PbTe/SnTe Semiconductor Heterostructure

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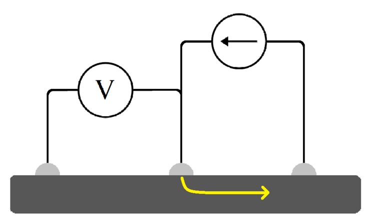
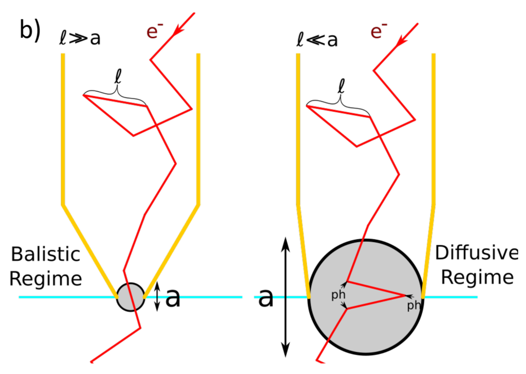
Motivation

Topological superconductivity represented by still elusive p-wave superconductors holds great promise for quantum computation and information storage. According to first experiments [1] and theoretical predictions [2], interface of semiconductor heterostructure with periodic misfit dislocations is a potential candidate for such superconducting mechanism. We have studied PbTe/SnTe heterostruture previously investigated in [3] and applied point contact spectroscopy (PCS). The results suggest the presence of p-wave superconductivity.

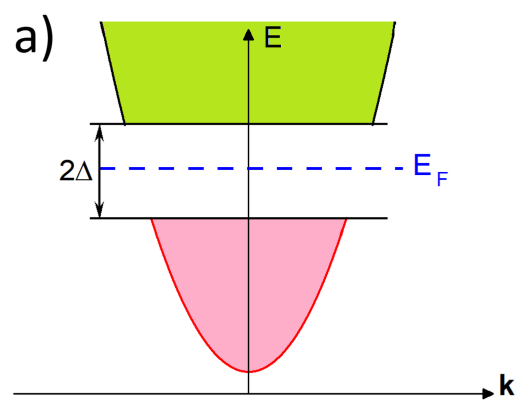
1) PCS Experiment



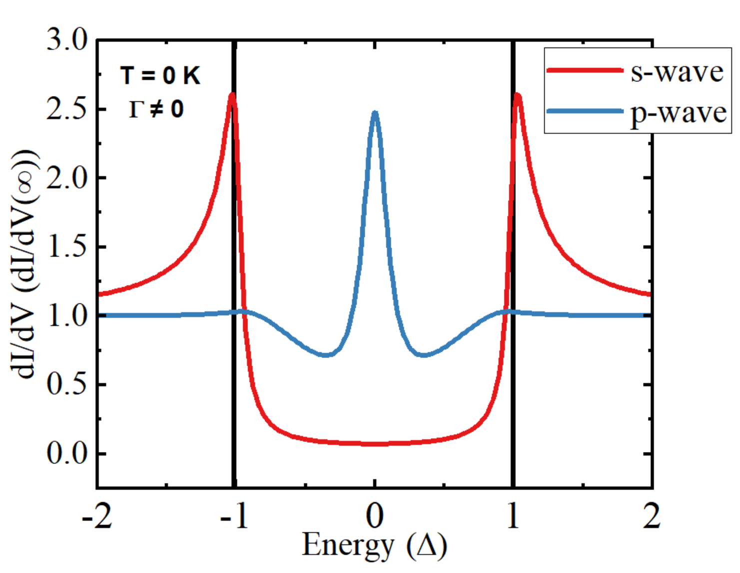
Point contact spectroscopy is a powerful transport technique to probe superconducting density of states. It relies on measuring differential conductance dI/dV at metal-superconductor contact, as illustrated above, which correlates to the quasiparicle density of states of the superconductor. When the contact is small enough that carrier moves in a ballistic regime, there is a straightforward correspondence between carrier energy and measured voltage $E = eV$, see below.

