Real-time functionalization and biosensing in subwavelength grating bimodal waveguides

(Student paper)

Luis Torrijos-Morán, Paula Martínez-Pérez and Jaime García-Rupérez
Nanophotonics Technology Center, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain
e-mail: luitorm2@ntc-upv.es

ABSTRACT

In this paper, we present for the first time experimental results of biosensing processes by using subwavelength grating bimodal waveguides as a refractive index sensors. We demonstrate the detection of 10ppm concentration of Bovine Serum Albumin (BSA) with a 190pm wavelength shift after a functionalization of the sensor surface with a layer of protein A/G in a continuous flowing system. Real-time data of each step is obtained, validating these kind of novel and highly sensitive SWG sensors for biosensing purposes.

Keywords: Subwavelength grating structures, bimodal waveguides, refractive-index biosensors, BSA detection, integrated photonic devices.

1 INTRODUCTION AND DESIGN

Subwavelength grating (SWG) waveguides have emerged as a promising alternative for a new kind of photonic devices with enhanced properties [1]. They are composed by a periodic dielectric repetition of a certain lattice in the propagation direction, whose period is relatively smaller than the effective wavelength of light. As a consequence, light propagates through these structures as if it were an homogeneous medium, but with the main advantage of a higher light-matter interaction of the field with the cladding [2], [3]. On the other hand, a new type of evanescent sensors based on bimodal waveguides [4], [5] have been demonstrated for biosensing applications. The underlying concept of these bimodal sensors stems from exciting two modes of the same polarization, the fundamental one acting as reference and the higher order mode acting as a sensing signal. At the end, a change in the cladding refractive index (RI) will be translated into a relative variation in the accumulated phase shift between both modes.

In previous work, we have experimentally demonstrated the use SWG structures as bimodal waveguides for highly sensitive RI sensing [6], [7], encompassing both ideas described above. Here, we present new experimental measurements including the biofunctionalization and the recognition of BSA by a SWG bimodal sensor, which validates for the first time the use of these devices as biosensors. The proposed design is depicted in Fig. 1a, where a displaced single-mode input waveguide excites the first two modes (even and odd parities in the y-axis direction) of the same transverse-electric (TE) polarization. Similarly, the power of both modes will be transferred into the fundamental mode of the output single-mode waveguide, thus creating an interference pattern in the transmission spectrum. Due to some dispersion properties of the modes propagating for these SWG structures [6], high spectral shifts are obtained for a change in the RI of the cladding. The design parameters are a=280nm, w_i=180nm, w_e=1400nm, d=350nm, with N=480 elements of the SWG bimodal region and accessed in and out with a single-mode waveguide of 450nm width. Figure 1b shows some scanning electron microscope (SEM) images of the fabricated sensor, using electron beam lithography, of 134.4 microns length on a silicon-on-insulator (SOI) wafer of 220nm height that has been used in the following biosensing experiments.

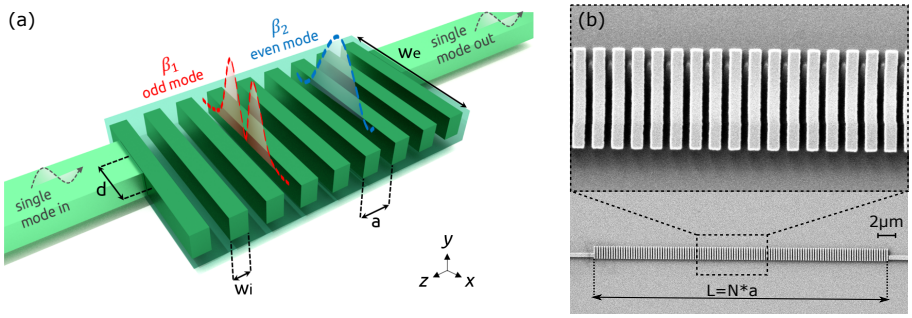

Figure 1. a) Skecth of the proposed design and its design parameters, composed by the single-mode input and output waveguides and the bimodal region of SWG elements. The fundamental mode (even mode) is depicted in blue while the first order mode (odd mode) is colored in red. b) SEM images of the fabricated sensor for the experimental validation, a complete structure and a detail of the SWG elements are shown.

