Summary

Topological quantum materials have sparked great interest to pursue electronically nontrivial phases. It is expected this new trend will keep on producing more exotic discoveries about novel quantum phases of topological matter. Regarding topological superconductors the physics of dispersive Majorana fermions on the surface is a new field of research, and also it is important for future applications in quantum computation. Investigating new types of topological phenomena in real materials is significant for both developing new devices and verifying theoretical models and predictions. Intrinsic topological superconductors are rare in nature, several concrete cases have been investigated extensively, such as Sr_2RuO_4, $Cu_xBi_2Se_3$, $Sn_{1-x}In_xTe$ and several noncentrosymmetric superconductors. The presence of Weyl and Dirac semimetals as a 3D analog of graphene shed further light on topological superconductors with their characteristic electronic properties, for instance protected Fermi surface states and a novel response to applied electric and magnetic fields. In this thesis we presented the experimental results on the type II Dirac semimetal $PdTe_2$ (Chapter 4-6) and the topological superconductor candidate $Sr_xBi_2Se_3$ (Chapter 7).

The first chapter may be read as a rather general introduction to topological materials, special attention was paid to TSCs and two candidates of TSCs $PdTe_2$ and $Sr_xBi_2Se_3$. In the second chapter we described the preparation and characterization of the samples, and the experimental techniques used in this thesis project. Chapter 3 dealt with the theoretical aspects relevant for this thesis project.

In Chapter 4, we discussed the superconducting properties of $PdTe_2$ investigated by dc-magnetization, ac-susceptibility and transport measurements. Our crystals clearly show type I superconductivity as demonstrated by the observation of the intermediate state probed by the differential paramagnetic effect measured by in the ac-susceptibility. In addition, superconductivity of the surface layer is found below $T_c^s = 1.33$ K $< T_c$. It persists up to $\mu_0 H_c^s(0) = 34.9$ mT and does not follow the standard Saint-James-de Gennes behavior. Resistance data point to an even larger critical field for the surface layer $H_c^R(0) \approx 0.30$ T. $PdTe_2$ is the only topological material for which type I superconductivity has been reported so far. This, together with the unusual superconducting phase diagram, calls for a close

examination of superconductivity in $PdTe_2$, especially in view of the existence of topological surface states.

In Chapter 5 we focused on a high-pressure transport and ac-susceptibility study of superconductivity in the type-I superconductor $PdTe_2$ (T_c = 1.64 K). T_c shows a pronounced variation with pressure: it increases at low pressure, then passes through a maximum of 1.91 K around 0.91 GPa, and subsequently decreases smoothly up to the highest pressure measured, $p_{max} = 2.5$ GPa. Type-I superconductivity is robust under pressure. The unusual surface superconductivity persists under pressure. Surprisingly, for $p \geq 1.41$ GPa the superconducting transition temperature for the surface T_c^S exceeds T_c of the bulk. This tells us surface and bulk superconductivity are distinct phenomena. We propose surface superconductivity possibly has a non-trivial nature and originates from topological non trivial surface states. This calls for quantum-oscillation experiments under pressure. In the same spirit it will be highly interesting to extend the experiments to higher pressures, especially because a pronounced change in the electronic properties of $PdTe_2$ is predicted to occur in the range 4.7-6.1 GPa: the type-II Dirac points disappear at 6.1 GPa, and a new pair of type-I Dirac points emerges at 4.7 GPa. Thus a topological phase transition may occur in the pressure range 4.7-6.1 GPa. This in turn might have a strong effect on (surface) superconductivity, because the tilt parameter of the Dirac cones passes the critical value of 1. We conclude further high-pressure experiments on $PdTe_2$ provide a unique opportunity to investigate the connection between topological quantum states and superconductivity.

In Chapter 6 we have investigated the superconducting phase of $PdTe_2$ (T_c = 1.6 K) by transverse field muon spin rotation experiments. μSR spectra were taken on a thin disk-like crystal in two configurations: with the field perpendicular to the plane of the disk ($N_\perp = 0.87$) and with the field in the plane of the disk ($N_\parallel = 0.08$). The $H - T$ phase diagram was scanned as a function of temperature and applied field. The μSR spectra have been analysed with a three component muon depolarization function, accounting for the superconducting domains, the normal domains and a background term. In the superconducting phase normal domains are found in which the local field is always equal to B_c and larger than the applied field. This is the hall mark of the intermediate phase in a type-I superconductor. The background term is predominantly attributed to muons stopping in the superconducting-normal domain walls. In conclusion, our μSR study provides solid evidence for type-I behavior in the bulk of the $PdTe_2$ crystal.

In Chapter 7 we have performed transverse field muon spin rotation experiments on single-crystalline samples of $Sr_xBi_2Se_3$ with the aim to determine the magnetic penetration depth, λ. Field-cooled μSR spectra measured for the ordered flux line lattice reveal however no additional damping of the μ^+ precession signal in the superconducting phase. From the data we infer a lower bound for λ

of 2.3 μm. By changing the applied magnetic field in the superconducting phase we are able to induce disorder in the vortex lattice. This results in a sizeable value $\sigma_{SC} = 0.36\ \mu\text{s}^{-1}$ for $T \to 0$. By analyzing the μSR time spectra with a two component function we obtain a superconducting volume fraction of 70 %. This provides solid evidence for bulk superconductivity in $Sr_xBi_2Se_3$. We signal a discrepancy between the superfluid density, n_s, calculated from λ within the London model, and the measured carrier concentration. Finally, we recall that the reported breaking of rotational symmetry in the small family of Bi_2Se_3-based superconductors deserves a close examination, notably because it offers an excellent opportunity to study unconventional superconductivity with a two-component order parameter.