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Exotic Phenomena in Quantum limit in nodal-line semimetal ZrSiS

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Introduction

In quantum limit, all carriers condense to the lowest Landau level, leading to possible exotic quantum phenomena such as Lifshitz transition and density waves. Usually, quantum limit is not easily achieved due to relatively large Fermi surface in metals. Fortunately, the nodal-line semimetal ZrSiS possesses a very small Fermi pocket with a characteristic quantum oscillation frequency of 8.4T [1], which represents the 2D Dirac states protected by non-symmorphic symmetry. The quantum limit of such Dirac bands can be reached in moderate magnetic field ~ 25 T, indicating that ZrSiS could be a nice platform to explore the novel quantum phenomena of Dirac fermions in quantum limit.

Experimental

We have synthesized ZrSiS crystals and carried out the high field magnetization studies. The measurements were performed by using the 65T pulsed field facility in NHMFL at Los Alamos.

Results and Discussion

As shown in Fig. 1, after subtracting the background signal from the sample holder, the sample magnetization of ZrSiS at $T=0.5$ K displays clear dHvA oscillations. The oscillation pattern can be viewed as the superposition of high frequency oscillations on the top of low frequency oscillations. This result is consistent with the previous low field observations by the SQUID magnetometer, which revealed dHvA oscillations with a high frequency of 240T and a low frequency of 8.4T, corresponding to the 3D nodal-line state and the 2D Dirac state protected by the non-symmorphic symmetry respectively [1]. Interestingly, above 25T where the 2D Dirac band enters the quantum limit, we have observed an unusual drop of magnetization. Such high field diamagnetism cannot be understood by the conventional theory for normal electrons, but appears to be in line with the properties of relativistic fermions. It has been predicted that the magnetization at the quantum limit saturates for normal electrons but vanishes for Weyl fermions. For Dirac fermions, magnetization at the quantum limit becomes strongly angular dependent and also vanishes at some center angles where the field is parallel to the line connecting the Dirac nodes in momentum space [2]. Therefore, the observed diamagnetism at the quantum limit is most likely to reflect the properties of relativistic fermions. To better clarify the origin of such unusual observations, further studies such as angular dependent magnetization and magnetic torque measurements are necessary.

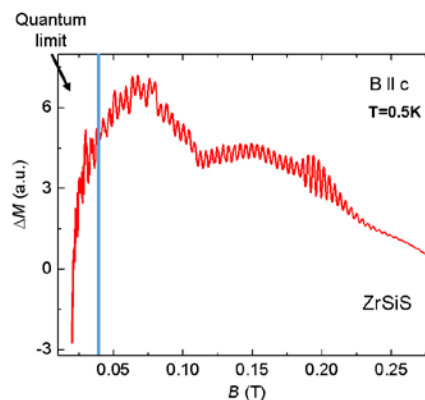


Fig. 1 Magnetization measurements at $T=0.5$ K in ZrSiS. dHvA oscillations are clearly seen when background is removed. The magnetic field is applied along the c-axis.

Conclusions

In this work, we have measured magnetization of ZrSiS up to 50T, and observed the unusual magnetization drop in the quantum limit of the 2D Dirac bands for ZrSiS, which could be ascribed to the properties of relativistic fermions. Such observations pave a way to further understand the quantum limit behaviors of relativistic fermions.

Acknowledgements

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