Whispering gallery mode lasers for biosensing applications

A. François,[1,2] N. Riesen,[1,2] T. Reynolds,[1] J.M.M. Hall[1] and T.M. Monro,[1,2] [1]The Institute for Photonics and Advanced Sensing, School of Physical Sciences, The University of Adelaide, Adelaide, SA 5005, Australia and [2]School of Engineering, University of South Australia, Mawson Lakes, SA 5095, Australia.

Whispering Gallery Modes (WGM) are optical modes occurring in resonators with at least one axis of revolution. WGMs have been at the forefront of developments in optical biosensing owing to their exceptional detection limits down to a single molecule (Baaske, Foreman & Vollmer, 2014). However, using WGM spectroscopy outside of research environments remains a considerable challenge as the WGMs, whether in spheres, toroids or capillaries, are interrogated using a cumbersome phase matching coupling scheme using either a fibre taper or prism. Fluorescent microresonators which instead permit remote excitation and readout of a WGM modulated fluorescence signal, do not suffer from the same practical constraints, enabling new applications such as *in vivo* sensing (Himmelhaus & Francois, 2009), tagging of single cells (Schubert *et al.*, 2015) and even turning a cell into an optical resonator (Humar & Yun, 2015). However, the lower Q factors realized for fluorescent resonators, which is associated with the very nature of the detection mechanism (Riesen *et al.*, 2015), poses a significant limitation.

We have shown that by combining the unique light guiding properties of microstructured optical fibres (MOF) with fluorescent microspheres, some of the intrinsic limitations of fluorescent microresonators can be alleviated. Modelling of WGMs in fluorescent microspheres has allowed us to pinpoint the ideal diameter for a large range of materials, enabling optimization of both the refractive index sensitivity and resolution and hence the detection limit (Reynolds *et al.*, 2015). We have also shown lasing in the smallest resonators ever in aqueous solution (Ø = 10 μm polystyrene) by tuning the dye concentration to avoid dye self-quenching, and minimizing the lasing threshold (François *et al.*, 2015). Moreover, achieving WGM lasing of a microsphere at the tip of a MOF has been shown to result in unprecedented Q factor enhancements – for example 2×10^4 above the lasing threshold, compared with ~ 10^3 for the same free floating microsphere below its lasing threshold. Building on these results, we have shown that the simple approach of combining lasing microspheres with MOFs improves the detection limit of specific biomolecules when used as a dip sensor (François, Reynolds & Monro, 2015). Furthermore, multiple lasing microspheres can be positioned onto the tip of a single MOF allowing for multiplexed sensing or dynamic self-referencing. This approach has shown tremendous potential for compensating non-specific binding in undiluted human serum without requiring complex surface treatment (Reynolds *et al.*, 2015).

Baaske MD, Foreman MR, Vollmer F. (2014). *Nat Nanotechnol* **9**, 933-939.
François A, Reynolds T, Monro TM. (2015). *Sensors* **15**, 1168-1181.
François A, Riesen N, Hong J, Afshar SV, Monro TM. (2015). *Appl Phys Let* **106**, 031104.
Himmelhaus M, Francois A. (2009). *Biosens Bioelectron* **25**, 418-427.
Humar M, Yun SH. (2015). *Nat Photonics* **9**, 572-576.
Reynolds T, François A, Riesen N, Turvey ME, Nicholls SJ, Hoffmann P, Monro TM. (2015). *Anal Chem* **88**, 4036-4040.
Reynolds T, Henderson MR, François A, Riesen N, Hall JMM, Afshar SV, Nicholls SJ, Monro TM. (2015). *Opt Express* **23**, 17067-17076.
Riesen N, Reynolds T, François A, Henderson MR, Monro TM. (2015). *Opt Express* **23**, 28896-28904.
Schubert M, Steude A, Liehm P, Kronenberg NM, Karl M, Campbell EC, Powis SJ, Gather MC. (2015) *Nano Let* **15**, 5647-5652.