Planar Tunneling Spectroscopy of Topological Insulator SmB_6

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Abstract

Samarium hexaboride (SmB_6) belongs to an interesting class of quantum matter known as topological insulators. To investigate its detailed topological nature, we have adopted planar tunneling spectroscopy [1,2]. Tunnel junctions were made by oxidizing the SmB_6 crystal itself for a barrier and evaporating strips of superconducting thin films as counter-electrodes (CE) [2]. Although a slow rate worked for the Pb, it was found that a much faster rate of ~50 Å/s was required for the Sn to form continuous CE strips. In this work, we have explored the dependence of those features representing the topological nature [1] on the CE, Pb or Sn. The differential conductance was measured and the asymmetric features are consistent with inelastic tunneling processes involving spin excitons in SmB_6. Regardless of which CE is used, the conductance spectra show the same features: an additional peak only in the positive bias branch as well as asymmetric temperature evolution of the superconducting coherence peaks. This work further supports our previous findings [1] as it rules out their phononic origin.

Background

In contrast to conventional insulators, which are insulating everywhere, topological insulators are conducting at surfaces.

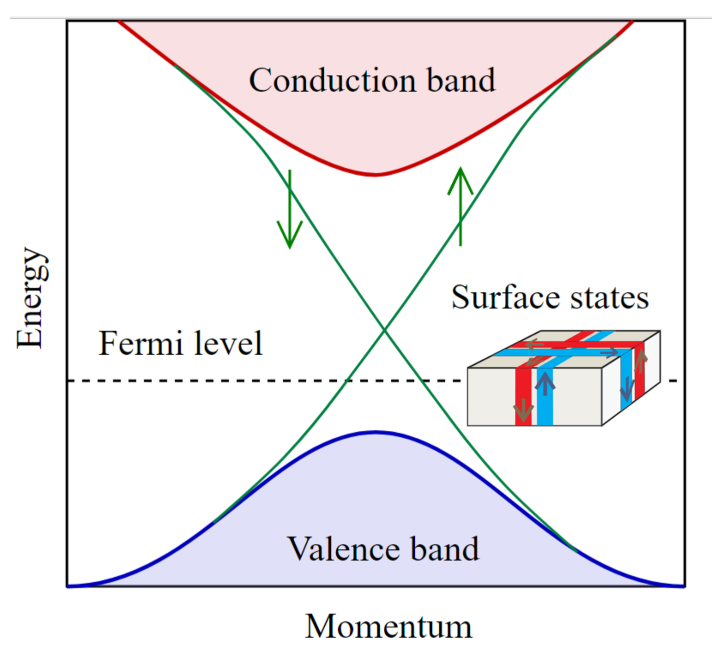

Fig. 1. What are topological insulators? Diagram of energy-band structure showing an energy gap in the bulk and conducting surface states. If the energy gap is small enough, there can be electron-hole pair excitations (excitons). Inset: Topologically protected surface states.

