Epitaxial Kagome Thin Films as a Platform for Topological Flat Bands and Dirac Cones

Shuyu Cheng,[1] M. Nrisimhamurty,[1] Tong Zhou,[2] Núria Bagués,[3,4] Wenyi Zhou,[1] Alexander J. Bishop,[1] Igor Lyalin,[1] Chris Jozwiak,[5] Aaron Bostwick,[5] Eli Rotenberg,[5] David W. McComb,[3,4] Igor Žutić,[2] and Roland K. Kawakami[1]

[1]*The Ohio State University, Department of Physics, Columbus, OH, USA*
[2]*University at Buffalo, Department of Physics, Buffalo, NY, USA*
[3]*The Ohio State University, Department of Materials Science and Engineering, Columbus, OH, USA*
[4]*The Ohio State University, Center for Electron Microscopy and Analysis, Columbus, OH, USA*
[5]*Lawrence Berkeley National Laboratory, Advanced Light Source, Berkeley, CA, USA*

Metals consisting of kagome lattices have interesting band structures consisting of topological flat bands and Dirac cones. Systems with flat bands are ideal for studying strongly correlated electronic states and related phenomena due to the smaller bandwidth W compared to the Coulomb repulsion U. Kagome metals such as CoSn have been recognized as promising candidates due to the proximity between the flat bands and the Fermi level. A key next step will be to realize epitaxial kagome thin films with flat bands to enable tuning of the flat bands across the Fermi level via electrostatic gating or strain. Here we report the band structures of epitaxial CoSn thin films grown directly on insulating substrates [1]. Flat bands are observed using synchrotron-based angle-resolved photoemission spectroscopy (ARPES). The band structure is consistent with density functional theory (DFT) calculations, and the transport properties are quantitatively explained by the band structure and semiclassical transport theory. We are also developing kagome metals that have the Dirac cones near the Fermi level, which are interesting for investigating the intrinsic anomalous Hall effect and to potentially realize the quantum anomalous Hall effect at elevated temperatures.

[1] Cheng *et al.,* Nano Letters, 23(15), 7107-7113 (2023).

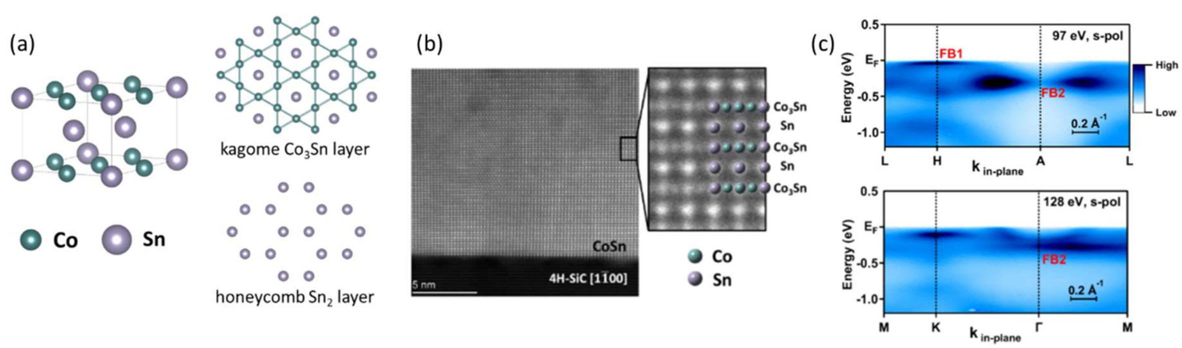

Figure 1. (a) Atomic lattice structure of kagome metal CoSn. (b) Cross-sectional of scanning transmission electron microscopy (STEM) image of CoSn. (c) Angle-resolved photoemission spectroscopy (ARPES) measurements flat bands (FB1, FB2) measured at $k_z = \pi$ (top) and $k_z = 0$ (bottom).

Supplementary Pages

We have nearly completed a study on the epitaxial thin films of kagome metals $TbMn_6Sn_6$ and $ErMn_6Sn_6$. These are members of the RMn_6Sn_6 (R = rare earth) family that has recently been studied in bulk crystals, but to our knowledge, there are no previous reports of thin film growth of these materials.

