Plasmonic Slot Waveguides for Localized Biomolecular Sensing Applications

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Abstract: A plasmonic slot waveguide excited by evanescent wave coupling of a silicon strip waveguide is studied to be used as a label-free biosensor. The plasmonic slot waveguide enables strong electric-field enhancement in a small volume inducing higher interaction between the light and the analyte.
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1. Introduction

In many fields the advances in fabrication technology have led to a reduction in size of devices by several orders of magnitude. One area that benefits in particular from this trend is the optical sensing especially by combining nano-structures to optical waveguides that pave the way for integrated optical sensors [1]. In fact, optical waveguides are the key elements of integrated photonics devices that perform mainly guiding in addition to other applications. This kind of technology is of great current interest for the development of sensors [2]. Single-cell analysis (SCA) – a new emerging field of research in life sciences – is increasingly recognized as the key technology for the explication of heterogeneous cellular behavior, which is not accessible from bulk measurements [3]. This work describes a new optical sensor, based on a plasmonic slot waveguide cavity (PSWC), which could achieve SCA by measuring the protein secretion of a cell under stress in a multiplexed manner on a 2D array (Fig. 1). In previous work we studied a periodic PSWC excited by a multimode slab waveguide [4]. The device has potential applications as a refractive index sensor in the near-infrared with a sensitivity of 730nm/RIU (Refractive Index Unit) nevertheless the aim to localize the sensing area is not fulfilled.

2. Discussion

We reduced the interaction volume by the use of a gold plasmonic slot waveguide which confines the optical mode in a sub-wavelength slot (Fig. 2) [5]. Thus, our configuration consists on adding a slot cavity made by gold on the silicon waveguide cladded by a SiO_2 layer. This plasmonic waveguide is excited by evanescent wave coupling from an underlying silicon strip waveguide. A polarization-maintaining (PM) lensed-fiber is used to couple a wide spectrum (1200-1650nm) form a supercontinuum laser source to the silicon waveguide. The transmitted spectrum, from which the resonance shift is extracted, is measured with an optical spectrum analyzer.

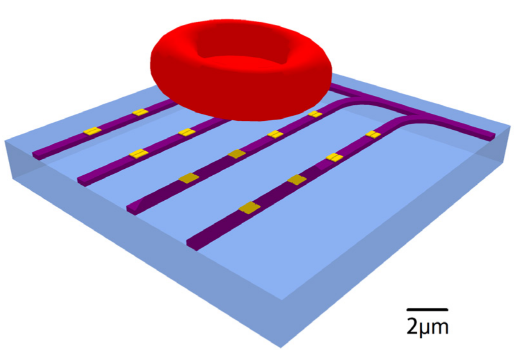

Fig. 1. Schematic view of a multiplexed 2D array of PSWC sensors on top of which a red blood cell is immobilized

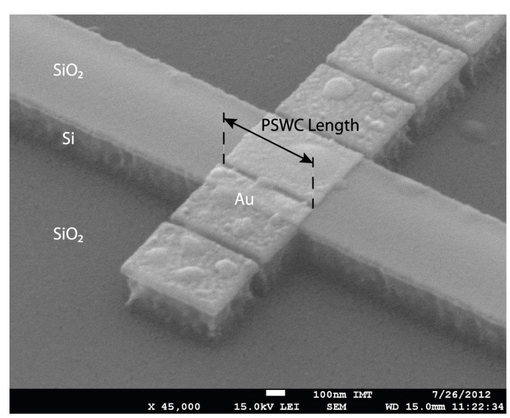

Fig. 2. SEM picture of the fabricated PSWC (a 10nm gold coating has been performed to facilitate the SEM observation)

We study the transmission as a function of the cavity length. A guided mode is excited and propagates along the metallic slot. One notes that the transmission greatly depends on the cavity length. In fact, interference harmonics of this guided mode lead to additional peaks in the transmission spectra as in a Fabry-Pérot cavity. In the Fig. 3 on can see this resonating behavior. This result is obtained using CST Microwave software based on FDTD simulation.

