Quantum magnetotransport and de Haas-van Alphen measurements in the three-dimensional Dirac semimetal $Pb_{0.83}Sn_{0.17}Se$

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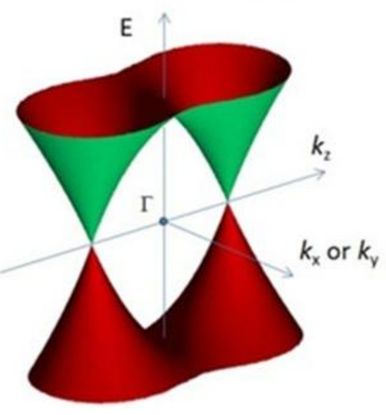
3D Dirac semimetal

Linear dispersion near touching points. | Band touching points.



Dirac dispersion in 3D (k-space) ⟶ 3D analogues of graphene.

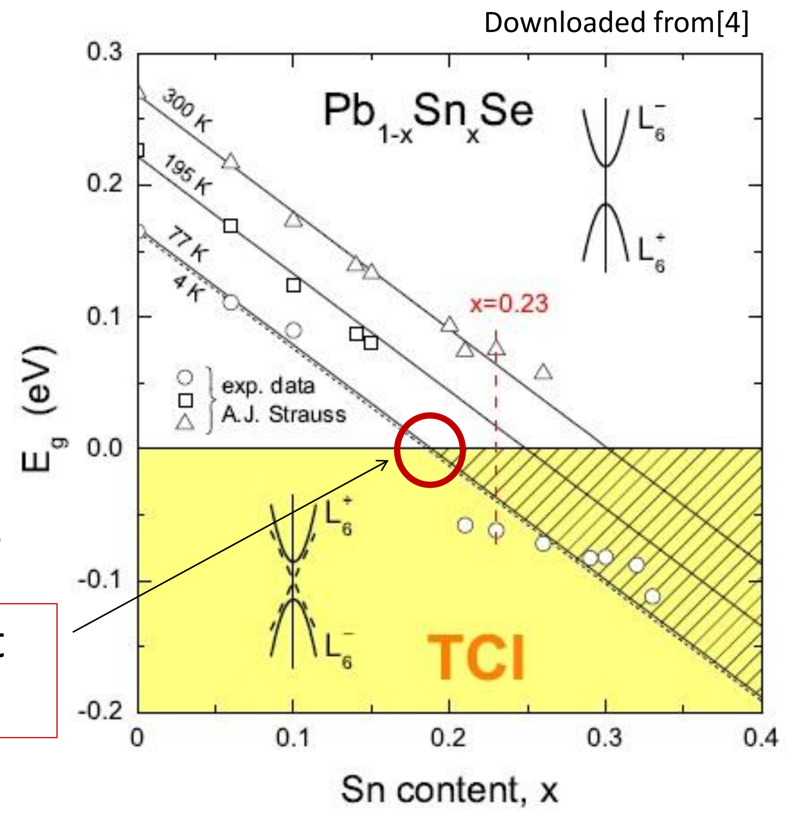
Dirac fermion physics:

