Time-Reversal Symmetry Breaking and Vortex Clustering in the Nodal-Line Semimetal $CaSb_2$

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Superconductivity in materials with non-trivial band topology provides a pathway to realizing topological superconductivity. The family of square-net materials, including those with Sb square-nets, hosts topologically non-trivial states, stabilized for a particular electron filling on the square-net atoms. By varying this electron filling, these Sb square-nets are susceptible to distortions and the formation of Sb–Sb zigzag chains with a reduced crystallographic symmetry. However, even in the MSb_2 materials with distorted Sb square-nets, a 2_1 nonsymmorphic symmetry keeps gapless topological states. In particular, Dirac nodal-lines and superconductivity appear in polycrystalline $CaSb_2$ [1,2].

Here, we investigate self-flux grown single-crystals of the superconducting diantimonide $CaSb_2$ using magnetization, electrical transport, and specific heat measurements. We observe type-II superconductivity with $T_c = 1.6$ K and evaluate the lower and upper critical fields for magnetic fields applied in different directions [3,4]. We also observe a metal-to-insulator-like transition below ~50 K at magnetic fields above ~3 T ($H \parallel c^*$). Our non-saturating magnetoresistance up to 14 T, Hall measurements, and the de Haas-van Alphen oscillations support $CaSb_2$ being a compensated semimetal [3]. Our experimental observations are consistent with band structure calculations, revealing an electronic structure with non-trivial topology related to the distorted Sb square nets.

Specific heat measurements suggest that $CaSb_2$ is a two-gap superconductor, consistent with our transverse-field muon spin relaxation (μSR) measurements [4]. Interestingly, we find evidence of time-reversal symmetry breaking (TRSB) below ~1 K in zero-field μSR only when muon spins are implanted perpendicular to the c^* direction [4]. Finally, we show evidence for vortex clustering and dynamics observed in scanning SQUID measurements with $H \parallel c^*$, which we attribute to a combination of repulsive and attractive interactions between vortices [5]. We discuss the possible origin of the TRSB in $CaSb_2$, and relate the vortex clustering to the two-gap nature of this weakly type-II superconductor.

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