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Synthesis and Physics in $YBa_2Cu_3O_7/La_{0.7}Sr_{0.3}MnO_3$ Heterostructures

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In this paper, we first address the strain effects on the transport properties of $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) thin films, and then utilize them as underlayer to suppress the superconductivity of $YBa_2Cu_3O_7$ (YBCO) film to explore its normal state properties at low temperature. Furthermore, the influence of LSMO on the critical current Ic of YBCO is also investigated. Our results show that the value of Ic is significantly reduced by adding the underlayer LSMO, which implies that the binding energy of superconducting pairs weakens by the proximity of polarized electrons in LSMO.

Key words: LSMO, YBCO, CMR, strain, proximity
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1. INTRODUCTION

Two important features of La-Sr-Ca-Mn-O manganite are its colossal magnetoresistance (CMR) [1] and large spin polarization [2], making it very attractive to both academic and industrial societies. Some reports have already demonstrated the effect of spin injection in cuprate/manganite heterostructure [3,4] and emphasized the ultimate usefulness of them for spintronic devices. However, it is not trivial to conduct the spin-injection experiment if it involves the techniques of making junction and lithography. Especially it may also be associated with the injection of quasi-particle [5]. From the Physics point of view, there have been many interesting phenomenon to explore on the heterostractures of superconductor/ferromagnetic-metal since 1960 [6], including the proximity effect, Andreev reflection, spin accumulation and the pair-breaking effect, which were rarely discussed in high-temperature-superconductors/CMR-manganite heterostructures. In this work, we fabricated a series of heterostructures of $YBa_2Cu_3O_7$(YBCO)/$La_{0.7}Sr_{0.3}MnO_3$(LSMO) with different thickness of LSMO, to investigate the correlation between the ferromagnetism and superconductivity and to utilize LSMO as ferromagnetic underlayer to study the proximity effects. Our data first demonstrated the strain effect on the transport properties of LSMO films with respect to various thickness, then, showed a complete suppression of superconductivity in a 150nm-YBCO layer on the top of 50-nm LMSO layer. Further measurements of the critical current I_c indicated a significant reduction of Ic with increasing the thickness of underlayer LSMO.

2. EXPERIMENTS

A series of LSMO films with various thicknesses (t) were fabricated by rf magnetron sputtering under identical deposition conditions on $LaAlO_3$ (LAO) (100) substrate as described in Ref. 7. After deposition, the samples were post-annealed at 920 °C under flowing oxygen. Following, the YBCO layers of 150 nm were grown on the top of LSMO(t) layer with t varying from 10 to 50 nm. The heterostructures of YBCO/LSMO were further post annealed at 700 and 360 °C under flowing oxygen. The experimental set-ups and the measuring techniques of resistivity and I-V characteristics were described in Ref. 8.

2. RESULTS AND DISCUSSION

Figures 1 and 2 demonstrate the x-ray diffraction patterns of single LSMO and YBCO layers, respectively. Based on the X-ray data, our LSMO film has a monoclinic structure with the *c*-axis preferred orientation and its lattice parameters are given by a = 5.387, b = 5.425, and c = 8. 026 Å; while the YBCO film has an orthorhombic structure with a = 3.731, b = 3.876, and c = 12. 043 Å.

Figure 3 displays the temperature dependent resistivity $\rho(T)$ for LSMO films with t = 20 and 50 nm. Our LSMO films with t equivalent or smaller than 40 nm are all insulators with a similar $\rho(T)$-curve as that of t = 20 nm. As seen in Fig.3, the 20 nm film behaves insulating with an upturn at low temperature, while 50 nm film first shows insulating feature that ρ increases with decreasing temperature, then, transits to metal at 360 K. The insulating behaviour for thin LSMO layer could be explained by the strain-induced localization [7]. However, compared with our early results in Ref. 7, the present LSMO films release their strain at a thinner thickness, which should be due to the reduction of oxygen disorder in our present films. The only difference in the synthesis condition between two works is the rate of oxygen flow. The rate used in present work is two times less than the previous one, which is 50 cc/min. Based on the fact that the electrons (holes) of LSMO could be localized in very thin layers due to the strain effect at the interface, the suppression of superconductivity becomes effective only when the strain of LSMO layer was released. This argument is consistent with our later observation that the YBCO turns to insulator at t = 50 nm.

