Recent Progress in High-Resolution Electron Energy Loss Spectroscopy in the Scanning Transmission Electron Microscope

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Instrumentation advances have pushed the energy resolution and sensitivity of electron energy loss spectroscopy (EELS) in scanning transmission electron microscopes (STEMs) into the meV range, all the while retaining atomic-sized probes. This now allows for probing the chemical and electronic structure of a wide range of materials systems with unprecedented detail, across the energy scale from the core-loss to the vibrational spectroscopy regimes.
For instance, methodological developments using the energy loss near-edge structure, which arises from core-level excitations, pave the way towards mapping electronic orbitals, such as π^* and σ^* states in epitaxial graphene, in real space. [1] In the low energy loss regime, a dark field EELS detection geometry is used to reveal atomic-scale variations in acoustic and optical phonon excitations in materials, while single-atom impurities can even be shown to have a characteristic vibrational response [2]. In a system consisting of Bi_2Se_3 films grown by chemical vapor deposition on epitaxial graphene, observations using these techniques highlight the interplay between the various phonon modes and the Dirac plasmons in the topological insulator Bi_2Se_3, in addition to a further direct interrogation of the chemical bonds.
Finally, the prospects for observing the excitation of spin waves, or magnons, arising from the collective excitation of the electrons' spin in a lattice and which qualitatively occupy the same energy range as phonons, are explored through preliminary experiments and the development of a theoretical framework based on the diffuse scattering of electrons due to magnons. [3]

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[2] F. S. Hage *et al.*, *Science* **367** (2020), aba1136
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