Graphene-based heterostructures under pressure

Bálint SZENTPÉTERI

Supervisor: Péter MAKK

Budapest University of Technology and Economics

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Summary

In my Ph.D. thesis, I investigated the effect of pressure on graphene-based heterostructures. The heterostructures were investigated with electrical transport measurements. I focused on the electronic and transport properties such as the evolution of the band gaps, the change of the spin-orbit coupling strength and the change of the scattering mechanisms by applying hydrostatic pressure.

I investigated the electronic properties of twisted double bilayer graphene around the magic angle. From both thermal activation and bias voltage-dependent measurements, I extracted the single-particle moiré gaps, which were found to decrease and fully close by increasing the pressure. To verify this theoretically, I calculated the pressure dependence of the moiré band gaps with the Bistritzer-MacDonald model, which qualitatively agreed with the experiments. From magnetotransport measurements, I verified the insensitivity of the twist angle to pressure by analyzing the Brown-Zak oscillations. Moreover, I also observed the signature of the decrease of the correlations, as at the half filling the gaps due to correlations close with pressure and I also observed an unusual magnetic field dependence of the gap at the charge neutrality.

In the next part, I investigated the proximity-induced spin-orbit coupling in WSe_2 and bilayer graphene-based heterostructures under hydrostatic pressure. The heterostructures are studied with low-temperature magnetotransport measurements. From Shubnikov-de Haas oscillations, I observed two Fermi surfaces of the spin split bands due to the SOC. I calculated the low-energy band structure of the heterostructure, which I used to calculate the Fermi surfaces at finite SOC. I found that at large charge densities, the difference of the bands is mostly determined by the Rashba-type SOC. To obtain the Rashba-type SOC strength, I fitted the model on the experiments where I found a large increase of the coupling strength with increasing pressure. I also obtained the Ising-type coupling strength from quantum Hall measurements. For this, I measured the positions of the Landau level crossings at different magnetic fields. I calculated the Landau level energies numerically and fitted the measured crossing points at $\nu = \pm 3$ filling factor to obtain the Ising-type SOC, which increased a large amount with applying pressure.

Finally, I investigated the transport properties of high-mobility devices, made of single-layer graphene, which is encapsulated within hBN crystals. From field effect measurements, I observed that the main scattering mechanism that is responsible for the resistance of graphene at low temperatures is the long-ranged scattering and it remains dominant under pressure. I also verified this with Shubnikov-de Haas oscillation measurements. I observed an increase in both the short- and long-range scattering by increasing the pressure, which led to a decrease in the mobility of the charge carriers. I observed with weak localization measurements the increase of the volume of ripples by increasing the pressure, which is consistent with the increased scattering rates with pressure. I also observed in the weak localization measurements that the short-range scattering is mainly due to the sample edges and their pressure dependence is negligible. I observed in magnetic focusing experiments, that the pressure doesn't change the scattering mechanism and has a negligible effect on the combined contribution of the electron-electron interactions and the acoustic phonon-electron coupling to the dephasing of the magnetic focusing signal. With temperature-dependent field effect measurements, I observed that the acoustic phonon-electron coupling has negligible pressure dependence and I showed that the remote interfacial phonon-electron coupling increases with pressure.

The experimental findings in this thesis give an insight into how important the interlayer interactions are in vdW heterostructures and their tunability with pressure. In the near future, I believe a vast amount of similar studies on various heterostructures will be executed especially focusing on twisted structures, where most of their properties are the result of the interlayer coupling.