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Atomic-scale characterization of the oxygen vacancy ordering in $La_{0.5}Sr_{0.5}CoO_3$ thin film grown on $SrTiO_3$ using in-situ cooling experiments

Xue Rui[1], Jeff Walter[2], Chris Leighton[2], Robert Klie[1]
[1.] Department of Physics, University of Illinois at Chicago, Chicago, IL, USA
[2.] Department of Chemical Engineering and Materials Science, University of Minnesota, Minneapolis, MI, USA

In recent years, epitaxial $La_{0.5}Sr_{0.5}CoO_3$ (LSCO) thin films have attracted increasing interest due to their intriguing electronic and magnetic properties, such as spin state crossovers [1] and magnetic phase separation [2], as the result of oxygen vacancy ordering. Previous study using high-resolution X-ray diffraction and geometrical phase analysis on LSCO thin films have demonstrated the interplay between the oxygen vacancy ordering and strain state from lattice accommodation between film and substrate [3]. Furthermore, epitaxial strained $LaCoO_3$ thin films are shown to exhibit ferromagnetic ordering at around 85 K, which is absent in bulk sample [4]. Here, we study the low temperature properties of LSCO thin film grown on $SrTiO_3$ (STO). In addition to the magnetic phase transition of LSCO at low temperature, STO undergoes the crystal phase transition at 105 K from cubic phase to tetragonal phase due to the rotation of TiO_6 octahedron [5]. The interaction between the magnetic ordering and the TiO_6 rotation will be examined.

Here, we utilize the aberration-corrected JEOL ARM200CF to acquire atomic-resolution high-angle annular dark field (HAADF) images combined with electron energy loss spectroscopy (EELS) analysis and in-situ cooling experiments operated at 200kV. The 11 nm thin LSCO samples were grown on STO (001) substrate using molecular-beam epitaxial synthesis. In-situ cooling experiments are conducted using Gatan 636 double tilt Liquid Nitrogen cooling holder.

To study the structure change as the function of temperature, HAADF images are acquired at room temperature (300 K) and low temperature (85 K), as shown in Figure 1. Each images at 300 K is recorded at the speed of 7 µs/pixel, while at 85K is averaged of five sequential recorded images with 2 µs/pixel. Different from previous characterization of LSCO thin film, we observed contrast variations in the form of stripes, both horizontal and vertical to interface, in the LSCO films at 300 K. These stripes are still visible at the lower temperature measurements. Direct quantification of the interatomic distances shows that the lattice spacing in dark layers (a_d) is different from that in the bright layers (a_b), a_b= 3.60 ±0.17 Å/a_d= 4.25 ±0.22 Å at 300 K while a_b= 3.70 ±0.30 Å/a_d= 4.00 ±0.20 Å at 85 K. EELS analysis is performed at different temperature, which is shown in Figure 2. The chemical shift and intensity variation of the O *K*-edge pre-peak, as well as the change in the Co L_3/L_2 ratio between 85 K and 300 K reflects the modification in spin state and oxidation state of Co. In my presentation, I will compare the atomic and electronic structures of LSCO films grown on STO and $LaAlO_3$ substrates to explore the effect of STO distortion on the magnetic properties of the LSCO film. [6]

