Photonic crystal waveguide sensor for low concentration DNA detection

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Integrated photonic sensors are currently attracting an increasing interest because of their high potential for a fast label-free analysis of very low concentrations of analytes, such as proteins, bacteria or DNA for instance [1]. Particular interest is focused on planar devices in silicon, such as ring resonators [2,3], photonic crystal based structures [4,5], or Mach-Zehnder Interferometers [6], as they are very sensitive to refractive index variation, have a small size, and can be fabricated on very large scale using CMOS fabrication techniques. In this work, we report experimental results showing the detection of double-strand DNA using a photonic crystal waveguide (PCW) based sensor, obtaining a lower detection limit of 22.2nM.

The PCWs used for the detection were fabricated in a silicon-on-insulator (SOI) wafer with 250nm-thick silicon layer on a 3μm-thick buried oxide layer. They were designed to have a guided TE mode with its band edge located around λ=1550nm, for what a lattice constant of 390nm and a hole radius of 111nm was selected. Light is coupled/collected to/from the PCW using 500nm-wide singlemode waveguides. 20μm-long PCWs were fabricated using e-beam lithography and Inductively Coupled Plasma (ICP) etching. A scanning electron microscopy (SEM) picture of the PCW is shown in Fig. 1.(a).

Surface activation is performed by exposing the chip to pure 3-isocyanatepropyl triethoxysilane vapour for 30 min. Then, a drop of streptavidin 0.1mg/ml in 0.1x phosphate buffer saline (PBS) is deposited on the sensing area and incubated in a humid chamber overnight at room temperature. Finally, a solution of ovoalbumin protein (OVA) 1% in PBS 0.1x is spread all over the chip and incubate for 30 minutes to block the remaining active sites.

For the experimental characterization, the TE transmission spectrum near the band edge of the PCW was continuously acquired using a tunable laser with a resolution of 1pm, as shown in Fig. 1.(b). In this region, transmission peaks created by the excitation of multiple-k modes in the slow-wave regime near the band edge and the cavity created in the PCW with the access waveguides appear, which are used to perform the sensing, as shown in the inset of Fig. 1.(b). The sensing experiment begins flowing the PBS 0.1x at 10μl/min (a flow cell is placed on the top of the chip and this flow rate is maintained for all the experiment) to obtain the baseline for the buffer solution. Then, we switched to a double-strand DNA solution with the end of one strand marked with biotin which has a high binding affinity with the streptavidin and will bind to the protein attached in the PCW surface, thus inducing a shift in the peak position. The end of the other strand is marked with digoxigenin (DIG) which has no affinity with streptavidin and is used later to confirm the binding of the DNA to the PCW surface by flowing anti-DIG antibody. Figs. 2.(a) and 2.(b) show the flowing sequence and the peak shift obtained for each substance.

For the lowest DNA concentration (0.2μM) we measured a peak shift of $\Delta\lambda_{DNA}$=5.8pm (1544.764nm-1544.7582nm). The noise level was estimated to be 0.645pm (standard deviation of peak position during continuous PBS1 flow), thus giving a lower detection limit of 22.2nM for direct DNA detection, what is in line (or even better) with state-of-the-art values reported for other planar photonic structures such as ring resonators [3]. Moreover the shift we observed when flowing anti-DIG (higher than 0.6nm) clearly confirms the binding of the DIG-marked DNA on the chip.

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References

[1] X. Fan, I.M. White, S.I. Shopova, H. Zhu, J.D. Suter, Y. Sun, Anal. Chim. Acta, **620** (2008), 8-26.
[2] K. De Vos, I. Bartolozzi, E. Schacht, P. Bienstman, R. Baets, Opt. Express, 15 (2007), 7610-7615.

[3] A. Ramachandran, S. Wang, J. Clarke, S.J. Ja, D. Goad, L. Wald, E.M. Flood, E. Knobbe, J.V. Hryniewicz, S.T. Chu, D. Gill, W. Chen, O. King, B.E. Little, Biosens. Bioelectron., 23 (2008), 939-944.
[4] N. Skivesen, A. Têtu, M. Kristensen, J. Kjems, L.H. Frandsen, P.I. Borel, Opt. Express, 15 (2007), 3169-3176.
[5] D. Dorfner, T. Zabel, T. Hürlimann, N. Hauke, L. Frandsen, U. Rant, G. Abstreiter, J. Finley, Biosens. Bioelectron., 24 (2009), 3688-3692.
[6] A. Densmore, M. Vachon, D.-X. Xu, S. Janz, R. Ma, Y.-H. Li, G. Lopinski, A. Delâge, J. Lapointe, C.C. Luebbert, Q.Y. Liu, P. Cheben, J.H. Schmid, Opt. Lett., 34 (2009), 3598-3600.

