Optical fiber technology is exhibiting unstoppable evolution in order to develop fibers capable of transmitting laser radiation with low loss, maintaining high beam quality and coverage of different optical spectrum regions, which is induced by continuously emerging new applications. Up to date many types of optical fibers have been designed and successfully fabricated, amongst which the Antiresonant Hollow-Core Fibers (ARHCFs) capable of guiding light within an air core have attracted significant attention. These fibers allow light to propagate in an essentially empty (air) core, away from the glass material from which majority of optical fibers are made of. This unique feature enables ARHCFs to overcome limitations present in solid core silica fibers, such as low damage threshold, high nonlinearities and optical spectrum coverage, which is significantly limited by the high loss of silica in the so-called mid-infrared (mid-IR) spectral region. Furthermore, the air core of an ARHCF can be filled with a liquid or a gas sample, which opens a wide range of new application windows, especially in the area of laser-based spectroscopy of gases.

In principal, laser-based gas sensors rely on the use of the absorption phenomenon. When gas molecules are illuminated with a laser beam, which wavelength strictly corresponds to the gas absorption line, the molecules simply absorb it. The level of absorption is strictly connected with the target gas molecules concentration and the length of the optical light-gas interaction path. This means, that the increase of the light-gas interaction path length within the gas sensor setup provides a relatively simple method allowing for obtaining significant enhancement in the sensor's sensitivity. Therefore, an access to non-complex and low-volume optical paths is highly desired and currently cannot be delivered by the commonly used bulk-optics-based solutions, e.g. bulky multipass cells. Hence, a gas filled ARHCF with the desired length could be a potential way for fulfilling this requirement. Another extraordinary advantage of the ARHCFs is the bandwidth of their transmission window, which can span over several hundreds of nanometers, in particular in the mid-IR, where majority of gases are characterized by their strongest and the most accessible absorption lines. The capability of guiding light over a broad spectral range opens a possibility for ARHCFs for being used in extensively studied over the last few years multi-gas sensors aided with broadband mid-IR light sources, the so-called mid-IR optical frequency combs (mid-IR OFCs). Successful integration of gas-filled ARHCFs with broadband mid-IR OFCs can pave the route towards novel type of non-complex, sensitive, versatile and broadband laser-based gas sensors, which are highly required for e.g. monitoring of greenhouse gases concentration, but are currently unavailable. However, the effective integration of both is not simple and requires in-depth research into the development of novel mid-IR OFC sources with parameters tailored to match the guidance characteristic of the ARHCFs and understanding the transmission mechanism of the broadband mid-IR light in these unique fibers, which is the main scientific goal of the proposed project.

Within this project we plan to focus on the development of broadband mid-IR OFC sources with the parameters (mainly optical spectrum) tailored with respect to the low-loss transmission window of the ARCHFs, which are provided (available at WUST) by the project Partner - Prof. Fei Yu and his Research Group from Shanghai Institute of Optics and Fine Mechanics (SIOM). The mid-IR OFCs will be generated via nonlinear processes, e.g. nonlinear optical frequency conversion in a periodically-poled lithium niobate (PPLN) crystal, induced by illuminating simultaneously the PPLN with dissimilar near-infrared ultrashort pulsed laser sources. We will investigate the impact of the ARCHFs' characteristic, in particular their light guidance mechanism, uniformity of low loss transmission window and structure, bending loss and coupling conditions on the transmission of the broadband mid-IR OFC light. Subsequently, the generated mid-IR OFC will be coupled into a gas-filled ARHCF to experimentally verify the suitability of their connection for multi-gas detection. This research will indicate how the parameters of the mid-IR OFCs and ARHCFs have to be tailored with respect to each other to obtain required sensitivity of the gas sensor utilizing both. It will provide the necessary for the project Partner data for the ARHCFs optimization, taking place within the realization of this project. In the final step, we will develop a novel type of a mid-IR OFC source based on the use of a PPLN waveguide and the single-pump-laser scheme, which will be integrated using a bulk-optics-free approach with a several tens of meters long gas-filled ARHCF. The ARHCF-based broadband gas sensors configurations will be compared with the similar setups utilizing, e.g. multipass cells to justify the correctness of the proposed approach.

This research will allow us to understand the mechanisms of generating mid-IR OFCs in the nonlinear media and their transmission through ARHCFs, leading to the development of novel fiber-integrated gas sensors for simultaneous detection of various gas molecules, in particular those characterized by spectrally broad absorption lines. The results of the project will be published in scientific journals and presented during international conferences.