

# Atomic-Scale Imaging of Interfacial Structure, Charge, and Phonon Dynamics

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How do atomic-scale structure, charge, and lattice dynamics collectively govern energy transport and functionality in materials, particularly at interfaces only a few atomic layers thick? A complete description of materials structure requires not only atomic arrangements, but also polarization, charge distribution, lattice dynamics, and interfacial configurations, each resolved at the relevant length scales. Resolving how these coupled degrees of freedom emerge and interact—especially at interfaces—remains a central challenge in modern materials science and applied physics.

In this talk, I will present recent advances in aberration-corrected scanning transmission electron microscopy (STEM) and electron energy-loss spectroscopy (EELS) that enable direct, quantitative measurements of structure, electrostatics, and dynamics with atomic resolution. These methods provide access to local electric fields, charge distributions, and polarization textures, and enable direct observation of domain-wall dynamics in ferroic materials. I will further introduce spatially and momentum-resolved vibrational EELS as a platform for probing phonon excitations with simultaneous real-space and momentum-space resolution. This approach reveals the evolution of phonon modes at defects and heterogeneities, their spatial localization, and their role in heat transport, particularly near interfaces. By integrating these capabilities, we establish a unified experimental framework for quantifying coupled structure–charge–dynamics relationships across length scales. More broadly, these advances move materials characterization beyond static structural descriptions toward a quantitative, multidimensional framework that directly links structure, charge, and lattice dynamics to function.



**Bio:** Xiaoqing Pan is the Henry Samueli Endowed Chair in Engineering at the University of California, Irvine, with joint appointments in Materials Science and Engineering and Physics and Astronomy. He is the founding director of the UC Irvine Materials Research Institute and the Center for Complex and Active Materials, an NSF Materials Research Science and Engineering Center (MRSEC). Pan is internationally recognized for pioneering advances in transmission electron microscopy (TEM) and spectroscopy that enable quantitative, atomic-scale imaging of structure, charge, and lattice dynamics in materials. His work has established new experimental methodologies for directly probing fundamental physical quantities, including electric fields, charge density, and phonon excitations,

with unprecedented spatial resolution. His research has led to major advances in understanding interfacial phenomena, ferroic materials, quantum materials, and complex alloys. He is a recipient of the NSF CAREER Award and the National Science Foundation of China Outstanding Young Investigator Award, and a Fellow of the American Physical Society, Materials Research Society, Microscopy Society of America, and American Ceramic Society. He has authored over 500 peer-reviewed publications in leading scientific journals.