NATIONAL HIGH MAGNETIC FIELD LABORATORY
2018 ANNUAL RESEARCH REPORT

Non-Saturating Large Magnetoresistance in Semimetals

Leahy, I.A., Lin, Y.P., Siegfried, P.E., Treglia, A.C. (University of Colorado Boulder), Song, J.C.W. (Nanyang Technological University, Singapore), Nandkishore, R.M. and Lee, M. (University of Colorado Boulder)

Introduction

The intensive recent investigations of topological semimetals have revealed a large number of semimetal compounds that exhibit very large non-saturating magnetoresistance. Multiple mechanisms for this magnetoresistance phenomenon have been theoretically proposed, but experimental classifications how to identify which mechanism is responsible in a wide range of materials are far from clear. Our results show that the magnetic susceptibility (χ) and the tangent of the Hall angle ($\tan\theta_H$) successfully capture the fundamental differences in seemingly similar, non-saturating large magnetoresistance, where charge compensation, energy dispersion, and the roles of disorder are markedly distinct, and provide empirical templates to characterize the origins of the extraordinary magnetotransport properties in the newly discovered topological semimetals and beyond [1].

Experimental

Single crystals of NbP, TaP, $NbSb_2$ and $TaSb_2$ were grown using the chemical vapor transport method following a known synthesis procedure. The magnetotransport measurements were performed with the applied field perpendicular to the direction of current on the plane up to 31 T down to 0.3 K. Magnetic susceptibilities of the samples were measured by a SQUID magnetometer.

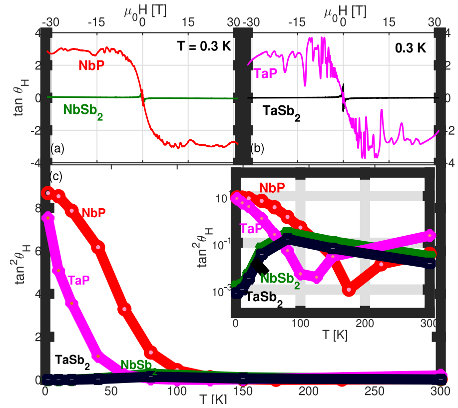

Fig. 1 *tan θ_H* comparison for 4 different semimetals as a function of applied field (A,B), where phophides's are clear saturated at larger value in H > 7 T. The rises at low temperature are distinct as well (C and inset)

Results and Discussion

We investigated magnetotransport and magnetic susceptibility of four different semimetals. We find that the combination of susceptibility and magnetotransport measurements allows us to cleanly characterize the non-saturating behavior of MR. The two phosphide materials (NbP and TaP), that we study and are known to be Weyl semimetals, are well described by a model of uncompensated semimetals with linear dispersion, wherein the MR results from guiding center diffusion with $\tan\theta_H \gg 1$ and field independent being crucial conditions to be satisfied [Fig 1]. The combination of measurements that we have made also allows us to extract the disorder strength and disorder correlation length in these materials, as well as the doping level [2]. Meanwhile, the antimonates ($NbSb_2$ and $TaSb_2$) are well described as compensated semimetals governed by two-band model with effectively quadratic bands, where $\tan\theta_H$ does not pertain to MR phenomena. More interestingly, χ (T) measured at low field (H < 1 T) also show distinct temperature dependences for both categories of materials, where a pronounced minimum occurs in phosphide samples, while the temperature-independent diamagnetic susceptibility that lies within a conventional Landau diamagnetism, as displayed in Fig. 2.

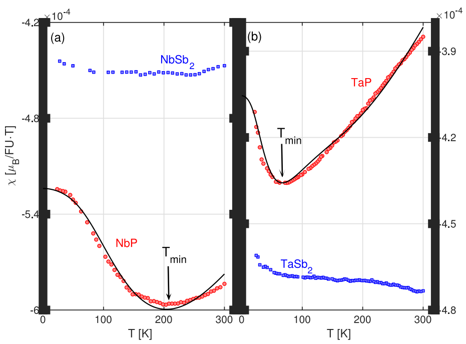

Fig. 2 χ (T) measured at 1 T. The minina occurs only in the phosphides, while T-independent in antimonates.

Conclusions

As large non-saturating MR became more ubiquitous in many new discovery of topological semimetals, our results highlight a distinct set of traits for nonsaturating MR and will serve as a primary touchstone to classify MR phenomena in materials, which in turn will provide design principles for material platforms and devices for technological application.

Acknowledgements

This work was supported by the University of Colorado Boulder Office of Research Innovation. A part of work was performed at the NHMFL, which is supported by National Science Foundation Cooperative Agreement DMR-1157490 and the State of Florida. This research was sponsored in part by the Army Research Office and was accomplished under Grant W911NF-17-1-0482 and the Singapore National Research Foundation (NRF) under NRF Fellowship Award NRF-NRFF2016-05.

References

[1] Leahy, I. A., *et al.*, Proceedings of the National Academy of Sciences, **115**, 10570 (2018);
[2] Song, J. C. W. et al., Physical Review B **92**, 180204 (2015)