**Advances in electron microscopy for atomic-scale insights to engineer functional oxide thin films**

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Many functional oxide materials can be sensitively tuned by careful control of the atomic lattice structure via epitaxial strain: macroscopic properties exhibit exquisite dependence on local parameters such as bond lengths, angles, and distortions. With recent and ongoing advances to improve spatial resolution and access various *in situ* conditions such as variable temperatures or electrical bias, scanning transmission electron microscopy (STEM) is a powerful tool to directly visualize and quantify relevant structure parameters with local sensitivity to inform future engineering of functional oxide films.

The layered Ruddlesden-Popper oxide Ca2RuO4, for example, exhibits a first-order isosymmetric insulator-to-metal transition (IMT) at elevated temperatures. Strain engineering through careful choice of substrate dramatically shift the transition temperature to either higher or lower temperatures, even suppressing it entirely in either direction (i.e., stabilizing purely metallic or insulating behaviour). At intermediate strains, mesoscopic structural analysis by x-ray phase reconstruction demonstrated the coexistence of metallic and insulating structural phases below the reduced IMT temperature[1]. Here, we employ variable-temperature cryo-STEM to track the nanoscale configuration and evolution of these divergent phases, spanning hundreds of nanometers with atomic resolution. Our results provide new insights about the relevant elastic and lattice energies and their competition in epitaxial films.

In some compounds, epitaxial strain can mimic the effects of other extreme conditions such as high pressure. Following its initial discovery under high hydrostatic pressure, the recent stabilization of superconductivity in compressively strained bilayer nickelate La3Ni2O7 thin films opened the door to exquisite investigation of atomic structure and bonding environments thought to drive superconductivity. Leveraging the highest accessible spatial resolution and light-element sensitivity enabled by state-of-the-art multislice electron ptychography, we survey a series of bilayer nickelate thin films spanning a full series of tensile and compressive strain, revealing a strain-dependent evolution of octahedral symmetry. We combine these experimental with strain-decomposed DFT calculations to investigate correlations between the observed atomic structure and superconductivity.[2]

1. Gorobtsov et al. *Advanced Materials* 36, 2403873 (2024).
2. Bhatt et al. *arXiv:2501.08204* (2025).