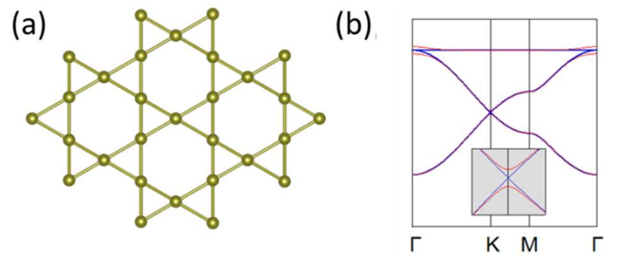

Figure S1. *(a) A schematic drawing of a 2D kagome lattice. (b) Band structure of the 2D kagome lattice calculated by tight-binding model. Red (blue) is with (without) spin-orbit coupling.*

Kagome lattices have garnered substantial interest because their band structure consists of topological flat bands and Dirac cones (Fig. S1). The RMn_6Sn_6 compounds are particularly interesting because the Mn kagome planes occupy their own atomic layers (Fig. S2a), in contrast to other kagome metals such as CoSn which have Sn atomic within the Mn kagome plane. The isolated nature of the Mn kagome planes in RMn_6Sn_6 have less hybridization and energy overlap with other bands in the material. This allows the topological flat bands or Dirac cones to be more isolated in energy, which is important for realizing the quantum anomalous Hall effect (QAHE).

The RHEED patterns (Fig. S2b), XRD and AFM (Fig. S3) are all good. Magnetization measurements show interesting properties (Fig. S4). The $ErMn_6Sn_6$ has an in-plane easy axis for all temperatures. The $TbMn_6Sn_6$ shows strong perpendicular magnetic anisotropy (PMA) at low temperatures and the magnetization transitions to in-plane near room temperature. These are consistent with bulk crystal samples. The perpendicular magnetization of $TbMn_6Sb_6$ is a necessary condition for QAHE, so we are encouraged by these early results.

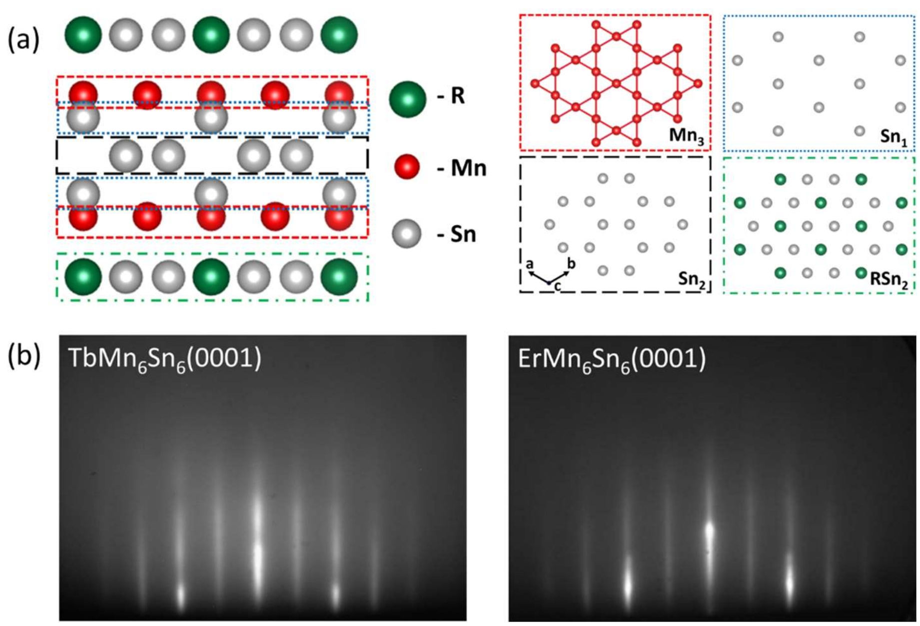

Figure S2. *(a) Atomic lattice of RMn_6Sn_6. (b) RHEED patterns of $TbMn_6Sn_6$ and $ErMn_6Sn_6$.*

