Invited: Novel microstructured fibres for optical sensing of gases

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Air/Silica Microstructured Optical Fibres (MOFs) provide a novel and enabling platform for absorption-based optical sensing of gases [1]. These fibres have arrays of wavelength-scale holes in their cross section, which run along the full length and define their waveguiding properties by way of their geometry and size. A wider variety of guidance mechanisms and optical properties is possible in MOFs, as compared to conventional fibres, due to the high index contrast between air and glass, and the almost endless variety of structures that can be realised with this technology.

Perhaps not surprisingly, these fibres have allowed significant advances in a number of application areas, and among these MOF appear in particular very promising for gas sensing. Indeed, the ease in accessing the guided optical field in Photonic Bandgap Fibres (PBGFs), where most of the optical power is located in a hollow core, or in index-guiding, small core MOFs engineered to achieve a very high evanescent field, is unprecedented and has no counterpart in conventional fibres. Photonic Bandgap Fibres, in particular, can accomplish both extremely high overlap factors and low propagation, bending and insertion losses, opening up the possibility for very efficient fibre-based sensor devices with extremely compact and flexible footprint, which can be interfaced with conventional fibre networks for remote interrogation and only require a very small amount of sample, of the order of microliters, to operate [2].

The implementation of these fibres in practical devices, however, requires addressing a number of issues, and this work describes the latest developments in what we have identified as two key areas. A first drawback arises due to the multimode nature of the most common types of hollow core PBGFs: since these fibres can in general support several modes over the meter-length scale that would be required for most sensor heads, modal interference can severely limit the ability to reliably detect weak lines from low level gas concentrations. It is therefore paramount to investigate the modal properties of PBGFs and the close interplay that exists between the fine details of the fibre structure and the number and type of optical modes supported by these structures. We have identified fibre structures that have potential to suppress unwanted modes, such as surface modes and higher order air guided modes, thus reducing the impact of modal interference effects. Another well-know obstacle is the difficulty to accomplish a stable optical input and output coupling to the PBGF, while providing gas access and diffusion into the fibre at a reasonable speed, in a compact fashion, i.e. ideally without the use of bulk optics. Filling the gas from the fibre ends results in unacceptably long response times, which would completely cancel out the advantage of high sensitivity in a PBGF-based sensor. We have pioneered the development of a technique [3], based on femtosecond laser machining, which allows the fabrication of fluidic side channels in PBGFs. Here we show that the channels allow much faster gas in-diffusion at very low loss penalty, opening up the possibility for compact multiport fibre-based sensor heads and reference cells where the concentration and pressure of the gas can be varied at will.

[1] M.N.Petrovich, et al., "Microstructured fibres for sensing applications", Photonic Crystals and Photonic Crystal Fibers for Sensing Applications. Edited by Du, Henry H. Proceedings of the SPIE, Volume 6005, pp. 78-92 (2005).
[2] E.Austin, et al., "Fibre optical sensor for C_2H_2 gas using gas-filled photonic bandgap fibre reference cell", Sensors & Actuators B, Volume139(1) pp.30-34 (2008).
[3] A.van Brakel, et al. "Micro-channels machined in microstructured optical fibers by femtosecond laser", Optics Express, Volume15(14), pp.8731-8736 (2007).