Planar Crystal Waveguide Biosensor

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Photonic crystal structures offer a much richer environment than traditional optical waveguides when it comes to sensing applications. This gives both advantages and challenges when setting out to make an optical biosensor. As with all sensors the critical issues are compactness, low price, high sensitivity, high selectivity, and easy fabrication and integration with other optical or electrical components. The interest in optical biosensors comes primarily from the potential for fast and effective recognition of DNA/RNA, proteins or other biological molecules, and chemical reactions for diagnoses of diseases, discovery of new drugs, and environmental control.
The basic setup for a crystal waveguide using the photonic band-gab edge for sensing purposes is shown in Fig. 1 along with a SEM image of the sensor element – the photonic crystal waveguide.

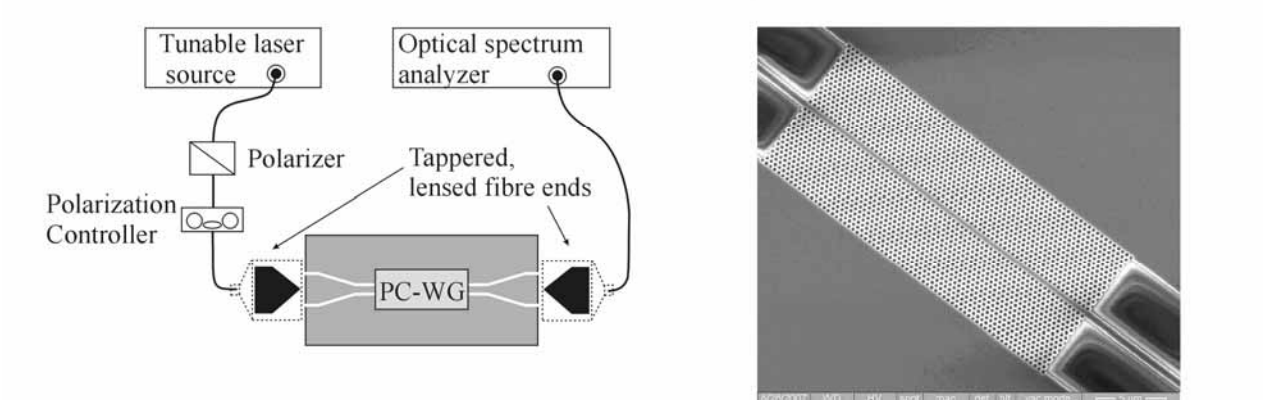

Fig. 1. Basic experimental setup and SEM-image of the sensor -element

The advantages of the device are that it is realized in silicon and can be integrated on a CMOS compatible SOI-wafer (silicon-on-insulator) along with other electronic and optical devices. The photonic crystal waveguide can be made very compact and the sample volume can also be reduced considerably compared to many other biosensors presented in the literature. It is realized in a SOI-wafer comprising a SiO_2 layer with a thickness of 2μm and refractive index 1.44, and a 320nm thick silicon slab with refractive index 3.48. A triangular lattice of holes with a single line-defect in the ΓK-direction is etched into the top Si layer using a lattice constant, a = 370 nm, and hole diameter, d = 240 nm. The length of the waveguide is 50μm.

The properties of crystal waveguides are highly influenced by changes in refractive index at the silicon surface, which is the property of the device we utilize, since bio-sensing typically involves detection of specific biological molecules at the sensor surface. One feature exploited as sensing probe is the transmission edge of the lowest band-gap defect-mode of the photonic crystal waveguide. This is the most obvious and robust property for sensor application [1]. It is seen as a sudden drop in transmission spectrum vs. wavelength and can be used for sensor probe as the wavelength position of this transmission drop increases/decreases with an increase/decrease in refractive index of the cover medium. The effect is dramatically amplified because both the E-field and the captured proteins are strongly localised near the interface. E-field localization is due to a combination of D-field continuity and a short range of the evanescent field in high-index structures. The captured proteins can be localized by using selective antibodies immobilized on the interface or simple chemical affinity. In both cases, a response time of a few minutes is attained, as shown in Fig. 2.

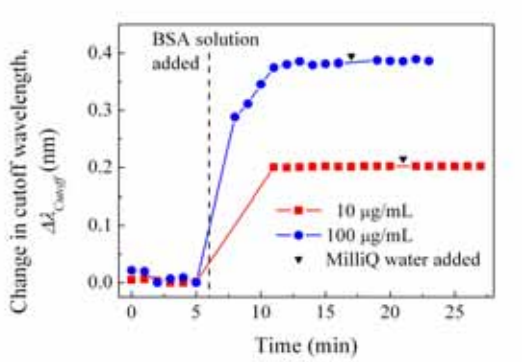

Fig. 2. Time measurements of the change in cut-off wavelength for two BSA solutions of 10µg/ml (red squares) and 100 µg/ml (blue circles)

Recently we discovered a new feature for the crystal waveguides, which will be superior to the transmission edge of the band-gap for sensor applications and allow sensitivity beyond that for present-day optical sensors based on cavities [2]. By exploiting polarization mixing properties for waveguides we have realized narrow band-pass filters, which we propose for sensitive sensor probes. The narrow feature shifts approximately the same amount in wavelength as the edge, but since it is several hundred times narrower, the sensitivity is greatly enhanced. We estimate that the sensitivity can hereby be enhanced by 200 times. For practical applications it is easy to integrate the necessary polarizers on the same chip, so no external polarization tuning will be needed. Further improvements in sensitivity and selectivity are possible by using two or more waveguides with different antibodies in balanced bridge configurations.

References

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[2] K. De Vos, I. Bartolozzi, P. Bienstman, R. Baets and E. Schacht, 'Optical biosensor based on silicon-on-insulator microring resonators for specific protein binding detection', Annual Symposium of the IEEE/LEOS Benelux Chapter, 213-216 (2006)