Proximity effect of superconductivity and magnetism in the $Nd_{0.7}Ca_{0.3}MnO_3/YBa_2Cu_3O_7$ bilayer

J. G. Lin[a)]
Center for Condensed Matter Sciences, National Taiwan University, Taipei, 106 Taiwan, Republic of China and Center for Nanostorage Research, National Taiwan University, Taipei, 106 Taiwan, Republic of China

Daniel Hsu
Center for Condensed Matter Sciences, National Taiwan University, Taipei, 106 Taiwan, Republic of China; Center for Nanostorage Research, and Department of Mechanical Engineering, National Taiwan University, Taipei, 106 Taiwan, Republic of China

W. F. Wu
Department of Mechanical Engineering, National Taiwan University, Taipei, 106 Taiwan, Republic of China

C. H. Chiang and W. C. Chan
Department of Physics, Tamkang University, Tamsui, Taipei, 251 Taiwan, Republic of China

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Temperature and current dependent resistivity are investigated in the single $YBa_2Cu_3O_7$ layer and the $YBa_2Cu_3O_7/Nd_{0.7}Ca_{0.3}MnO_3$ (YBCO/NCMO) bilayer with the thickness of each layer being 200 nm. Our results show that the onset temperature (T_{con}) of the superconducting transition in YBCO layer is linearly suppressed by current with a rate of 0.1 K/mA. However, T_{con} of the NCMO/YBCO bilayer is reduced effectively from 54 to 30 K with increasing the applied current from 1 to 40 mA, which indicates an enhanced effect of pair breaking by the polarized quasiparticles. © *2007 American Institute of Physics*. [DOI: 10.1063/1.2710325]

I. INTRODUCTION

The subject of superconducting systems incorporated with polarized spins has attracted considerable attention due to its importance from both academic and application viewpoints.[1–3] In particular, the diffusion of spin-polarized carriers from a manganite to a high temperature superconductor[4–6] and the proximity effects of these two compounds[7–12] are under extensive study. For example, Holden *et al.*[10] studied a proximity-induced metal-insulator transition in $YBa_2Cu_3O_7/La_{0.7}Ca_{0.3}MnO_3$ superlattices accompanied by a suppression of the free-carrier density. This transition was attributed either to a long-range charge transfer from $YBa_2Cu_3O_7$ to $La_{0.7}Ca_{0.3}MnO_3$ or alternatively to a strong coupling of the charge carriers to the different and competitive kinds of magnetic correlations. Recently, the experimental result of neutron reflectivity indicated some kind of magnetic proximity in multilayer $YBa_2Cu_3O_7/La_{0.7}Ca_{0.3}MnO_3$.[12] The feature of this proximity is suggested to be either an antimagnetic phase within $YBa_2Cu_3O_7$ or a magnetic dead layer in $La_{0.7}Ca_{0.3}MnO_3$. Most probably, the induced magnetic layer within $YBa_2Cu_3O_7$ may be a region where the superconducting pairs are broken by the exchange field. However, it is still not clear whether this magnetic layer is intrinsically determined or can be controlled by selecting different ferromagnetic materials. According to literature, a controllable way of breaking the superconducting pairs might be the injection of polarized spins into $YBa_2Cu_3O_7$.[5,7] However, many spin-injection experiments suffered from inadequate control of samples.[13] In this work, we fabricate the bilayer system $Nd_{0.7}Ca_{0.3}MnO_3/YBa_2Cu_3O_7$ and use the electrical current flowing from $Nd_{0.7}Ca_{0.3}MnO_3$ to $YBa_2Cu_3O_7$ to modulate the density of polarized quasiparticles within $YBa_2Cu_3O_7$. In order to distinguish the effect of polarized quasiparticles from that of ordinary quasiparticles, a parallel study on a pure YBCO is also conducted.

