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S/TEM Investigation of the Structure of $(Bi,Sb)_2Te_3$/h-BN Heterostructures Grown by Molecular Beam Epitaxy

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Topological insulators are promising materials for magnetoelectronic applications. Therefore, bismuth chalcogenides have emerged as materials of interest due to their strong spin–orbit coupling, which results in spin–momentum locking. This property has enabled the demonstration of properties such as spin-transfer torque [1], current-induced spin polarization [2,3], and room-temperature spin injection [4].

Bi-chalcogenides have been grown and studied on a variety of substrates [2-7] to improve both the film quality and properties due to the substrate–topological insulator interaction. One area of interest is the growth of topological insulators on two-dimensional materials, which may provide benefits such as structural compatibility, enhanced properties, or transferability for integration into new device geometries. Because such heterostructures of two-dimensional materials are at the forefront of materials' development for next-generation electronic devices, it is desirable to understand their structural features at the atomic level.

Here, we present results from the characterization of $(Bi,Sb)_2Te_3$ films grown on hexagonal boron nitride (h-BN). The films were grown onto h-BN supported by a Si substrate by molecular beam epitaxy (MBE), after which the $(Bi,Sb)_2Te_3$/h-BN heterostructures were transferred onto transmission electron microscopy (TEM) grids for analysis. By plan-view study using TEM, the grain structure of $(Bi,Sb)_2Te_3$ was investigated, as well as of details of atomic features at grain boundaries. We determined (1) the composition using energy dispersive X-ray spectroscopy (EDX) and electron energy-loss spectroscopy (EELS), (2) the relative orientations of $(Bi,Sb)_2Te_3$ grains by electron diffraction experiments and Multislice simulations, and (3) the atomic arrangement at $(Bi,Sb)_2Te_3$ grain boundaries using high-angle annular dark-field scanning TEM (HAADF-STEM) imaging. Cross-sectional samples have also been prepared by focused-ion-beam (FIB) milling. HAADF-STEM imaging of cross-sectional samples has revealed a sharp $(Bi,Sb)_2Te_3$/h-BN interface at which the characteristic five-atom-thick "quintuple layer" layer can be resolved. Figure 1 shows EELS and HAADF-STEM characterization of $(Bi,Sb)_2Te_3$/h-BN heterostructures, including grain boundary and dislocation images at atomic resolution. This work was performed on an FEI Titan G2 60-300 S/TEM equipped with a Schottky X-FEG gun, operated at 200 kV [8].

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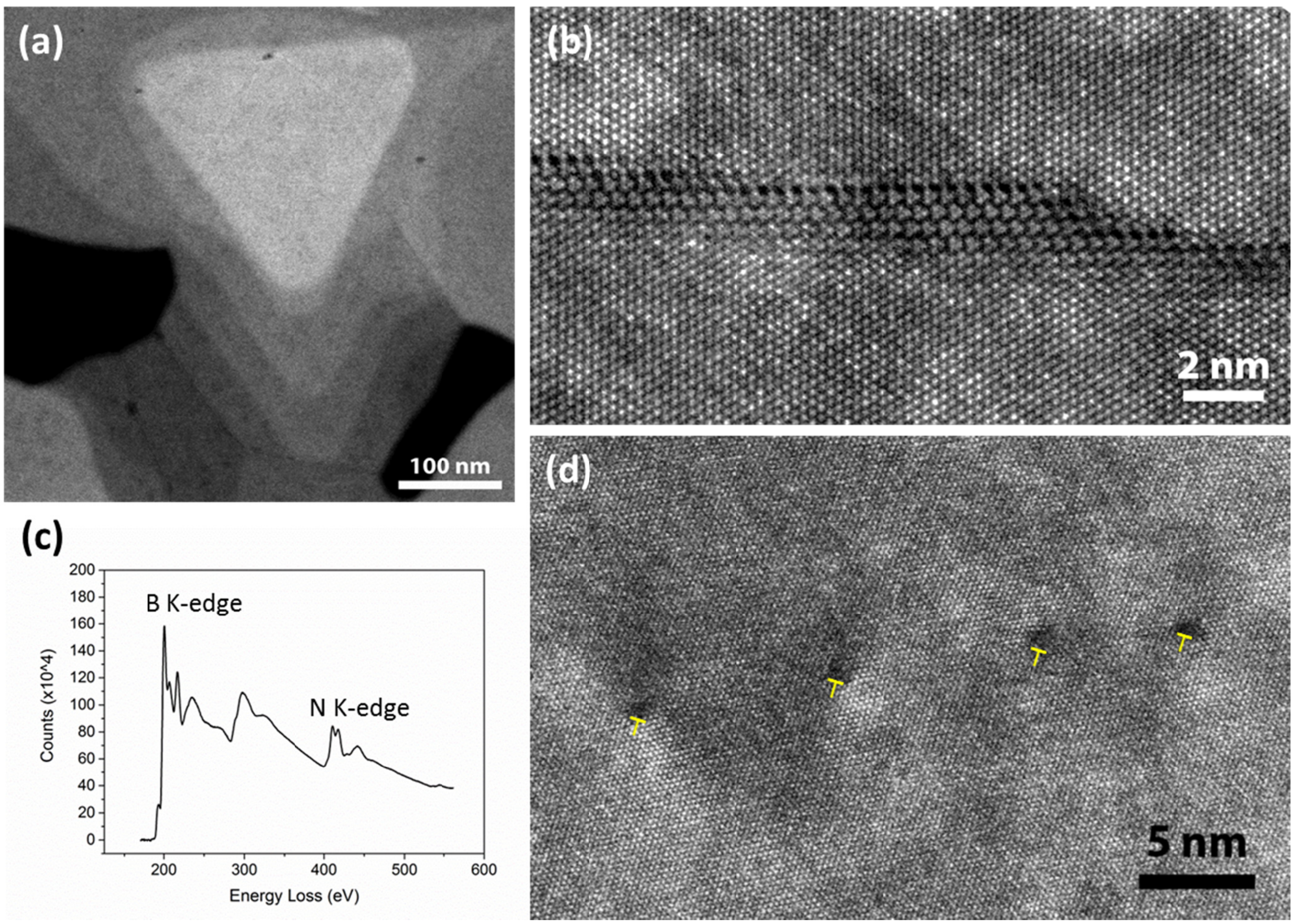

Figure 1. Characterization of $(Bi,Sb)_2Te_3$/h-BN heterostructures: (a) HAADF-STEM image showing tiered $(Bi,Sb)_2Te_3$ growth, (b) FFT low-pass filtered HAADF-STEM image of a grain boundary between $(Bi,Sb)_2Te_3$ grains, (c) EELS spectrum with peaks corresponding to h-BN, and (d) HAADF-STEM image of a dislocation array in a $(Bi,Sb)_2Te_3$ film.