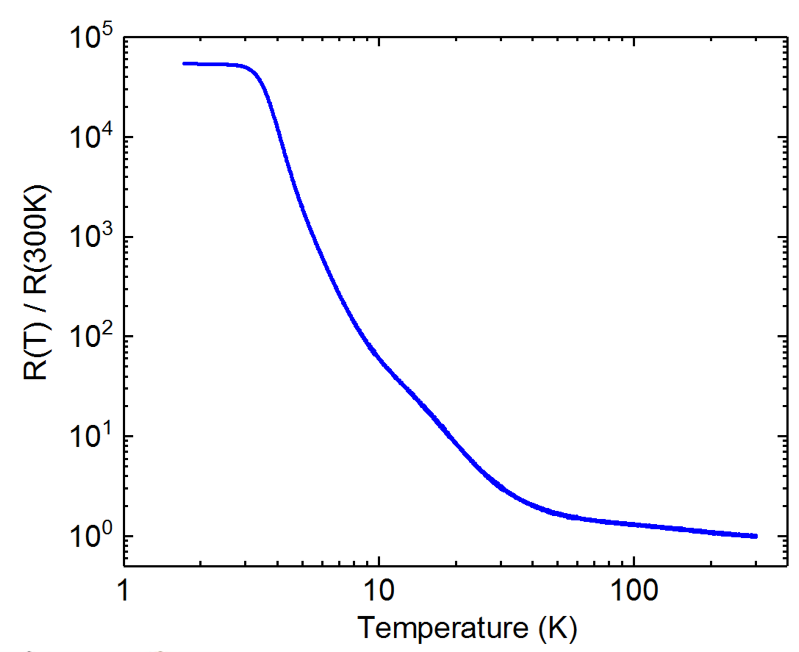

Fig. 2. Temperature dependence of electrical resistance in SmB_6. Rapid increase below ~50 K is due to the insulating bulk, whereas the saturation below ~4 K is mainly believed to originate from the topological surface state.

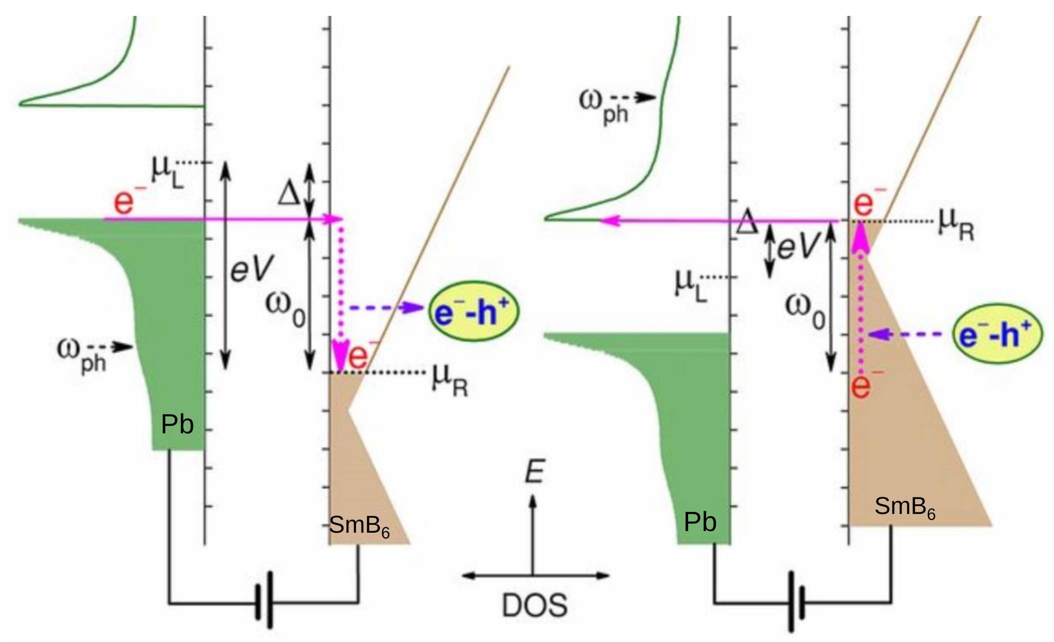

Fig. 3. Schematic diagram for planar tunneling spectroscopy between SmB_6 and Pb (superconducting). From differential conductance ($g(V) \equiv dI/dV$) data, one can deduce the density of states (DOS).

Spin excitons open up additional channels for tunneling.

Experiment

The SmB_6 junctions were made on flux grown single crystals where the tunnel barrier layer was formed by oxidizing the crystal itself. The superconducting CE strips were deposited using thermal evaporation. While a slow deposition (~9 Å/s) produced continuous Pb strips, it caused discontinuity in Sn strips. A faster rate of ~50 Å/s was found to produce a conducting top electrode, as shown by Fig. 4.