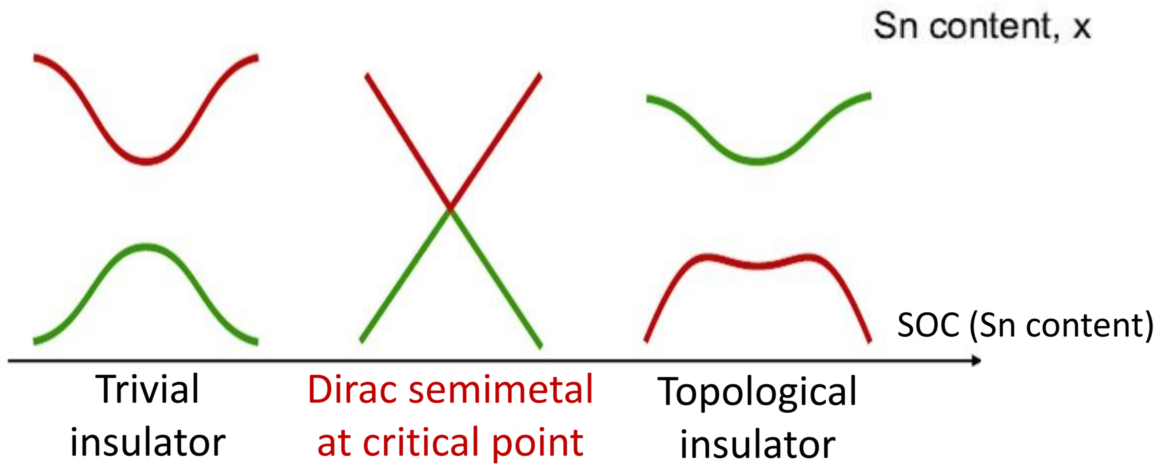
- High mobility and low effective mass.
- Large LMR.
- Interesting transport properties.
- Fundamental physics (Weyl semimetal).

$Pb_{1-x}Sn_xSe$

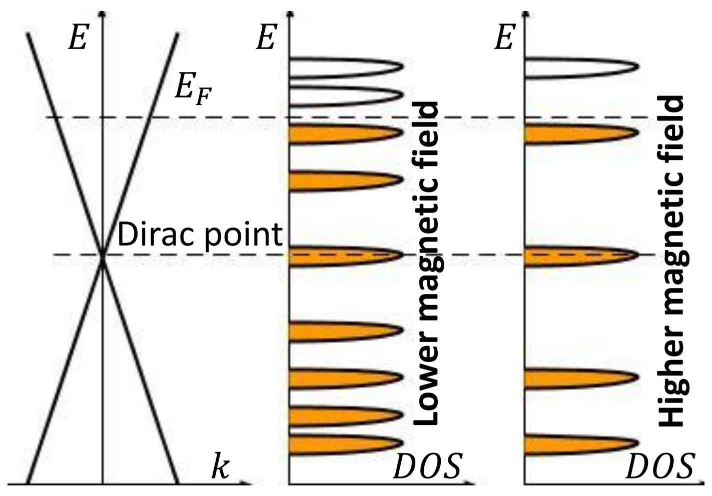
Semiconductor with temperature and Sn-content dependent E_G ⟶ band inversion for $x > x_c$ (topological phase transition at x_c ⟶ example of TCI [1,2]).

3D Dirac semimetal at $x = x_c \approx 0.17$ [3].





Quantum oscillations



Electrons in a strong magnetic field ⟶ Landau levels. Increasing field leads to the periodicaly crossing of Landau levels and E_F ⟶ oscillation of physical quantities with 1/B.

Lifshitz-Kosevich formula

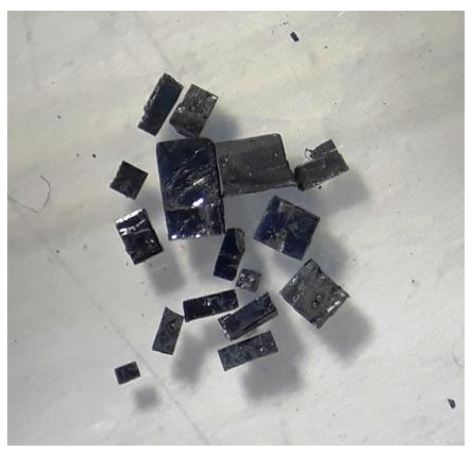
$$\Delta X(B,T) = A_0 A_T A_D A_s \left(\frac{B}{F}\right)^{1/2} \cos\left(\frac{2\pi F}{B} + \varphi_p + \varphi_M\right)$$

ΔM ⟶ de Haas-van Alphen oscillations (dHvA)
$\Delta\sigma$ ⟶ Shubnikov de Haas oscillations (SdH)

