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**Author:** Kelly, Simon J.  
**Title:** Complex oxides studied by scanning tunneling microscopy/spectroscopy  
**Issue Date:** 2012-04-03
Summary

This thesis presents scanning tunneling microscopy (STM) and scanning tunneling spectroscopy (STS) measurements performed on the surface of thin-films of metallic manganites, cobaltite oxides, and on the ferromagnetic surface of ferromagnetic/superconducting (FS) bilayers. In all cases, the local electronic density of states (LDOS) of these samples is mapped from both numerically differentiated current-versus-voltage curves and from conductance maps made using a lock-in amplifier. This could be done at different temperatures between about 330 and 1 Kelvin, and in magnetic field up to a few Tesla. The aim is to connect salient features in the LDOS to the physics of the systems under consideration. With STM/S the sample surface’s electronic properties can be mapped with nanometer or finer resolution, providing one of the advantages over other techniques such as planar-junction tunneling spectroscopy. Specifically, in the oxide systems there is the question whether electronic phase separation (a spatial separation of metallic and insulating areas in the sample) can be found and connected to the presence of the metal-insulator transition (in the manganites), or an intrinsically low-temperature inhomogeneous state (in the cobaltites). A related question is whether and how the local electronic properties change under influence of an applied magnetic field. In the case of the FS bilayers, the issue is whether the signature of an inhomogeneous superconducting order parameter, which is known to be induced in the ferromagnet by the proximity of the superconductor, can be found.

Chapter 1 provides a general introduction to the thesis

Chapter 2 provides a brief description of the experimental equipment, and an introduction to STM and STS along with details of some salient features of the underlying technology. This includes a discussion of the issues of the coarse approach of tunneling tip to sample surface, and the amplification of the weak tunneling currents.

Chapter 3 presents STM/S measurements of thin-films of La$_{0.67}$Ca$_{0.33}$MnO$_3$ with the goal of exploring how film morphology and substrate-induced strain relate to electronic homogeneity. The results of these measurements can be divided into two groups based upon the film surface morphology alone: flat and rough surfaces. Flat films are characterized by atomically smooth terraces, with unit-cell step heights between terraces. Rough films are characterized as having no apparent terraces and no apparent unit-cell step heights. STS measurements indicate that flat films are electronically homogeneous while rough films are electronically inhomogeneous. Flat films were also electronically inactive, with tunneling spectra unaffected by changes in temperature or applied magnetic field. Rough films, on the other hand, responded to an applied magnetic field, displaying an overall increase in metallic areas with
increasing field, consistent with the percolation model of colossal magnetoresistance. Substrate-induced strain was shown to play no role in electronic homogeneity. It seems likely that films of this material with flat surfaces have undergone a change in electronic structure as compared to the bulk, driven by the change in symmetry.

Chapter 4 presents STM/S measurements on La$_{1-x}$Sr$_x$CoO$_3$ (LSCO) films with $x = 0.5$, for the purpose of exploring the relationship between film thickness and electronic homogeneity. These results show that film thickness drives the electronic homogeneity of cobaltite films. Evidence from the literature indicates that bulk LSCO with $x \leq 0.18$ is electronically inhomogeneous, while bulk LSCO with $x > 0.18$ is not. Published magnetoresistance and small angle neutron scattering measurements have demonstrated that thin film LSCO, even for $x = 0.5$, is inhomogeneous if thinner than a critical thickness ($t^*$) of about 8 nm. In this chapter STS measurements show that the film that we studied which was thinner than $t^*$ was electronically inhomogeneous, with metallic grains ranging from 5 to 30 nm that form clusters of up to 100 nm in size; while the film that was thicker than $t^*$ was homogeneous, with uniform electronic properties. As both films were rough, with no apparent atomically smooth terraces, this indicated that the surface morphology plays no role in the inhomogeneity. The STM data indicate that the metallic clusters detected on the electronically inhomogeneous film are magnetic since they are sensitive to an applied magnetic field. Overall, the data are consistent with a picture of the inhomogeneous film being composed of ferromagnetic clusters embedded in an insulating matrix, with some of those clusters being pinned and unresponsive to an applied field.

Chapter 5 presents STM/S measurements on a ferromagnetic/superconducting bilayer composed of a Nb film capped by a thin film of CuNi, a weak ferromagnetic alloy. These measurements were intended to probe the order parameter induced by the superconductor into the ferromagnet. This order parameter is expected to not only decay as a function of the distance from the FS interface (which is caused by the exchange energy of the ferromagnet) but also to oscillate; meaning that the quantum mechanical phase of the order parameter can switch from zero to $\pi$. The signature of this phase change is a change from a gapped quasiparticle DOS when the order parameter is positive (zero state) to an inverted DOS where the order parameter is negative ($\pi$ state). Measurements of a rough FS bilayer display a variety of tunneling spectra from deeply gapped to flat. Inverted spectra were occasionally measured but were not reproducible. The zero-bias maximum of these inverted spectra were too large and did not have a characteristic dip or kink at the gap energy as seen in planar junctions, making it questionable whether these inverted spectra were evidence of the $\pi$-phase. Model fits to gapped spectra are used to estimate the local F-layer thickness. Combined with the measured F-layer topography, the local F-layer thickness can be used to estimate the morphology of the underlying Nb layer. This calculated morphology was significantly rougher than typical Nb films grown under identical conditions. This suggests that other factors contribute to the measured variation in the spectra. A likely candidate is Ni-clustering. Such Ni-clusters would lead to variations in the exchange energy that could in turn produce the spectra variations seen in these measurements.