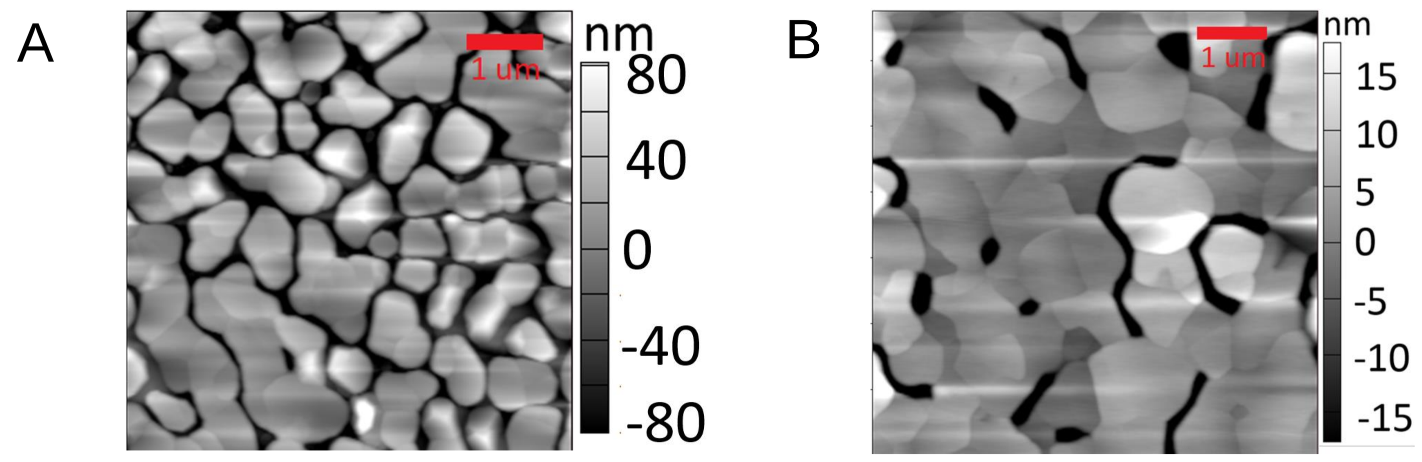

Fig. 4. Atomic force microscope images of Sn strips. (A) Discontinuous strip deposited at 9 Å/s (B) Continuous strip deposited at 50 Å/s

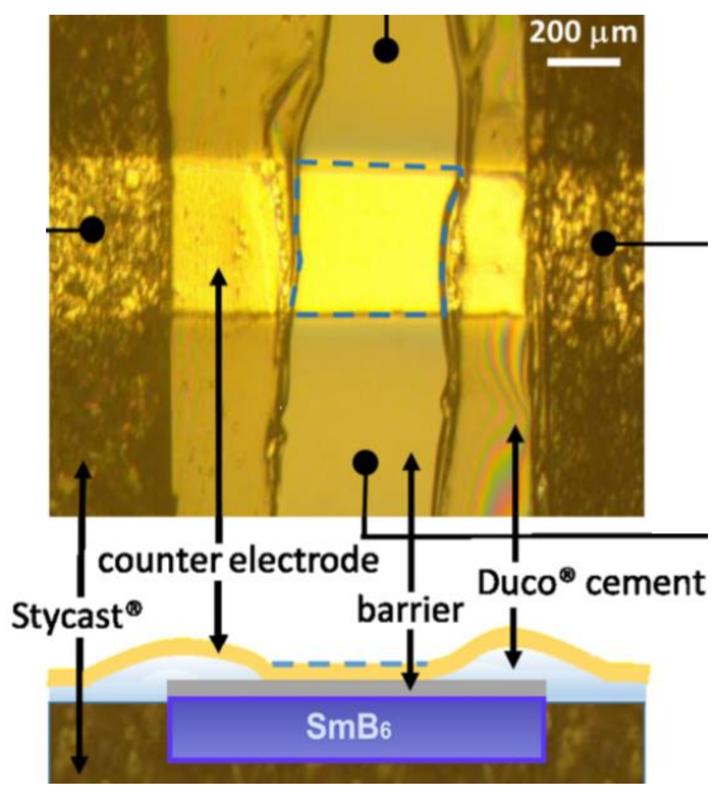

Fig. 5. Typical SmB_6 tunnel junction structure.

