Many aspects our modern lives require precise methods of detecting or determining the concentration of solids, liquids or gases, e.g. homeland security, environmental protection or medical applications. Historically, bulky and expensive apparatus and complex, time consuming substrate preparation was required for analysis of the analyses using mass spectrometry or chromatography methods. One of the most intensively researched alternative involves using laser spectroscopy. This technique requires a coherent source with optical frequency matching the absorption spectrum of the target analyte gas, liquid or solid. The analyte is illuminated with a laser beam and the resulting changes in the light parameters or the physical properties of the analyte itself can be used to determine its concentration with great sensitivity (down to single parts per trillion) and selectivity. Recent decade brought a tremendous breakthrough in laser spectroscopy with the development of reasonably-priced mid-infrared (mid-IR) photo-detectors and novel, compact and energy-efficient laser sources - quantum cascade lasers (QCLs), interband cascade lasers (ICL's). This is mainly due to the fact, that the mid-IR wavelength region is filled with strong absorption lines of numerous molecules, therefore laser-based gas spectroscopy is mainly executed in this particular spectral region. The rapid development of reliable QCLs and ICLs provided a stable ground on which cost-effective out-of-lab applications of laser-based gas spectroscopy could be designed. Although a heap of theoretical and experimental work has been done in the field of laser spectroscopy, designing a sensor capable of detecting very small quantities of gas particles is still not a trivial task, especially if the sensor has to work in out-of-lab environment. This problem boils down to several design and construction aspects of such sensors. One of most significant problems is connected with achieving a required minimum detection limit. According to Beer-Laberts law, sensitivity of a given laser-based gas spectrometer can be improved by elongating the gas-laser interaction path-length. A widely used, yet not perfect method of increasing the absorption path relies on incorporating a multipass cell into the gas spectrometer. The laser beam is reflected multiple times between a set of mirrors (up to several hundreds) inside a fragile glass cell filled with the analyzed gas. Absorption cell are used in pair with most of the popular laser spectroscopy techniques: absorption spectroscopy, dispersion spectroscopy, photothermal spectroscopy, Faraday rotation spectroscopy, etc. Unfortunately, multipass cells having a reasonable optical length are expensive, bulky, heavy and are a known source of thermal and vibrational noise and long-term drifts in the sensor systems. A promising method of mitigating most of the abovementioned limitations relies on incorporating hollow-core fibers (HCFs) into laser-based gas sensors. In such configurations the excitation laser beam is conveniently coupled into a relatively large hollow core of the fiber (>30 µm), which is subsequently filled with the analyzed gas samples. Although experimental work documenting proof-of concept configurations have been presented, this technique is currently severely limited due to narrow low-loss transmission windows of available fibers. This results in reducing the effective detection region to absorption lines of gas molecules localized in the <3.5 µm region. Moreover, non-perfect design of modern HCFs introduces mechanical instability, high-bend losses and non-singlemode transmission of longer wavelengths, which lead to intermodal interferences causing unwanted background modulation of the spectroscopic signals.

In this project we plan to design and fabricate novel types of so called anti-resonant hollow-core fibers (AR-HCFs) having a set of parameters desired in fiber-based gas-spectroscopy applications. The main goal will be to achieve record-low transmission losses as far into the mid-IR as possible (3 – 5 µm), which will permit detecting various gases having strong absorption spectrum in this particular wavelength region. Moreover, significant theoretical and experimental work will be devoted to achieving purely singlemode operation of the fibers, thus minimizing the cons of currently available fibers with inferior design. A separate part of the project will be devoted to designing, setting-up and optimizing several dissimilar configurations of laser gas spectrometers, which will incorporate the newly designed AR-HCFs serving as low-volume, compact and robust alternative for standard, cumbersome multipass cells. The constructed sensors will be characterized, thoroughly tested and compared with traditional, multipass cell-based sensors with similar parameters. In this part of the project we will also experimentally verify the possibility of utilizing photothermal detection in gas-filed AR-HCFs as technique for selective and sensitive estimation of the target analyte concentration. A separate, yet comparably interesting research task will involve experimental verification of the possibility of utilizing gas filled AR-HCFs as gain medium for optically-pumped mid-IR lasers.