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Spatially resolved gas pressure measurement in hollow-core optical fibres via four-wave mixing

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Hollow-core optical fibres (HCFs) guide light in an air-filled hole and have lower loss, increased power handling capability, and lower latency than solid fibres. HCFs can be further improved by evacuating the core, while filling and pressurising them with bespoke gases allows for tunability of chromatic dispersion and optical nonlinearity. For such applications, methods to measure the pressure inside the fibre are needed; for example, studies using OTDR have achieved 1.5 m spatial resolution. Here we investigate pressure measurements via four-wave mixing (FWM).

FWM happens when a strong pump and weak signal pulse interact, generating a third idler wave. The idler power depends on pump-signal interaction length (determined by group velocities), phase mismatch, and optical nonlinearity. As chromatic dispersion can be measured or simulated, idler power is a measure of the nonlinearity and thus of gas pressure. Changing the time delay between the launched pump and signal pulses changes where in the fibre they interact, providing spatial resolution.

We simulated the effective index and nonlinear mode area of a tubular anti-resonant HCF (core diameter 20.5 um, 7 cladding capillaries) using COMSOL Multiphysics for near-infrared wavelengths. These parameters were then used in the coupled amplitude equations (cw operation) and the nonlinear Schrödinger equation (pulses) to calculate the idler power.

Our results show that pumping close to the zero-dispersion wavelength (P=100 kW peak, 1.14 um) with the signal 15 nm away (45 m walk-off length), the generated idler power reaches 10% of the pump at 1 bar. At 1.3 um we get 1.3x10^(-5) conversion (walk-off 3 m, 10 nm separation), while at telecoms wavelengths of 1550 nm we obtain 4.3x10^(-6) conversion (walk-off 1.9 m, 10 nm separation).

Our numerical results indicate that FWM can provide a viable solution to high-resolution pressure measurements of the gas inside hollow-core optical fibres.