

## Defects and Strain Accommodation in Epitaxial $\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3/\text{La}_{0.7}\text{Sr}_{0.3}\text{CoO}_3$ Heterostructures

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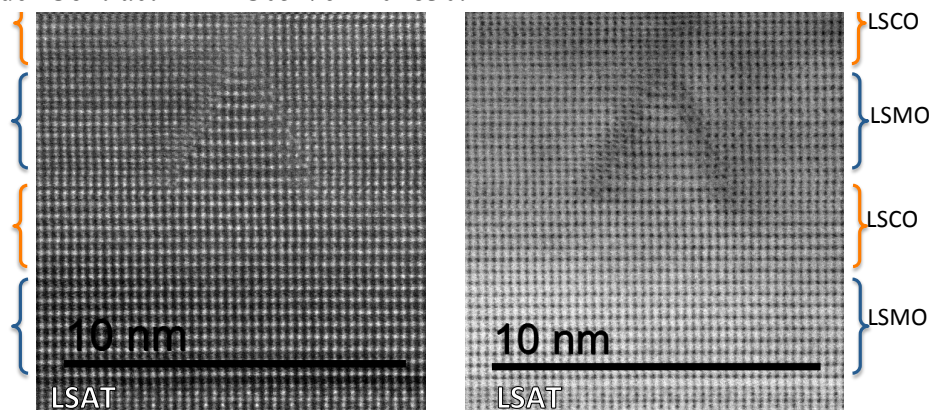
Transition metal perovskite ( $\text{ABO}_3$ ) oxides display a rich range of electrical, magnetic, and optical properties. Unexpected behavior that develops in heterostructures as a result of interface effects is of particular interest [1]. Magnetic and electrical properties in these materials develop via indirect interactions of B-cation electrons through a network of corner-sharing oxygen octahedra. These properties are extremely sensitive to both atomic shifts that cause changes in the B-O-B bond angle or length, and to modification of electronic character. Cation substitution, epitaxial misfit strain and coherence, or charge transfer, can be manipulated in heterostructures to bring about these atomic shifts or alteration of electronic character, in order to engineer materials with properties that match our specific needs.

Here we employ several complementary, state-of-the-art electron microscopy characterization techniques, including aberration corrected scanning transmission electron microscopy (Cs-corrected STEM) imaging, electron energy loss spectroscopy (EELS-SI), STEM energy dispersive x-ray spectroscopy (STEM-EDS), and position averaged convergent beam electron diffraction (PACBED) to examine  $\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3/\text{La}_{0.7}\text{Sr}_{0.3}\text{CoO}_3$  (LSMO/LSCO) superlattices (SL) and bilayers (BL) grown on  $\text{La}_{0.30}\text{Sr}_{0.70}\text{Al}_{0.65}\text{Ta}_{0.35}\text{O}_3$  (LSAT) substrates. These epitaxial specimens, created using pulsed laser deposition (PLD), demonstrated interesting properties driven by magnetic coupling between the two materials [2] [3]. The design of the heterostructures is based on the assumption that interfaces of epitaxial films are fully strained with little or no intermixing, and that films are free of defects. In reality, no film is perfect. Imperfections in the substrate, contamination, fluctuations in growth conditions, or growth beyond a material and strain-dependent critical thickness can all cause defects in films. Many of these defects cause the aforementioned changes in the critical B-O-B bond or in electronic character, and as such, will influence the magnetic and electric properties of the engineered heterostructures. The result could be enhanced, muted or unexpected properties. It is important to examine what is grown, after bulk characterization, in order to determine if these defects or strain accommodations affect the properties, and to measure the capacity of the material to contain imperfections and still perform as desired.

