Ultrahigh Sensitivity Slot-Waveguide Biosensor on a Highly Integrated Chip for Simultaneous Diagnosis of Multiple Diseases

Daniel Hill*[1], Benito Sanchez[1], Amadeu Griol[1], Guillaume Maire[2], Fabian Dortu[2],Laurent Vivien[2], Anne-Sophie Stragier[2], Delphine Marris-Morini[2], Eric Cassan[2] Andrzej Kaźmierczak[3], Domenico Giannone[3], Kristinn B. Gylfason[4], Hans Sohlström[4], María José Bañuls[5], Victoria González-Pedro[5], A. Maquieira[5], Carlos A. Barrios[6], M. Holgado[7], R. Casquel[7]

[1]*Centro de Tecnología Nanofotónica, Universidad Politécnica de Valencia, Camino de Vera s/n, 46022 Valencia, Spain*

[2] *Institut d'Electronique Fondamentale, CNRS UMR 8622, Bât. 220, Université Paris-sud 11, F-91405 ORSAY cedex – France*

[3] *Applied Photonics Departement, Multitel a.s.b.l., rue Pierre et Marie Curie, 2, B-7000 Mons, Belgium*

[4] *Microsystem Technology Laboratory, School of Electrical Engineering, KTH – Royal Institute of Technology, Osquldas väg 10, SE-10044 Stockholm, Sweden*

[5] *Departamento de Química, Universidad Politécnica de Valencia, Camino de Vera s/n, 46022 Valencia, Spain*

[6] *Instituto de Sistemas Optoelectrónicos y Microtecnología, Universidad Politécnica de Madrid, ETSI Telecomunicación, Ciudad Universitaria s/n, 28040 Madrid, Spain*

[7] *Centro Láser, Universidad Politécnica de Madrid, Campus Sur, Madrid, Spain*

**Corresponding author: dhill@ntc.upv.es*

Abstract

Here we review some recent photonic related developments from the FP6-IST-SABIO project (026554) such as a demonstration of label-free optical biosensing with slot-waveguides and tolerance analysis of high efficiency silicon nitride surface grating couplers.

Summary

SABIO is a multidisciplinary project involving the emerging fields of micro-nano technology, photonics, fluidics and bio-chemistry, targeting a contribution to the development of intelligent diagnostic equipment through the demonstration of a compact polymer based and silicon-based CMOS-compatible micro-nano system. It integrates optical biosensors for label-free biomolecular recognition based on a novel photonic structure named slot-waveguide with immobilised biomolecular receptors on its surface. The slot-waveguides provide high optical intensity in a subwavelength-size low refractive index region (slot-region) sandwiched between two high refractive index strips (rails) [1] leading to an enhanced interaction between the optical probe and biomolecular complexes (antibody-antigen). As such a biosensor is predicted to exhibit a surface concentration detection-limit lower than 1 pg/mm^2, state-of-the-art in label-free integrated optical biosensors, as well as the possibility of multiplexed assay, which, together with reduced reaction volumes, leads to the ability to perform rapid multi-analyte sensing and comprehensive tests. This offers the further advantageous possibility of assaying several parameters simultaneously and consequently, statistical analysis of these results can potentially increase the reliability and reduce the measurement uncertainty of a diagnostic over single-parameter assays. In addition, the SABIO micro-nano system device applied to its novel protein-based diagnostic technology has the potential to be fast and easy to use, making routine screening or monitoring of diseases more cost-effective.

The flexibility of label-free biomolecule optical sensing technologies permits simplification of assays and time–resolved kinetics measurement for biomolecular interactions. Furthermore the use of integrated photonic devices permits high sensitivity, small size and high scale integration. A recently reported [2] integrated photonic sensor based on slot-waveguide sensor exhibited a bulk ambient sensitivity as high as 212.13 nm/RIU (refractive index unit), which is more than twice as large as that exhibited by other ring resonator optical sensors based on conventional strip waveguides. More recently the detection of label-free molecular binding reactions on the surface of a slot-waveguide ring resonator has been demonstrated [3] through the use of Bobine Serum Albumin (BSA) protein and antiBSA. The device consists of a 70-μm-radius slot-waveguide ring resonator made of Si_3N_4 on SiO_2 with the Si_3N_4 rails of the slot-waveguide ring separated by 200 nm (wslot) and their widths are 400 nm and 550 nm for the outer and inner rails, respectively[2]. Sensing of antiBSA-glutraldehyde and BSA-antiBSA affinity reactions were then studied on the sensing chip through optical characterization. The estimated limits of detection of the device for antiBSA and BSA molecules are 1.66 ng/ml and 52.6 ng/ml, limited by wavelength resolution, comparing favourably with the performance of state-of-the-art integrated photonic biosensors based on conventional strip waveguides.

For coupling light into integrated optics structures surface grating couplers are ideal due their high efficiency and enablement of light injection anywhere on the wafer. The refractive index contrast of silicon nitride is about 0.5, high enough in photonic structures to guarantee a reasonably strong light confinement, while allowing a sensitivity reduction to fabrication imperfections (such as interface roughness) that is problematic for higher confinement levels such as that for silicon-on-insulator structures. Experimental coupling efficiencies >60% for totally and partially etched silicon nitride grating couplers have been seen [4] and more recently angular and wavelength -3 dB tolerances reaching 4° and 50 nm, respectively, have been determined. Alignment tolerances, i.e. the variations of the coupling efficiency when the incident beam waist position relative to the grating is changed in the 3 space dimensions were also determined. The alignment tolerance parallel to the grating is slightly greater than the grating width itself and depends on the beam waist, and along the optical propagation axis it can reach several 100 µm. Perpendicularly to the grating grooves, the coupling efficiency profile appears to be particularly influenced by the duty ratio of the grating.

Summary

1. V. Almeida, Q. Xu, C.A. Barrios, and M. Lipson, “Guiding and confining light in void nanostructure,” Opt. Lett. **29**, 1209-1211 (2004).
2. C.A. Barrios, K.B. Gylfason, B. Sanchez, A. Griol, H. Sohlström, M. Holgado and R. Casquel, “Slot-waveguide biochemical sensor,” Opt. Lett. **32**, 3080-3082 (2007).
3. C. A. Barrios, M. J. Bañuls, V. Gonzalez-Pedro, K.B. Gylfason, B. Sanchez, A. Griol, A. Maquieira, H. Sohlström, M. Holgado, and Rafael Casquel, “Label-free optical biosensing with slot-waveguides”, Opt. Lett. **33**, 7, 708-710 (2008)
4. L. Vivien, G. Maire, G. Sattler, D. Marris-Morini, E. Cassan, S. Laval, A. Kazmierczak, D. Giannone, B. Sanchez, A. Griol, D. Hill, K.B. Gylfason, H. Sohlström, Opt. Exp. **16**, 1, 328-333 (2008)