Local evanescent, array coupled (LEAC) biosensor response to low index adlayers

G. Yuan[1], M.D. Stephens[2], D.S. Dandy[2], J.K. Gerding[3], A. Van Orden[3] and K.L. Lear[1]
[1]*Electrical and Computer Engineering Department, Colorado State University, Fort Collins, CO. USA*
[2]*Chemical and Biological Engineering Department, Colorado State University, Fort Collins, CO. USA*
[3]*Chemistry Department, Colorado State University, Fort Collins, CO. USA*
gwyuan@engr.colostate.edu, kllear@engr.colostate.edu

Abstract: Experiments on planar optical waveguide based local evanescent array coupled biosensors using low-index photoresist and polystyrene nanoparticle adlayers are reported. Near-field scanning optical microscopy measurements are in close agreement with beam propagation method simulations.
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1. Introduction to LEAC biosensors

Point-of-care clinical diagnostics, food safety, environmental monitoring, and biosecurity applications provide impetus for label-free, simultaneous detection of small volumes of multiple pathogens or other protein based species using a compact sensor. In response, we are investigating a novel optical immunoassay sensor concept that permits the detection of up to hundreds of target analytes in separate regions along a single planar waveguide using local detection [1]. The local, evanescent, array coupled (LEAC) biosensor concept, illustrated in Fig. 1, relies on biomolecular adlayer formation via specific binding of a target analyte to one of several localized patches of immobilized bioprobes to modify the waveguide cross-section and thus the optical field under the patch. A buried array of evanescently coupled photodetector elements along the length of the waveguide, each opposite a region of specific probe type, locally sense the modification in the evanescent field due to adlayers of bound analytes.

Near-field scanning optical microscopy (NSOM) studies have been performed to investigate the field modification phenomena prior to fabrication of waveguides over buried photodetector arrays. Previous work on an initial proof-of-concept single mode waveguide structure with a 88 nm thick SiN_x core on SiO_2 lower cladding demonstrated a strong optical modulation response due to a 17 nm artificial adlayer of SiN_x (n = 1.8) constructed by appropriately patterned etching outside the adlayer region [2]. To better mimic the low refractive index of a biological molecule-based adlayer (n = 1.43), experiments have been conducted using artificial adlayers consisting of photoresist or polystyrene nanoparticles and are reported here. The measured results are shown to be in agreement with numerical simulations.

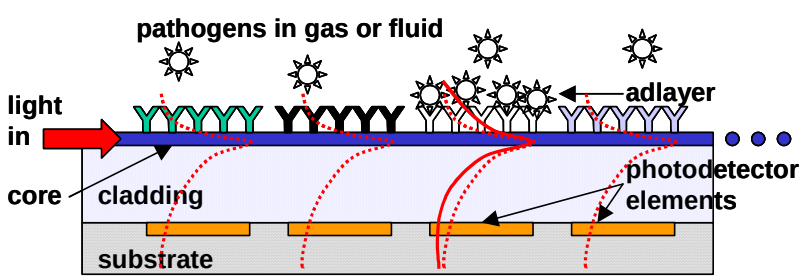

Fig. 1. A biomolecular adlayer on a single-mode optical waveguide effectively increases the thickness of the core layer, thus decreasing the evanescent field tail absorbed by the underlying detector. The curves illustrate the mode profiles at different positions along the waveguide.

2. Measurements and simulations

For the waveguides, a 105 nm thick SiN_x film is deposited on a SiO_2/Si wafer using NH_3/argon sputtering, where the SiO_2 cladding thickness is about 2 μm. Air serves as the upper cladding, allowing the NSOM (α-SNOM, WiTec) to interrogate the evanescent field at that surface. A 2 μm wide rib waveguide core was defined by dry etching 16 nm of the surrounding SiN_x layer in a CF_4/O_2 plasma. An artificial adlayer of photoresist (Shipley 1818, n = 1.56) was patterned by photolithography to create a 10 μm wide bar oriented perpendicular to the waveguide. The photoresist thickness ranged from 90 to 120 nm as determined by the topographic profiling capability of the NSOM system.

Fig. 2(a) shows a longitudinal cross-sectional view of the waveguide and the photoresist adlayer configuration. The three regions of the waveguide before, coincident with, and after the adlayer are referred to as Regions I, II and III, respectively. All regions support only one guided mode, TE_{00}. Light from a 654 nm laser diode via a 4 μm core diameter single mode fiber is coupled into the waveguide approximately 4 mm to the left of the area shown, to assure a stable mode in Region I. Similar to our previous observations [2], transient modal interference originating from the mode beating between the bound mode and the leaky mode is expected in Region III. The modulation depth of the optical intensity oscillations is directly related to the adlayer's thickness and refractive index. The modulation depth is defined as the difference between the input intensity in Region I and the minimum intensity in Region III immediately after the adlayer resulting from the destructive interference of the bound and leaky modes.

