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Sensing in hollow-core photonic crystal fibres

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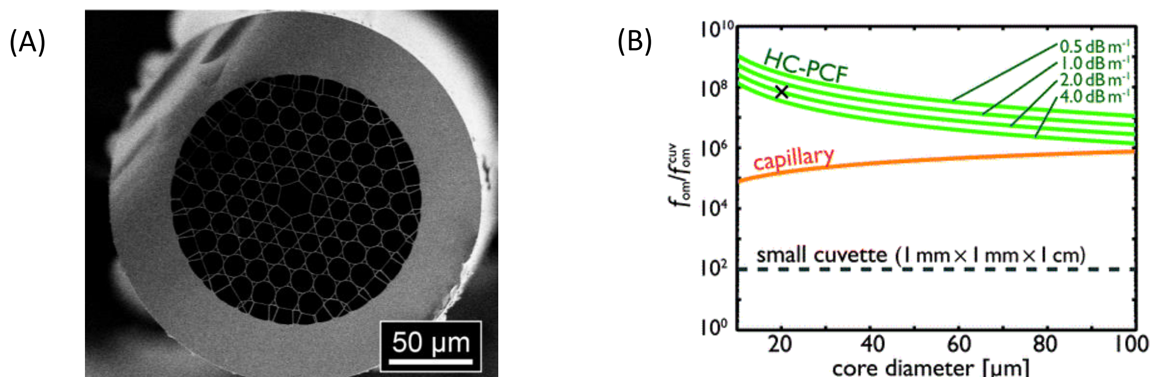
Research topics – Hollow-core PCFs, sensing

See Optofluidics Group website: https://www.np.phy.cam.ac.uk/research-themes/optofluidics



Introduction

Hollow-core photonic crystal fibres (HC-PCFs) consist of a central cylindrical hollow channel with a typical radius of ~ 10 µm (the 'core') surrounded by a periodic arrangement of smaller channels (the 'cladding'), running along the entire length of the fibre (see Figure A). Sensing in HC-PCFs can be achieved by analysing changes in absorbance, fluorescence, Raman scattering, effective refractive index or surface plasmon resonances.

Conventional on-chip optofluidic circuits suffer from short light-matter interaction lengths (a few cm) or rely on surface-bound evanescent fields of embedded waveguides. This limits the detectability of low analyte concentrations or restricts sensing to regions close to the surface. Hollow-core photonic crystal fibres (HC-PCFs) mitigate these limitations by enabling the guidance of light through liquids, enhancing the light-matter interaction.

Maximising the light-matter interaction is particularly important for photochemical reactions with low quantum yields: reaction chambers with long interaction lengths and small cross sectional areas are suitable for this purpose. Compared to a standard 1-cm cuvette, the light-matter interaction in a HC-PCF can be enhanced by 10^8 times (see Figure B).

The nano-scale reactor volumes also minimises material consumption. For comparison, conventional cuvette measurements require a sample volume of at least 3 ml to fill a 1-cm cuvette, whereas a typical HC-PCF system only requires sub-µL sample volumes to fill a 1 m HC-PCF. The precision provided by optofluidics in terms of light and fluidic control means hollow-core photonic crystal fibres are a good platform for rapid screening, with readily translatable results for up-scaling to continuous flow systems.

References

- M. Cubillas et al. Photonic crystal fibres for chemical sensing and photochemistry. *Chemical Society Reviews*, 42(22):8629, 2013.
- M. Schmidt et al. Chemical and (Photo)-Catalytical Transformations in Photonic Crystal Fibres. *ChemCatChem*, 5(3):641-650, 2013.

Aims of the practical

- Understand how to build a fibre-based optofluidic set-up.
- Track the progress of a redox reaction using the absorbance of methyl viologen as an indicator. AND/OR (time-dependent)
- Detect a Raman signal from micromolar concentrations of Rhodamine 6G.

Questions

- Explain the two different mechanisms for light guidance down a HC-PCF. Which mechanism applies to the kagomé HC-PCF?
- What are the advantages of studying photochemistry in a HC-PCF compared to in a cuvette?
- How could we deduce information about diffusion and surface adhesion properties of an analyte within the HC-PCF?
- Give a few examples of systems that can be studied by this technique.
- Can HC-PCFs be used in an entirely different context?
- What are the limitations of the technique?

Experimental details and procedures

Absorbance Experiment:

1. Make up a photochemical solution of

Component	[Stock]	Volume Required	[Solution]
N-doped graphitic carbon dots	5 g/l	0.1 ml	0.04375 g/l
Methyl Viologen	1 mM	0.04 ml	0.35 µM
EDTA	0.2 M	0.5 ml	0.00875 M
MilliQ Water		12 ml	

2. Purge the photochemical solution with nitrogen gas for 10 minutes.
3. Wash the HC-PCF by flowing MilliQ water through the fibre (use syringe provided)

4. Couple the NKT Photonics SuperK Compact supercontinuum laser into the HC-PCF using the power meter and camera provided. The fundamental mode (Gaussian) should be excited. Save an image of the fundamental mode when fully aligned.
5. Open Spyder2 and run the *SpectrometerTimelapse* Python code. Set the save location to R:\3-Temporary\SUPUVIR18\.
6. Set the integration time such that the modal peak for the reference solution (water) is as close to 60,000 counts as possible. Set the spectra number to 2000.
7. Flow the photochemical solution into the fibre and start the measurement and timer.
8. 3 minutes into the measurement turn on the 365 nm UV lamp to side-illuminate the fibre.
9. Analyse the spectral data using the Jupyter Notebook provided.

Raman Experiment:

1. Wash the HC-PCF by flowing MilliQ water through the fibre (use syringe provided)
2. Couple the Sprout-G, diode pumped solid-state laser (DPSS) into the HC-PCF using the power meter and camera provided. The fundamental mode (Gaussian) should be excited. Save an image of the fundamental mode when fully aligned.
3. Run the local spectrometer control software to visualize an image of the HC-PCF facet onto the CCD Camera of the Pixis/Acton Spectrometer (Princeton Instruments). Save the back-reflected image. Set the save location to R:\3-Temporary\SUPUVIR18\.
4. Flow the 1 µM Rhodamine 6G solution into the fibre and check for the HC-PCF / spectrometer / CCD alignments.
5. Move the spectrometer turret and grating at the angular position corresponding to the centre wavelength used for Raman excitation (either 633 nm or 785 nm). Collect an Image from the CCD camera (spectrograph).
6. Set the integration time and the spectrometer slit size to increase spectral resolution and detect the Rhodamine 6G Raman vibrational band.