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Microscopy and Chemical Analysis of Topological Insulator Bi_2Se_3 and Topological Crystalline Insulator SnTe Nanostructures

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Topological insulators and topological crystalline insulators are a new quantum matter whose band structure belongs to a different topology compared to a regular, trivial insulator [1, 2]. The physical consequence of this is manifestation of conducting surface or edge states that are spin-polarized and Dirac-dispersive. The unique electronic property of the surface states opens opportunities to study previously inaccessible fundamental condensed matter phenomena such as Majorana fermions [3] and magnetic monopoles [4] and to design future spin-based device applications. A plethora of experiments have been carried out to investigate the exotic electronic properties of the surface states in topological insulator Bi_2Se_3 and topological crystalline insulator SnTe.

Nanostructured Bi_2Se_3 and SnTe are ideal to study and exploit the properties of the surface states due to the large surface-to-volume ratios, which enhance the surface effects. In addition, the nanostructure morphology can play an important role in confining the surface electrons to follow well-defined paths for interference experiments. Magnetic and charge-compensation doping has also shown to be important for controlling the surface state property. This highlights the critical need to carefully characterize the morphology, atomic structure, and chemical composition of topological insulator and topological crystalline insulator nanostructures.

In this talk, I will present structural and chemical characterizations of Bi_2Se_3 nanoribbons and SnTe nanoplates using scanning transmission electron microscopy and showcase how their structures determine their electronic properties. For chemical analysis, X-ray energy dispersive spectroscopy (EDX) was proven very useful due to the high atomic number elements such as Bi and Te that make up topological insulators and topological crystalline insulators. Monochromated electron energy-loss spectroscopy (EELS) was used to probe plasmonic and optical properties of these materials in thin platelet forms.

A few examples I will discuss are 1) analysis of chemical compositions of $Bi_2(Se_xTe_{1-x})_3$ nanoribbons and nanoplates and resulting changes in the lattice constant, plasmon excitations, and electron carrier density (Fig. 1) [5], 2) Electron energy-loss spectroscopy investigation of plasmonic and optical property changes due to dielectric molecule intercalation into Bi_2Se_3 nanoribbons (Fig. 2) [6-8], and 3) characterization of Indium doping concentrations in SnTe nanostructures, which induces superconductivity (Fig. 3) [9, 10].

The structure-property relation of topological insulator and topological crystalline insulator nanostructures, elucidated by analytical electron microscopy studies, provides an essential guide to improve the material quality for enhanced electrical transport properties of these materials.

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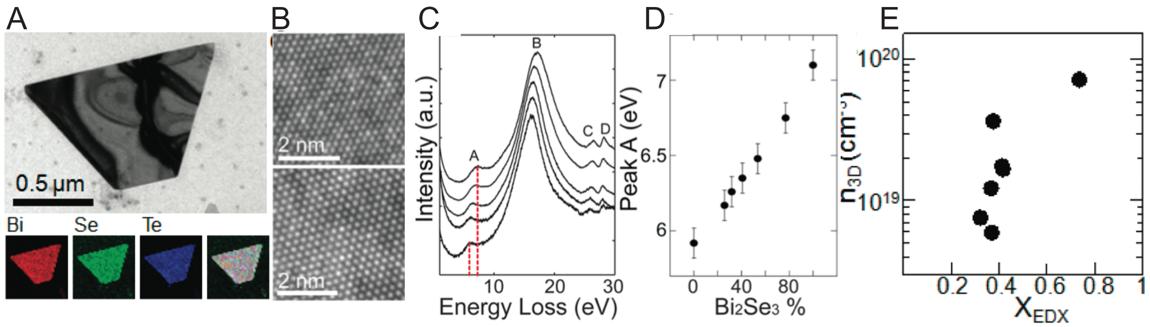

Figure 1. (A) Chemical analysis of $Bi_2(Se_xTe_{1-x})_3$ nanoplates by EDX. (B) TEM image of Bi_2Se_3 (top) and Bi_2Te_3 (bottom). (C) EELS spectra showing the surface plasmons of $Bi_2(Se_xTe_{1-x})_3$ nanoplates. (D) Surface plasmon peak linearly scales with the Se/Te ratio. (E) Carrier density scales with the Se/Te ratio.

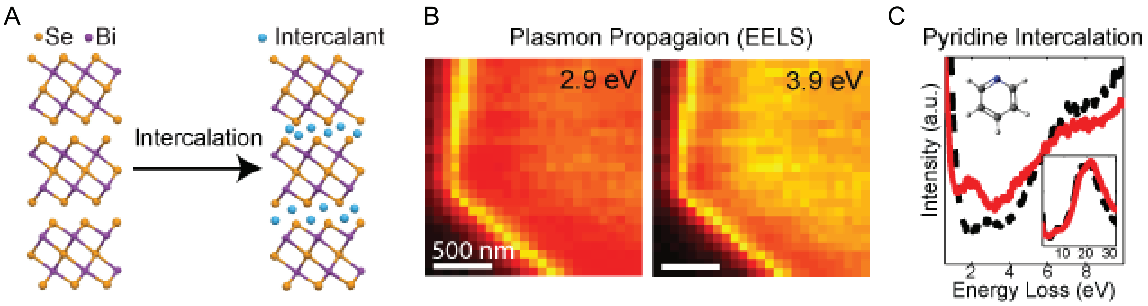

Figure 2. (A) Intercalation into the van der Waals gap of Bi_2Se_3. (B) Plasmon propagation in a Bi_2Se_3 nanoplate by EELS mapping. (C) Optical property change by pyridine intercalation into Bi_2Se_3.

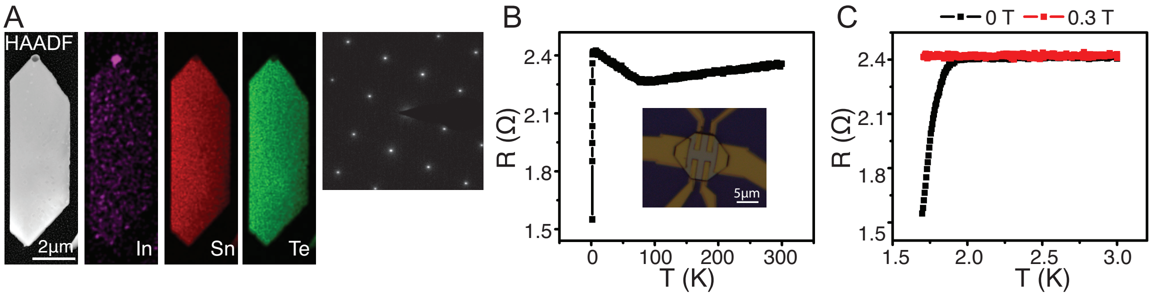

Figure 3. (A) Chemical analysis of In-doped SnTe by EDX. (B) Superconductivity induced by the In doping. (C) Field-cooled resistivity measurement confirms the superconductivity.