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New Advanced Electron Microscopy to Discover New Quantum Materials

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The discovery of extraordinary new quantum materials with striking properties has caused great excitement, and promises to transform signal processing and computation. We have performed integrated research on three materials (1) Graphene (G) - electrons that move as massless particles at a constant speed; (2) Topological Insulators (TI) - mobile surface electrons with spins fixed to the direction of motion; and (3) Nitrogen-vacancy (NV) Centers in Diamond - a single spin stores a bit of quantum information. Remarkably, the quantum phenomena displayed by these materials persists at room temperature, changing the rules for signal processing and computation and opening the way for quantum electronics.

These quantum materials are ideally suited to layered atomic-scale structures that control the flow of charge and spin in graphene and TI materials, with memory and optical input/output channels provided by NV-centers in diamond. We have imaged and characterized high quality graphene and graphene-like materials, such as hexagonal boron nitride (hBN) and hybrid graphene-hBN structures. Until now, most experimental demonstrations of the remarkable properties of graphene have been done using exfoliated graphene sheets. We have imaged Bi_2Te_2Se, which has a lower bulk carrier density and higher mobility than Bi_2Se_3. Aberration-corrected electron microscopy has been used to characterize MBE-grown films with high resolution at low beam voltages (40 & 80kV) to directly visualize structural defects and relate them to performance.

Using angle-resolved photoemission, we have also detect a pair of correlated Dirac cones near the Fermi level with a 30 meV mass gap acting as a source of Berry curvature in a Fe_3Sn_2 kagome bilayer structure (Fig. 1). We show this behavior is a consequence of the underlying symmetry properties of the bilayer kagome lattice in the spin-orbit coupled ferromagnetic state. This report provides the first evidence for a ferromagnetic kagome metal and an example of emergent topological electronic properties in a correlated electron system. This offers insight into recent discoveries of exotic electronic behavior in kagome lattice antiferromagnets and provides a stepping stone toward lattice model realizations of fractional topological quantum states in other materials systems (Fig 2).

The imaging and analysis of quantum materials presents new challenges on how to minimize surface and sample damage while imaging and analyzing structures at the direct atomic level, new approaches are needed in order to corelate materials properties with structure , we present some of our multi modal approaches in this presentation [5].

References:

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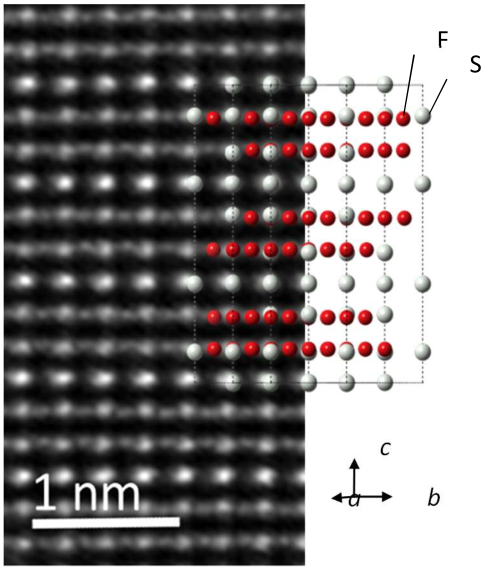

Figure 1. 80 keV Aberration corrected STEM image Fe_3Sn_2 layers of hexagonal single crystals Forming a bilayer kagome lattices are spaced by individual stanene layers

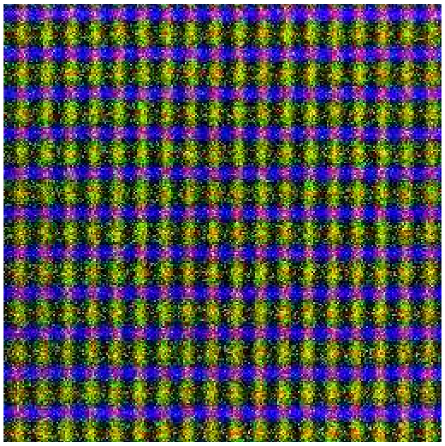

Figure 2. Atomic resolution EDS map of the $Co_3Sn_2S_2$ again indicating the Kagome structure. (With thanks to Dr. Onishi JEOL Japan)