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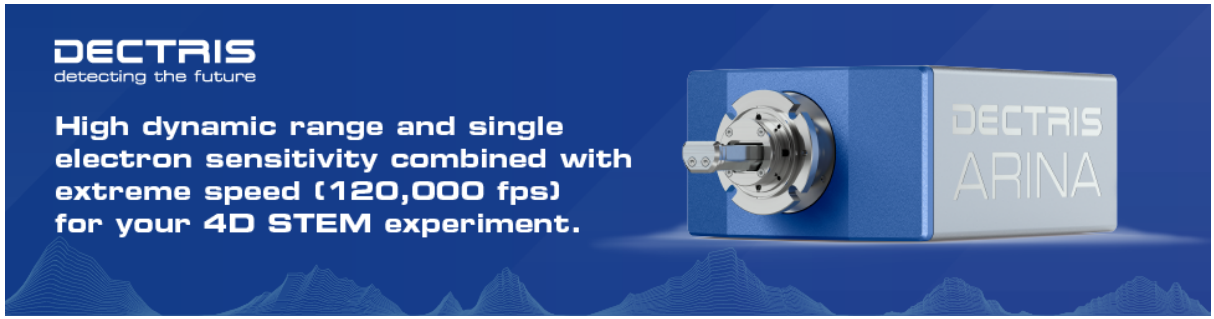

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doi:10.1017/S1431927622006754
Microsc. Microanal. 28 (Suppl 1), 2022
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Methods for Multi-Layer van der Waals Heterostructures Topological Materials Discovery via STEM and LEEM

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We have performed integrated research on three distinct Topological materials systems. It is possible to form via controlled growth systems heterointerfaces in bulk materials, we present the example of our newly synthesized material $Ba_6Nb_{11}S_{28}$ (see Fig. 1a) [1]. This material naturally realizes vdW coupled heterointerfaces between transition metal dichalcogenide (TMD) monolayers (hexagonal NbS_2, *H*-NbS_2) and insulating spacers Ba_3NbS_5 (see Fig. 1b). TEM diffraction taken along the c-axis shows that the hexagonal spacer and TMD layers, (Fig. 1c&d), orange and blue, respectively) are commensurate. The electronic band structure can be understood as that resulting from superimposing a periodic potential defined by Ba_3NbS_5 onto monolayer *H*-NbS_2. This is similar to the mechanism which yields flatbands and strongly correlated physics in twisted-bilayer graphene and TMD heterostructures. Low Voltage electron microscopy has been used to characterize grown materials with high resolution at low beam voltages (40 & 80kV) to directly visualize structural defects and relate them to performance [2].

Key to this understanding is the Kagome type 2-D materials Using angle-resolved photoemission, we have also detected 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 [3, 4]. 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 offers insight into recent discoveries of exotic electronic behavior in kagome lattice antiferromagnets and provides a steppingstone toward lattice model realizations of fractional topological quantum states in other materials systems [5, 6].

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 and multi techniques approach in this presentation.

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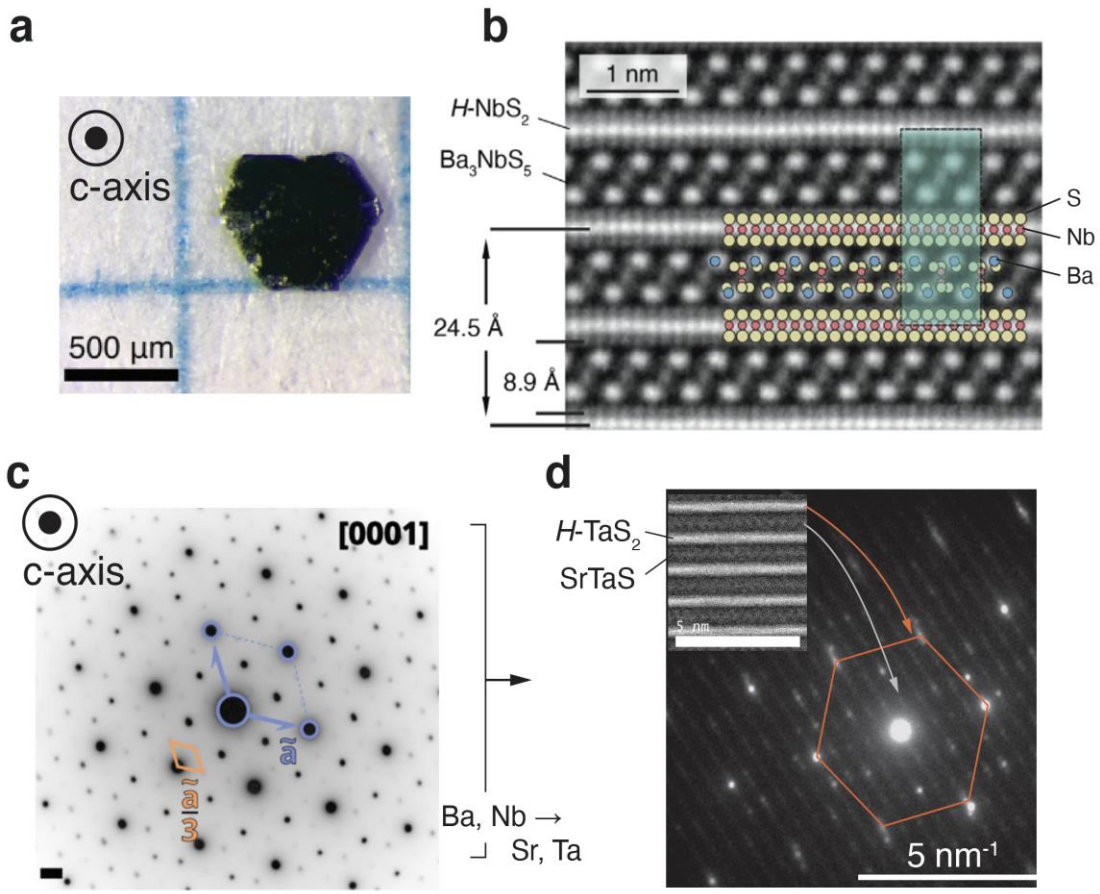

Figure 1. (a) Optical image of $Ba_6Nb_{11}S_{28}$ crystal (b) High-resolution TEM cross-section showing alternating *H*-NbS_2 and Ba_3NbS_5 layers. (c) TEM diffraction image of $Ba_6Nb_{11}S_{28}$ sighted along the *c*-axis. (d) inset, High-resolution TEM cross-section of *H*-TaS_2 containing compound. main, TEM diffraction sighted along *c*-axis of *H*-TaS_2 .

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[7] This work was supported by the STC Center for Integrated Quantum Materials, NSF Grant No. DMR-1231319. Portions of 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.

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