Investigation of 2D hybrid nanostructures

Summary

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The family of two-dimensional (2D) materials has grown rapidly over the last two decades, making it possible to tailor the physical porperties of graphene by creating van der Waals heterostructures that combine graphene and other 2D materials. For example, by bringing graphene in close proximity to transition metal dichalcogenides (TMDs) in such heterostructures, a large SOC can be induced in graphene. This, on the one hand, gave a significant boost to the field of spintronics. The combination of the large spin diffusion length in graphene and the ability to manipulate spins by electric fields are key elements to realize information storage and logic devices that utilize the spins of electrons. On the other hand, this so-called proximity-induced SOC has opened new possibilities to engineer topological phases in graphene, leading to the experimental observation of a peculiar band-inverted phase hosting helical edge states in bilayer graphene.

In this thesis, I set out to explore the nature and size of induced SOC in graphene/TMD heterostructures, to boost its strength and to incorporate such heterostructures in superconducting circuits. I present the fabrication of van der Waals heterostructures based on graphene and TMDs that allow the investigation of the proximity-induced SOC. Low-temperature transport measurements are used to determine the type and strength of the induced SOC and reveal a large spin-relaxation anisotropy in these heterostructures. Hydrostatic pressure can be used to squeeze the layers of van der Waals heterostructures. By reducing the layer distances, the strength of the induced SOC can be significantly enhanced. The hydrostatic pressure is applied in a pressure cell where kerosene acts as the pressure mediating medium. A measurement in this thesis shows that the electronic quality of graphene is preserved by encapsulating graphene in hexagonal boron nitride (hBN). Furthermore, I also present that the proximity-induced SOC can be enhanced by hydrostatic pressure in a bilayer graphene/TMD heterostructure and the band-inverted phase can be extended as a result. Furthermore, the effect of SOC on superconductivity in graphene/TMD heterostructures is studied. Josephson junctions are formed by fabricating superconducting electrodes on the heterostructures. SOC is expected to manifest as a phase shift in the current—phase relation (CPR) of the Josephson junctions. For this reason, CPR measurements are presented on graphene/TMD Josephson junctions. Recently, multiterminal Josephson junctions (MTJJs) were proposed theoretically as a platform to artificially engineer topologically non-trivial band structures. Therefore, fabricating multiple superconducting terminals provides an alternative to SOC to engineer topological phases in Josephson junctions. In this thesis, transport measurements on a graphene-based MTJJ are presented. The results are compared to simulations based on a resistively shunted Josephson junction network model. It is shown that self-heating effects have to be considered in the simulation to reproduce the main features of the measurements.