

The aim of the project is to understand the mechanisms that determine the possibility of using two-dimensional materials to build a new type of memory and neuromorphic systems, i.e. those that mimic the work of the human brain. At the heart of the project is the concept of resistive switching. We talk about this phenomenon when the electrical resistance changes while the current flows through the material. Importantly, the value of this altered resistance is retained even when the current stops flowing and can be changed multiple times when the current is triggered again. This allows resistive switching to store data as different resistance values corresponding to different bits. Additionally, resistive switching works similarly to the work of the synapses that connect neurons in the human brain. Information repeatedly flowing between neurons can strengthen the synapses that connect them and facilitate association, just as the current flowing through the resistive switching element can increase its conductivity.

In recent years, it has been shown that resistive switching can occur faster and more efficiently than other physical processes that are currently used to store information and can revolutionize the data storage market. At the same time, the use of resistive switching to build neuromorphic circuits would mean a complete change in the approach to building computers, in which, like in the human brain, information would be computed directly in memory instead of being constantly transferred between memory and processor. It seems extremely advantageous to use two-dimensional materials for the purposes of resistive switching. Such materials can form atomically thin and strong sheets at the same time. One of them is graphene, but this family, as shown by the discoveries of the last decade, is much wider. Thanks to such materials, it is possible to build memories and computing systems that are extremely thin (almost transparent) or extremely densely packed and at the same time dissipate heat very efficiently. First attempts to build resistive switching systems based on two-dimensional materials gave very promising results. However, to take full advantage of their capabilities, it is necessary to understand the basic physical and chemical mechanisms that drive resistive switching processes. Such processes in two-dimensional materials take place at atomic level and in this project they will be analyzed at this scale.

In this project, instead of the standard fixed electrode, a moving nano-probe of an atomic force microscope will be used for resistive switching. This approach will allow to carry out the switching process with high precision, and then to study the effects it has on the atomic and electrical structure of the material. Thanks to this, it will be possible to show what kind of local material transformations are related to the resistive switching of two-dimensional systems and e.g. if it is possible to mimic all synaptic functions if we use only a single sheet of the two-dimensional material. The project will also answer the question of how close two resistive switching areas can be, i.e. what is the physical limit of the packing density (integration) of memory chips, which is a fundamental issue in miniaturization and has a decisive impact on the performance of electronic devices.