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Advances in the Optical Sensor Design and Functionality for Diverse Applications

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Abstract—*Optical sensors have many applications in R&D, national defense and commercial markets such as medical diagnostics and process control. But the challenges to the design and functioning of an optical sensor for a particular application require knowledge of optical, material, and environmental properties that affect sensor performance. SENSORS address all aspects of optical sensors from source and detection technologies, sensor configurations, and processing approaches to applications. The application of the micro fabricationtechnologiesto chemical sensors is becoming very common and the number ofreports has rapidly been increasing. The advantages brought bythese technologies are: reduced size, small sample volume, andidentical, highly uniform, and geometrically well-defined elements. In some (but not all) of thecases, response becomes faster and fabrication cost is reducedcompared with macroscopic counterparts. Among various typesof chemical sensors, optical sensors will be mostbenefited from the rapidly advancing technology. In other words, miniaturization can be regarded as one aspect of the development of optical sensors. The microfabricationtechniques and the knowledge of opto-chemistry applied tothese sensors and systems are diverse. By utilizing our accumulated knowledge, it would become more realistic to construct designs which would help in on-site monitoring analytes of biological relevance. This report will be an aidin designing novel sensors of the next generation.Glass, silicon, and ceramics are indispensable substrates in fields where flexibledisposable sensors are more preferable. In such cases, plasticsheets such as polyimide, polycarbonate, and polyester are goodalternatives. We have tried to design optical sensor for dissolved oxygen and glucose using ormosils on disposable sheets.*

Keywords*: Sensors, ormosils, dissolved oxygen , glucose.*

1. INTRODUCTION

Theapplicationofthemicrofabricationtechnologiesto chemical sensors is becoming very common and the number of reports has rapidly been increasing. Recent advances in nanotechnology have made it possible to fabricate a great variety of structures with special optical, mechanical and electrical properties. The advantages brought by this technology are: reduced size, small sample volume, and identical, highly uniform, and geometrically well-defined elements. These phenomena are characteristic of the nanoscale but can usually be explained fairly well by classical physics operating on homogenous materials. For instance, plasmon resonances in metallic nanostructures emerge as solutions to Maxwell's equations [1,2], molecular adsorption can induce cantilever bending through surface stress [3] and high surface to volume ratios can cause the conductivity of semiconductors to depend on the external environment [4]. All these principles have been demonstrated to work as signal transduction mechanisms in surface-based analysis, leading to sensors operating through optical, mechanical or electrical detection [5] as the signals are induced by more or less generic molecular properties such as refractive index, mass or charged groups. Therefore, sensor specificity relies heavily on efficient surface functionalization strategies [6]. Furthermore, the integration of sensors can be realizedeasily for multianalyte detection. In some (but not all) of the cases, response becomes faster and fabrication cost is reduced compared with macroscopic counterparts. This report will be an aid in designing novel sensors of the next generation. These optical sensors range from micro-probes to large devices used for standoff monitoring of industrial and environmental species. In such cases, plastic sheets such as polyimide, polycarbonate, and polyester are good alternatives. In this report we have used ormosil films for efficient encapsulation of lumonophore and enzyme, on plastic sheets, for designing sensors for dissolved oxygen in environmental samples and glucose in blood samples.

2. RESULTS AND DISCUSSION

2.1 Methodology for film preparation

Different ratios of silaneprecursorspentafluorophenylpropyltrimethoxysilane (PFTMOS)/ *n*-octyltrimethoxysilane (C_8TMOS)/ trimethoxypropyylsilane (C_3TMOS) were taken. In detail, 0, 0.169, 0.338, 0.507 ml of PFTMOS, 0.838, 0.755, 0.671, 0.587 ml of C_8TMOS, and 0.479, 0.431, 0.383, 0.335 ml of C_3TMOS were mixed in a glass vial, respectively along the sequence. To the mixture, 1.25 ml of EtOH (22 mmol) and 0.4 ml of 0.1 N HCl (containing 22 mmol H_2O and 0.04 mmolHCl) were then added. The capped mixtures were sonicated for 2 h at room temperature. These optimized materials were sequestered with luminophorePt(II) octaethylporphine (PtOEP) and then spin-casted onto polycarbonate surface to create a thin layer xerogel.

2.2 Advantages associated with miniaturization

The common advantages of sensor miniaturization and to evaluate theextent to which they really enhance sensor performance let us consider the system in Fig. 1 [7]. The subject of miniaturization mainly depends on the sensoractive area *A*, where analyte binding occurs and generates a signal. The sensor surface is exposed to asample with volume *V*, in which we find the analyte present at a concentration *C*(molar). The numberof molecules available is then *VC* and the mass of analyte available is *VCM*, where *M* is the molecularmass. The sensor operates by transducing molecular adsorption on *A*into a detectable signal thatincreases (generally linearly) with the surface coverage *Γ* (mass per unit area). As a result of surfacefunctionalization, there will be a certain number of binding sites available on *A* and there is a definedmaximum surface coverage *Γ*max. Increasing *Γ*maxis one strategy to improve the performance of anysurface-based sensor, which is possible with nanomaterials. Alternatively, it will be better to consider the consequences of the chosen size of *A*,especially in relation to *V*, *C* and *M*. The quantity that determines *Γ* is normally *C*, while *V* does not come into play even forrelatively large *A*[7].

