Abstract of doctoral dissertation

Numerical investigation of the dynamics of selected nonlinear phenomena in multimode optical fibers

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The numerical studies carried out within the framework of this dissertation were aimed at demonstrating that the dynamics of selected nonlinear phenomena depends significantly on the modal composition of the excitation. Several new nonlinear processes occurring in multimode optical fibers have been investigated numerically, including: discretization of conical emission in step-index and GRIN fibers in the normal, near-zero and anomalous dispersion regimes; energy conversion between two polarization modes of the fundamental mode of a birefringent microstructured fiber, occurring during the propagation of a trapped vector soliton; and the intermodal-four-wave mixing process occurring between polarization modes $LP_{0,1}$ i $LP_{1,1}$ in a Panda-type birefringent optical fiber. To this end, advanced numerical tools have been developed to model nonlinear light propagation in few-mode and multi-mode optical fibers.

Verification of the usefulness of the developed numerical tools and applicability of various numerical models was carried out for the case of discretized conical emission observed for the first time in these numerical studies for multimode fibers. In this case, the possibility of conical emission generation in fibers with a step and graded refractive index profiles was analyzed by stimulating them with a laser beam of power close to the critical power. The dynamics of the occurrence of this phenomenon looks similar to the case of supercontinuum generation, where the contribution to the broadening of the spectrum of different nonlinear processes depends on the applied dispersion regime. The generation of discretized conical emission in the normal dispersion regime begins with pulse splitting in space-time and moderate spectral broadening, followed by optical shock to transfer energy to higher-order modes according to the phase-matching condition causing the formation of an X-shaped filament in the spectral domain. The obtained results confirmed that the discrete nature of the set of modes of the guided optical fiber ensures the discretization of conical emission. In addition, the successful numerical generation of conical waves for Gaussian beam excitation with a waist close to the spatial width of the fundamental mode allows us to think that the experimental observation of the phenomenon is also possible.

Nonlinear energy conversion processes associated with the propagation of vector solitons in birefringent microstructured fibers were also investigated. In this case, a set of two coupled nonlinear Schr\"odinger equations taking into account vector Raman scattering was used. The possibility of energy transfer between two orthogonal polarization mods was analyzed depending on the way the fiber is excited: along the slow or fast axis, and equally exciting both polarization modes. In the case analyzed, two possible energy transfer mechanisms were identified: mixing of polarization modes due to the non-ideal nature of the fiber resulting in the failure to maintain the polarization state over long distances, and orthogonal Raman scattering. It was shown that, especially in situation of equal excitation of two polarization modes, orthogonal Raman scattering can lead to energy transfer between polarization modes and consequently affect the polarization state of propagating solitons.

Numerical studies were also carried out for multimode birefringent fiber analyzing the possibility of tuning the spectrum obtained from intermodal-four-wave mixing process by excitation of different spatial/polarization modes. The role of phase birefringence in the phase matching condition indicating the possible location of additional bands generated by the processes of intermodal-four-wave mixing was explained. The obtained computational results were confronted with the results of measurements carried out in commercially available fibers. A very good quantitative agreement of the positions of the generated bands of multiple intermodal-vectorial four-wave mixing was achieved.