Planar photonic crystal waveguide biosensor

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Abstract: *We present protein detection using a planar photonic crystal waveguide sensor. Experimental results of refractive index measurements show good agreement with simulations. The sensor has been used for protein detection and showed successful detection with excellent signal to noise ratio of proteins with concentrations around 10 µg/ml (0.15µMolar).*

Introduction

In the past 20 years, the research within biosensing has experienced increased intrest. Biosensing is a wide term that includes areas like fast and effective recognition of DNA/RNA, proteins or other biological molecules, recognition of chemical reactions for diagnoses of diseases, discovery of new drugs, and environmental control. In connection with biosensing, increased focus has been on the development of integrated optical biosensors, as they have the potential to be made compact with high sensitivity, and to be easily fabricated and integrated with other optical or electrical components.

The research in integrated optical biosensors has resulted in a wide range of devices and still new ones are suggested, especially those requiring easier fabrication methods. Amongst the well-proven methods suggested for biosensors, a few wide-known methods can be mentioned: optical waveguides, SPR-devices, resonant mirrors, interferometers, cantilevers and optical fiber-based devices.

We present a biosensor based on a planar photonic crystal. The advantages of the device we suggest are that it is realized in silicon and can be integrated on a SOI-wafer (silicon-on-insulator) along with other electronic and optical devices. Thus, the fabrication technology used for the sensor is the same used for CMOS electronic devices.

The suggested planar photonic crystal waveguide (PC-WG) sensor has been tested for both refractive index (RI) measurements and protein detection. The PC-WG can be made very compact and the sample volume to be analyzed can also be reduced considerably compared to the earlier suggested devices mentioned above.

Photonic crystal waveguide sensor

The basic property of a PC-WG is that a given bandwidth of light can be guided in the waveguide as the light is confined laterally by the band-gap of the photonic crystal (PhC) and vertically by total internal reflection (TIR), akin to conventional waveguide structures. Fig. 1(A) shows the experimental setup and a top-view of the configuration of the PC-WG sensor is illustrated in Fig. 1(B).

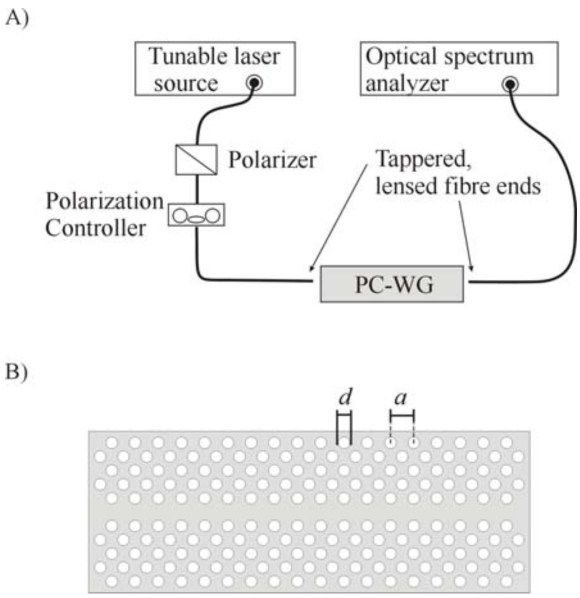

Fig. 1: A) Experimental setup. B) Top-view of the photonic-crystal waveguide configuration.

The properties of the PC-WG are highly influenced by changes in RI at the silicon surface, both on the top of the layered structure but also at the sidewalls of the holes due to the field distribution, which is decaying fast into the cover medium. This can be an advantage in biosensing as it will typically involve an aqueous cover medium containing biological molecules. The detection of specific biological molecules is primarily done by immobilizing molecules at the surface, resulting in a RI change exactly where the evanescent field is strongest leading to a high detection efficiency. The penetration depth of the field into the holes depends on the wavelength and distance of the hole from the waveguide defect. Based on finite-difference time-domain (FDTD) simulation of this structure and SNOM measurements on a similar structure the penetration depth of the tested sensor can be approximated to 100 nm.

