Development of high sensitivity biosensors using SOI photonic crystal waveguides

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Integrated planar photonic devices have become one of the main candidates for the development of high performance lab-on-a-chip devices [1]. Two main advantages of these devices for sensing applications are their high sensitivity and their reduced size, which makes it possible both to detect very small analytes without the need of markers (label-free detection) and to integrate many of these devices on a single chip to perform a multi-parameter detection. Moreover, the CMOS-compatibility when fabricating these planar photonic devices on silicon-on-insulator (SOI) allows a huge reduction of their costs and increase of their production volume.

In this work, we report experimental biosensing results using SOI planar photonic crystal waveguides (PCW). The experimental results comprise refractive index (RI) sensing, label-free detection of antibodies [2] and label-free detection of single strand DNA (ssDNA) [3]. In these experiments, we have used Fabry-Perot fringes appearing in the slow-light regime near the edge of the guided band. These fringes become very sharp as we get close to the band edge, making the determination of their position more accurate, thus allowing a reduction in the limit of detection.

For the refractive index sensing experiments, we flowed several dilutions of ethanol in DIW (Deionized Water), having a RI variation between dilutions of 1.3×10^{-3} RIU (Refractive Index Units). By tracking the shift of one of the Fabry-Perot fringes at the band edge, we have obtained a sensitivity of 174.8 nm/RIU and an estimated detection limit of 3.5×10^{-6} RIU (from the noise in the peak position).

For the label-free detection of antibodies, we bio-functionalized the PCW with bovine serum albumin (BSA) antigen probes (we have used 3-isocyanatepropyl triethoxysilane (ICPTES) in vapour phase for the activation of the surface). Then, we flowed the complementary anti-BSA antibody with a concentration of 10 μg/ml during enough time to achieve a monolayer on the top of the BSA-functionalized chip. From the wavelength shift of the tracked peaks, together with the noise level of the peak position and the surface density for a close-packed anti-BSA monolayer, we have calculated a surface mass density detection limit below 2.1 pg/mm^2. Concerning the total mass detection limit, if the active region of the PCW is considered, a value of ~0.2 fg is obtained.

Finally, for the label-free detection of ssDNA, we used a similar bio-functionalization strategy in order to attach biotinylated ssDNA probes on the PCW surface. Then, we flowed ssDNA 0.5 μM complementary to the probes in the PCW surface. We have measured a peak shift of 47.1 pm. Using the noise level of the peak position, we estimated a detection limit of 19.8 nM for the ssDNA hybridization detection.

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References

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Figures

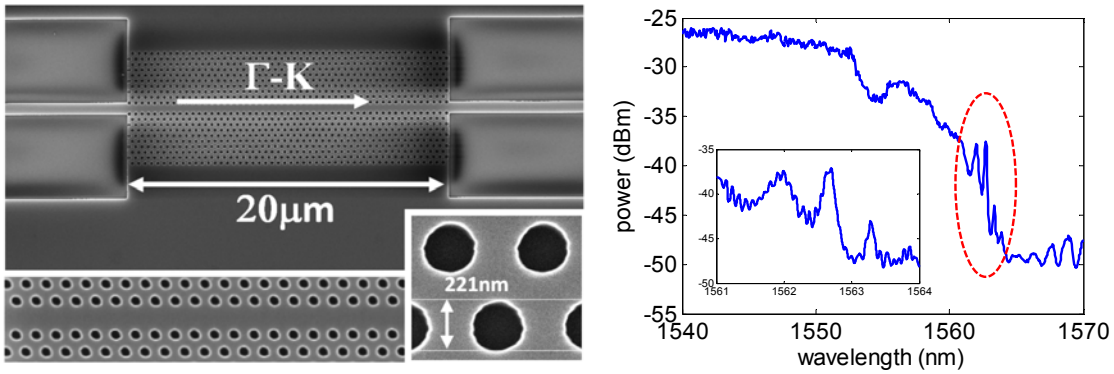

Fig. 1. (Left) SEM image of one of the SOI photonic crystal waveguides used in the experiments, where a row of holes is removed in the Γ-K direction (W1-type), with close-up view of the sensor area and photonic crystal holes (insets). (Right) Spectrum of the PCW in the region of the band edge when having DIW as upper-cladding. Fabry-Perot transmission fringes at the band edge are marked with dashed red line and enlarged in the inset.

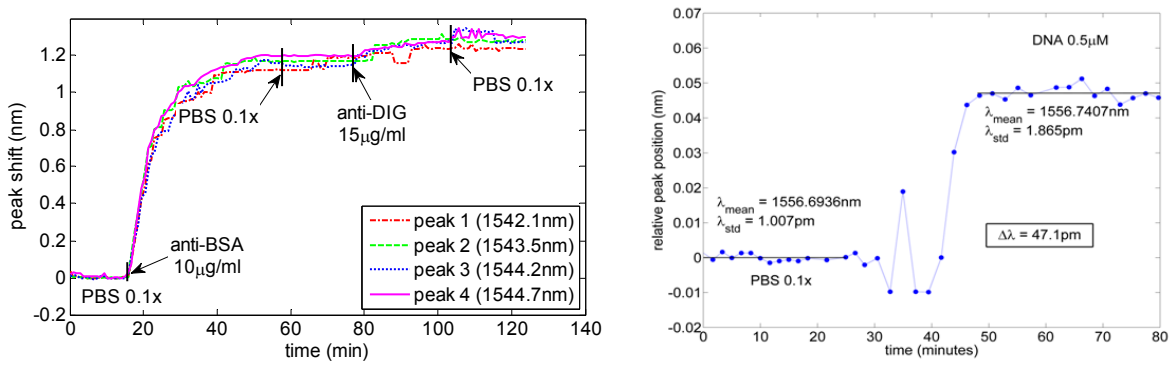

Fig. 2. (Left) Wavelength shift vs time for the label-free anti-BSA 10 μg/ml detection experiment. Each line (color and style identified in the legend) correspond to the relative shift of each tracked peak respect its initial wavelength position. (Right) Wavelength shift vs time for the label-free ssDNA 0.5 μM sensing experiment.