Engineering Interfaces in Cuprate Superconductors

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Abstract

Using an advanced molecular beam epitaxy system for atomic-layer engineering of complex oxides we have fabricated a variety of superlattices with stacked layers of $La_{2-x}Sr_xCuO_4$ doped to different levels. In superlattices formed by stacking highly overdoped, metallic $La_{1.5}Sr_{0.5}CuO_4$ and insulating La_2CuO_4 layers we have observed superconductivity at temperature as high as 30 K, even though neither of the building blocks was superconducting. Different possible mechanisms of this superconductivity are discussed.

Keywords: High Temperature Superconductivity, Molecular Beam Epitaxy, arificial superlattices;

1. Introduction

High-temperature superconductors (HTS) are intrinsically multi-layered materials where metallic CuO_2 layers are stacked with other metal-oxide layers, so called "charge-reservoir blocks", that provide mobile holes to CuO_2 layers. It is tempting, although challenging experimentally, to try creating new HTS compounds by growing artificially multi-layered structures with different stacking layers. The technique we use is atomic layer-by-layer molecular beam epitaxy (ALL-MBE) [1]. It provides for precise stoichiometry and thickness control and enables material engineering at various levels – down to a single atomic layer.

In this study we report on epitaxial growth of atomically smooth $La_{2-x}Sr_xCuO_4$ (LSCO) films over a broad range of doping levels (x = 0 to 0.50), as well as a variety of artificial superlattices. The later include some that were built by alternating layers of highly overdoped, metallic but not superconducting $La_{1.5}Sr_{0.5}CuO_4$ and undoped, insulating La_2CuO_4 (LCO). In what follows, we refer to these as $[nxLSCO : mxLCO]_k$ superlattices, where *n* and *m* are the numbers of unit cells of LSCO and LCO layers, respectively, in one superlattice period, and *k* is

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the number of superlattice periods. We have observed superconductivity with the critical temperature $T_c \approx$ 30 K even in the finest, $[1xLSCO : 1xLCO]_k$ superlattices.

2. Experimental

Our ALL-MBE system has been described elsewhere [2]. We have studied hundreds of single-phase LSCO films doped to different levels. Reproducibility of the film quality and transport properties is excellent. Atomically smooth films without secondary phase precipitates are grown with yield close to 100%. The r.m.s. surface roughness as low as 2–3 Å is observed by atomic-force microscopy [3].

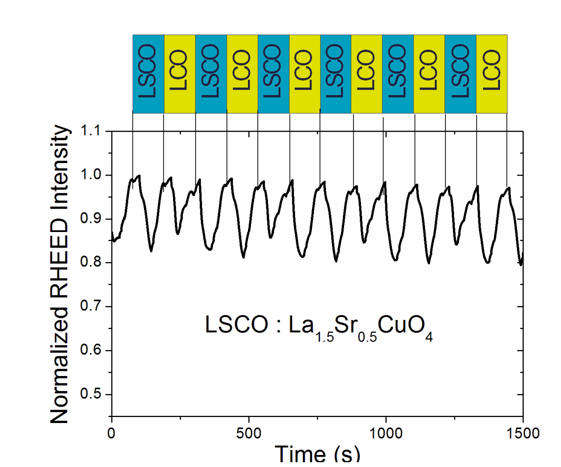

Fig. 1. RHEED Intensity oscillations during growth of 6 periods of $[1xLSCO : 1xLCO]_k$ superlattice.

We have grown $[nxLSCO : mxLCO]_k$ superlattices on $LaSrAlO_4$ substrates at 700° C and $8{\cdot}10^{-6}$ Torr ozone pressure. The typical RHEED intensity oscillations are shown in Fig. 1 for 6 periods of the [1xLSCO : 1xLCO] superlattice. After growth, the films were annealed in high vacuum at 200° C for half an hour to remove excess oxygen from the LCO layers. The resonant X-ray scattering (P. Abbamonte and S. Smadici, unpublished) shows that the interfaces between LSCO and LCO layers are sharp - there is no significant Sr diffusion from one layer to the other.