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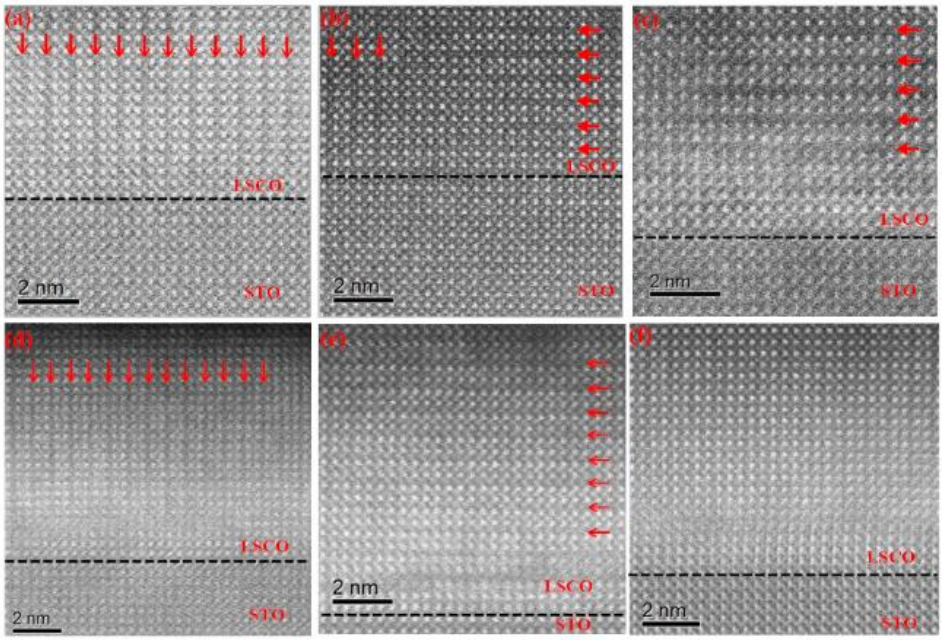

Figure 1. Representative atomic resolution HAADF images near the LSCO/STO (001) interface at 300K (top panel) and 85K (bottom panel). The red arrows mark the dark stripes on the film.

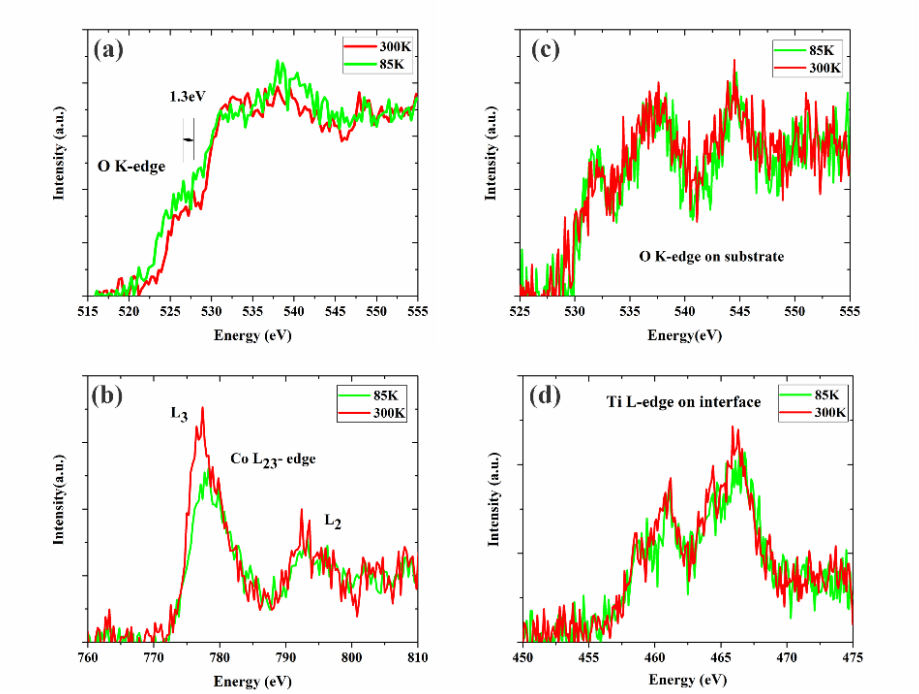

Figure 2. (a) O K-edge spectra shows the shift and higher intensity between 85 K and 300 K. (b) Co L-edge spectra shows the higher L_3 peak at 300K. (c) O K-edge spectra on STO shows the same fine structure and intensity between 85 K and 300 K. (d) Ti L- edge spectra on interface shows the higher intensity on 300K.

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