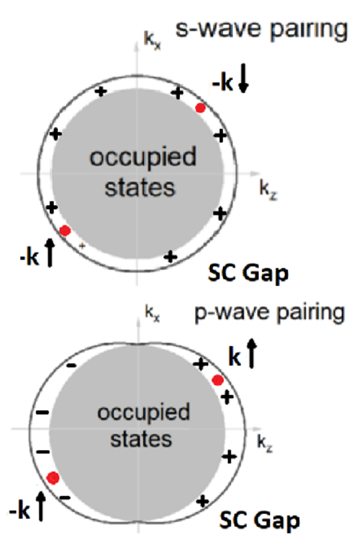


2) Superconductor Gap

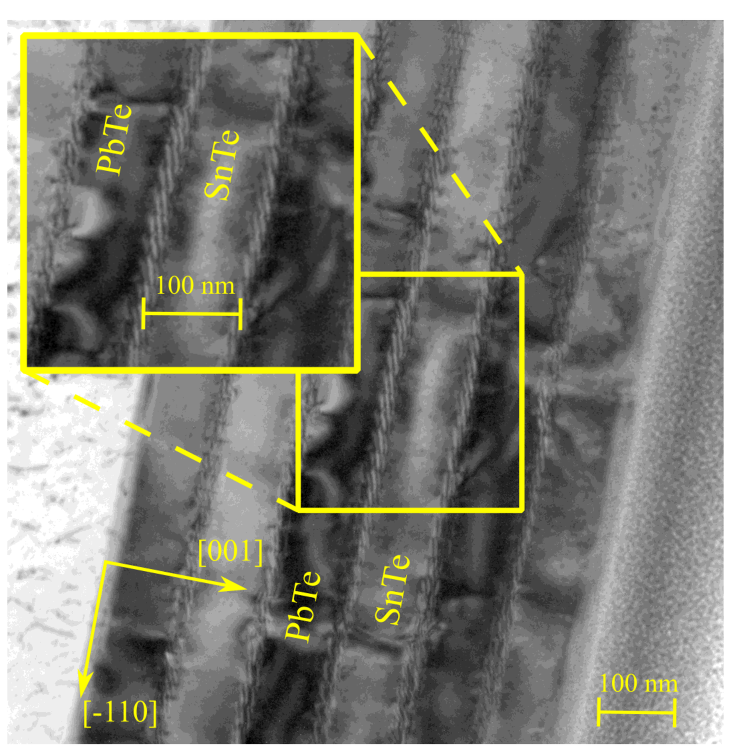


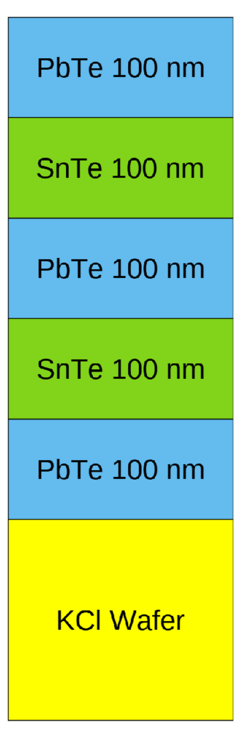
Superconductors have an energy gap of magnitude 2Δ around Fermi level, comparable to thermal energy scale. Symmetry of the pairing potential can be identified from distinct fingerprints in PCS spectra. Here s- and p-wave type of orbital wavefunction is shown.