(Top panel) An optical image of a real junction. The dashed square shows the junction area.

(Bottom panel) Schematic cross-sectional diagram. Duco® cement is painted to define the junction region. The CE is deposited through a shadow mask.

Results

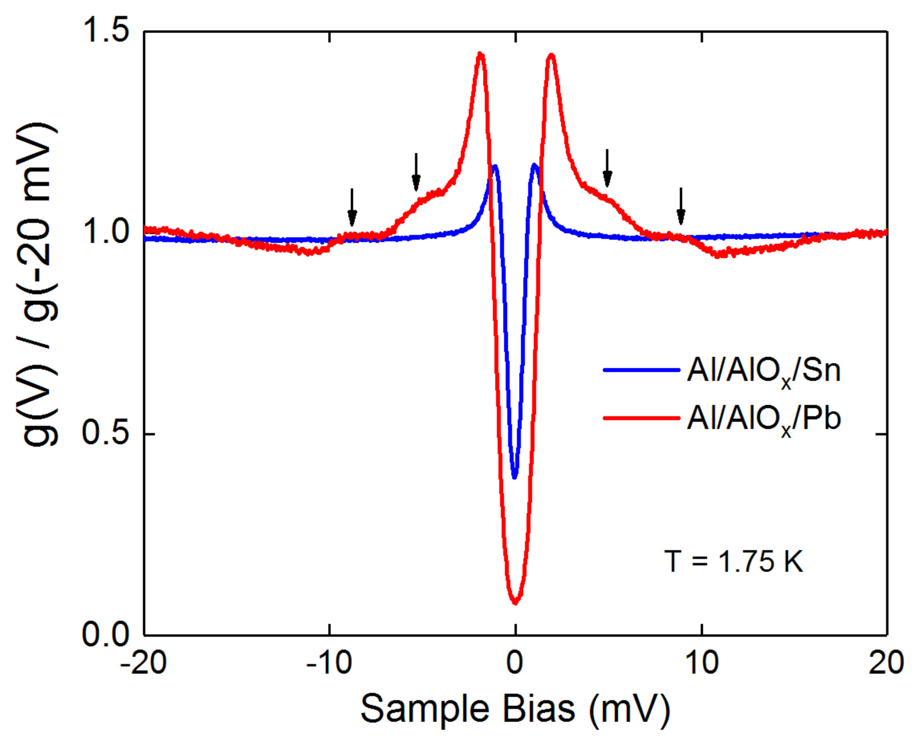

Fig. 6. Conductance spectra for $Al/AlO_x/Pb$ (T_c=7.2 K) and $Al/AlO_x/Sn$ (T_c=3.8 K) tunnel junctions. The shape resembles the DOS of the superconducting CE including the two sharp peaks ("coherence" peaks) at the superconducting gap edges. For Pb, additional features appear due to the phonons mediating stronger electron-electron pairing, as indicated by the arrows.

