer self-assembled films. To accelerate the self-assembly process, spin assembly of the dye film is used [1-2]. The oxygen-sensitive dye tris(2,2'-bipyridyl dichlororuthenium) hexahydrate was used as a transducer molecule for the enzyme glucose oxidase [3-5]. An interpolyelectrolyte complex of the dye with the negatively-charged polyion poly(sodium styrenesulfonate) (PSS) was created and alternately layered on the surface of the modified waveguide with positively-charged polyion poly(diallyl dimethylammonium) chloride (PDDA). Glucose oxidase was then layered over the dye film using conventional layer-by-layer self-assembly with the polyion poly(ethyl enimine) (PEI). A PDMS channel fabricated using a multilayer SU-8 mold was mated to the waveguide structure. The channel was designed to restrict diffusion of the analyte to the enzyme from solution to a single direction, facilitating the use of single dimension, transient, finite-difference equations to model the system. The significance of this technique was that the fluidic system was modified based on the analyte/oxygen diffusion model, rather than attempting to create a three-dimensional model of a simpler fluidic channel. Optical packaging of the waveguide was also simplified by using a monolithic

interface with self-aligning interconnects, avoiding the requirement for conventional optical alignment systems but required re-design of the waveguide system [6]. Packaging of the PDMS channels was achieved using a simple, yet extremely robust and reusable process of coring ports with a modified 20-gauge syringe needle. Stainless steel tubes of the same dimensions as the needle outer diameter into the cored ports were then compression fitted into the cored ports. Alignment of the connecting tubing to the microfluidic channel was guaranteed using this technique, and angle-cored ports were also fabricated to provide sealing of the fluidic channel to the waveguide. Limited characterization focusing on multiphysical interactions of each component of the sensing system was performed, and the completed device was tested using solutions of glucose.

III. RESULTS

Despite the complex, multiphysical nature of the device, fabrication interactions were minimized by innovative techniques during the device inception and design. Significant convolution of design was addressed involving the optical waveguide and microfluidic structure, although the design evolution prioritized the waveguide and its packaging ahead of the fluidics. Meshing of the waveguide with the self-assembly process (via surface modification) proved to be an unexpectedly significant part of the design and characterization process, leading to development of peripheral techniques in waveguide design [7]. Separate testing of the PDMS-syringe needle interconnects yielded outstanding robustness and flexibility, and demonstrated capability for almost any PDMS-based microfluidic device [8]. Preliminary testing of the completed device has demonstrated successful detection of glucose, although correlation of test data to the model has not yet been completed.

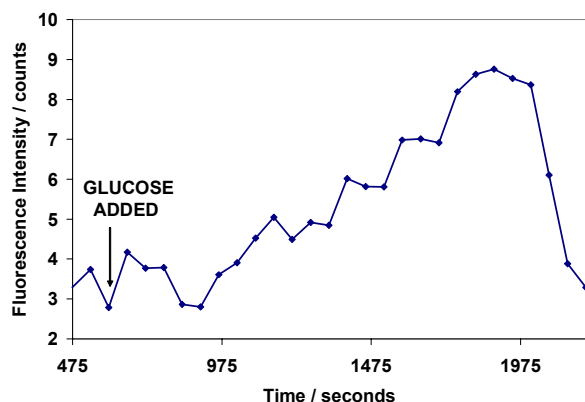


Fig. 3. Drift-corrected and normalized sensor response to a 10mg/mL glucose solution. The time taken for the fluorescence to return to the initial baseline value is proportional to the analyte concentration. The drift was observed to be a linear decrease over time, theoretically due to dye photobleaching. The bleaching effect was reversible with time, indicating a non-permanent deactivation of the dye.

IV. CONCLUSIONS

A microfabricated glucose sensor was successfully designed and fabricated using a multiphysics approach. The design philosophy can be applied to any biosensor design, allowing more creative solutions to be found for unique sensing issues. The design process also acts as a source for novel fabrication techniques, extending the field of general microsystem design. From this particular sensor design, a custom SU-8 surface modification process, a monolithic PDMS waveguide fabrication process, self-aligning waveguide packaging and an extremely robust PDMS fluidic system interconnect have evolved and can thus contribute to further studies in microsystem design.

REFERENCES

- [1] S. S. Lee, J. D. Hong, C. H. Kim, K. Kim, J. P. Koo and K. B. Lee, "Layer-by-Layer Deposited Multilayer Assemblies of Ionene-Type Polyelectrolytes Based on the Spin-Coating Method", *Macromol.*, vol. 34, pp. 5358-5360, Jul. 2001.
- [2] P. A. Chiarelli, "Polyelectrolyte Spin-Assembly", *Langmuir*, vol. 18, no. 1, pp. 168-173, Jan 2002.
- [3] D. A. Chang-Yen and B. K. Gale, "An Integrated Optical Oxygen Sensor Fabricated Using Rapid-Prototyping Techniques", *Lab-on-a-Chip*, vol. 3, pp. 297-301, Jun. 2003.
- [4] D. A. Chang-Yen and B. K. Gale, "An Integrated Glucose Sensor Fabricated Using PDMS Waveguides on a PDMS Substrate", *Proc. SPIE*, vol. 5345, pp. 98-107, Dec. 2003.
- [5] M. Fang, P. S. Grant, M. J. McShane, G. B. Sukhorukov, V. O. Golub and Y. M. Lvov, "Magnetic Bio/Nanoreactor with Multilayer Shells of Glucose Oxidase and Inorganic Nanoparticles", *Langmuir*, vol. 18, no. 16, pp. 6338-6344, Aug. 2002.
- [6] S. Camou, J. P. Gouy, H. Fujita and T. Fujii, "PDMS 2D Optical Lens Integrated with Microfluidic Channels: Principle and Characterization", *Lab-on-a-Chip*, vol. 1, pp. 40-45, Jan 2003.
- [7] D. A. Chang-Yen, R. Eich and B. K. Gale, "A Monolithic PDMS Waveguide System Fabricated Using Soft-Lithography Techniques", *J. Lightwave Tech.*, in review.
- [8] A. M. Christensen, D. A. Chang-Yen and B. K. Gale, "Characterization of Interconnects Using in PDMS Microfluidic Systems", *J. Micromech Microeng.*, in review.