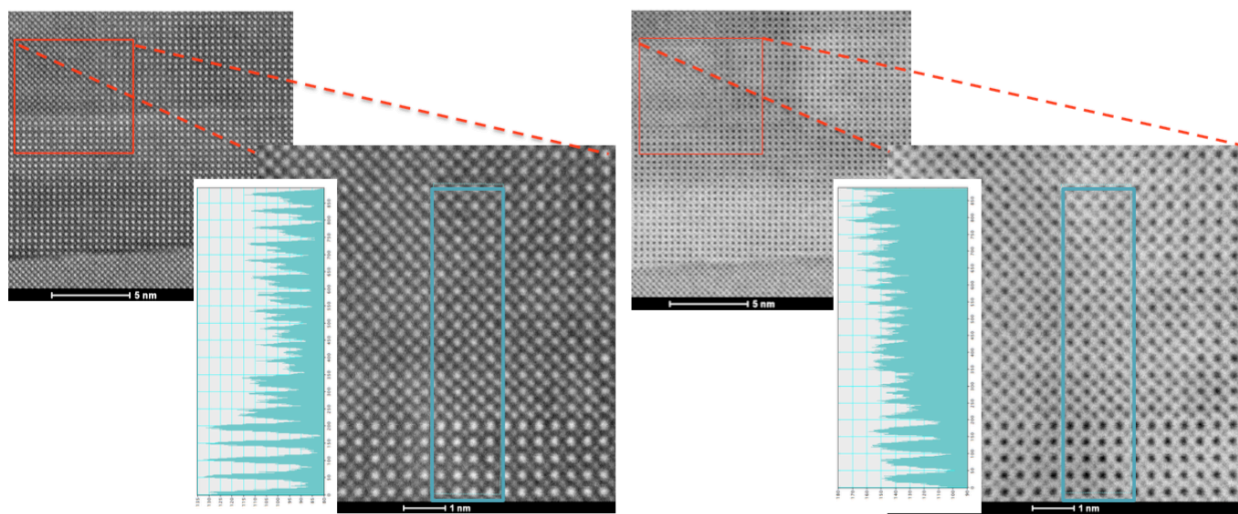
While the interfaces in the SLs are generally abrupt and coherent, we observe several defects in the heterostructures, including stacking faults, antiphase boundaries, strain inhomogeneity, and vacancies. Some defects appear to be limited to either a specific layer or interface, such as only LSMO (Figure 1) or only the substrate/film interface. The BLs also have abrupt and coherent interfaces. Significantly fewer large defects are observed in the layers; however, there are periodic areas along the substrate/film interface where strain is inhomogeneous. Some structural imperfections, such as ordered oxygen vacancies, so-called Brownmillerite structures, can be created by beam interactions with the sample, thus it is important to recognize and minimize these artifacts.

## References:

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- [2] Malik, V.K., et al., *Magnetic correlation between  $\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$  and  $\text{La}_{0.7}\text{Sr}_{0.3}\text{CoO}_3$  layers in artificial superlattices*. Journal of Applied Physics, 2013. **113**(15).
- [3] Li, B., et al., *Unconventional switching behavior in  $\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3/\text{La}_{0.7}\text{Sr}_{0.3}\text{CoO}_3$  exchange-spring bilayers*. Applied Physics Letters, 2014. **105**(20).
- [5] This work furthers research that was supported by the Swiss National Science Foundation Grant PBF2-134402 and the Defense Advanced Research Projects Agency Grant N66001-11-1-4135, and was supported in part by the National Science Foundation (NSF) Grant No. DMR 1411250 through the University of California at Davis, the Laboratory Directed Research and Development (LDRD) Program: Chemical Imaging Initiative at Pacific Northwest National Laboratory (PNNL), and the Environmental Molecular Sciences Laboratory (EMSL), a national scientific user facility sponsored by the DOE's Office of Biological and Environmental Research and located at PNNL. PNNL is a multiprogram national laboratory operated by Battelle for the DOE under Contract DE-AC05-76RL01830.



**Figure 1.** Stacking faults in a LSMO/LSCO SL, confined to the second LSMO layer. The first LSMO layer has phase contrast indicating a strain variation compared to following layers of LSMO



**Figure 2.** Area of antiphase boundaries in LSMO/LSCO SL where the substrate has a stepped surface