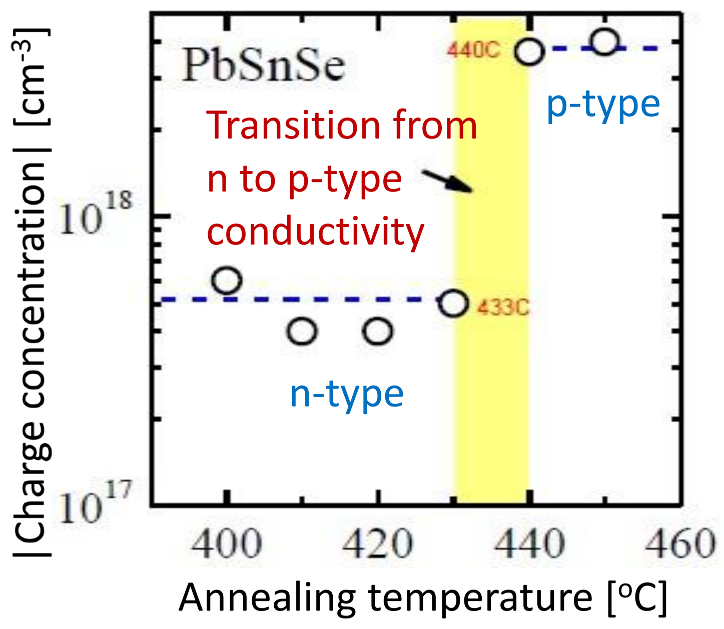
From prefactors, frequency and phase the effective cyclotron mass, quantum scattering time, Berry phase and Fermi surface parameters can be determined.

Synthesis and annealing

High-purity materials in an evacuated double quartz tube were melted at 1100 °C for several days. ⟶ The crystallization was carried out by a slow cooling down to 900 °C.



Pieces cut from a single-crystal ingot were isothermally annealed in Se vapours at temperatures from 433 °C to 440 °C ⟶ tuning the chemical potential.



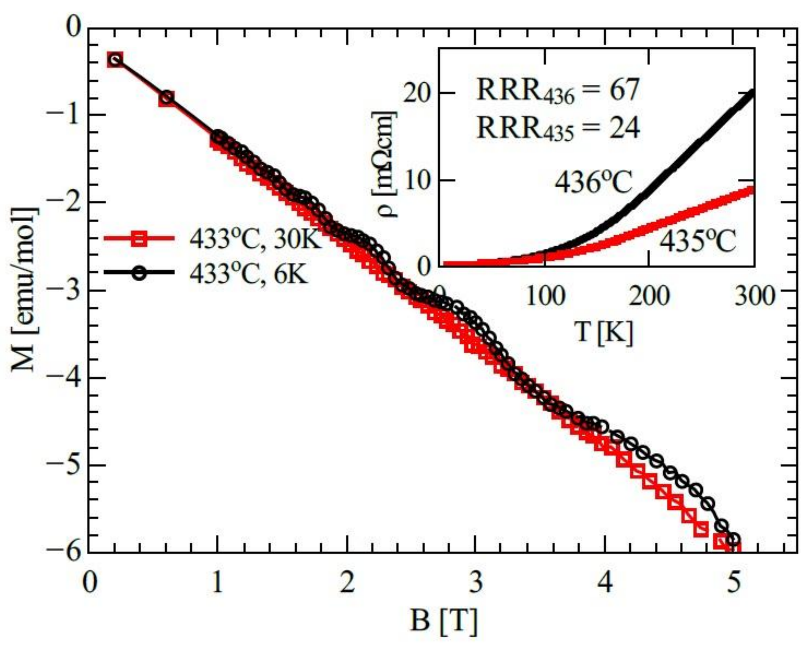
Absolute value of charge concentration vs. annealing temperature. In the p-type samples no quantum oscillations are observed.