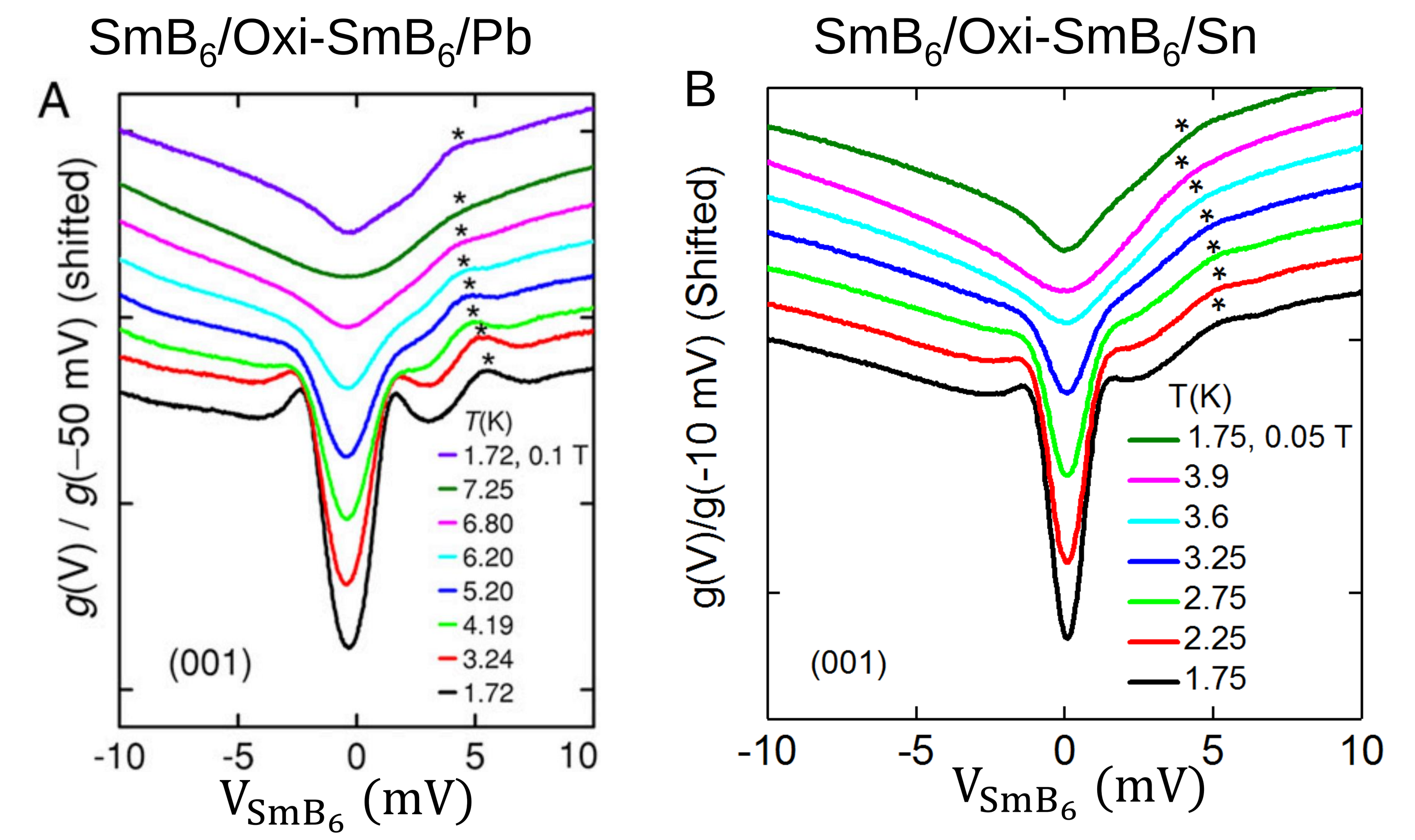

Fig.7. Conductance curves for SmB_6 junctions shifted vertically for clarity. The asterisks show the temperature evolution of the peak as the superconductor is driven normal as the temperature is raised.

