Superconductivity in over-doped cuprates induced by ferroelectric polarization

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The structure-property relationships in oxide films have traditionally been focused on their "bulk" phenomena. Recently, several studies have determined that the interfacial properties contain a wide breadth of new physics and chemistry on a length scale not observable in the bulk of the film. Several examples of these phenomena include the discovery of 2-dimensional electron gas behavior at the $LaAlO_3/SrTiO_3$ interface, superconductivity existing between two non-superconducting cuprates, and electric field control of spin polarization between ferroelectric and ferromagnetic layers.[1–3] In many applications such as non-volatile memory, ferroelectric tunnel junctions or GMR heterostructures, this interfacial behavior is the key to developing novel materials and devices with greatly improved performance.

Previously, our group has explored the ferroelectric field effect in $PbZr_{0.2}Ti_{0.8}O_3$ (PZT)/$La_{1-x}Sr_xMnO_3$ (LSMO) heterostructures as a means to control the hole concentration in the ultrathin LSMO layer (5 nm) by switching the ferroelectric polarization.[4,5] Confirmation of this phenomenon was revealed by a drastic modification of the electronic and magnetic ground states depending upon the direction of the polarization. A large enhancement in the Curie temperature and decreased resistivity, indicative of hole accumulation at the interface, were clearly observed. Thus, it is clear that the ferroelectric control of various physical order parameters is a viable approach.

Here, we show another example of the ferroelectric field effect control of electronic ground states in $La_{2-x}Sr_xCuO_4$ (LSCO). LSCO exhibits a complex phase diagram which includes metallic and insulating regions separated by a superconducting dome with a maximum critical temperature, T_c, of 40 K at $x = 0.15$ as shown in Figure 1.[6] The wide range of the physical properties offered in LSCO is the result of increased hole-doping with substitution of lower valent Sr^{2+} for La^{3+}. It is well known that the origin of the superconductivity in LSCO relates to the CuO_2 plane; thus the amount of charge carriers within the CuO_2 plane is an important control parameter for observing superconductivity. We believe that such behavior can be influenced by electrostatic doping, similar to that of LSMO due to the short length scale. Additionally, previous studies on the YBCO-$BiFeO_3$ interface has demonstrated that electrostatic control of the superconducting, critical temperature is possible.[7]

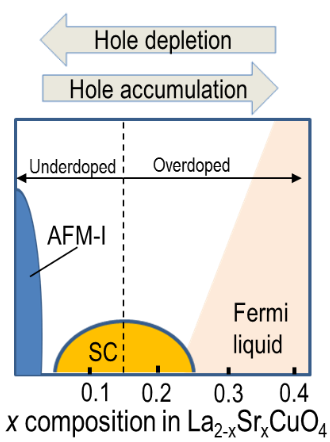

Figure 1. Phase diagram of $La_{2-x}Sr_xCuO_4$ illustrating wide-range of properties with hole-doping.

In this presentation, we report recent results on the electronic behavior of pulsed laser deposited $La_{1.6}Sr_{0.4}CuO_4$ epitaxial films capped with a highly polar ferroelectric PZT layer. We have determined from *dc* transport measurements that the over-doped cuprates, which are nominally non-superconducting, can become superconductors by effective hole depletion via the ferroelectric field effect as demonstrated in Figure 2. A downward polarization of the PZT layer was confirmed by piezoresponse force microscopy, which corresponds to hole depletion at the interface. We provide further evidence of the hole depletion by studying the O K-edge prepeak region from X-ray absorption spectra of $La_{1.6}Sr_{0.4}CuO_4$ films with and without a PZT overlayer. Through the various characterization techniques, we show that the field effect can take advantage of the cuprate's inherent sensitivity to hole doping. Therefore, it is possible to create superconducting "switches" by the formation of a charge accumulation or depletion layer at the interface between LSCO and PZT. These results strongly suggest that electrostatic control of the interfacial state has the ability to mimic the effect of chemical substitution in the LSCO phase diagram and turn on superconductivity in conventionally non-superconducting $La_{1.6}Sr_{0.4}CuO_4$.

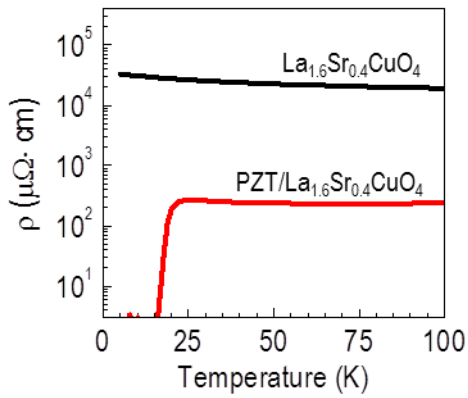

Figure 2: Resistivity of PZT-capped and as-grown 20 nm thick over-doped $La_{1.6}Sr_{0.4}CuO_4$ on $LaAlO_3$-001.

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