Tools of the trade

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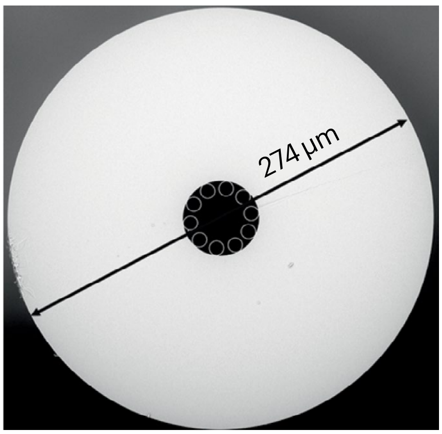
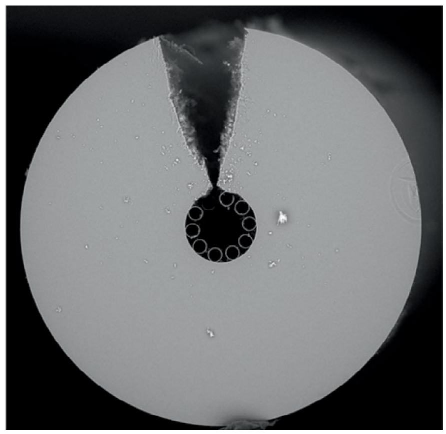
Femtosecond laser machining of microchannels in hollow core fibres





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Femtosecond laser micromachining could enable the use of hollow core fibres (HCFs) for gas detection with a fast response time and high sensitivity. In an HCF, light is guided with low loss in a gas-filled core. This design transforms the fibre into a compact, lightweight gas cell, for which the fibre length and minimum coiling diameter determine the cell size. In the conventional measurement configuration, gas enters the core of an HCF through the fibre's end facets and the gas then fills the light propagation path. This increases the gas–light interaction length and enables gas composition analysis using techniques such as absorption or Raman spectroscopy.

The sensitivity can be further improved by using a longer fibre to increase the path length. However, it takes more time to fill a longer fibre with gas, so the improved sensitivity can come at the cost of slower overall sensor response time, which depends on the filling time. For fibres that are longer than several tens of metres, the filling time becomes too long for practical applications. In addition, only filling the HCF from the end facets prohibits a distributed sensing configuration, which is highly desirable for some applications such as gas leak detection in pipelines or greenhouse gas monitoring. To solve this issue, the gas needs to enter the fibre from the side. This can be achieved by creating side microchannels along the fibre, which can facilitate faster filling times and enable spatially resolved gas monitoring.

Microprocessing using a femtosecond laser presents a unique method to fabricate microchannels in HCFs, which enables a tailored geometry and spacing of channels, leading to low optical loss. The use of femtosecond pulses is crucial. Compared to nanosecond or picosecond lasers, they reduce heat diffusion and therefore damage to the surrounding material. With femtosecond pulses, material modification relies on nonlinear optical absorption instead of thermal process, which provides localized material removal while maintaining high efficiency and control.

After aligning the fibre with the laser, high-energy, short pulses are focused on the HCF surface through a microscope objective and the ablation process begins. A low pulse energy (0.4 µJ) is used to remove the fibre's polymer coating, which is a thin layer around the cladding used to protect the fibre. Then the fibre's glass jacket is gradually ablated with a high pulse energy (0.8 µJ) until it is fully perforated. The laser pulses used to remove the fibre coating and to ablate the glass, as a typical example, may have a central wavelength of 1,030 nm, 200 fs pulse duration and a repetition rate of 50 kHz.

There are different approaches to create microchannels, including manual coating removal and alignment. However, an automated system is better for manufacturing a large number of holes in a single fibre length. For example, machine vision can help to precisely position the HCF in the focus of the laser beam. In our setup, we use nanoprecision stages to move the fibre in the x–y directions to shape the channel, and the z-axis of the stage adjusts the objective to ensure that the laser's focal point remains on the glass surface as material is removed during the ablation process. Prior knowledge of the fibre structure is essential to determine the spacing of the channels and avoid damaging the surrounding structures in the fibre.

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Competing interests
The author declares no competing interests.