Van der Waals heterostructures: from fabrication to hydrostatic pressure experiments

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Summary

In my PhD thesis, I summarise the results of my PhD work, which are mainly related to the development of the assembly of *van der Waals (vdW) heterostructures* at the BME Nanoelectronics Lab, the fabrication of nanocircuits built on them, and the low temperature transport experiments on these nanocircuits both at ambient pressure and also in a high hydrostatic pressure environment.

After a theoretical introduction, I describe the *dry stacking assembly* method, which is the prevalent technique to produce vdW heterostructures. I present a transfer microscope setup that I installed in the BME Nanoelectronics Lab in the initial phase of my PhD work, which is the main instrument used in the assembly process. It is followed by the fabrication process of the nanocircuit surrounding the sample and its conventional measurement method in a cryogenic environment.0 I also show two examples, how the installed transfer setup, as a versatile tool, can be used to produce various different devices at nanoscale other than vdW heterostructures.

In the next chapter, I present the successful exfoliation of single layer flakes of BiTeI (SL BiTeI) for the first time. The polar structure of BiTeI results in a giant Rashba-type spin–orbit coupling (SOC), which makes it a promising building block in spintronics applications, but leads to a difficulty in cleaving thin flakes of it. A modified mechanical exfoliation technique on a *stripped gold* surface yields SL BiTeI flakes of lateral size up to 50–100 µm. I provide evidence using scanning probe measurements that the coverage is single layer and almost perfectly continuous in the sample areas, which are observable under optical microscope.

In transport experiments, establishing electrical contacts to the sample is essential. The common practice in the case of vdW heterostructures is the use of one-dimensional edge contacts on the boundary of the graphene flake. I discuss another approach to create electrical contacts, which are *inner point contacts* (PCs) inside the flake and away the boundary. This arrangement leads to a topological separation of the contacts from each other and the boundary, that leads to an insulating behaviour in the quantum Hall state. Using high out-of-plane magnetic field measurements, I successfully demonstrated this insulating behaviour.

An interesting direction in studying vdW heterostructures is the manipulation of the interlayer coupling using hydrostatic pressure, after the fabrication of the sample. However, the conventional way of performing transport measurements on nanocircuits is incompatible with the hydrostatic pressure environment. I present a novel experimental technique based on a dedicated sample holder head built in a conventional piston-cylinder hydrostatic pressure cell to overcome this problem and perform hydrostatic experiments on nanocircuits without imposing any special requirement upon them. Experiments under at least 2 GPa pressure can be performed using 8–12 electrical lines contacted by electrostatic discharge safe wire-bonding technology. I demonstrate the efficient protective role of a hexagonal boron nitride (hBN) capping layer against the chemically advert kerosene environment, which is used as a pressure medium inside the cell.

The hydrostatic pressure is expected to push the component layers closer to each other, which increases the interlayer coupling. Finally, using the new measurement setup, I present hydrostatic pressure transport experiments on an hBN/graphene/WSe_2 heterostructure, which is known for the presence of proximity-induced SOC in the graphene layer due to its neighbour WSe_2. Performing magneto-conductance measurements at four different pressure from ambient up to 1.8 GPa in increasing order, I demonstrated a clear transition from the weak localisation to the weak anti-localisation signal. Detailed data analysis along with auxiliary field effect measurements were carried out to discern the effect of chirality from that of the SOC. I successfully demonstrated that the measured change in the magneto-conductance was due to the enhancement of the Rashba SOC by ca. 70%, which is in accordance with the theoretical expectations.

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