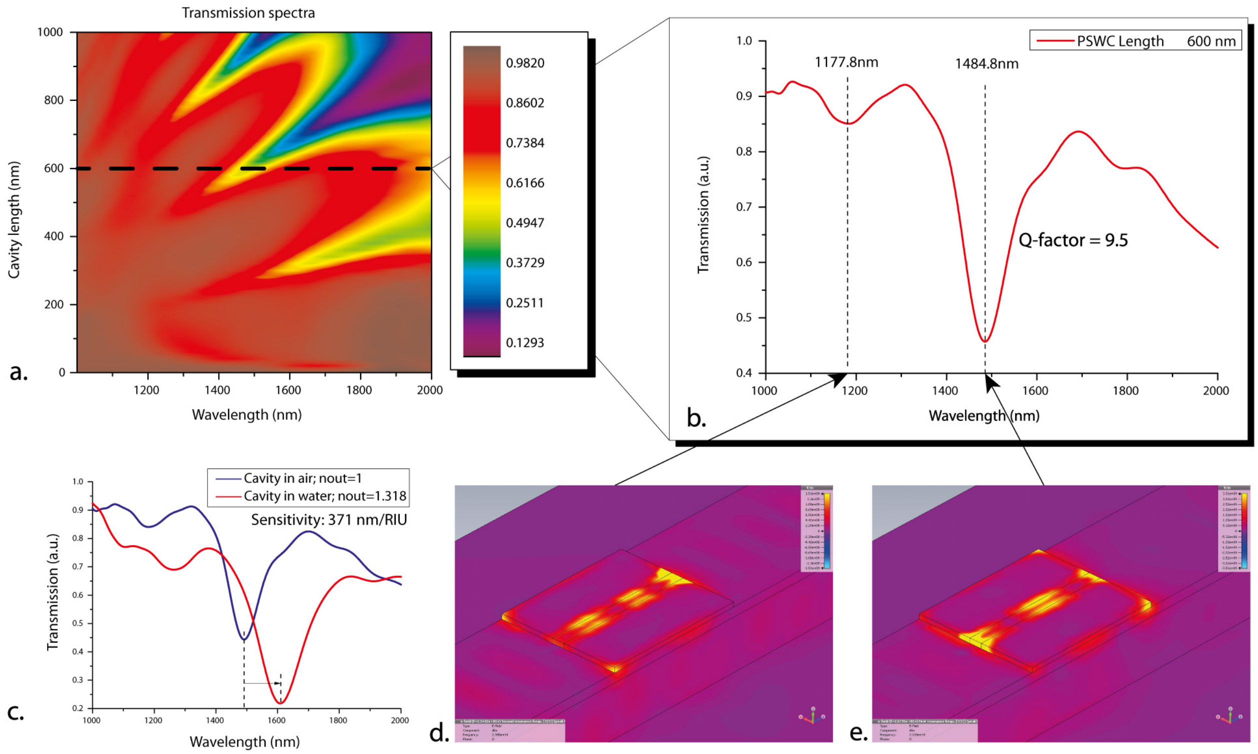

Fig. 3. **a,** Transmission spectra map calculated with CST MWS of a PSWC excited by the fundamental TE mode of an underlying silicon strip waveguide for cavity lengths from 0 to 1000nm in 20nm steps. **b,** Transmission spectrum for a cavity length of 600nm extracted from graph **a**. **c,** Two PSWC transmission spectra showing a resonance red-shift of 371nm/RIU during a change of refractive index of the surrounding medium shown. **d, e,** Absolute E-field at the first and second resonance frequency represented with a colored linear scale.

For a given cavity length (L=600nm), where the resonant peak is located at 1.55µm, we study the sensing properties of a PSWC on a single mode waveguide. It turns out that such a device is sensitive to refractive index changes in a sub-attoliter volume. The cavity shape is optimized thanks to a parameter study and its sensitivity can be maximized to 370nm/RIU. The sensitivity drops compared to the periodic PSWC array because of the lack of lateral coupling between adjacent structures. Nevertheless, the Q-factor of the resonance of the single PSWC is increased because of the higher coupling between the fundamental mode of the silicon waveguide and the PSWC.

3. Conclusions

We studied the periodic PSWC and the single PSWC. We showed the potential of this nano-structure as refractive index sensor of the surrounding medium. A simple Fabry-Pérot resonator can be a good model to discuss and understand nano-cavities. Future work will focus on microfluidic integration and single-molecule detection.

4. References

[1] J. N. Anker, W. P. Hall, O. Lyandres, N. C. Shah, J. Zhao, and R. P. V. Duyne, “Biosensing with plasmonic nanosensors,” *Nature Materials*, vol. 7, no. 6, pp. 442–453, 2008.

[2] X. Fan, I. M. White, S. I. Shopova, H. Zhu, J. D. Suter, and Y. Sun, “Sensitive optical biosensors for unlabeled targets: A review,” *Analytica Chimica Acta*, vol. 620, no. 1–2, pp. 8–26, Jul. 2008.

[3] C. Schubert, “Single-cell analysis: The deepest differences,” *Nature*, vol. 480, no. 7375, pp. 133–137, Dec. 2011.

[4] Q. Tan, A. Cosentino, M. Roussey, and H. P. Herzig, “Theoretical and experimental study of a 30nm metallic slot array,” *J. Opt. Soc. Am. B*, vol. 28, no. 7, pp. 1711–1715, Jul. 2011.

[5] G. Veronis and S. Fan, “Modes of Subwavelength Plasmonic Slot Waveguides,” *Journal of Lightwave Technology*, vol. 25, no. 9, pp. 2511–2521, Sep. 2007.