Design of optical fibres with advanced modal control properties

Within the last decade unique properties of higher-order modes (HOMs) have been in focus of many researchers all around the world and found application in sensing, group velocity dispersion compensation and nonlinear frequency conversion among others. Development of optical communication systems has increased interest to HOMs as independent spatial data channels for mode division multiplexing (MDM). The primary aim of this thesis is the investigation, modelling and experimental evaluation of HOMs in an optical fibre of advanced design, suitable for a MDM implementation. In order to achieve this goal, an interferometric-based fibre characterisation technique, known as a cross-correlated (C2) imaging, was explored. An alternative modal reconstruction approach by 2D Fourier transform was presented, that allowed to extract intensity and phase distributions of the fibre mode from a single interferogram, acquired by a camera at a specific time delay. Aforementioned reconstruction technique was implemented for a flexible C2 imaging, which was realised by an application of a tunable and highly flexible light source. Current configuration of the C2 set-up gave an opportunity to investigate an influence of a spectral shape and bandwidth on a temporal resolution of the method and to form the input spectrum according to experimental requirements of the fibre design. A demonstration of the flexible C2 imaging was performed by a characterisation of a step-index fibre (SMF28) and a distributed mode filtering (DMF) rod fibre over a broad range of wavelengths. Results of the measurements are compared with numerical simulations revealing a good agreement. One of the method's advantages is an ability to identify all 3 operational regimes of the DMF rod fibre. For sensitivity verification of the flexible C2 imaging the modal cutoff for a polarisation maintaining (PM) step-index fibre was estimated. A set of repeatable measurements for characterisation of LP11 close to the cutoff wavelength were performed. Based on a spread of the detected modal powers a standard deviation was calculated for the each set of measurements, revealing sensitivity of the set-up to the highly suppressed modes. In the concluding part of the imaging techniques investigation, the C2 approach was compared with the spatially and spectrally (S2) resolved imaging, by measuring modal properties of a hollow core anti-resonant photonic crystal fibre, designed for high power beam delivery. In the second part of the thesis, was presented a model of a 19-cell hollow core (HC) photonic bandgap fibre (PBGF), that possesses a low transmission loss of approximately 4dB/km within 50nm of the C-band. From a numerical simulation were determined the effective refractive indices of the fibre modes, modal losses and intermodal delays. As a result, were selected two groups of the full vectorial modes, that can compose type of modes supported by the fibre for a data transmission under a MDM scenario. To confirm the results of simulation an experimental characterisation of the modelled 19-cell HC PBGF was conducted. A modal content evaluation within a broad wavelength range was performed by a modified S2 technique with a spectrogram approach. Results of the experimental and numerical fibre analysis were compared. It was revealed, that in 10m of the fibre within a low loss bandwidth propagated predicted LP01, LP11 and LP02 modes. A characterisation of 325m of the fibre was made by a time-of-flight technique (ToF), that confirmed results obtained for the S2 spectrogram. The methods of OAM mode excitation were investigated and the set-up for mode multiplexing and demultiplexing was built and tested. Obtained results demonstrated an improbability of OAM modes propagation in the 19-cell HC PBGF of 325m length.