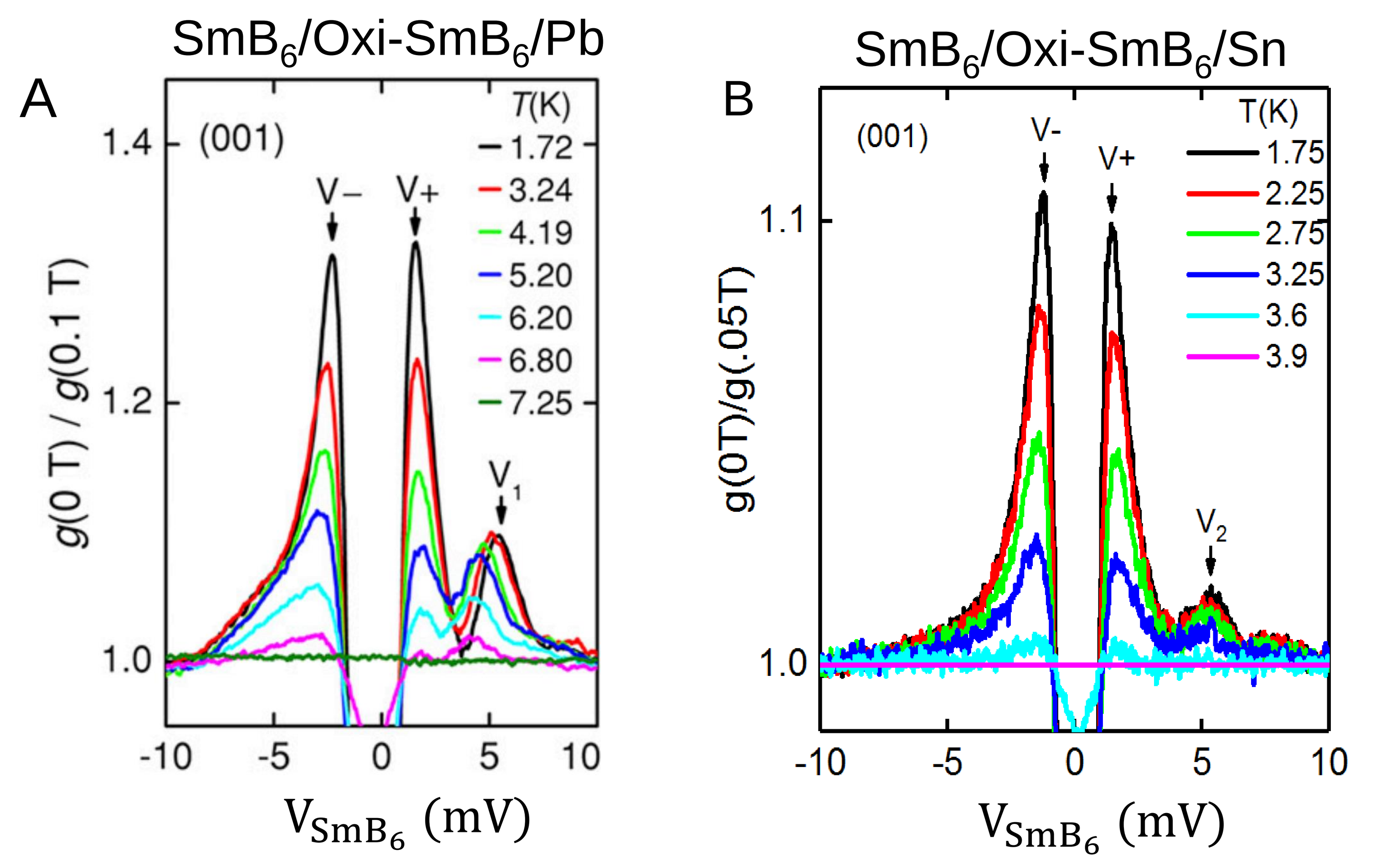

Fig. 8. Conductance curves from Fig. 7 normalized by the ones taken under finite magnetic fields driving the CE normal.

The conductance peaks at V- getting stronger than those at V+ with increasing temperature is due to the absorption of bosons (as seen in Fig. 8). The additional peak ($V_{1,2}$) is due to the emission of spin excitons (as seen in Figs. 7 & 8). These features correspond to the tunneling diagram shown in Fig. 3. The spin exciton features are visible regardless of whether Sn or Pb is used as the CE, supporting our earlier claims [1].

References

[1] Park, W. K., Sun L. Noddings, A., Kim, D.-J., Fisk, Z., & Greene, L. H. (2016). Topological surface States interacting with bulk excitations in the Kondo insulator SmB_6 revealed via planar tunneling spectroscopy. *Proceedings of the National Academy of Sciences* ***113***, 6599-6604.

[2] Sun, L., Kim, D.-J., Fisk, Z., & Park, W. K. (2017) Planar tunneling spectroscopy of the topological Kondo insulator. *Phys. Rev. B*, ***95***, 195129-195139.

Acknowledgements

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