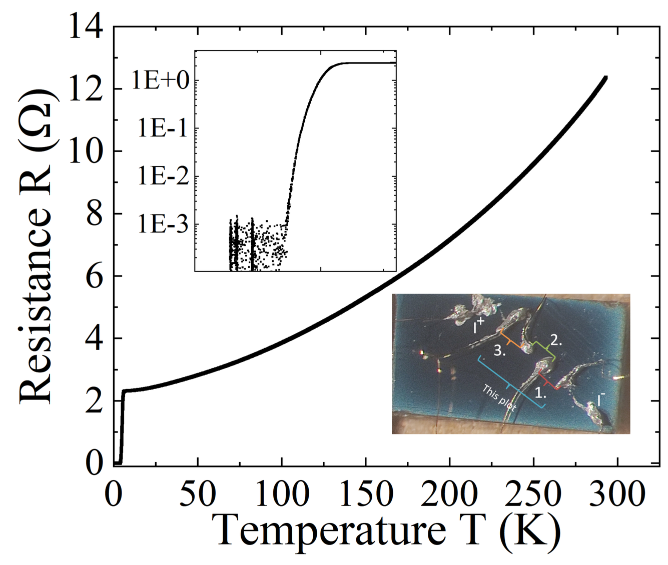
3) Samples



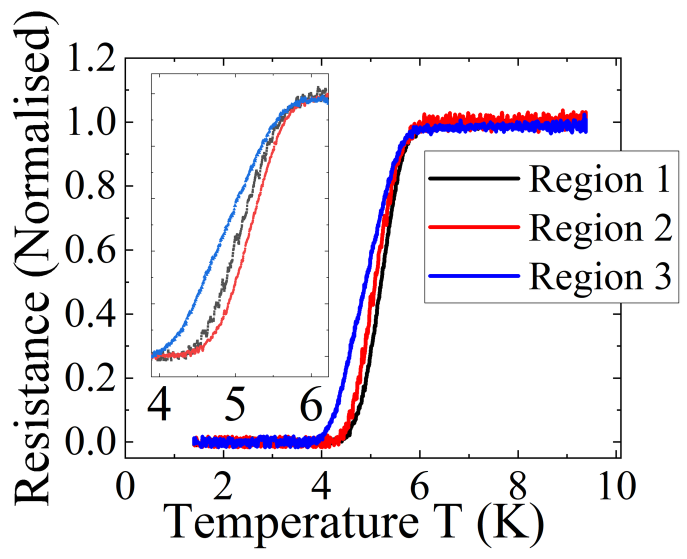


Above PbTe/SnTe heterostructure was grown with MBE technique on thick KCl (100) substrate. Transmission electron microscopy confirms the presence of periodic grid of dislocations induced by high lattice mismatch (2%), which is a prerequisite for the superconductivity to appear [1]. Electrical connection to the sample was realised with silver paste, and same contacts were used for PCS.

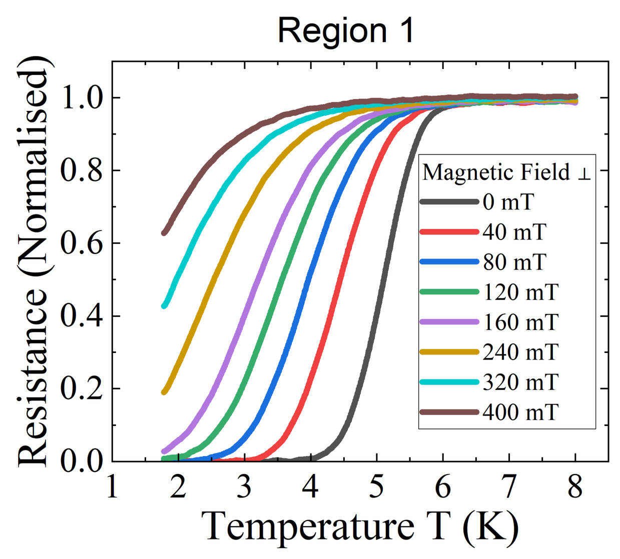
4) Global Superconductivity of the Sample