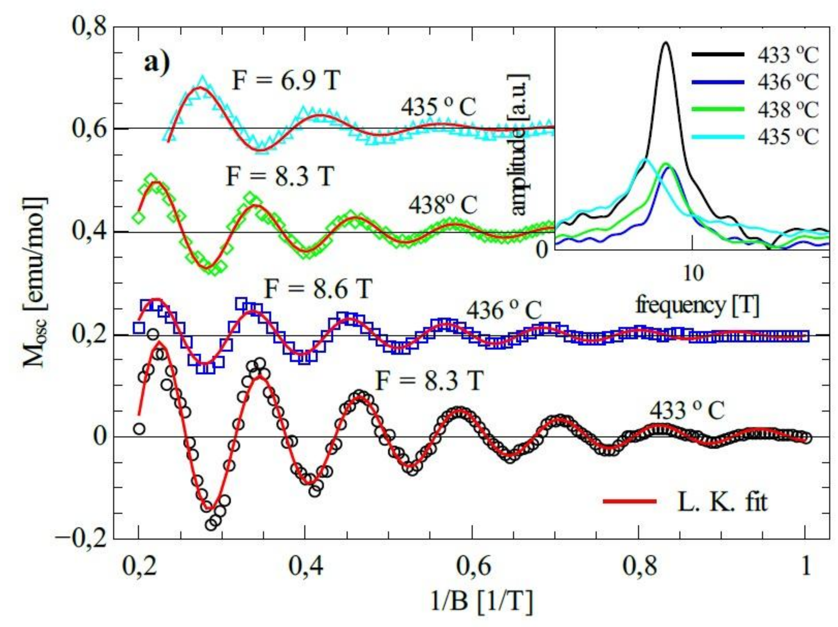
By increasing the annealing temperature from 433 °C to 440 °C transition from n to p-type conductivity takes place.

In samples annealed at 435 ± 1 °C the chemical potential is closest to the band touching point.

Magnetization measurements

The B-field dependence of magnetization. Field was applied along the [001] direction (there are 4 Dirac points at the L points of the Brillouin zone).





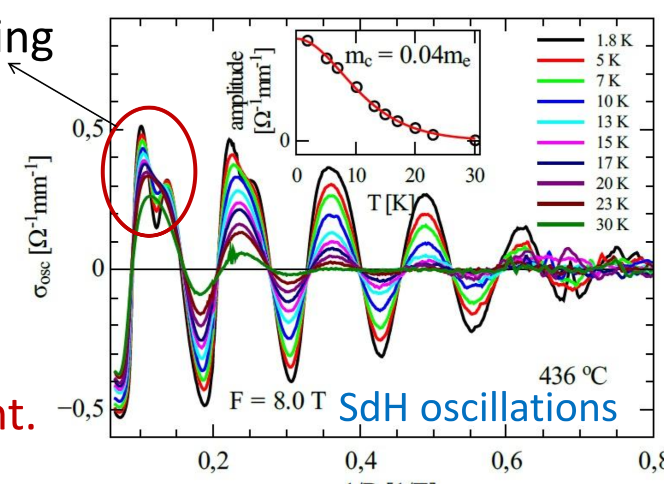
Pure oscillatory part of magnetization for different annealed samples at 5 K.

- The magnetization was measured by SQUID in the B-field up to 5 T and in the temperature range from 5 K to 300 K.
- The dHvA oscillations are observed down to 1 T and up to 30 K.

