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Silicon-on-Insulator Microring Resonator for Biosensing

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Label-free biosensors attempt to overcome the stability and reliability problems of biosensors relying on the detection of labeled molecules. We propose a label-free biosensor based on microring cavities in Silicon-on-Insulator (SOI) that fits in an area below $10x10\mu m^2$*. The resonance wavelength shift that occurs when the surroundings of a cavity is changed, is used for sensing. While theoretically the performance for bulk refractive index changes is moderate* (10^{-5})*, this device performs outstanding in terms of absolute molecular mass sensing (theoretical sensitivity of 1fg molecular mass) thanks to its extremely small dimensions. We use the avidin/biotin high affinity couple to demonstrate good repeatability and detection of protein concentrations down to 10ng/ml.*

Introduction

Optical label-free biosensors for protein detection attempt to overcome the drawbacks of commercialized microarrays, which rely on the detection of labeled molecules. This intermediate labeling step however complicates the detection process and decreases reliability. When biomolecular interaction takes place at the surface of an optical cavity, the resonance wavelength will shift. The semiconductor surface is chemically functionalized with receptor molecules that specifically interact with the target molecule. SOI offers a high refractive index contrast suitable for the fabrication of nanophotonic circuits including micron- and submicron sized optical cavities of very high quality. The enhanced light-matter interaction in a cavity increases the sensitivity while keeping the sensor's dimensions small [3]. Integrated in a microfluidic setup thousands of cavities can be lined up in arrays for multiparameter sensing within a few square millimeters.

SOI microrings for biosensing

Light with a wavelength $\lambda = \frac{n_{eff}L}{m}$, $m = 1,2,...$ resonates in a microring resonator with circumference L. This results in a sharp dip in the transmission. A change in the refractive index of the ring's environment shifts the resonance spectrum, which can be monitored by scanning the wavelength and by measuring the intensity profile at one well chosen wavelength. The sensitivity increases with increasing quality factors Q of the resonator. The Q-factor expresses the peak's width: $Q = \frac{\delta\lambda_{3dB}}{\lambda_{resonance}}$. Q-factors over 20,000 are easily achievable with our fabrication process and optimized design, the 3dB peak width is 75pm. Deep ultraviolet (UV)lithography, the technology used for advanced complementary metal-oxide-semiconductor (CMOS) fabrication offers both the required resolution and the throughput needed for commercial applications [1].

Measurements

Water with different sodium chloride concentrations is flown across the ring resonator in order to characterize the sensor for bulk refractive index sensitivity. Fig. 1a shows a linear shift of the resonance wavelength with increasing salt concentration of 70nm/RIU. The variations are very small, proving a very high refractive index sensor's stability. A shift of one fifteenth of the peak width is easily measurable, so a minimal detectable wavelength shift of $5pm$ corresponds with a minimal detectable refractive index shift of 10^{-5} RIU. In the present work we used the avidin/biotin system which has a high affinity constant and therefore has a stable and specific interaction, as a model of biomolecular interaction. Biotin was immobilized on the aminofunctionalized silicon surface. We compare the resonance wavelength of the cavity immersed in PBS, before and after being in contact with avidin solution (avidin in PBS), no bulk refractive index changes are involved. The evolution of the wavelength shift for different avidin concentrations compared to the reference PBS resonance wavelength is shown in Fig. 1b. For avidin concentrations above $10\mu g/ml$ the surface is fully covered, the resonance wavelength shift saturates. The estimated lowest detectable concentration, for a minimal detectable wavelength shift of 5pm, is $10ng/ml$. This compares well with commercially available label-free protein detection methods [2].

Measuring the output intensity at one wavelength is used for real time interaction detection. Graph 1c shows real time measurements for 10ng/ml and 50ng/ml avidin concentrations. The rise time is due to both the protein interaction rate and the mixing in the flow cell.

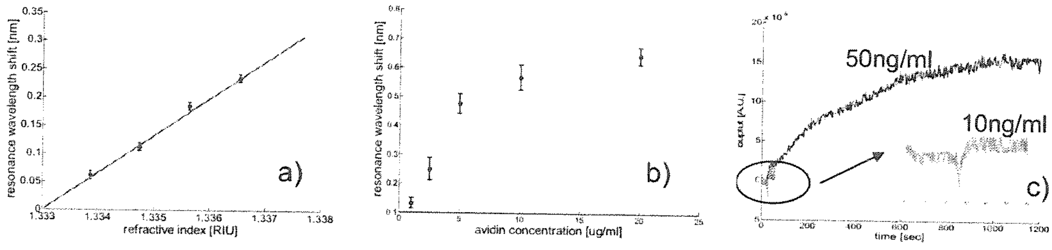

Figure 1: a) Resonance wavelength shift versus bulk refractive index change. b) Quantitative avidin/biotin detection with an SOI microring cavity. c)Real-time measurement of avidin/biotin interaction

Conclusions

We have demonstrated a highly miniaturized optical label-free biosensor based on a Silicon-on-Insulator microring cavity with Q factors over 20000. The refractive index sensitivity is 10^{-5} independent of the microring's radius. Measurements reveal proper operation of the device, being able to detect avidin concentrations down to 10ng/ml which compares favorably with commercial biosensing applications.

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