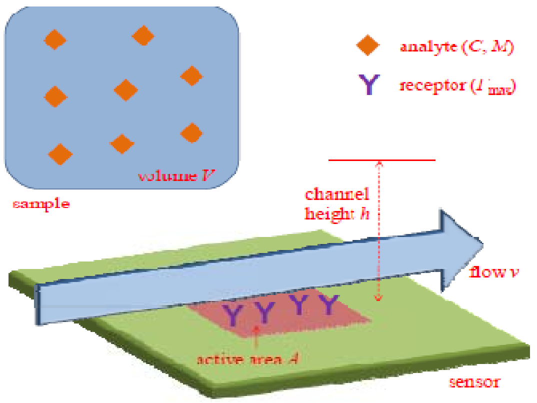

Fig. 1: The principle of a surface-based sensor system operating *in vitro*. On the active area *A* there are recognition elements for the target analyte, which has molecular weight *M* and is present in a sample of volume *V* at concentration *C*. The sample solution is introduced to the surface in a channel with height *h*, possibly with continuous flow at an average velocity *v*. The maximum surface coverage of the analyte*Γ*max is defined by the number of receptors (and *M* implicitly).

2.3 Multiple sensing on prepared films

High clarity of polycarbonate makes it a good support, especially where spectroscopic determinations are required.Polycarbonate being a thermostable polymer can be used for immobilization of thermostable enzymes required for high temperature transformations or making DNA or protein chips or immunoassays.The O_2- responsive sensor elements are based on sequestration of a luminophore with in a xerogel.The glucose-responsive biosensor elements are formed on top of the O_2 sensor elements by doping glucose oxidase with in the optimized ormosil.O_2 and glucose sensors are based on luminophore quenching.For O_2 detection, the relationship between the O_2 concentration in the sample and luminescence is direct.For glucose detection, we use glucose oxidase, which oxidizes D-glucose to gluconic acid with the consumption of O_2.

$$\text{D-glucose}+O_2 \xrightarrow{\text{GOx}} \text{D-gluconolactone}$$

$$+H_20_2$$

$$\text{D-gluconolactone}+H_2O \longrightarrow \text{D-gluconic acid}$$

Oxygen sensing properties of PtOEP encapsulated in ormosil films were characterized by the I0/I value ,where I0 and I represent the detected luminescence intensities from a film exposed to 100% nitrogen and 100% oxygen.

Stern – volmer quenching constant, K_{sv}, was obtained from the following equation:

$$I_0/I = 1+ K_{sv}[O_2];$$

Where I_o, I and [O_2] are the luminescence intensities in the absence and presence of oxygen and oxygen concentration, respectively [8]. K_{sv} was obtained from a linear plot of (I_o/I)-1 versus $[O_2]$

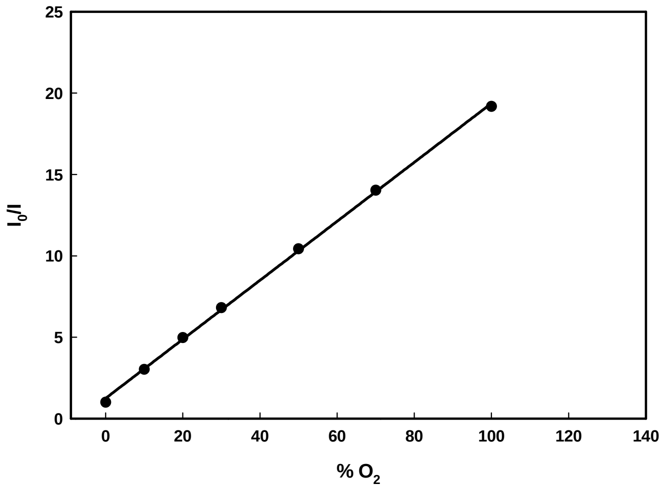

Fig. 2: Stern-Volmer plot of O_2 responsive film on polycarbonate

Further the ormosil films encapsulating enzyme glucose oxidase were successfully used for monitoring glucose in samples.

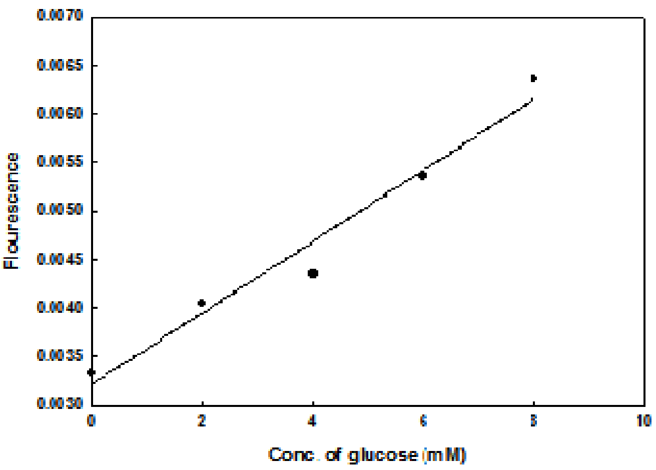

Fig. 3: Emission fluorescence data of glucose oxidase encapsulatedormosil film on polycarbonate in the presence of different conc. of glucose

3. CONCLUSION

Optical sensors hold a lot of promise for miniaturization of sensors and preparation of technology which would be cheap.An interesting feature of these miniaturized sensors is the dependence of their response on the sensor size. Unlike in larger sensors we find that under normal operating conditions the signal increases with the sensor diameter rather than its volume. This interesting dependence partially negates the signal loss due to the sensor miniaturization. These sensors are capable of detecting very low analyte concentrations for noninvasive and non-degenerative analyses in a wealth of different promising applications. It is also believed that the cost of individual sensors will be radically reduced and sensors will be more easy to use for the end-users.

4. ACKNOWLEDGEMENT

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