Infrared radiation is often used in sophisticated technology as well as in everyday life. An important range of this radiation is mid infrared. It means the light with wavelengths in the range from several up to tens of micrometers. This radiation is selectively absorbed by compounds important for environmental protection, medical diagnostics and public safety. Hence systems of mid-infrared sources and detectors are the most sensitive sensors of such substances, useful e.g. as markers for certain diseases and vapors of explosives. They can detect even one molecule of such chemicals among a billion of others. These potential applications, as well as others in the field of military and telecommunications, make mid-infrared sources and detectors interesting objects of studies in many research centers around the world. Among them is the Institute of Electron Technology in Warsaw which is the place of research in the field of quantum cascade lasers, actually one of the most promising sources of mid-infrared radiation.

Twenty years after the presentation of the first prototype, quantum cascade lasers are quite mature devices. They operate reliably in the room temperature and have already found some practical applications. However, the physics of these devices is not fully explored yet. The primary goal of the project is to carry out fundamental research on the physical phenomena occurring inside the quantum cascade lasers. The sizes of these semiconductor lasers are the main difficulty of this issue. Sizes of their active regions are in range from a few up to a dozen micrometers. It is the same order of magnitude as the wavelength of emitted radiation. At the same time this tiny area contains hundreds of ultra-thin semiconductor layers of different properties. This makes the description of the physical phenomena inside the laser non-trivial and demanding experimental verification which, for the same above reasons, is difficult to perform.

A particular issue of the project is the study of the light intensity distribution immediately after the radiation leaves the laser, in the so called near-field. Knowledge of this distribution will give information on how electrical current and heat flows through the structure. These subtleties are lost during further path of the light. Therefore the popular measurement of the light distribution far away of the laser (in the far field) does not give such accurate information. But in order to measure the distribution in the near field, we need to perform the measurement with high resolution. If the studied area has sizes in range of microns, it has to be measured with even higher resolution – of nanometers. Otherwise, there will be too few data points to get any valuable information.

An additional difficulty of measurements is the rate of changes of quantum cascade laser state during operation. The near-field measurement methods used so far to study mid-infrared lasers are scanning methods. It means that the measurement of the entire distribution consists of step-by-step reading of power values in the following spatial points. During the detection in the consecutive point the laser state can change and the total measured distribution will not take into account these rapid changes. In this case it will include only the average state.

The solution proposed in the project is to create a special one-dimensional array of thermoelectric nano-detectors. Instead of the sweeping with one detector, the simultaneous measurements by multiple detectors arranged in a line will be performed. Each detector will be of the nanometer size. This will allow high-resolution testing of time varying properties of the quantum cascade lasers.

The creation of such an array of detectors, as well as single detector, will be a valuable secondary effect of the project. Currently the most popular mid-infrared detectors are expensive and contain toxic elements as mercury and cadmium. According to the EU directive, these substances are to be gradually withdrawn from the European market. The detector created for the project purposes will be inexpensive and based on environmentally safe compounds of silicon. In addition, it will be a thermoelectric detector and therefore will respond not to the specific wavelengths, but to the energy of photons being transformed into heat. This makes the detector universal. It will also enable analogous studies of such quantum cascade lasers that emit terahertz radiation.

The project implementation will have a multilateral impact on the state of knowledge on the mid-infrared sources and detectors. The main area of the research will be the measurement leading to the better understanding of the physical phenomena inside the quantum cascade lasers. In addition to the dominant cognitive aim, the carrying out of the studies will have also other scientific or practical implications. It will enable the further improvement of quantum cascade lasers and will lead to creation of the new mid-infrared detector.