Piezoreflectance spectroscopy of van der Waals crystals and heterostructures

The aim of this project is to build an experimental set-up for measurements of piezoreflectance spectra with spatial resolution at the level of a few micrometers and then use this set-up in the study of van der Waals crystals (vdW) and vdW heterostructures based on these crystals in order to understand the optical properties of such semiconductor systems.

vdW crystals are similar to graphite, from which individual layers, i.e. graphene layers, can be separated through the exfoliation process, which are characterized by interesting electrical properties (e.g. very high carrier mobility) and thus can be used in electronics. In the case of vdW crystals, the situation is similar, with the difference that they are semiconductor materials with an open energy gap, which gives perspectives for the use of these materials in optoelectronics, i.e. the area combining the optical and electrical properties of semiconductors, where the basic semiconductor devices are light detectors, light emitting diodes or lasers. Currently, the scientific world is very interested in vdW heterostructures (MX2/YPS3: where M = Mo or W; Y = Fe, Ni, Mg, Co, …), in which single layers of different van der Waals crystals are joined together. The properties of such heterostructures depend on the angle between these layers, which is responsible for the different Moiré patterns in such heterostructures. Such heterostructures will be the subject of research in this project. For this purpose, we want to use piezoreflectance, which should be a very sensitive method for studying this type of structure, but so far it has not been applied to them.

Piezoreflectance belongs to modulation spectroscopy, the operation of which consists in periodic changes of a given parameter in the studied sample (in piezoreflectance it is stress), which causes changes in the reflectance spectrum of the studied sample. Using phase-sensitive signal detection, these changes can be measured with a sensitivity of $\Delta R/R \sim 10^{-6}$. Thanks to the differential nature of this method, the background signal is eliminated and only where we expect optical transitions, changes in the reflectance signal can be observed. In piezoreflectance measurements, the main challenge is to apply periodic stresses to the studied sample. For macroscopic samples, this is done quite easily by gluing the sample onto piezoceramics, which can be resized by applying a voltage to the piezoceramics. In this way, changes in the size of piezocermics are transferred to the adhered sample. In the case of single layers of vdW crystals, it is difficult to imagine that a sample of a few micrometers and a few nanometers thick could be attached to piezoceramics with a glue. However, our recent research has shown us that such samples are very firmly attached to the substrate due to electrostatic interactions [1]. Therefore, we conducted an experiment in which we exfoliated MoS_2 directly onto polished piezoceramics and observed that in this way we were able to modulate the stresses in MoS_2 and measure piezoreflectance spectra. This observation is the basis of this project, in which we want to develop a method of applying reversible periodic strain to micrometric sized vdW heterostructures and use the advantages of the piezoreflectance method in the study of this type of heterostructures.

[1] R. Oliva, T. Wozniak, P. E. Faria Jr, F. Dybala, J. Kopaczek, J. Fabian, P. Scharoch, and R. Kudrawiec, *Strong Substrate Strain Effects in Multilayered WS_2 Revealed by High-Pressure Optical Measurements*, ACS Applied Materials & Interfaces 14, 19857−19868 (2022).