Guided Mode Resonances For Sensing And Imaging

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Abstract. We discuss the latest developments in guided mode resonances for sensing and imaging and compare them to alternative approaches such as plasmonic nanohole arrays.

1 Introduction

Resonant nanophotonic concepts offer interesting opportunities for sensing and imaging applications. These concepts include microring resonators, gratings/photonic crystals as well as plasmonic nanostructures such as nanoparticles and nanohole arrays. Our work focuses on guided mode resonances (GMRs) in dielectric arrays. Such guided mode resonances in the context of sensing were first described by Magnusson [1] and then further developed by Cunningham, who referred to them as photonic crystal biosensors [2].

2 Sensing

The key advantage of the guided mode resonance approach is that GMRs are easily excited by out-of plane illumination using simple collimated light sources, including LEDs. This ease of coupling allows them to be used in low-cost packages, including integration into removable cartridges that are inserted by untrained personnel for point-of-care applications. An artist's impression of a possible realisation is shown in fig. 1. The ease of coupling is due to the fact that GMRs are leaky modes, which means that they do not achieve the high Q-factors achievable with guided-mode optics devices, but that they can be readily excited with a collimated beam with large alignment tolerances. The challenge, therefore, is to achieve high performance while retaining the advantage of simple interfacing. An additional challenge is the readout, which in many cases requires an external spectrometer.

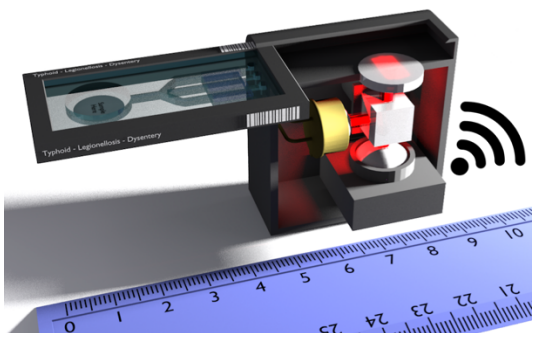

Figure 1. Artist's impression of a handheld sensor device exploiting the simple excitation of guided mode resonances.

By chirping the period or fill-factor of the GMR [3], we have been able to solve the spectrometer problem by integrating the sensing and the readout function into the same structure.

Inspired by the success of sensing and imaging with plasmonic nanohole arrays [4], we have also explored nanohole arrays in silicon (fig. 2a) and have obtained remarkable results; in particular, we have observed beautiful Fano resonances with a Q-factor of 200-300 (fig. 2b, factor 5-10 higher than a plasmonic resonance) as well as a very high surface sensitivity which is comparable to that of the plasmonic equivalent.

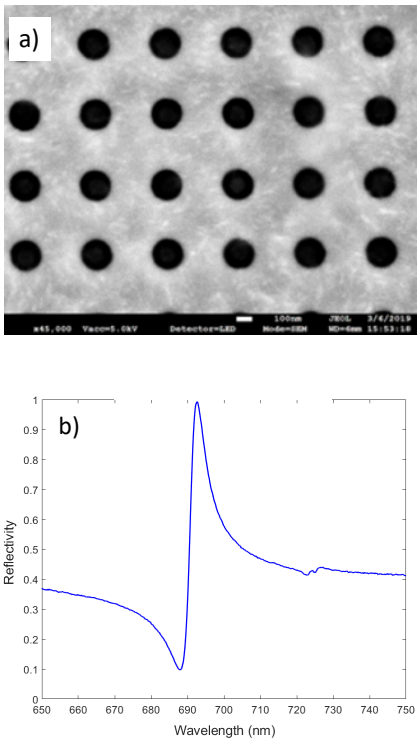

Figure 2. a) Nanohole array of 470 nm period realised in hydrogenated amorphous silicon. b) Corresponding Fano resonance. Note the large dynamic range and the near-100% reflectivity at a wavelength below 700 nm, which highlights the low loss of the hydrogenated a:Si material.

Finally, we are now implementing common-path interferometric methods which further increase the available sensitivity. As a result, our detection limit is now in the Δn≈1e-6 regime, which is comparable to much

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more sophisticated approaches yet still compatible with a handheld device.

3 Imaging

The idea of the chirped GMR approach is that it converts spectral information into spatial information that can be easily picked up by a simple camera, i.e. it exploits the imaging capability of the GMR; one can therefore also think of a GMR as an array of sensors. Given the high sensitivity, it should then be possible to detect proteins locally, i.e. in the proximity of a cell. Taking this idea further, we have used the technique to image human cells and the proteins they secrete, which allows us to see how cells communicate in health and disease. Since the technique is label-free, cells can be directly taken from patients with minimum preparation. We used the technique to map the secretion of the signaling protein thrombopoietin (TPO) from individual human HepG2 cells and quantified the heterogeneity of TPO expression as a function of the desialylated platelet concentration (fig. 3) [5].

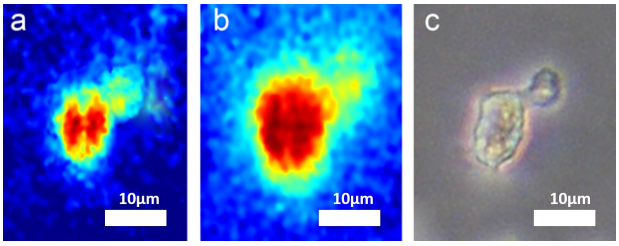

Figure 3. a) Human HePpG2 cell imaged at the beginning of the experiment (t=0 min). b) The same cell at t=84 min. It appears larger because it has secreted thrombopoietin (TPO). The same cell imaged by phase contrast microscopy; the image does not change during the same experiment. The spatial resolution is higher but phase contrast is not able to see protein secretion.

4 Conclusion

Overall, the versatility of the GMR approach makes it very attractive for both sensing and imaging applications. It also offers multiple degrees of freedom which offer opportunities for further optimization.

References

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