

Colloquium

Surface-sensitive studies of electronic properties in 2D materials



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Abstract: Two-dimensional (2D) materials provide a unique platform in which structural, electronic, and functional properties are governed almost entirely by surface and interfacial effects. Thus, understanding and controlling these properties is essential for their integration into future electronic and energy-efficient technologies. In this presentation, representative results are obtained by using advanced surface-sensitive experimental approaches that enable the investigation of 2D materials, such as graphene, germanene, and transition metal chalcogenides, at the atomic scale. Scanning Tunneling Microscopy (STM) is employed to probe and locally manipulate structural and electronic properties with atomic precision, while complementary synchrotron-based techniques offer element-specific and surface-resolved access to electronic structure, chemical states, and interfacial phenomena. The results demonstrate how lattice registry, Moiré superstructures, interfacial coupling, and local structural distortions strongly influence the electronic landscape of 2D systems, leading to spatial modulations of charge density, work function, and local density of states. Local nano-contacts created by STM further reveal how mechanical deformation and layer decoupling can be used to tune charge injection and junction behavior at the nanoscale. By combining photoemission spectroscopy, polarization-dependent x-ray absorption, electron diffraction, and first-principles calculations, our studies separate the roles of structural asymmetry and electronic orbital character in driving anisotropic electronic responses and how intrinsic properties can be controlled. Overall, these findings highlight the critical role of surfaces, interfaces, and local structural effects in shaping the electronic behavior of 2D materials, offering new pathways for their controlled manipulation in future nanoscale and quantum technologies.