Hybrid van der Waals heterostructures. Synthesis and studies of electronic and mechanical properties at the nanoscale with data classification by machine learning algorithms

The project focuses on the synthesis and characterization of the properties of two-dimensional materials joined together in layered systems only through the interaction of van der Waals forces. Each such system is a hybrid whose properties are not a simple sum of its components. Unique physical phenomena can occur at the interface of these materials. Currently, high hope is associated with the use of such hybrid structures in electronics, optoelectronics and spintronics. The whole field of research originates from the discovery of graphene as an atom-thin layer of carbon. The two-dimensionality of this material is associated with its unusual electronic and mechanical properties that are not present in any other system. The discovery of graphene caused a rapidly growing interest in other two-dimensional materials, which now form a large family of systems with special properties including two-dimensional metals, insulators and semiconductors. In recent years, it has been shown that the real potential is not related with the low-dimensional materials themselves, but rather with their systems. By overlapping two atomic thin layers of different substances, we obtain a hybrid with more complex and unique properties. For this reason, these systems are difficult to describe and in particular to modify for the purposes of particular applications. The key to understand and further adapt the properties of hybrid materials composed of two-dimensional layers is to achieve full control over their synthesis. At present, most hybrid systems are manufactured by mechanical stacking of individual layers on each other. This technology, although sophisticated and difficult, does not ensure full surface cleanliness of the combined layers and is additionally not reproducible and not scalable. The obtained systems have unique physical properties, whereas they are disturbed by oxidation or damage of particular layers during stacking. The solution to the problems of building multilayer hybrid systems is their direct synthesis using molecular beam epitaxy (MBE) or chemical vapor deposition (CVD) methods. However, such synthesis in the case of two-dimensional systems is extremely complex and the way to its optimization using traditional methodology is very long. The presented project aims to overcome the existing difficulties by changing the approach to the synthesis and characterization of materials. Hybrid systems will be produced in laboratory conditions in an experimental setup that is a unique combination of MBE and CVD methods. At the same time, to optimize the synthesis, which is characterized by the multiplicity of parameters, a comprehensive characterization of the basic electrical and mechanical properties will be used at the nanometer scale without exposing of the sample to ambient conditions. In addition, the classification methods from the machine learning methodology will be used to analyze these measurements. This will allow in particular for a systematic analysis of data measured by spectroscopic studies and comparing them with the parameters of synthesis process, exploration of which has not been possible until now in a full and systematic manner by traditional methods. Thanks to this, it will be possible to obtain information that is crucial for the process of growth optimization of hybrid structures. Such controlled approach will enable the development of appropriate synthesis methods and will answer many questions related to the properties of this type of structures. The project is interdisciplinary in nature, as concepts in the field of materials science, physics and computer science come together in it. This allows for making progress in the field of synthesis of new materials due to the vast adaptation and optimization of growth based on the solutions developed by each of these fields of science.