In the world of modern technology, there is a constant race to create faster, smaller, and more energy-efficient electronic devices. One direction that could bring about a true revolution is spintronics – a field that, in addition to classical electric charge, also utilizes the electron's spin, or its intrinsic angular momentum. If this spin can be controlled, it could significantly enhance the capabilities of information transmission and storage.

This research project focuses on creating p-n junctions that function not only as traditional diodes but also as elements of opto-spintronics – that is, systems responsive to both light and spin. These junctions will be constructed from two-dimensional materials composed of one or just a few layers of atoms. The main components of the junctions are transition metal dichalcogenides (TMDCs) – materials that combine excellent optical and electronic properties. They naturally form "p" (rich in positive charge carriers – holes and "n" (rich in negative charge carriers –electrons) regions, enabling the construction of a p-n junction. What's novel in this project is that one side of the junction will be spin-polarized, meaning its electrons will have aligned spins. This effect is not achieved through direct magnetic doping, but via the so-called proximity effect – placing a thin layer of magnetic material nearby is enough to influence the behavior of electrons in the adjacent TMDC layer.

The research will be carried out in three main stages:

1. Construction and characterization of p-n junctions: The first step will involve fabricating the junctions by stacking thin layers of different materials – like an "atomic sandwich". The inherent p- and n-type properties of TMDC semiconductors will be used, along with techniques of electrostatic doping via an external electric field to achieve different types of charge carriers. The junctions will be studied in terms of their electrical and optical properties.
2. Investigation of the magnetic proximity effect on the one side of the junction: The next step involves adding a magnetic layer and observing changes in the optical properties of the TMDC layer in contact with the magnetic material. This phenomenon will be analyzed by measuring the degree of circular polarization of luminescent emission. These measurements will confirm the presence of the magnetic proximity effect in the junction.
3. Testing opto-spintronic functionality: In the final stage, the fabricated magnetic junctions will be tested in two modes. First – how the emitted light (electroluminescence) changes when current flows through the junction. A key question is whether the light shows a defined polarization linked to the electron spin. Second – what current or voltage the junction generates when illuminated with light of different polarizations. The goal is to observe not only the classical photovoltaic effect, but also its spintronic counterpart.

To realize the project, advanced technological methods will be used, including work in special oxygen-free gloveboxes (to prevent oxidation of magnetic materials), measurements at low temperatures and in magnetic fields, and advanced spectroscopy techniques.

The project lies at the intersection of three cutting-edge fields: 2D materials, optoelectronics, and spintronics. Although spin-related phenomena in two-dimensional materials have been studied before, no one has yet constructed a p-n junction in which one element acquires magnetic properties solely through proximity to a ferromagnetic layer. We expect to observe spin polarization in p-n junction, generated by a magnetic proximity effect. This effect should be visible in the degree of circular polarization of electroluminescence and photodetection dependent on the polarization of the illuminated light. This work will therefore demonstrate not only new physical effects but also take the first steps toward devices that could be used in future spintronic computers, light detectors, or energy-efficient electronic components.