The resistance of single-phase LSCO and LCO films and $[nxLSCO : mxLCO]_k$ superlattices was measured using the standard four-point contact method. The typical temperature dependence of resistivity for (a) a highly overdoped LSCO films and (b) insulating undoped LCO film, are shown in Fig. 2; neither shows any sign of superconductivity down to 4 K. However, as it is seen in Fig 2(c), the $[1xLSCO : 1xLCO]_k$ superlattice is superconducting with $T_c \approx 30$ K.

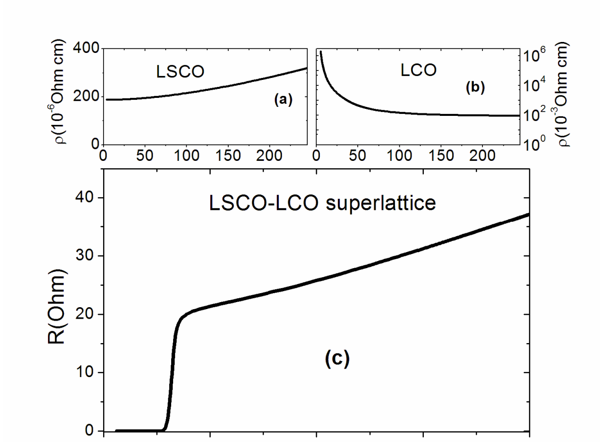

Fig. 2. Resistivity versus temperature for (a) overdoped LSCO film (x=0.5), (b) undoped LCO films, and (c) $[1xLSCO : 1xLCO]_{20}$ superlattice.

The most interesting open question here, and the subject of our ongoing research, is whether this superconducting transition is due to charge reconstruction (depletion and accumulation) at the interface due to the difference in electrochemical potential and band bending, to oxygen doping at the interface (perhaps enabled by these electrostatic interactions) or to Sr diffusion from overdoped layer to underdoped and formation of very thin nearly-optimally-doped layer.

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References

[1] I. Bozovic, J. Eckstein and G. Virshup, Physica C 235 (1994) 178.
[2] I. Bozovic, IEEE Trans. Appl. Superconduct. 11 (2001) 2686.
[3] I. Bozovic, G. Logvenov, et al., Phys. Rev. Lett. 89 (2002) 107001; Nature 422 (2003) 873; Phys. Rev. Lett. 93 (2004) 157002.

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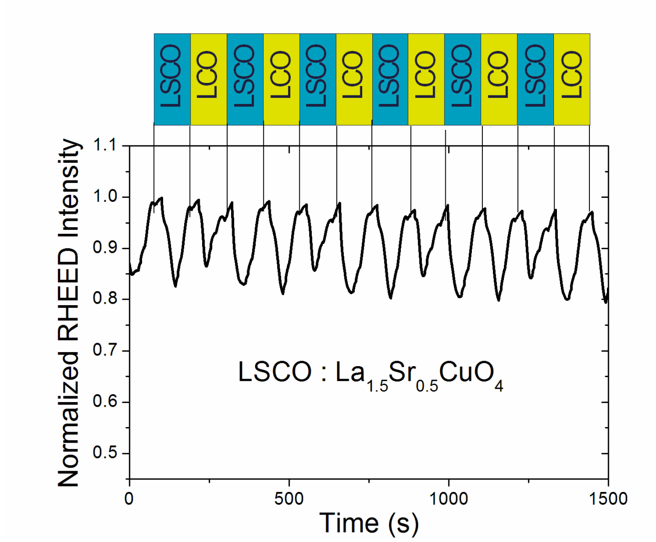

Fig. 2. Resistivity versus temperature for (a) over-doped LSCO film (x=0.5), (b) undoped LCO films, and (c) [1xLSCO : 1xLCO]$_{20}$ superlattice.