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Angular dependent de Haas-van Alphen effect of 2D Dirac electronic states in Fe_3Sn_2

Ye, L. (MIT, Physics); Chan, M.K. and McDonald, R.D. (LANL, NHMFL); Checkelsky, J.G. (MIT, Physics)

Introduction

The kagome lattice has long been investigated in the context of magnetic frustration and is known to host the exotic quantum spin liquid phases [1]. Recently there has been a growing interest in the electronic sector of kagome lattice metals [2,3]. The band structure expected from tight-binding model shows several remarkable features including flat bands and a pair of Dirac bands at Brillouin zone boundary; with the introduction of spin-orbit coupling to the ferromagnetically ordered phase, a gap opens at the Dirac point, as shown experimentally for the case of Fe_3Sn_2 [2] (crystal structure shown in Fig. 1(a)), and this topologically non-trivial gap generates considerable anomalous Hall responses in the system [2].

In our previous photoemission experiment, the Dirac electron states were found to be quasi-two-dimensional and two copies of the Dirac cones separated in energy are observed at K and K' [2]. The observation of the Dirac states suggests that Fe_3Sn_2 realizes the kagome band features in its electronic structure. Nevertheless, as photoemission is known as a surface sensitive experimental technique, and the dispersionless nature in k_z may also be indicative of surface states, it is crucial to provide complementary measurements of these Dirac states which are bulk-sensitive.

Experimental

We addressed this question exploiting piezo-resistive torque magnetometry (see Fig. 1(b) inset) in the pulsed field facility in LANL up to 65 T and at low temperature in 3He environment down to 0.4 K to observe magneto-quantum de Haas-van Alphen effects. With rotating the sample in the magnetic field (Fig. 1(a)), we have examined the angular dependence of the oscillation frequency to focus on the dimensionality of the electronic states.

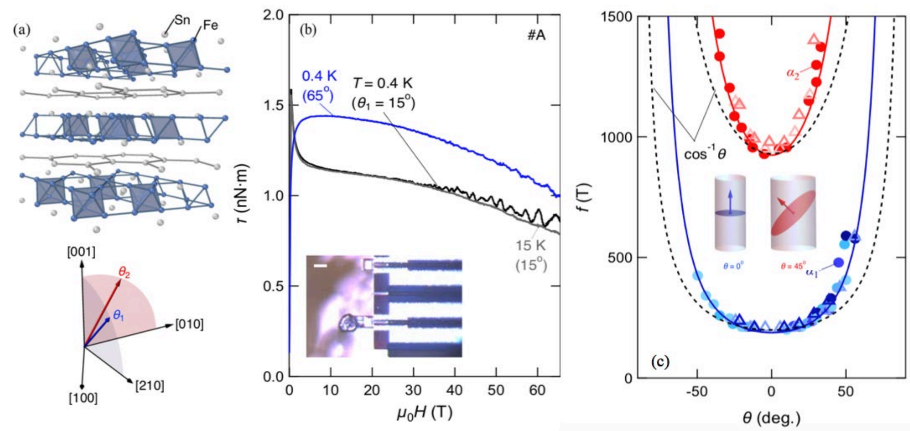

Fig.1 (a) Crystal structure of Fe_3Sn_2 and a schematic of the rotation of magnetic fields defining θ_1 and θ_2. (b) Typical torque traces at $\theta_1 = 15^o$ and 65^o. Inset shows an optical image of a piece of Fe_3Sn_2 single crystal mounted on a piezoresistive cantilever. (c) Angular evolution of the two quasi-2D branches of the oscillation, which is faster than $1/\cos\theta$ (dashed lines). The Inset shows a schematic of the change of Fermi surface with moment direction.

Results and Discussion

At low temperatures, we have observed quantum oscillations that onset from ~ 20 T in the torque signal (Fig. 1(b)). These oscillations are smeared out at elevated temperature (T = 15 K). Among all the frequency branches we identified two of them with the Dirac states, and both evolve with θ faster than $1/\cos\theta$ (expected for an ideal cylindrical Fermi surface, see Fig. 1(c)). We assign this evolution to a change of the band structure along with the moment direction (Inset Fig. 1(c)). This suggests a strong coupling of the Dirac electronic states with the orientation of the ferromagnetic moments, presumably via a moderate strength of spin-orbit coupling [4]. Our observations also confirm the bulk-origin of the previously observed Dirac electronic states [2,4].

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References

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