Gas sensors are devices which detect gas molecules by electrical signals. The high standards of living in the human environment and industry, and the needs of medical diagnoses by analysing exhaled breath require the development of gas sensors towards high sensitivity and selectivity, low cost and power consumption. The project aims to develop a gas detection system utilising fluctuations (low-frequency noise – 1/f noise) generated in gas sensors made of two-dimensional materials (e.g., graphene, molybdenum disulfide, and other transition metal dechalcogenides – e.g., tantalum sulfide). These materials are characterised by a high active surface to volume ratio. Their heights are of a few atoms only, and therefore can be used as channels in field effect transistors (FETs). Consequently, we can expect low power consumption and extremely high sensitivity when an electrical signal of moderate-intensity (voltage or current noise) is induced by the adsorption-desorption events of single molecules present in the ambient atmosphere.

The set-up will record the low-frequency noise and estimate the statistical parameters (e.g., power spectral density, probability distribution, level-crossing statistics) to determine the composition of the selected gas mixtures, such as volatile organic compounds, present in the exhaled breath and characteristic of some diseases (e.g., ethanol, acetone, formaldehyde, NO_2, etc.). The gas sensors will be modulated by some physical parameters (operating temperature, pressure, UV light, gate voltage) to enhance the information contained in the recorded noise. We will apply a nonlinear algorithm to optimise the detection process of the investigated gas mixtures, and to reduce the impact of humidity on the detection accuracy.

Graphene and molybdenum disulfide have effectively been used for gas sensing applications to detect selected chemical vapours by measuring the 1/f noise in a back-gated device by independent researchers. Another two-dimensional material, 1T-TaS_2, exhibits the exotic phenomena called charge density waves (CDW), which induces an additional 1/f noise component. This effect can increase its potential for gas sensing when the 1/f noise changes rapidly at phase transitions, at elevated temperatures. It is an open question if 1/f noise at the transition temperatures can be modulated by the ambient atmosphere.

The project should point out the most promising two-dimensional materials from the considered set for gas sensing applications by using a fluctuation enhanced sensing (FES) method, based on 1/f noise measurements. **We expect to confirm the thesis that gas sensors made of two-dimensional materials and utilising the FES method will be able to determine concentrations of the components of ambient gas mixtures.**

We plan to make FET gas sensors using the selected two-dimensional materials. These sensors should be susceptible to selected gases at low concentrations, even up to single molecules. Gas sensors made of 1T-TaS_2 will be investigated at selected temperatures and elevated pressures to observe CDW generating additional low-frequency noise components. We hope that the observed profound change of noise intensity at phase transitions due to the CDW phenomenon can be utilised for gas sensing applications.

The project work plan will be developed based on direct cooperation between Gdańsk University of Technology and the Institute of High Pressure Physics of the Polish Academy of Sciences. Both groups will cooperate with the team of Prof. Alexander Balandin (https://balandingroup.ucr.edu/) from the University of California – Riverside, USA, and work on two-dimensional materials. The research plan conducted will be divided into five tasks:

- *Preparation of measurement set-up for gas sensors.* The available set-up will be advanced to include humidity of various levels and measurement automation.
- *Preparation of gas sensors using selected two-dimensional materials.* We will prepare FET gas sensors using two-dimensional materials for the channels. Thick-film low cost gas sensors of two-dimensional materials will be also prepared by spin coating.
- *Experimental studies of 1/f noise in the prepared gas sensors under selected environmental conditions and an ambient atmosphere of given gas mixtures.* The studies will determine the 1/f noise generated in the prepared gas sensors at selected working conditions.
- *Development of an algorithm to detect the components of gas mixtures by analysing the DC parameters and 1/f noise of the investigated gas sensors.* We will focus on selecting the algorithms which are the most accurate for determining gas mixture components and reducing the effect of the varying humidity level due to practical applications.
- *Synthetic analysis of the research results.* We expect to observe novel results of 1/f noise for the CDW phenomenon in the samples made of 1T-TaS_2 and breakthroughs in understanding the underlying mechanisms of 1/f noise in two-dimensional materials.

Gas sensing of high sensitivity and selectivity is crucial for emerging medical applications and life safety. Our project should enhance the gas sensitivity of organic compounds at low concentrations. Moreover, we should shed light on 1/f noise mechanisms in two-dimensional materials and the CDW phenomenon.