The band-gap of the PhC is the interesting property for sensor application. A sudden drop in the transmission spectra vs. wavelength is observed where the transmission of the fundamental photonic band-gap (PBG) defect mode is no longer possible. The change in wavelength position of this transmission drop is used for detection of RI changes in the cover medium of the sensor, as the wavelength position increases with an increase in RI of the cover medium.

Refractive index measurements
We tested the fabricated sensor and compared the results with 3D FDTD simulations for different homogeneous cover solutions. In Fig. 2(A) the resulting changes in wavelength position vs. changes in cover RI are shown for both the measured and calculated transmission curves. These results show that the method for applying the different solutions, the detection, and the reading of the signals give very reliable results.

Protein detection
Protein detection was successfully achieved with the fabricated sensor. A solution of 1 mg bovine serum albumin (BSA) and 1 mL MilliQ water was used for one experiment (a concentration of 15μMolar). In Fig. 2(B) steady response spectra for a solution of pure MilliQ water and the BSA solution are shown. A shift in cutoff wavelength of 0.6 nm is observed between the steady response for MilliQ water and the BSA solution, respectively. Before terminating the experiment the cover solution is changed back to MilliQ water and no shift in cutoff wavelength is observed, indicating that the BSA proteins have adsorbed onto the sensor surface. In addition we performed ellipsometry measurements on a silicon surface for the same concentration, which resulted in a protein layer thickness of 3.6 nm.

An estimate of the sensor response based on the change in wavelength position of the measured transmission signals is consistent with calculations and ellipsometry measurements of protein adsorption on the sensor surface. Furthermore, the estimate shows that the PC-WG sensor has a very high spatial sensitivity in the close vicinity of the sensor surface.

Protein concentrations down to 10 μg/mL have been detected with excellent signal to noise ratio and these results will be presented. However, even this low concentration does not express the lower sensitivity limit for the sensor, as the presented sensor is not optimized for biosening and can be improved in numerous places. Firstly, smaller changes in the cutoff wavelength should be possible to detect with acceptable signal-to-noise ratio. The sensitivity may also be increased by improvements of the sensor setup such as introducing temperature and coupling stabilization, continuous measurements of a reference waveguide and balanced bridge detection techniques.

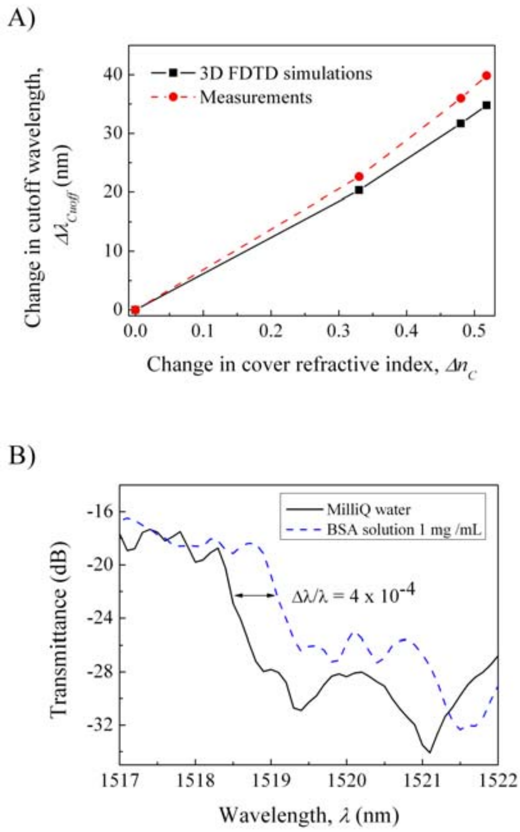

Fig. 2: (A) Curves showing the experimental (circles, dashed line) and simulated (squares, solid line) changes in wavelength position of the band-gap edge vs. changes in cover RI. (B) Measured curves before (solid line) and after (dashed line) protein adsorption on the sensor surface.

Conclusion
We present a photonic-crystal waveguide used for RI measurements and protein detection fabricated on a commercial SOI wafer using conventional CMOS fabrication procedures. A good sensitivity is demonstrated although the sensor is not yet optimized for biosensing application. A significant sensitivity-enhancement is therefore realistic.

Acknowledgments
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