Integrated optical directional coupler sensor for pesticide analysis

B. J. Luff, R. D. Harris and J. S. Wilkinson
Optoelectronics Research Centre, University of Southampton, Southampton SO17 1BJ, UK

J. Piehler, A. Brecht and G. Gauglitz
Institute für Physikalische und Theoretische Chemie, Eberhard-Karls-Universität, Tübingen, Germany

R. A. Abuknesha
GEC Marconi Materials Technology Ltd, Hirst Division, Borehamwood, UK

Integrated optical transducers for the measurement of interactions between biological molecules and the specific detection of chemical and biochemical species are the subject of growing interest. Targeted applications include environmental monitoring, industrial process control and medical diagnostics. Integrated optical devices are capable of delivering the high detection sensitivity achievable through optical techniques in a compact format, and offer the potential for the detection of several analytes simultaneously through the fabrication of multiple transducers on a single chip. Here we describe the use of a new type of integrated optical sensor applied to the detection of low concentrations of the pesticide atrazine in aqueous solution. The transducer is based on a planar waveguide directional coupler structure fabricated by Ag^+–Na^+ ion-exchange in a low-index glass substrate. This sensor has the advantage of differential outputs, which gives improved signal-to-noise characteristics and offers the potential for the simultaneous measurement of the real and imaginary parts of the refractive indices of bulk or thin-film analytes.

Figure 1 illustrates the configuration of the directional coupler sensor. The operation of the sensor relies on guide 2 being isolated from changes in the superstrate media. Above guide 1 is a 'window' in the isolation layers; changes in the superstrate then cause a change in the difference in propagation coefficients, $\Delta\beta = \beta_1 - \beta_2$, where β_1 and β_2 are the propagation coefficients of guides 1 and 2 respectively. Assuming the input power P_0 is launched into guide 1 and the media are non-absorbing, the output from guide 2 is given as

$$P_2 = \frac{\sin^2[\sqrt{(\kappa L)^2 + (\Delta\beta L/2)^2}]}{1 + (\Delta\beta/2\kappa)^2} P_0$$

where L is the length of the device and κ is the coupling coefficient, which expresses the strength of the coupling between the two guides and depends on the overlap between the two modal fields. The power emerging from guide 1 is then given by $P_1 = P_0 - P_2$. Control over the operating point in this design is achieved by variation of the width w_2 of guide 2. Design parameters have been established using a beam propagation method (BPM) model [1]. A y-junction was included in the device design to split the input signal and provide a reference to determine excess losses in the structure. An important feature of the device is the use of low-index fluoropolymer overlayers (Teflon AF and FEP) to isolate guide 2. These layers are formed by thermal evaporation and patterned using a standard liftoff technique.

A wall-jet flow cell and flow-injection system is used to deliver biochemical reagents to the sensor at a conrolled rate. In order to determine atrazine concentration, an atrazine derivative is immobilised on the surface of the exposed waveguide (guide 1) by coupling

to a dextran carrier polymer. Atrazine antibodies (affinity purified anti-atrazine IgG) in solution are then able to bind specifically to the antigen bound on the surface, causing a change in the distribution of power between the two outputs of the coupler. Figure 2 shows a typical measured test cycle using 1 μg/ml anti-atrazine, where the total signal response is represented by the difference between the two outputs, $P_1 - P_2$. The sum of the two outputs remains constant, indicating that no significant signal absorption occurs. The low concentration of antibody results in the binding curve being diffusion limited and linear. Lowering the concentration of antibody below 1 μg/ml gives a correspondingly reduced linear binding rate.

To perform an atrazine determination, an indirect immunoassay procedure is applied as follows. Prior to introducing the sample to the sensor, the antibody solution is incubated with the test solution containing the unknown concentration of atrazine. The free atrazine will bind with a fraction of the antibody and block its ability to bind to the antigen on the surface, reducing the binding rate. The more atrazine in the test solution, the more antibody is blocked. Thus, the concentrations of unknown test solutions of atrazine may be determined from measurements of the slopes of the binding curves, following calibration against standard solutions. Regeneration of the transducer surface to prepare the sensor for another assay is achieved by application of a pepsin solution, which causes the antibody to denature and provide free antigen on the surface. The whole test cycle is completed in approximately 20 minutes. Preliminary measurements indicate a limit of detection for atrazine of below 1 μg/l.

A full discussion of the sensor design will be given and detailed atrazine concentration measurements presented. The performance of the sensor will be fully described in terms of sensitivity and specificity, and prospects for future applications will be considered.

References

[1] B. J. Luff, R. D. Harris and J. S. Wilkinson, Proceedings, 7th European Conference on Integrated Optics (1995).

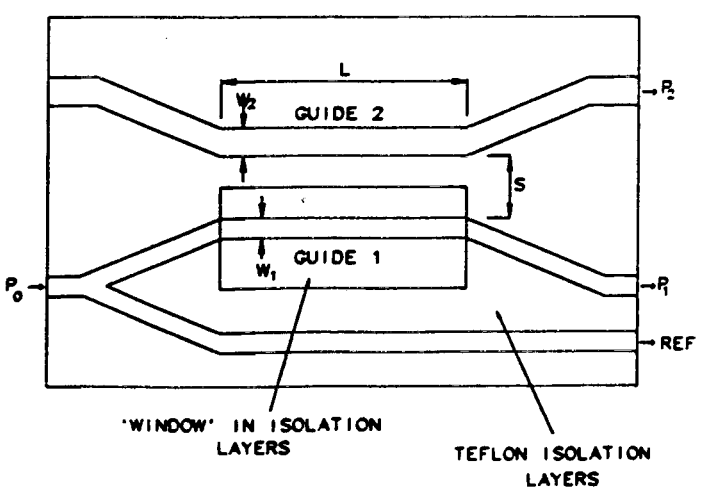

Figure 1: Sensor configuration

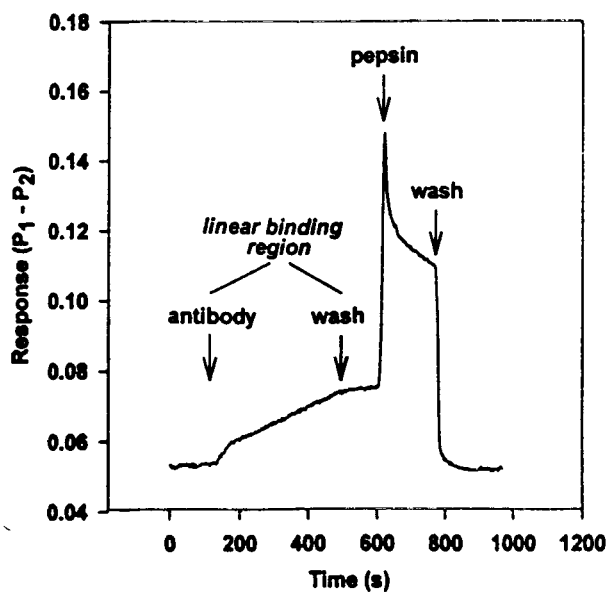

Figure 2: Measurement cycle