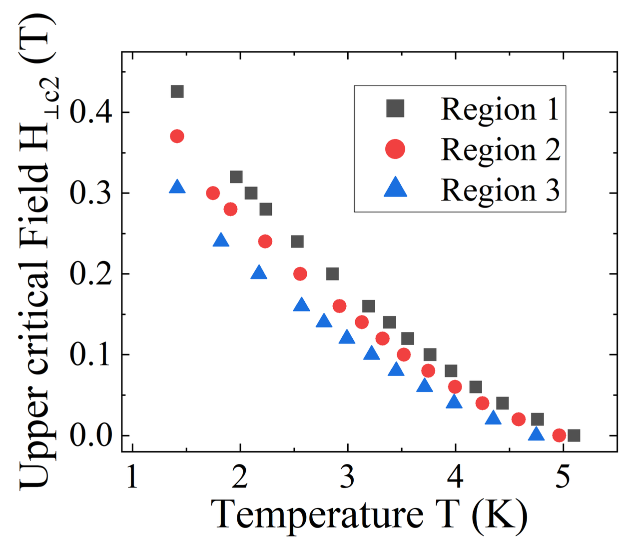


The sample exhibits complete superconducting transition by three orders of magnitude resistance drop around $T_c = 5$K (left). More detailed investigation reveals that the the sample properties differs slightly bewteen regions (right). It is suggested, that the quality of the superconducting phase can be related to local defects of the dislocation grid defects. This effect was demostrated by the fact that the T_c rises for hetoerostuctures with more layers, as it improves the global quality oh dislocations [1,4]. Outside of the superconducting region, the resistance of the sample rises exponentially, as expected for strongly degenerated semiconductors.



5) Upper critical magnetic feld H_{c2}





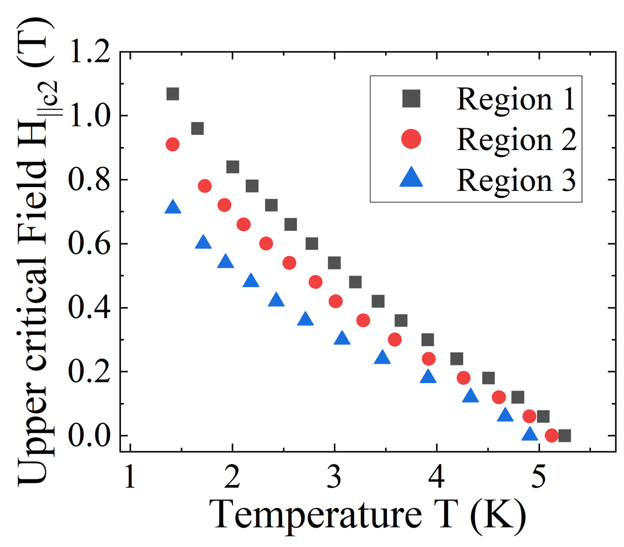
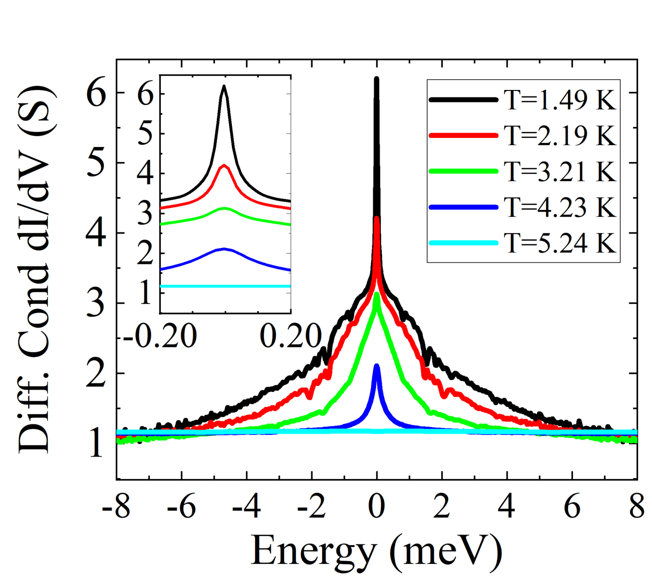
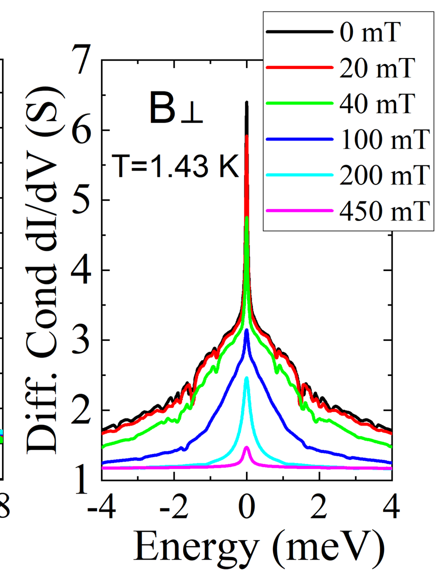