Figures

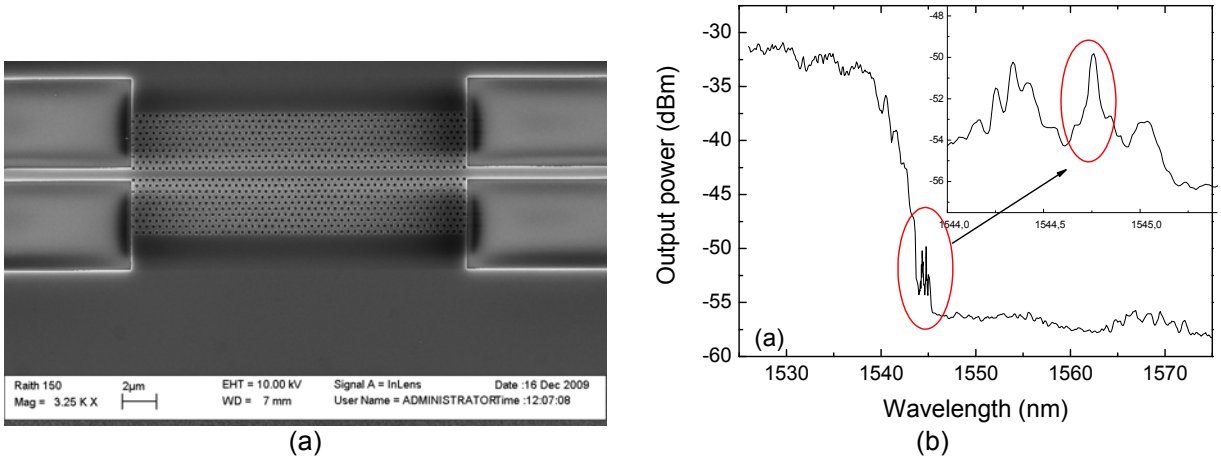

Fig. 1. (a) SEM image of the photonic crystal waveguide used for the sensing, (b) Spectrum of the photonic crystal waveguide in the region of the band edge.

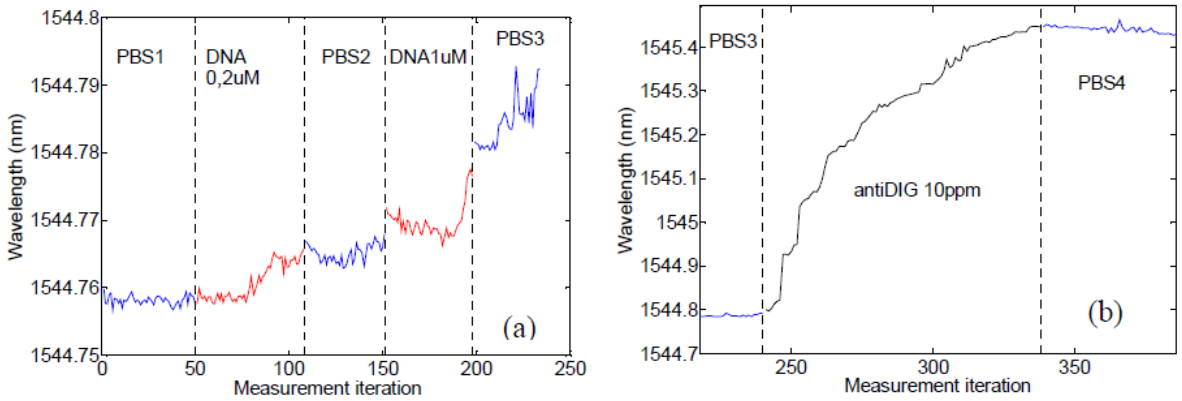

Fig. 2. Wavelength shift vs measurement iteration (each iteration lasts approximately 1 minute), for double-strand DNA (left) and anti-DIG (right) flowing. Flowing sequence is: PBS 0.1x, DNA 0.2µM, PBS 0.1x, DNA 1µM, PBS 0.1x, anti-DIG 10ppm, and PBS 0.1x (all were flown for more than 30 minutes to ensure molecular binding).