The goal of the project is to analyze the effect of spectral compression of the ultrashort pulses in dispersion-engineered optical fibers. The possibility to use the spectral compression of the pulses enables the realization of a source that generates narrow-linewidth tunable pulses in a broad wavelength range of 1600-1800 nm. Such laser can be potentially used in optical coherence tomography (OCT), which requires narrow linewidth (< 1 nm) for the proper penetration depth and a broad spectral range for high axial resolution.

Narrow-linewidth tunable sources find applications in many scientific and industrial areas, such as spectroscopy, nonlinear microscopy, metrology, or optical communication. In particular, they can be used as sources for OCT, such as so-called swept-source OCT. The OCT has become popular as a minimally-invasive method for imaging biological tissue with promising results. However, there are few requirements for the OCT laser source. Such laser must have a narrow linewidth to provide proper penetration depth, and also cover broad bandwidth, and operate with fast tuning to provide high-resolution imaging. The OCT has been for long dominated by 800 nm and 1300 nm spectral windows. Recently, a new spectral range of 1700 nm has seemed promising as it offers minimal water absorption in this range. As a result, light can go deeper into the tissue compared to the 1300 nm window. However, there is a technical issue, that no gain media are operating in this spectra range. To avoid this problem we can use nonlinear fibers together with ultrashort pulses.

When we provide ultrashort pulses generated by a femtosecond laser to the nonlinear fiber, they will be affected by linear effects such as dispersion and fiber attenuation but also several nonlinear effects. One of them is the soliton-self frequency shift. This effect leads to the generation of radiation (so-called optical solitons) at longer wavelengths than the pump source. Therefore, when we pump the nonlinear fiber, we can generate solitons in the wavelength range up to 2000 nm by changing only the input power of the laser. As a result, we can obtain a tunable source, however, with the broad spectra widths, at the level of 20-50 nm. To use this source for OCT, the solitons should be spectrally compressed. The analysis of the spectral compression effect of the tunable pulses will be an essential part of the project. To obtain the spectral compression, we will provide the pulses to the developed fiber with an increasing dispersion profile. Such fiber can be fabricated with the use of two commercially available fibers: standard single-mode fiber (SMF) and dispersion-shifted fiber (DSF). Since the average dispersion of the fiber combined with SMF and DSF is increasing with the fiber length, the pulses in such fiber will be temporally broadened. And because the pulse duration is inversely proportional to its spectral width, the pulses will be spectrally compressed. When we properly combine the SMF and DSF lengths we can reach the compression of the solitons' spectral widths to the level of < 1 nm. As a result, we obtain a tunable narrow-linewidth source that can operate in the wavelength range of 1600-1800 nm which meets the OCT requirements.

The project will include both theoretical and experimental research. The numerical simulations will concentrate on modeling the spectral compression phenomenon to find the optimal fiber segments for developing the fiber with an increasing dispersion profile, and as a result to achieve the most effective compression effect and the smallest linewidth. The experimental analysis will include the assembling of the setup that will contain the femtosecond laser and the optical fibers: nonlinear fiber to obtain the spectral conversion effect and the increasing-dispersion fiber for spectral compression. The impact of the solitons' optical power and their spectral widths on the spectral compression efficiency will be examined. Next, the spectrally-compressed tunable solitons will be amplified in a fiber amplifier based on Thulium-doped fiber to achieve power levels sufficient for later applications. The last step of the project will consider the verification of the applicability of the source for optical coherence tomography of the chosen samples.

The project refers to the current problem of a rapidly tunable laser source whose parameters would address the needs of biomedical applications. The study will provide a deeper insight into the analysis of the effects of ultrashort pulses behavior in optical fibers with varying dispersion profiles which as a result will lead to the realization of a new kind of fiber laser.