Figure on the left shows the temperature evolution of the sample (region 1) resistance in perpendicular magnetic field. During numerous temperature cycles no intermediate transitions were observed. For three sample regions the critical magnetic field $R(T_c) = 0.5R(T_N)$ was determined in perpendicular and parallel configuration (middle and center figure). It is worth noting that there is change of the trend in this dependency around $4K$, which can be understood as dimensionality change of the superconductivity [4].

6) PCS results

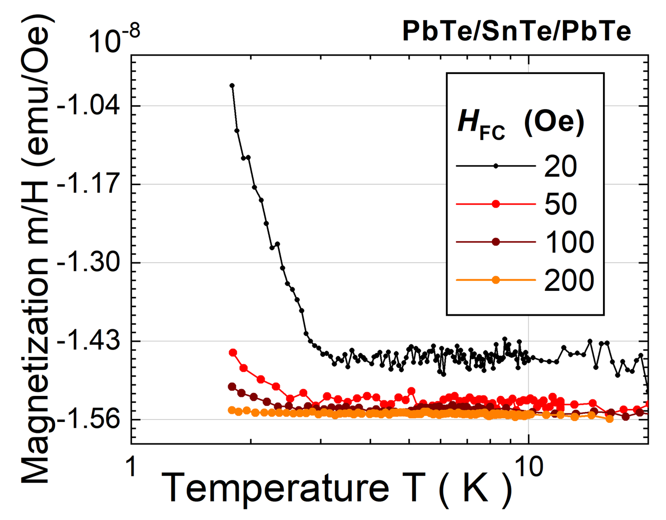




Example of temperature and mangetic field dependence of PCS spectra. The features in the PCS are very pronounced in the comparison to the normal region of the spectra and their presence is strongly correlated with the appearance of global superconducting phase. The most relevant feature in this experiment is large zero bias conductance peak. Moreover, it seems that additional sharp zero bias peak of unknown origin appears below 3.2 K.

However, due to relativly large conductivity of the contact, current needed to achive energy scale relative to the energy gap was also close to the critical current of the sample, introducing additional features without relevant physical interpretation. More experiments are needed to fully identify the superconductivity type in this material [5]. It is worth to mention here that PCS of cleaved bulk topological crystalline insulators (TCI - SnTe falmily of compounds) exihibited also ZBC peaks [6], but these were found possible explanation in ferromagnetic instabilities which appear on the edge of atomic height steps on cleaved surfaces. [7]

7) Magnetometry



During SQUID magnetometry experiments, one of the investigated samples gave paramegnetic signal at low temperaturese, which can possibly attributed to spin-triplet superconductivity. However due to to overall temporal instability of the sample properites, the experiment was hardly repeatable, yet very promising.

8) Topological States

Due to strain present in the system, all components of the examined heterostructure can undergo transition to topological crystaline insulator (TCI) states near the interface. According to [2], dislocation array produces periodically varying strain, acting on the TCI states, creating topologically flat bands. Moreover, it was already observed [1,4], that the superconducting state in such system is confined to the semiconductor interface. These two facts, along with the observed p-wave-like spectra suggest presence of topological superconductivity.

9) Summary

- The PbTe/SnTe heterostructure was investigated using soft point contact spectroscopy at low temperatures.
- Measured PCS spectra display interesting zero bias anomaly, possibly hinting p-wave superconductivity but contact realisation require futher refinement.
- The instance of paramagnetic Meissner effect was found in one sample, but result is hard to duplicate due to structure instability.

References

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Acknowledgment

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