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Magnetic Interactions in Perovskite Oxide Superlattices

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Complex materials with multiple order parameters hold the promise to yield multiferroic systems with highly-tunable and stimulus-sensitive properties as required for sensing and information technology applications. In particular, the perovskite oxides (ABO_3) have garnered much attention due to the possibility of creating epitaxial superlattices composed of stacks of alternating sublayers, each with their own order parameter, formed with atomic-scale control, and designed to exploit interactions at and across interfaces.

In this work, we investigate thin films and superlattices composed of the antiferromagnetic (AFM) insulator $La_{0.7}Sr_{0.3}FeO_3$ (LSFO) and the ferromagnetic (FM) metal $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) using a combination of structural, magnetic, and electrical characterization techniques. These samples were grown by pulsed laser deposition equipped with a reflection high energy electron diffraction system to accurately monitor the growth process with unit cell accuracy. In particular, soft x-ray magnetic spectroscopy and photoemission electron microscopy (PEEM) provide chemically selective information on the electronic structure and the magnetic (FM and AFM) characteristics of each layer. We find that the diverging behavior of the FM and AFM order parameters with decreasing sublayer thickness and temperature results from the competition between the different magnetic interactions (exchange coupling, electronic reconstruction, and long-range interactions). For the LSMO sublayer, the Curie temperature and saturation magnetization decreases monotonically, while the resistivity increases with decreasing sublayer thickness such that no magnetism exists for a sublayer thickness below three unit cells. These results are in agreement with reports in the literature for single layers of LSMO. In contrast, the Néel temperature and the magnetic anisotropy of the LSFO sublayer decrease more slowly with decreasing sublayer thickness, such that even at three unit cell thickness, it remains in the AFM state. Furthermore, contrast analysis of PEEM images (Figure 1) with varying orientation of the x-ray polarization indicates that the presence of the high density of interfaces and the 2D nature of the superlattice structure confines the AFM spin axis to lie in-the-plane of the film, while it cants out-of-plane for a single layer LSFO film.

A delicate balance of the magnetic interactions exists for a superlattice with sublayer thicknesses of six unit cells each such that a robust 'spin-flop' exchange interaction is observed. [1] The exchange coupling between the LSFO and LSMO sublayers causes the AFM spin axis to re-orient upon the application of an in-plane magnetic field and to maintain a perpendicular alignment between the FM and AFM moments. A large increase in the coercive field and magnetoresistance for this superlattice are additional factors

affected by the exchange interaction. For decreasing LSMO sublayer thickness, the ferromagnetism is lost, while for increasing LSFO sublayer thickness, the magnetic anisotropy of the LSFO layer dominates. Understanding the competition between these interactions provides a promising means to separately control the FM and AFM order parameters in superlattice structures, independent of strain or chemical effects.

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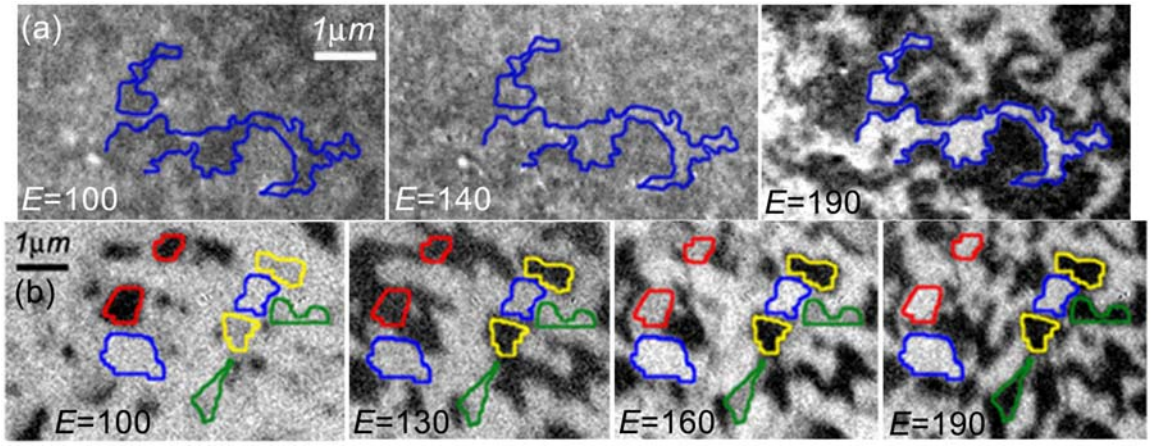

Figure 1: PEEM images of (a) superlattice and (b) 40-nm thick LSFO film as the x-ray polarization rotates from out-of-plane (E=100) to in-plane (E=190).