DISPERSION AND NONLINEARITY IN PHOTONIC CRYSTAL FIBERS

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Photonic crystal fibres (PCF) have proven to be a wonderful playground for nonlinear fibre optics, from the very high nonlinearities and strong waveguide dispersion to be obtained using small-core fibres formed from soft glasses, to the broad possibilities of nonlinear optics in a gas-filled hollow fibre. The opportunities can be considered to arise as a result of the extraordinary control which photonic crystal fibre (PCF) designs offer over the fibre performance. The key parameters measuring the significance of the nonlinear response of a fibre are the nonlinear coefficient and the dispersion, which between them govern the propagation of pulses in fibres. In a solid-core photonic crystal fibre (as illustrated in fig. 1 (a)) the nonlinear coefficient can be greatly enhanced by using a strong waveguide, squeezing the light very tightly into a tiny solid core. The resultant high intensities enable the observation of dramatic nonlinear effects [1] over very short fibre lengths. However, such strongly-guiding fibres are also highly dispersive: their propagation constants change radically with wavelength because the core size and the wavelength are comparable [2]. This gives rise to a dramatic dispersion curve for the guided modes. This unusual dispersion has a strong influence on the nonlinear optical processes in the fibers, enabling fine control over the nonlinear interactions [3] and enabling new effects to be observed [1,4].

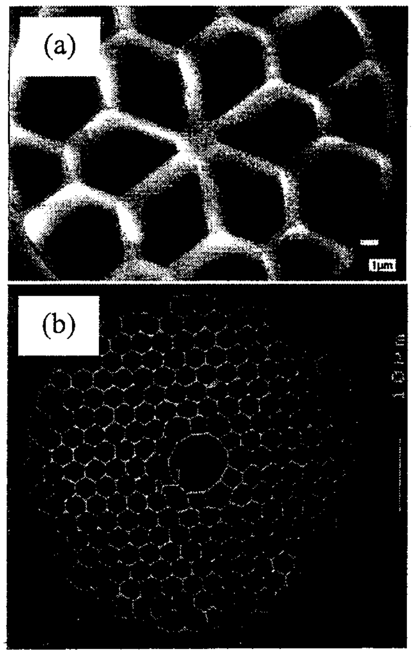

Figure 1 Solid-core (a) and hollow-core (b) photonic crystal fibres. The solid core fibre has a core diameter of 2μm, while that in the hollow core is 7μm.

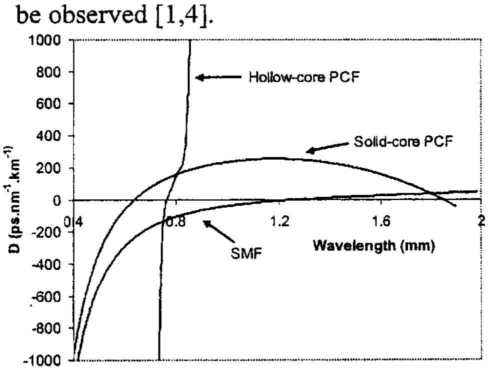

Figure 2 Group-velocity dispersion in standard single-mode fibre (SMF), in solid-core silica PCFwith a 1.7 μm core diameter and in a hollow-core fibre designed for use at 800nm wavelength.

Strong waveguide dispersion is also a feature of hollow-core fibres as illustrated in figure 1 (b). However, in this case the dispersion arises because the guided mode is confined in a low-index core region, usually filled with gas. An example of a group-velocity dispersion curve in a standard fibre and in solid-core and hollow-core PCF is shown in figure 2. The hollow-core fibre only guides light over a limited range of wavelengths, in which the dispersion goes from being highly normal to highly anomalous, with a reduced-slope region around the bandgap centre in which the dispersion is slightly anomalous [5]. The solid-core fiber is anomalous over a finite spectral range from about 0.6μm to 1.8μm [6], enabling solitonic effects in

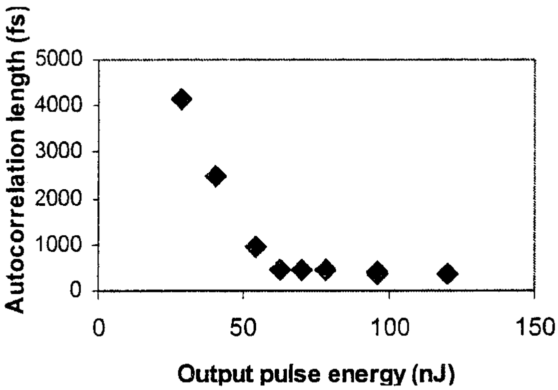

Figure 3 Pulse length at the output end of a 5-meter piece of hollow-core fibre, as the input pulse energy is increased.

the important spectral window around 850nm [1,7], in which the dispersion of standard fibre is normal. These coupled with the very high nonlinearity of the fibres have led to applications in frequency metrology [8] and optical coherence tomography.

On the other hand, light guided in a hollow core fibre can mean that the nonlinear coefficient is several orders of magnitude below that of standard fibres. This results from the very low nonlinear response of non-resonant gases compared to solid silica – the value of the nonlinear refractive index in air is around three orders of magnitude less than in glass. This fact, coupled with the relatively low Raman response and the anomalous group-velocity dispersion in hollow-core fibres enables the delivery of high-power femtosecond solitons over fibre lengths of several metres [9] as illustrated in figure 3. Propagation of femtosecond pulses at these energies in standard fibre is completely impossible – not only will the GVD mean that the pulses are massively stretched in time, but this situation is made far worse by the strong self-phase modulation and Raman scattering in the silica core. The examples presented here are but a sample of the broad range of interesting and useful nonlinear-optical effects being discovered in photonic crystal fibres.

References

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