Nonlinear phenomena in multimode fibers – multimode solitons and frequency conversion

The invention of a laser triggered numerous discoveries, applications and contributed to the emergence of new research fields. One of them is nonlinear optics, which deals with the interaction of high intensity light with matter. "*Daily life without NLO would be missing the high quality fiber optics systems that power the internet, the technology that enables advanced medical devices, the important laser-based analysis tools used for medical diagnosis, characterizing new materials, monitoring pollution in air and water … and green laser pointers*" [1].

The nonlinear phenomena are particularly effective in optical fibres – the glass fibres with a diameter comparable to the diameter of a human hair. The light squeezed on such a small surface has high intensity, what leads to the enhancement of nonlinear phenomena. Additionally, the light in the optical fibers can propagate on very large distances, what increases the nonlinear effects' importance.

The most of research on the nonlinear phenomena in the optical fibers concerned single mode fibers. The single mode fibers, due to their design, support only one mode at a given light frequency (which is related to a colour). The "mode" means here a specific light distribution in the space. The single mode fibers are used in telecommunication network for sending information. A capacity of telecommunication networks is multiplied, by sending information on different frequencies (colours). Recently, also usage of multimode fibers in the telecommunication networks is considered. The multimode fibers support many modes (spatial distributions) at the given frequency (colour). Sending information in the different modes allow for further multiplication of the capacity, although the methods of sending, routing and receiving information in many modes at the same time must be developed. **High hopes for overcoming those challenges are pinned on the nonlinear phenomena in multimode fibers, which will be investigated in this project.**

We chosen two interesting phenomena, which were demonstrated experimentally recently. Namely, the formation and propagation of **a multimode soliton pulse** and **an inter-modal frequency conversion**. The soliton is the name of the light pulse (more generally, the electromagnetic wave pulse), which propagates in constant shape. Usually, a chromatic dispersion guides to broadening and distortion of the pulse, what makes correct information readout impossible (the chromatic dispersion is a medium's property, which describes a difference of energy transport velocities between different frequencies). The nonlinear effects can balance a dispersion effect for the high intensity pulses, what makes soliton propagation possible. The formation and the propagation of the solitons were investigated mainly in the single mode fibers. The formation of solitons in the multimode fibers (multimode solitons), which is a more complex process, due to mutual modes' interactions, is currently under investigation. In this project, we will analyze possibility of controlling this phenomenon by tailoring optical fibers properties.

The inter-modal frequency conversion is the phenomenon of transferring the energy of light propagating at the given frequency in one mode to the different mode at the different frequency. This phenomenon can be potentially applied in elements of multimode telecommunication networks.

The planned research will allow deepening a knowledge on nonlinear fiber optics and will point direction to control nonlinear phenomena in multimode fibers. It will be investigated, what conditions are needed to enable formation, propagation on long distances and interaction of multimode solitons. Additionally, we will also define the conditions for inter-modal frequency conversion. In the project we will design and fabricate silica based multimode fibers with germanium doping. Subsequently, we will investigate the influence of fiber properties on nonlinear phenomena. The obtained results will answer if and how optical fibers' parameters modify observed processes.

We will begin the project with computer simulations of nonlinear pulse propagation to define requested fibers' properties. Next, by numerical calculations, we will design the multimode fibers with such properties and fabricate the fibers (with developed technologies). The properties of fabricated fibers will be measured. In the next step, we will perform experimental works concerning nonlinear effects. We expect that obtained results will show how and to what extent the nonlinear phenomena in multimode fibers can be tailored.

[1] E. Garmire, "Nonlinear optics in daily life," Optics Express **21**(25): 30532 (2013).