Combining STM, AFM, and Magnetotransport Measurements for In-Operando Studies of Quantum Materials

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Abstract: Research in new quantum materials require multi-mode measurements spanning length scales and correlations of atomic scale variables with macroscopic functions. In this talk I describe the historical development of a multi-mode instrument achieving μeV tunneling resolution with *in-operando* measurement capabilities of scanning tunneling microscopy (STM), atomic force microscopy (AFM), and magnetotransport inside a dilution refrigerator operating at 10 mK. I illustrate the capabilities of this new instrument in the study of quantum Hall edge states in graphene devices. The edge states, a set of alternating compressible and incompressible strips, are formed at the electrostatic pn junction boundary geometrically defining the Hall bar. To comprehensively characterize these microscopic objects, we apply all capabilities of the new instrument using modalities of AFM, STM, and magnetotransport measurements at mK temperatures. The Kelvin probe force microscopy (KPFM) mode of AFM detects the chemical potential transitions when Landau levels are being filled or emptied as a function of back gate potential. With KPFM we can map the dispersion of the Landau levels across the quantum Hall edge boundary as a function of density and spatial position, including resolving the $\nu = \pm 1$ edge modes.

Bio: Joseph Stroscio is a NIST Fellow and Project Leader in the Physical Measurement Laboratory at the National Institute of Standards and Technology (NIST). He received a B.S. and an M.S. in Physics from the University of Rhode Island, and a M.S. and Ph.D. in Physics from Cornell University. Stroscio's passion in instrument design began during his graduate work in Professor Wilson Ho's group at Cornell University, where he performed innovative studies of surface phonon and plasmon excitations with low energy electron energy loss spectroscopy. Upon leaving Cornell, Stroscio worked as a postdoctoral researcher at the IBM T. J. Watson Research Center, where he pioneered the development of scanning tunneling microscopy (STM) and spectroscopy measurements in ultra-high vacuum (UVH) with Dr. Randal M. Feenstra in the mid-1980s. Stroscio performed some of the first UHV scanning tunneling spectroscopy measurements, which showed that the STM does not simply image atoms but measures the energy-resolved local density of electronic states.

After leaving IBM, Stroscio joined NIST in 1987 to lead the scanning tunneling microscopy effort in the Electron Physics Group at NIST. His current research focus is on low-dimensional electron systems in graphene and related 2D materials. Throughout his career Stroscio has had a passion for instrument design, creating some of the most advanced scanning probe microscopes. His latest creation includes a multimode instrument combining STM, AFM, and magnetotransport measurements at mK temperatures.

Stroscio is a Fellow of AAAS, APS, and AVS. He has received the Arthur S. Flemming Award, the Department of Commerce Silver and Gold Medal Awards, the Sigma Xi Young Scientist Award, the Nano50 Award, the AVS Nanotechnology Recognition Award, and the NIST Samuel Wesley Stratton Award. He is a recipient of the Presidential Rank Award, Heinrich Rohrer Grand Medal, and the Joseph F. Keithley Award.