Magnetoresistance

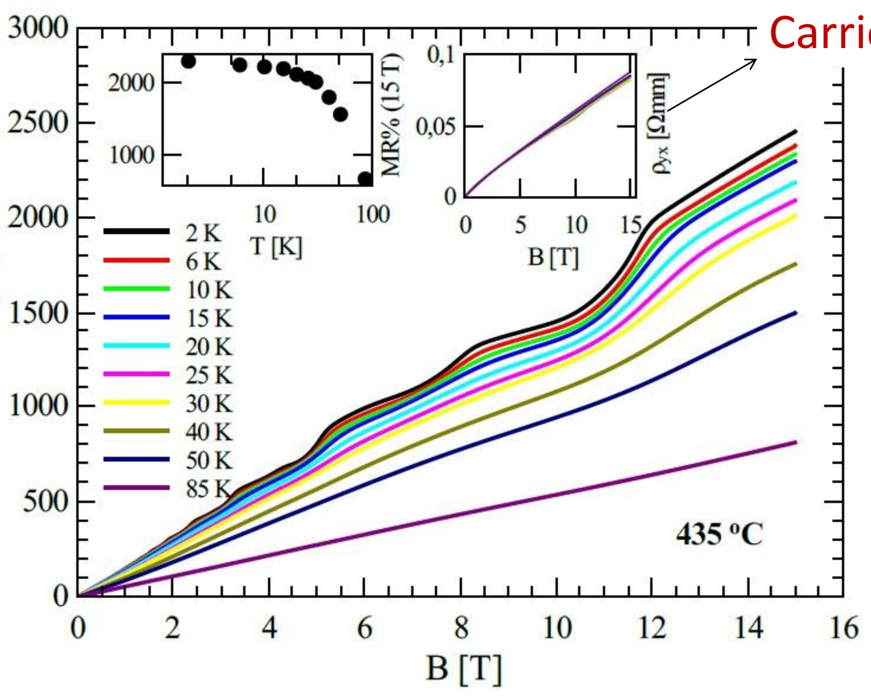
- The Hall bar configuration with spot-welded contacts was used.
- The magnetoresistance was measured in the B-field up to 15 T in samples annealed at 435 °C and 436 °C.
- From 2 K to 85 K.

Zeeman splitting

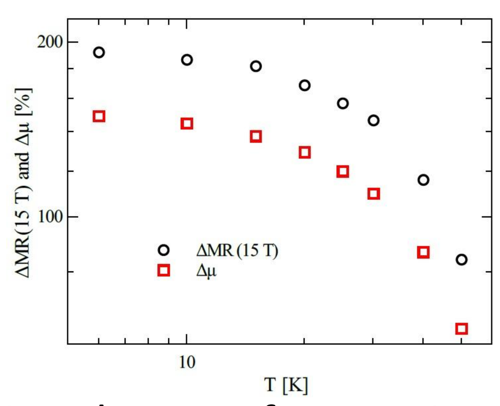


SdH oscillations

Carrier density is T-independent.



Large nonsaturating LMR with quantum oscillations at temperatures below 30 K. Temperature dependence of MR at 15 T and Hall resistivity are shown in the insets.



Relative change of MR at 15 T and mobility with temperature ⟶ MR scales with mobility.

Acknowledgments
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Conclusion

- Linear magnetization and strong LMR accompanied by quantum oscillations at low temperature have been found in $Pb_{0.83}Sn_{0.17}Se$ semimetal.
- Annealing in Se vapours at temperatures from 433 °C to 440 °C results in the crossover from n to p-type conductivity.
- Fermi surface parameters are extracted using the LK theory.
- The decrease of MR with temperature can be explained by the change in the mobility of carriers.

Fermi surface parameters from Quantum oscillations:

$k_F = 0.016$ Å^{-1} $n = 5.9 \cdot 10^{17}$ cm^{-3} $m_c = 0.04 m_e$

$E_F = 48$ meV $\tau_Q = 3.4 \cdot 10^{-13}$ s $\gamma \approx \pi$

$v_F = 4.6 \cdot 10^5$ m/s

References:

[1] Fu L 2011 *Phys. Rev. Lett.* **106** 106802
[2] Ando Y and Fu L *Annu. Rev. Condens. Mater. Phys.* **6** 361
[3] Orbanić F, Novak M, Baćani M and Kokanović I 2017 *Phys. Rev.* B **95** 035208
[4] Dziawa P et al 2012 *Nat. Mater.* **11** 1023