Optical propagation through the waveguide with the photoresist adlayer structure was simulated by a two-dimensional bidirectional beam propagation method (BPM) with no adjustable parameters using commercial software by RSoft with the results shown in Fig. 2(b). The incident beam was assumed to be the TE_{00} mode, and the adlayer thickness was taken as 100 nm. The thin blue curve in Fig. 2(c) shows the measured light intensity along the top surface of the waveguide in Region I and III, and along the top surface of the photoresist in Region II. The simulated optical intensity on the same surfaces, shown by the thick red curve in Fig. 2(c), agrees very well with the measured results. The signal modulation immediately after the adlayer is 42% of the input signal. Fig. 1(d) shows the dependence of modulation depth on adlayer thickness as predicted by the BPM simulations. Use of buried detectors is expected to give even stronger signals and thus enable sensing of thin adlayers.

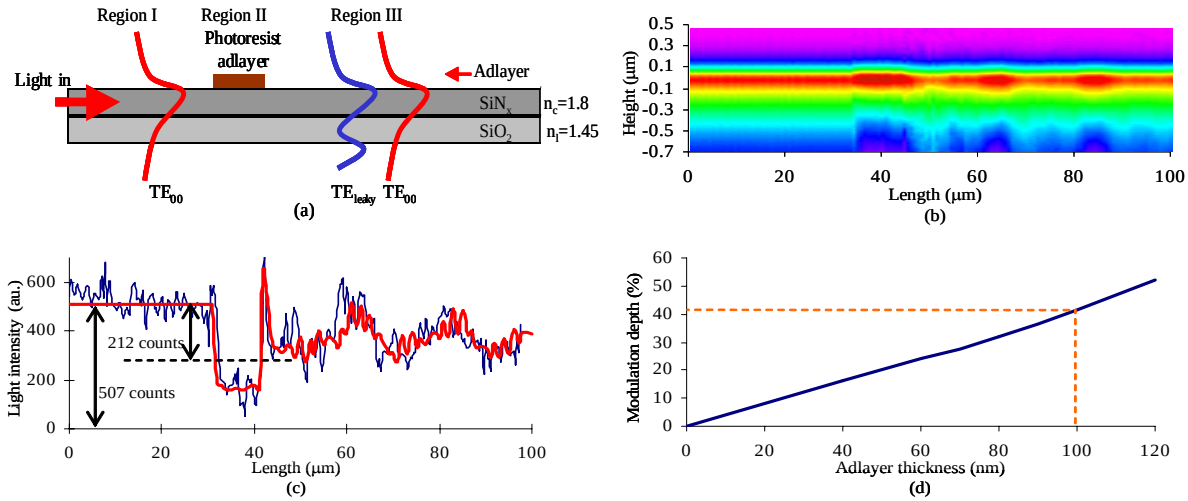

Fig. 2. (a) Longitudinal cross-sectional view of the waveguide and photoresist adlayer configuration, (b) false color plot shows the BPM simulated electrical field distribution, (c) the corresponding plots of the NSOM measured (thin blue) and BPM simulated (thick red) light intensity along the top surface of the waveguide in Region I and III and the photoresist in Region II, (d) modulation depth vs. adlayer thickness.

In addition to the photoresist adlayer, measurements were also performed on a semi-infinite nanoparticle adlayer. The layer consisting of 40 nm diameter polystyrene nanoparticles was stamped on the waveguide to form, in principle, a single height step. As with the photoresist, oscillations in the optical field were expected in the light distribution after the transition at the edge of the nanoparticle adlayer. However, an exponentially decaying curve without oscillations was observed, and this behavior was attributed to the non-uniform distribution of the nanoparticles in the adlayer and thus strong light scattering loss. This result may indicate the need for relatively uniform binding of actual target analyte layers. Continuing investigations will be reported at the conference.

3. Summary

The LEAC biosensor concept has been demonstrated with low index adlayers of photoresist and nanoparticles. NSOM was used to directly measure the optical intensity modulation due to the photoresist adlayer in good agreement with BPM simulations. The authors thank NIH for sponsorship via Grant No. EB00726.

4. References

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