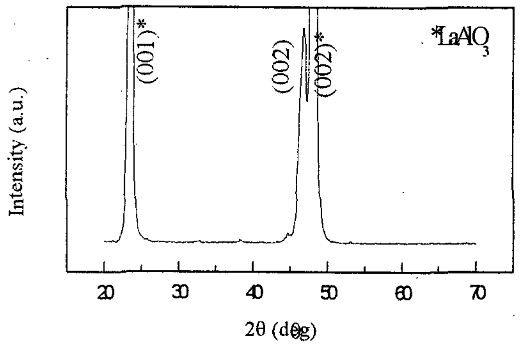

Fig. 1 The x-ray diffraction pattern for LSMO layer.

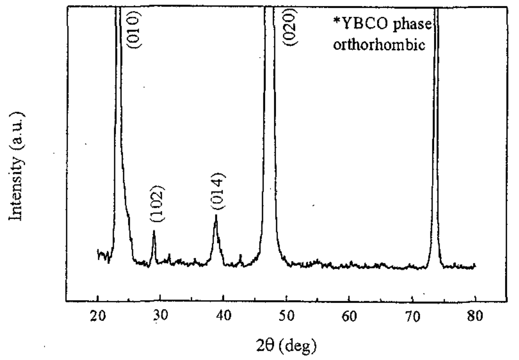

Fig. 2 The x-ray diffraction pattern for YBCO layer.

Figure 4 is the voltage-current (V-I) characteristics of YBCO/LSMO heterostructure with t = 0 to 40 nm at 1.9 K. At t = 50 nm, V-I curve could not be obtained because the sample turns to insulator and its resistivity at 1.9 K becomes too high to be measured. The V-I curves in Fig. 4 show the typical characteristic of superconducting weak links with two superconducting layers separated by a very thin insulating layer. The critical current Ic of superconductor is generally taken to be the value of current at which V = 1 micro-volt. Therefore, Ic equals the half-width of the plateau of V-I curves over which V < 1 micro-volt.

As indicated in Fig. 4, the width of plateau reduces with adding the LSMO layer, suggesting that Ic is significantly suppressed by the presence of LSMO, which is most probably caused by the modification of the energy gap in YBCO film. In principle, the energy gap is proportional to the critical current. Since the energy gap is the minimum binding energy of superconducting pairs, the reduction of Ic implies that the binding energy of these pairs were weaken by the polarized electrons of LSMO. This phenomenon is very similar to that of gapless superconductivity [9], in which the Bose condensate of the Cooper pairs does not contain all the pairs due to the pair breaking effect of magnetic impurity. Another possibility for the decreasing of Ic maybe the degrading of the crystallinity of YBCO overlayer, which requires our further investigation.

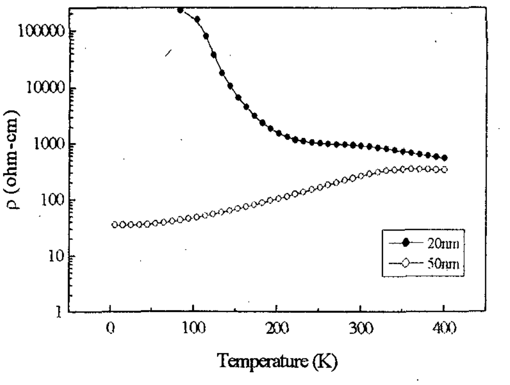

Fig. 3 Resistivity vs. temperature for LSMO with various t. Solid circles represent the data for t = 20 and open circles denote the data for t = 50 nm.

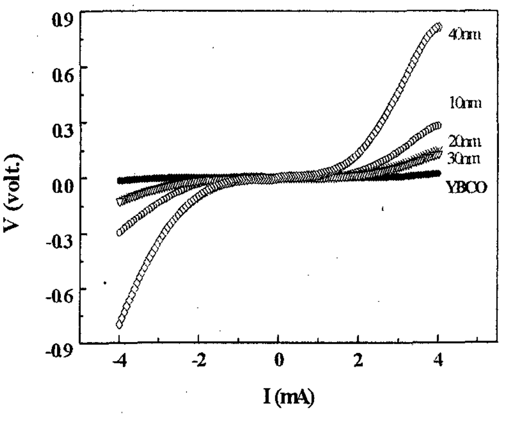

Fig. 4. V-I curves for YBCO/LSMO(t) with various t.

4. CONCLUSION

We first study the thickness dependent resistivity of LSMO thin films to determine the critical thickness for the strain releasing, and then utilize them as the ferromagnetic underlayer to suppress the bulk superconductivity of $YBa_2Cu_3O_7$. Our results reflect a possibility that the superconducting binding energy of the Cooper pairs in

YBCO becomes weakening gradually by the proximity effect of spin-polarized electrons of LSMO.

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