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Simulation of electromagnetic wave propagation in photonic crystal fibres

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A thesis submitted in fulfilment of the requirements for the degree of Master of Philosophy in Lasers and Applied Optics

2017

Abstract

COMSOL Multiphysics software was used to investigate photonic crystal fibre (PCF) designs for control of propagation characteristics when pitch and air hole diameter were varied. The simulations have shown that characteristics of wave propagation in PCFs can be controlled by choosing appropriate structural parameters and fibre design suitable for specific supercontinuum generation (SCG) applications. Bandgap effect, dispersion, confinement and bend loss were analysed for the different photonic crystals whose hole diameter to pitch ratios (DPR) ranged between 0.2 to 0.8. Confined wavelength increased with increasing air filing fraction. When air filling fraction was less than 0.625, confinement loss was high. Varying the DPR enabled tailoring of dispersion. We have also simulated the propagation of femtosecond laser pulses in PCFs, identified nonlinear effects responsible for spectral broadening and explained the associated dynamics. The generalised nonlinear Schrödinger equation was used to model wave propagation and the symmetrised split step Fourier method used to obtain propagation solutions used in the MATLAB simulations. fibre parameters were estimated for an all normal dispersion (ANDi) PCF, NL-1050NEG-1 with a DPR of 0.39 and also for the birefringent PCF, whose DPR is 0.7, used to investigate polarisation effects on SCG. Obtained simulated output for ANDi PCF was compared with experiment for different input pulse powers. Spectral plots were obtained for 800 nm pump wavelength, 80 fs pulses with average powers of up to 568 mW, which resulted in broadening of spectra to a span of 327 nm suggesting that spectral broadening increases with pump power. Low average powers (10 mW to 100 mW) resulted in broadened spectral output that was symmetric and due to dominant self-phase modulation (SPM). Minimum dispersion effects were observed on the temporal pulse broadening. Significant broadening was observed with loss of symmetry in the output spectrum for average powers above 150 mW. A sensitivity analysis was also done on the simulation program using the obtained plots for the ANDi PCF, by studying the effect of varying fibre or pulse parameters. Broader spectra were obtained at longer wavelengths than 800 nm due to normal dispersion, optical wave breaking (OWB) and SPM. Our simulations showed that at small pump pulse durations (below 100 fs), spectral broadening was concluded within 0.025 m of propagation and SPM was the dominant nonlinear effect coupled with stimulated Raman scattering (SRS). OWB was significant on pulse duration above 150 fs. Self-steepening was observed to accelerate the completion of spectral broadening in the ANDi PCF. Spectral broadening could not be observed when nonlinear effects were not coupled with dispersion. Normal dispersion and nonlinearity complement each other to result in extreme broadening whereas anomalous dispersion counteracts with nonlinearity leading to soliton formation and more efficient broadening from soliton fission. Spectra spanning 400 nm and 192 nm were obtained in the anomalous and normal dispersion regimes respectively when pump pulses with 150 mW average power and 50 fs duration at 800 nm wavelength were used. In the birefringent fibre whose beat length was 0.68 µm, pulses launched with either vertical or horizontal polarisation showed neither decoupling nor change in state of polarisation. The slow axis had greater dispersion and generated wider spectra than the fast axis. When pumping with polarised light at an angle to the vertical axis, mode coupling from cross phase modulation was observed resulting in the state of polarisation changing periodically every beat length during propagation. The state of polarisation of output spectra was sensitive to small variations in fibre length. Simulations agreed well with experiments and results in literature.