The discovery of graphene in 2004, the first layered material composed of carbon atoms arranged in a hexagonal honeycomb structure, started the development of a new class of layered materials. Graphene was obtained in a very simple way - by separating the adjacent graphite layers using an adhesive tape. This method was called micromechanical exfoliation. Later it turned out that it is also applicable in the production of single layers (so-called monolayers (MLs)) of other layered materials, such as transition-metal dichalcogenides (TMDs). TDMs monolayers consist of three atomic layers: one layer of molybdenum or tungsten atoms surrounded by sulfur, selenium, or tellurium layers. The advantage of such materials over graphene, which is semimetal, is the existence of the energy bandgap, a nonzero distance in the energy range between the conduction and the valence bands. Bulk crystals of such materials are semiconductors with an indirect bandgap, while in a two-dimensional form the bandgap becomes direct, which allows them to emit light efficiently in the visible range.

The basic optical properties of TMDs such as molybdenum disulfide (MoS_2), molybdenum diselenide ($MoSe_2$), tungsten disulfide (WS_2), tungsten diselenide (WSe_2) and molybdenum ditelluride ($MoTe_2$) have already been well investigated. In recent years, the production and research of different alloys of TMDs, such as WS_xSe_{2-x} and $Mo_xW_{1-x}Se_2$, have begun, but their optical properties have not been studied in detail yet. The main advantage of TMD alloys is the possibility to tune the emission and absorption energy range by modifying the relative ratio of each element in a given alloy (x). This opens up new possibilities for the use of such materials in the production of optoelectronic devices such as transistors and photovoltaic cells operating in a specific wavelength range.

The aim of this project is to uncover basic optical properties of MLs of different TMDs alloys encapsulated in hexagonal boron nitride (hBN) flakes. In the literature, the knowledge of such material systems is currently quite limited. The optical properties of these materials are determined by the existence of the quasi-particles, so-called excitons. An exciton is an electron-hole (e-h) pair bound by the Coulomb force. In two-dimensional materials, there are not only single e-h pairs but also complexes composed of an e-h pair and an extra electron or a hole or comprising two e-h pairs. Due to the electronic structure of TMD MLs, the several different excitonic complexes are observed.

In this project, samples of MLs of TMDs will be produced and encapsulated in hBN. Prepared structures will be characterized using an optical microscope and photoluminescence experiment. Then the optical response of prepared samples will be investigated using both the emission and absorption type of experiments additionally as a function of temperature and in in-plane and out-of-plane magnetic fields with respect to the ML plane. The encapsulation of MLs in hBN allows to study excitonic complexes in high quality MLs, apparent in narrow emission lines and absorption resonances. Such optical spectroscopy give the insight into the structure of excitons. In the external magnetic field, the energy of the excitons changes, which is manifested by the shift of the peaks in the measured spectra. The so-called g-factors, describing the Zeeman effect, are a quantity that characterizes this shift. In the TMDs alloys, these parameters reach extraordinary values, which stimulates current experimental and theoretical research. Obtained results will allow us to acknowledge the optical properties, i.e. excitonic properties, of ML of various TMD-s alloys. Understanding of these effects is fundamentally important for the study of these materials and their technological applications.

The most important expected effect of this project is the identification of the excitonic complexes in ML of TMD alloys, which determines their optical properties. Such knowledge is necessary if we would like to use this new class materials of TMD alloys in the production of lasers and detectors for the desired wavelengths.