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3D-Atomic-Scale Analysis of Magnetoelectric Multiferroic Topologies via Scanning Transmission Electron Microscopy and Spectroscopy Complemented by Atom Probe Tomography

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Magnetoelectric multiferroic higher order topologies are an emerging solution for future low-power spintronic and quantum devices, due to a combination of their atomic-scale tunable multi-functionality and mobility. In addition to their potential for next-generation interactive technology, topologies with spin to charge coupling are a fertile ground for the exploration and engineering of new states of matter. In our recent report we have shown the presence of vortex topologies present in room temperature magnetoelectric multiferroic $Bi_6Ti_xFe_yMn_zO_{18}$ thin films by atomic-scale scanning transmission electron microscopy (STEM) polarization mapping.[1,2] We find these chiral polar textures at antiphase boundaries within the thin films. Such topologies related to crystalline defects should be analyzed three-dimensionally to truly understand their formation. In this presentation, will discuss the use of atom probe tomography (APT) combined with scanning transmission electron microscopy (STEM) and spectroscopies to analyze the Fe and Mn elemental segregation at topological defects.

For $Bi_6Ti_xFe_yMn_zO_{18}$ the magnetic cation partitioning increases the probability of nearest-neighbor magnetic interactions in the central unit cell layer by up to 90% compared to random distributions over the other available B-sites.[3] Using atomic resolution STEM with corresponding energy dispersive X-ray (EDX) and electron energy loss spectroscopy (EELS) elemental mapping we can determine the location of Fe and Mn within the unit cell. Although electron spectroscopy characterization is also possible for topological defects (Figure 1), using this method we only have a 2D projected view of these 3D microstructural features. As the topologies themselves are the active regions within such material systems, it is vital that we explore the higher order elemental segregation in full real space. We hence used APT's unique 3D characterization capability to move beyond the 2D projection of the elemental segregation knowledge, with an aim to unravel the magnetic cation partitioning of complex 3D vortices and associated crystallographic defect topologies. Theoretical calculations confirm the subunit cell cation site preference and charged topology energetics. We will discuss the opportunities APT characterization methods can bring to the field multiferroic higher order topology physics.

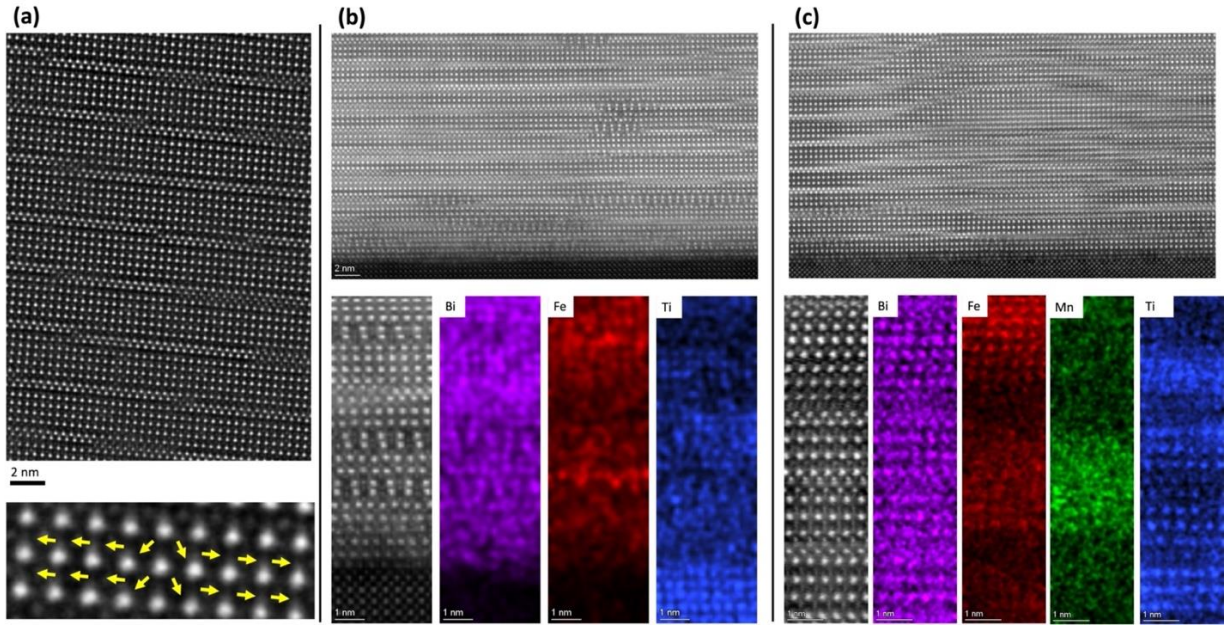

Figure 1. (a) STEM imaging at out of phase boundaries with corresponding polarization mapping, (b) alternating unit cell restructuring with corresponding EDS mapping (c) out of plane restructuring with corresponding EDS mapping.

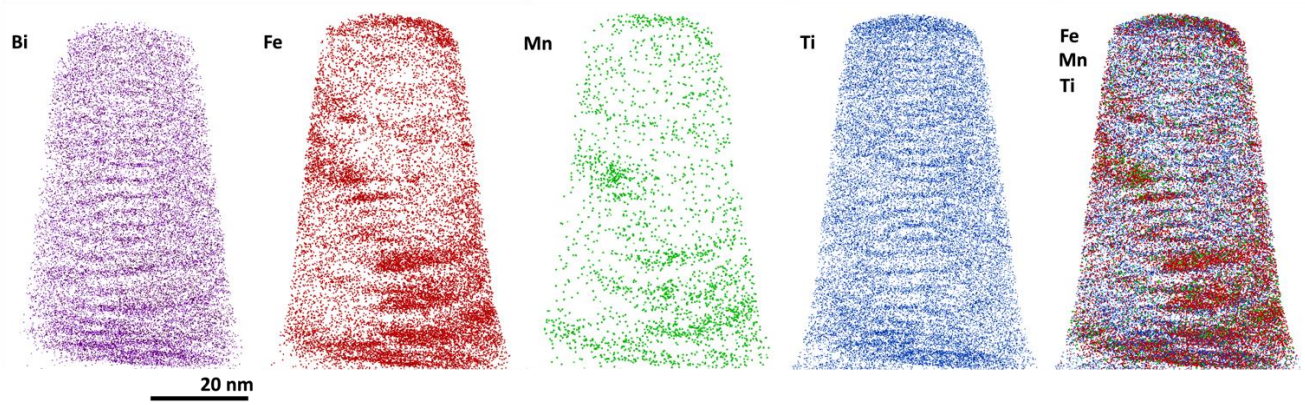

Figure 2. APT atom maps showing distribution of the Bi, Fe, Mn, TiO at topological defects.

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