Popular abstract

The field of two dimensional (2D) materials science was inaugurated by the discovery of graphene, a layer carbon atoms forming a hexagonal lattice. This inspired fabrication of other 2D crystals, including monolayer and few-layer hexagonal boron nitride (hBN), transition metal dichalcogenides (TMDs) such as tungsten diselenide (WSe_2), oxides, and others. Their properties result in a large spectrum of applications in electronics, mechanics and spintronics.

Devices which combine various properties can be obtained in heterostructures obtained by stacking layers of different materials on top of each other. Creation of such structures is often compared to assembling Lego, where each block represents a layer or few layers of 2D crystals. Imagine each block can be assembled with an arbitrary angle. We cannot do that with Lego, but in the world of 2D materials, there is no such limitation, and, as a bonus, this can lead to even more exotic properties: for example, two layers of graphene stacked with an angle of about 1.1° can become a superconductor.

Our objective is to investigate heterostructures composed mainly of graphene, hBN, and TMDs. TMDs are semiconductors possessing strong spin-orbit coupling (SOC), whereas graphene has very low SOC. If graphene is placed on a TMD substrate, the former gains significant SOC via the proximity effect. That way graphene, a material attractive for electronic devices, can additionally gain properties useful in spintronics. When there is a small twist angle between the TMD and graphene crystal lattice, the SOC gets new components, offering even more potential in spintronic applications. One of our goal is to investigate such heterostructures as plaftorms for spin manipulation.

Another phenomenon occurring in twisted layers are moiré patterns. Combining two lattices with a small angle creates moiré superlattices, with the period of the order of tens of nanometers, much larger than the periodicity of natural lattices of fractions of nanometers. By stacking a conductive material, such as graphene, with other crystals, the resulting artificial lattices uncover a lot of interesting physics. For example, in external magnetic field, it was predicted that for the field strength such that the flux through the unit cell is of the order of h/e, the magnetic flux quantum, many phenomena can be observed, for example the Hofstadter butterfly or Brown-Zak oscillations. However, their observation in natural lattices would require magnetic field of the order of 10^4 T, which is not possible to obtain in laboratories. In artificial superlattices, on the other hand, thanks to the large unit cell, the required magnetic fields can be as low as ≈ 10 T, a much more accessible value. We are not only limited to moiré patterns. Superlattices can also be obtained by creating periodic gates underneath graphene, offering flexibility in the geometry of the induced periodic pattern.

In our investigations we will theoretically study devices combining graphene and other materials, simulating the electrostatics and conductance properties, with the objective to understand their fundamental physics and to propose versatile devices that can drive the progress in electronics and spintronics.