Summary

This thesis describes a number of experiments in which electronic transport was used to probe high magnetic field and uniaxial strain effects on various quantum materials. After a basic introduction on quantum materials, uniaxial strain and quantum oscillations, an overview is provided of experimental aspects relevant to work performed during this PhD. The underdoped iron pnictide $Ba(Fe_{1-x}Co_x)_2As_2$ was successfully used as a benchmark material in order to verify proper functionality of the used Razorbill strain cells and mounting method. Experimental investigation focused on single crystals of four different types of quantum materials: Dirac nodal-line semimetals, bismuth dichalcogenides, elements, and transition metal di- and trichalcogenides.

In this work the established Dirac nodal-line semimetal ZrSiS has been further investigated in order to elucidate the effect of uniaxial strain on its delicate electronic structure. The magnetoresistance of a sample was measured under tensile (up to 0.34 %) and compressive (up to -0.28 %) strain exerted along the a axis and in magnetic fields up to 30 T. A systematic weakening of the peak structure in the Shubnikov-de Haas frequency spectrum was observed upon changing from compressive to tensile strain. This effect may be explained by a decrease in the effective quantum mobility upon decreasing the c/a ratio, which is corroborated by a concurrent increase in the Dingle temperature.

A second Dirac nodal-line semimetal that was studied is ZrSiTe. We aimed to study its magnetoresistance to gain a better understanding of the effect of uniaxial strain on the magneto-elastoresistance and Shubnikov-de Haas oscillations of ZrSiTe. This would allow for the results to be linked to those of its sister compounds ZrSiS and ZrSiSe, which have both been uniaxially strained previously. Since de Haas-van Alphen oscillations have been observed experimentally in ZrSiTe in the past, it was somewhat expected our sample would exhibit Shubnikov-de Haas oscillations as well. However, the oscillations were absent in our measured sample, attributed to the small residual resistance ratio (7.7) of our sample and the fact that the de Haas-van Alphen oscillations in the literature were quite weak.

From a new family of layered superconductors, the bismuth dichalcogenide $LaO_{0.8}F_{0.2}BiS_{2-x}Se_x$ ($x = 0.5$ and $x = 1.0$) was characterized at higher

magnetic fields than before with the aim to better comprehend the extremely large in-plane B_{c2}. Typically attributed to its local inversion symmetry-induced Rashba-type spin-orbit coupling, the B_{c2} greatly exceeds the conventional paramagnetic and orbital limits. Our research specifically aimed to examine how the Josephson vortex state in relation to the local inversion symmetry could be the key mechanism responsible for the high B_{c2}. Our data shows no change in the upwards trend of the B_{c2} as T approaches 0 K. Additionally, the calculated out-of-plane coherence lengths $\xi_{\perp}(0)$ are not small enough to suggest the presence of Josephson vortices, leading us to reason that there is no Josephon vortex state present in this family of $BiCh_2$-based superconductors. Further research could perhaps provide a more decisive picture regarding the dimensionality of $BiCh_2$-based systems at low temperatures, perhaps corroborating our findings.

Uniaxial strain experiments were performed on $LaO_{0.8}F_{0.2}BiSSe$, one of the two doping levels of the crystals mentioned above. We observed a substantial decrease in B_{c2} and a small decrease in T_c when uniaxial stress was applied along the a axis, similar to the nematic superconductor $Sr_xBi_2Se_3$, validating our aim to explore the effect of uniaxial strain on the nematic superconductivity of $LaO_{0.8}F_{0.2}BiSSe$. The bowtie mounting method was used, reaffirming its potential and verifying its functionality. In the future, strain studies could perform uniaxially strained B_{c2} and T_c measurements along other axes, possibly shining light on the strain-tunability of nematic superconductors with a tetragonal crystal structure.

A uniaxial strain study on bulk bismuth (Bi) and doped bismuth ($Bi_{0.96}Sb_{0.04}$) was performed with the intention of bridging the gap between theoretical literature and previous experimental studies on bismuth, ideally gaining a better understanding of the three-dimensional topological properties of bismuth under strain. We report the observation of two systematic strain effects: a change in quantum mobility with strain, and a frequency shift, likely due to a change in quasiparticle pocket size with strain and implying a lifting of electron pocket degeneracy in line with the literature. Though theoretically predicted, no apparent trivial to topological or semimetal to semiconductor phase transitions were observed in either Bi or $Bi_{0.96}Sb_{0.04}$, suggesting our strain amounts were too low and prompting future research to perform a uniaxial strain study on bismuth using larger strains.

Highly oriented pyrolitic graphite was exploratively investigated using uniaxial strain with the aim to know more about the effect of uniaxial strain on materials with a topological character. A small change in fast Fourier transform amplitude with tensile strain was observed, which was linked to a change in quantum mobility. This could be the result of increased crystallite alignment, as that would lower structural disorder and enhance quantum oscillatory phenomena. Future uniaxial strain studies could aim to apply strains of a larger magnitude.

With the goal being to improve the understanding of the competition between the superconducting phase and charge density wave phase, $NbSe_2$ and $ZrTe_3$ were experimented on using uniaxial strain. No shift in T_c or T_{cdw} was detected for both materials. With the literature predicting otherwise, it leads one to believe that the absence of uniaxial strain effects is perhaps the result of the strain values not being large enough to sufficiently change the band structure of the materials in a way that it would alter the measured resistance data. Future studies should aim to perform similar experiments at higher strain values while remaining within the elastic regime of the samples.

$IrTe_2$ is a transition metal dichalcogenide like $NbSe_2$, but owes its charge ordered phase not to charge density wave physics but to dimer formation. With the intent of studying the strain tunability of T_s and its effect on T_c, uniaxial strain experiments were successfully performed on $IrTe_2$ using the bowtie method, but no change in T_s or T_c with strain was observed. With no availability of samples large enough for the conventional mounting method, and since the conventional mounting method tends to be more reliable, future studies could aim to acquire larger samples and corroborate our results.

Overall, we hope the work presented in this thesis has added value to the foundation of uniaxial strain research, which is in its early stages. The ability to measure the electronic properties of crystals at higher strain values is desirable, emphasized both here and in recent review papers [29, 43]. With plenty of new and interesting physics still to be discovered, we firmly believe that uniaxial strain will continue to be an invaluable tuning parameter for the elucidation of emergent phenomena in quantum materials.