Identifying Topological Materials for Quantum Computing Applications

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Depending on the composition, Quantum Materials may act as conductors, insulators, semiconductors or even as superconductors. Combinations of different quantum materials are of high interest to explore new phenomena and act as the foundation for future electronic devices at the nanometer scale. Our quantum materials research reaches from defect formation in graphene to the characterization of hybrid quantum materials. We present our work utilizing Low-Voltage Monochromated EELS and Low-Voltage High-Resolution Electron Microscopy (LV HREM). Together, these often improve the contrast to damage ratio obtained on a large class of samples. The exploration and synthesis of constitute only one aspect of the challenges in the development of new topological materials, another challenge is their characterization. Since the phenomena appear at very restricted and dedicated conditions, the characterization method must have very high sensitivity, resolution, localization and precision.

Transmission electron microscopy is a powerful technique to investigate structural, compositional or electromagnetic properties of topological materials. Especially, recent implementation of aberration correction in the transmission electron microscopy made chemical and structural characterization with very high spatial resolution and sensitivity possible. This in turn allows with spatial resolution in the range of picometers for characterization of superconductor and topological materials, where small compositional variations have large effects on the material properties. The crystal structure and composition determine the electromagnetic properties of the materials. To be able to understand, analyze and control these properties, both crystal structure and composition need to be known precisely.

For topological materials 2005 was an important milestone as a consequence the realization of the existence of a metallically conductive surface state in an insulator material. Within couples of years, the experimental evidences of the surface state followed the theory studies. A high spin orbit coupling creates edge states where quantum spin Hall Effect can exist in the absence of an external magnetic field. The discovery of the new phenomenon opened up an intensive discussions in condensed matter, and even very well-known conventional material systems such as Bi2(Te,Se)3, BiSb alloys etc., became "exotic" and highly investigated materials again.

One idea is using the kagome lattice as a topological switch. The kagome lattice is a two-dimensional network of corner-sharing triangles (Fig. 1) [1] known as a platform for exotic quantum magnetic states [2 - 4]. Theoretical work has predicted that the kagome lattice may also host Dirac electronic states [8] that could lead to topological [5] and Chern [6] insulating phases, but these have evaded experimental detection to date. Fe3Sn2 is a rare metallic Kagome ferromagnet, which synthesis as a single crystal has not previously been reported. We study this single crystal as well as other topological insulators with the particular interest in the correlated behavior in topologically non-trivial materials. The (S)TEM images mapped with low voltage EELS show the atomic structure of the layered material (Fig. 2), and the magnetic force microscopy measurements reveal the magnetic anisotropy of the crystal on the surface [7].

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Funding Acknowledgement:

This work was supported by the STC, Center for Integrated Quantum Materials, NSF Grant No. DMR-1231319. This work was performed at the Center for Nanoscale Systems (CNS), a member of the National Nanotechnology Coordinated Infrastructure Network (NNCI), which is supported by the National Science Foundation under NSF award no. 1541959.

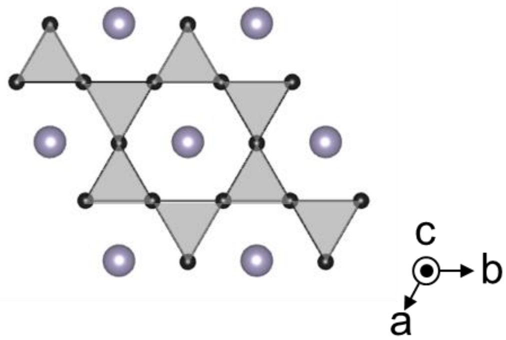

Figure 1. Spin-Obit Kagome Metal Structure

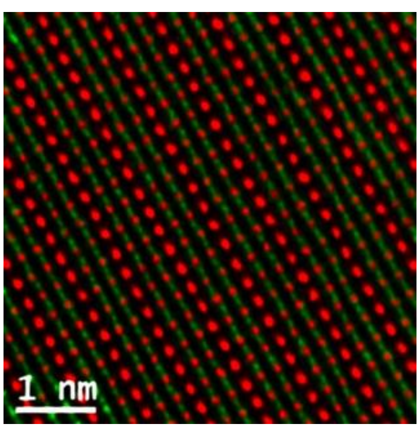

Figure 2. Spin-Obit Kagome Metal, Fe_3Sn_2. High Angle Angular Dark Field Image (HAADF) overlayed with atomic number contrast false coloring (right).