Excitation of Metallic Nano-Cavities by a Silicon Waveguide for Localized Sensing Applications

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Summary

Strong Electric-field enhancement in small volumes is the key for label-free single-molecule sensing. We have investigated the excitation of single and multiple metallic nano-cavities by evanescent wave coupling in the near-infrared by a silicon wire waveguide.

Introduction

Sub-wavelength resonators are of great interest for label-free single-molecule sensing by refractive index change [1] or Raman spectroscopy [2]. The strong confinement of the resonant mode can be achieved by plasmonic resonant nano-cavities.

In our previous work we demonstrated the simulation, fabrication and characterization of periodic slot waveguide cavities (SWC) excited by a multimode slab waveguide [3]. The device has potential applications as a refractive index sensor in the near-infrared. The sensitivity is 730nm/RIU (Refractive Index Unit). In this paper we extend our work along two axes. The first axis extends the single stripe of SWC to multiple stripes. As a result we get more measurements at once, but we lose localization. The other axis investigates the realization of a single SWC on top of a single mode waveguide. In the second case, the field is strongly localized, but less light is available for the measurements.

Results and discussions

Figure 1 shows the cascaded SWC array and the transmission spectrum in air. Compared to earlier measurements of a single stripe, the resonance dip is increased by 50%. The sensitivity does not change, but the increased resonance dip contrast enhances the sensor resolution. On the other hand, a local change in the refractive index (e.g. by a protein) in one of the slots would be difficult to be detected and furthermore impossible to be localized. However, one

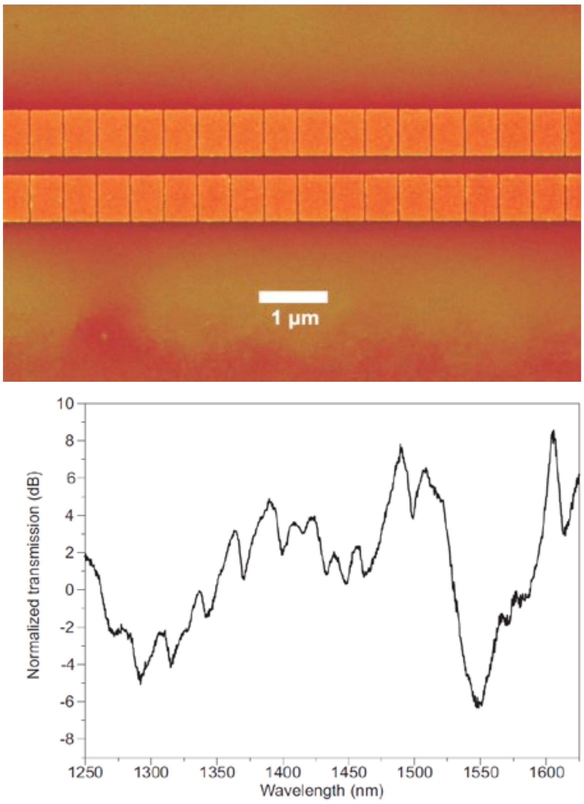

Fig. 1: SEM image of the cascaded SWC array and its corresponding transmission spectrum in air.

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may think about a sub-diffraction limited optical microscope that uses these resonances to localize proteins by detecting their far-field scattering.

In the second part, we study the sensing properties of a single SWC on a single mode waveguide. It turns out that such a device is sensitive to refractive index changes in a sub-attoliter volume. Its simulated transmission spectrum (Fig. 2) shows a resonance dip amplitude 6 times larger than the response of the single SWC array [3]. The interaction of the modes between the single-mode waveguide and the SWC is larger than for the slab-waveguide coupled to the periodic SWC. However, the sensitivity of the single SWC dropped to 261nm/RIU.

To acquire a better understanding of the limits of a plasmonic resonant cavity, we will, in on-going work, also investigate the classical bow tie shaped antenna which has been extensively studied and which shows strong resonance and field confinement [4]. The bow-tie nano-cavitiy is a well-suited optical structure to locally enhance the electromagnetic field, as it is required in sub-diffraction limited Raman spectroscopy.

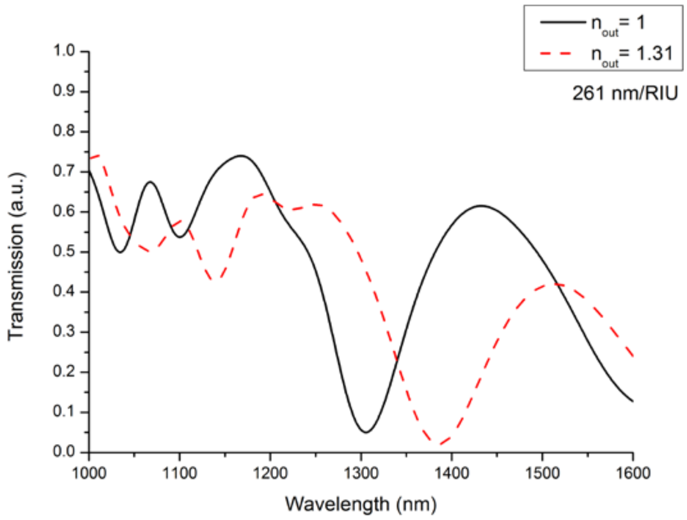

Fig. 2: Transmission spectrum of the single SWC in air and in water.

Conclusions

We analysed the cascaded SWC array and the single SWC. We discussed the differences between both types of cavities. We showed the resonance shift as function of the change in refractive index of the surrounding medium for both nano-structures. Finally, we compared the confinement of the electromagnetic field. A simple Fabry-Pérot resonator can be a useful approximation to discuss and understand nano-cavities. Future work will focus on the investigation of new cavities and upon their scaling behaviour.

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References

[1] P. Zijlstra, P. M. R. Paulo and M. Orrit, *Nature Nanotech.*, **7**, 379-382, 2012.
[2] J. N. Anker *et al.*, *Nature Mater.*, **7**, 442-453, 2008.
[3] Q. Tan, A. Cosentino, M. Roussey and H.-P. Herzig, *J. Opt. Soc. Am. B*, **28**,1711-1715, 2011.
[4] H. Fischer and O. J. F. Martin, *Opt. Express,* **16**, 9144-9154, 2008.