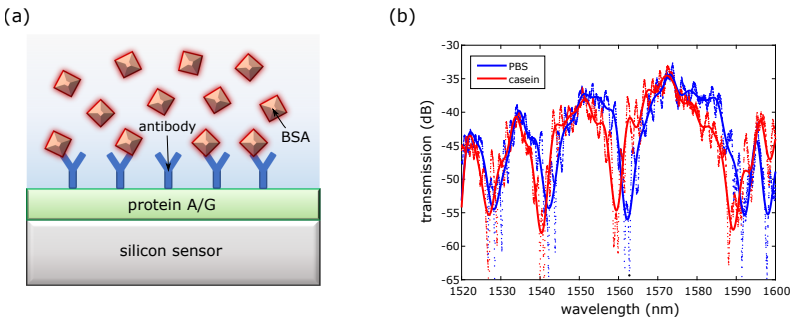

Figure 2. a) Sketch of the biofunctionalization and detection processes carried out in the experiments. In green the layer of protein A/G is depicted, in blue the antibody receptors and in red the targets molecules of BSA. b) Transmission spectra of a SWG bimodal waveguide of N=480 elements of a=280nm, w_i=180nm, w_e=1400nm and d=350nm. The spectra for PBS and casein as surrounding media are depicted in blue and red, respectively.

2 BIOSENSING RESULTS

The whole chip has been placed over a sample holder for the optical characterization. To this matter, a coherent TE polarized light from a tunable laser has been vertically coupled into the chip by using grating couplers. At the output, light was collected by an optical power meter that was previously synchronized with the laser. In addition, a methacrylate cell was disposed over the sensor in order to flow different analytes over time. The entire biosensing process is depicted in Fig. 2a, formed by a functionalization stage of protein A/G on the silicon surface of the sensor and casein as a blocking solution. Over the protein layer, the antibody will be flowed as the receptor molecule with the aim of detecting the target analyte of BSA at the end. Figure 2b shows the transmission spectra of the sensor over two different solutions, in Phosphate Buffered Saline (PBS) and casein, which are the baselines of the protein A/G and the BSA, respectively. As it can be seen, there is an increment in the cladding RI between PBS and casein that is translated into a negative wavelength shift, as it was predicted in [7]. Moreover, four different peaks are available as a consequence of the destructive interferences produced by both modes for wavelengths around 1520nm, 1540nm, 1560nm and 1590nm. Therefore, four different detection signals on each peak will be processed afterwards, where the most sensitive are the ones placed at higher wavelengths.

The optical setup was able to record around four spectra per minute. Over each one, a lorentzian fitting of the mentioned peaks was carried out. The detection signals are based on the minimun of these fitting peaks, therefore showing a point every fifteen seconds. The concentrations of the dilutions are 10μg/ml of protein A/G, 1mg/ml of casein, 50μg/ml of Antibody and 10μg/ml of BSA. Figure 3a shows the functionalization process of the protein A/G layer that has been placed on the sensor surface. It can be seen how there is absolute wavelength shift that remains after certain minutes of flowing protein A/G. In Fig. 3b and c we can see the change of baseline between PBS and casein, and the deposition of the antibody on the sensor surface. Finally BSA was flowed in Fig. 3d, showing an optical detection between 190pm and 320pm, of optical wavelength shift.

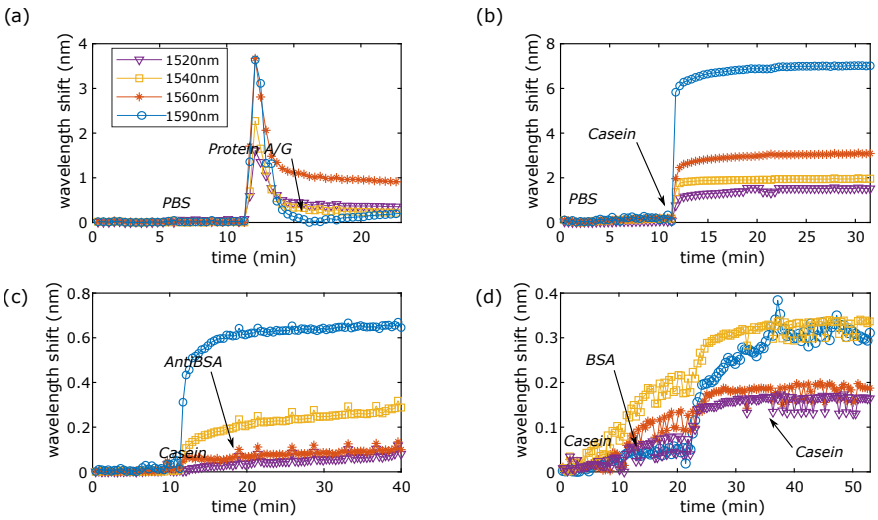

Figure 3. Optical measurements of PBS and protein A/G (a), PBS and casein (b), casein and antibody (c) and casein and BSA (d). The flowing rate was 20μg/ml in all the measurements.

3 CONCLUSIONS

To conclude, real-time optical measurements of a functionalization and biosensing experiment using bimodal SWG waveguides is presented. More in detail, a 10ppm of BSA is detected for the first time in these kind of structures, which validates SWG bimodal waveguides as biosensors. Future optimization of the measurements and biosensing studies will be carried out to further evaluate the limits of these SWG sensors in the area of integrated biophotonics.

4 ACKNOWLEDGMENTS

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