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Photonic Crystal Fibres with and without inscribed Bragg grating:

numerical studies of linear and nonlinear light propagation for specific applications

Summary

The invention of the optical fibre was one of the most noticeable technological breakthroughs in the recent history. Optical fibres steadily replaced copper wires and satellite links in telecommunication systems industry and, along with the development of microelectronics and of advanced IT software, laid the foundations for our information society. Optical fibres have also been used in other fields of industry. It was observed that the influence of external factors such as stress, strain, temperature or pressure is reflected in the characteristics of the transmitted light. This fact is used in optical fibre sensors, which proved to be very versatile in use, resistant to harsh environment and often more sensitive than conventional sensors. They are immune to electromagnetic interference, small, light-weight, biocompatible, chemically inert, and they offer the unique feature of distributed sensing.

The recent introduction of air channels in the cross-profile of optical fibres provides the engineers with new possibilities to harness light and to tailor its properties. In particular, the microstructure can create a photonic bandgap in the cladding. In analogy to the band structure of the semiconductor crystals in which forbidden energy gaps exist for electrons, dielectric structures with a periodic distribution of the refractive index forbid photons of specific wavelengths to propagate in some directions. This provides a novel guiding mechanism, which can guide light in hollow core. Furthermore, the microstructure provides a great flexibility in the design of Photonic Crystal Fibres (PCF) and to date an amazing variety of fibres with air-hole inclusions have been reported.

In this thesis we analyze both the solid- and hollow-core Photonic Crystal Fibres. We also look at the possible properties of fibre Bragg gratings written in PCFs. We present the theoretical and numerical methods used to describe and model the guiding properties of microstructured fibres. We describe in detail the anisotropic Plane Wave Method, which we implemented and developed during our research. Furthermore, we show how this numeric tool can be used with th Nonlinear Coupled Mode Theory to model linear and nonlinear light propagation in fibre Bragg gratings in PCFs.

In the first part of this thesis we discuss the features of the microstrucutred fibres in the context of optical fibre sensing. We analyze the polarimetric properties of PCFs with elongated core and investigate the influence of the external transverse stress on the polarimetric response of such PCF. We also analyze the possible guiding regimes in the hollow core photonic bandgap fibres with holes infiltrated with a Liquid Crystal (LC). The external factors influence the optical properties of the periodic microstructure in the cladding, which causes the limits of the photonic bandgap to shift. We show how an external electric field can alter the bandgap structure of the fibre by changing the refractive index of the LC in the holes. We conclude the first part of this thesis with a design study of silica hollow- core fibres for transmission in the mid-Infrared part of the optical spectrum.

The second part of this thesis is devoted to the Bragg gratings inscribed in PCFs.
First, we we analyze theoretically the coupling properties of Bragg gratings written in highly birefringent photonic crystal fibres with doped core and we show how they can be tuned by the parameters of a microstructured fibre. The results indicate large differences in the interaction between the grating and the two linearly polarized fundamental modes. We show fibre designs which provide single-mode operation with high birefringence and at the same time high coupling efficiency of the grating. Such features can be used in fibre sensors, in fibre laser configurations or to introduce a polarization dependent feedback in a long external cavity system with a semiconductor laser.

Secondly we conduct a numerical study of the temporal and spatial dynamics of light in Bragg gratings in highly nonlinear Photonic Crystal Fibre for a CW input signal. We observe not only bistability of the intensity vs. transmitted and reflected light but also complex dynamics. We demonstrate that for values of the input intensity above the bistable region the steady state may undergo a super- or subcritical Hopf bifurcation. For some ranges of the input intensity we also observe a coexistence of two periodic attractors. The dynamics and more particularly the features in the bifurcation diagram strongly depend on the parameters of the fibre. Consequently we suggest that by a proper design of the photonic crystal fibre cladding we can adjust nonlinear features of the Bragg gratings such as the width of the bistable region, the intensity at which the bifurcation occurs as well as the characteristics of the dynamics at high input intensity.
We also study the impact of the polarization of the input light on the hysteresis region and on the polarization nonlinear dynamics in birefringent fibres. We show that for a small angle between the polarization plane of the linearly polarized input light and one of the principal axes of the fibre there is a shift of the hysteresis threshold towards lower input intensities. We also observe oscillations of low- and high-frequencies in the upper, high-transmission branch which in the non-birefringent case is steady-state. We show that the original power distribution between the polarizations oriented along the fibre axes significantly changes due to the nonlinear cross-coupling in the grating with one polarization acting as a pump for the other.