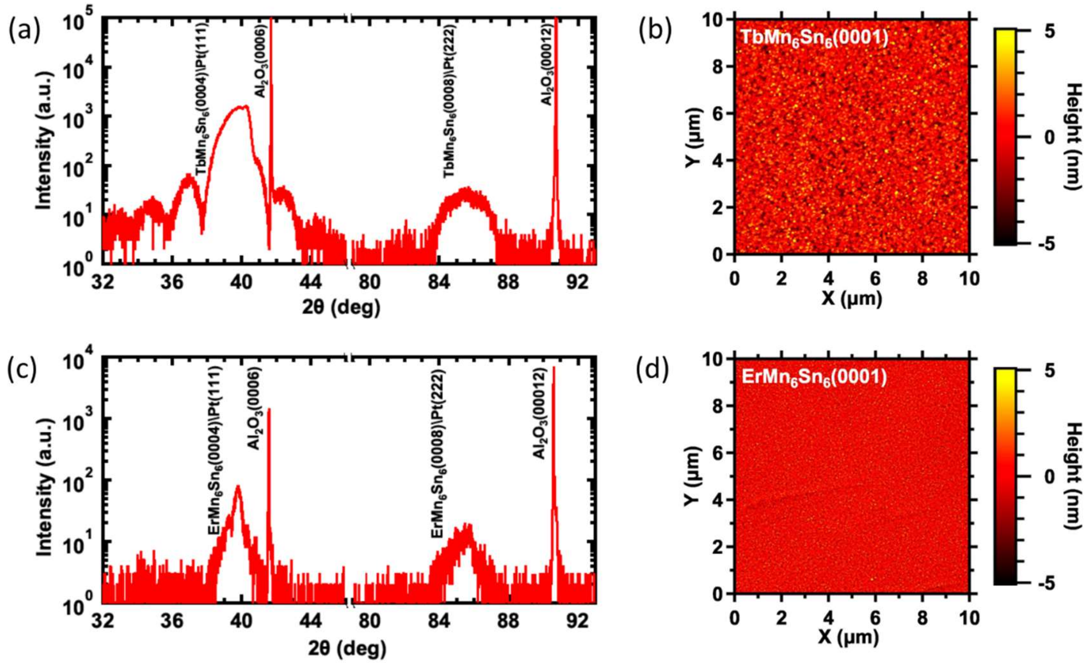

Figure S3. *(a,b) XRD and AFM of $TbMn_6Sn_6$. (c,d) XRD and AFM of $ErMn_6Sn_6$.*

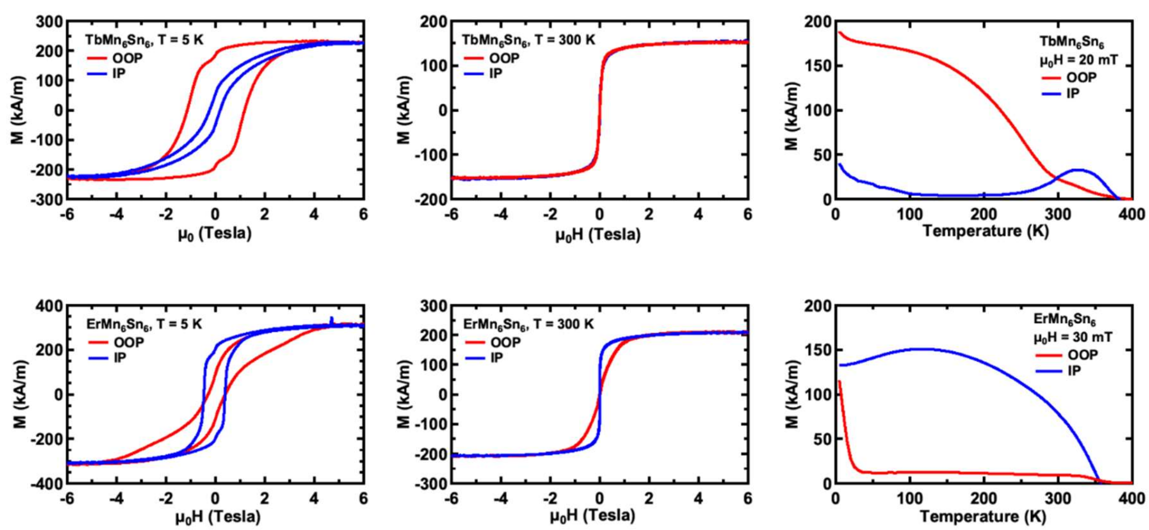

Figure S4. *(top) SQUID measurements of $TbMn_6Sn_6$. (bottom) SQUID measurements of $ErMn_6Sn_6$.*