II. EXPERIMENT

Individual layers of $Nd_{0.7}Ca_{0.3}MnO_3$ (NCMO) and $YBa_2Cu_3O_7$ (YBCO) were first deposited separately on $LaAlO_3$ (LAO) single crystal substrate by a commercial pulsed laser deposition system (Neocera Pioneer 180) with a KrF (248 nm) laser. Both the YBCO and NCMO layers were epitaxially grown on the LAO substrate at the temperatures of 850 and 780 °C, respectively, in the flowing O_2 atmosphere of 50 mTorr. The same growth conditions were adopted to fabricate the bilayer system of NCMO/YBCO/LAO. In addition, the bilayer sample was postannealed at 400 °C for 60 min under an oxygen pressure of 300 Torr. Powder x-ray diffraction and scanning electron microscopy (SEM) were utilized to determine the phase purity and the thickness of the sample, respectively. The thickness of both YBCO and NCMO layers was 200 nm. On the top of NCMO, four Pt leads were attached to the surface using silver paint. The temperature and current dependent resistivity were measured in a close-cycle low temperature system.

a)Author to whom correspondence should be addressed; jglin@ntu.edu.tw

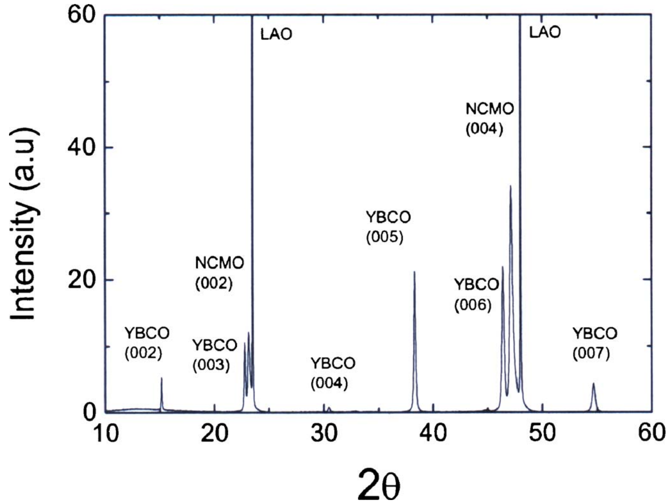

FIG. 1. XRD pattern for a NCMO/YBCO/LAO bilayer with all the peaks being identified as (001).

III. RESULTS AND DISCUSSION

Figure 1 shows the x-ray diffraction pattern of NCMO/YBCO/LAO. As one can see, only the (001) peaks are observed, indicating that both NCMO and YBCO layers have good crystalline structures with c axis perpendicular to the film surface. X-ray diffraction patterns for single NCMO and YBCO layers are also measured, and all the lines are identical with those observed in NCMO/YBCO bilayer.

The resistivity ρ vs temperature T for single NCMO and YBCO layers are plotted in Fig. 2, with the input current $I = 0.1$ mA. For YBCO, a metal-superconductor transition occurs at an onset temperature T_{con} around 87.9 K and its offset temperature is around 86.0 K. The onset of transition temperature is defined as the crossing point of an extended line from the steepest slope of transition and an extracted line of the normal state; the offset temperature is the crossing point of the extended line and x axis; both are indicated by the arrows in Fig. 2. The difference between T_{con} and T_{coff} is defined as the transition width ΔT_c, which is an indication of the homogeneity of oxygen distribution in the sample. The narrower, the more homogenous it is. ΔT_c is around 1.9 K in our single YBCO layer, which is a reasonable value for an YBCO thin film. In addition, the normal state is a linear function of T. For NCMO film, an insulatinglike behavior is

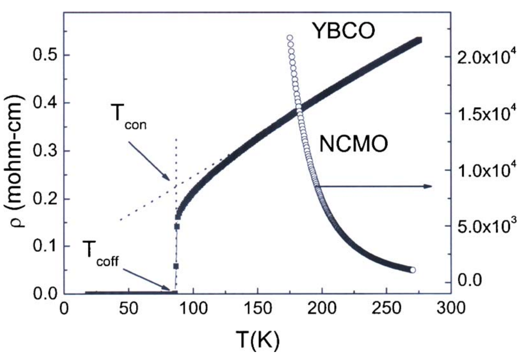

FIG. 2. Resistivity (ρ) vs temperature (T) for single YBCO layer and a single NCMO layer (with the right scale). The arrows indicate the positions of T_{con} and T_{coff}.

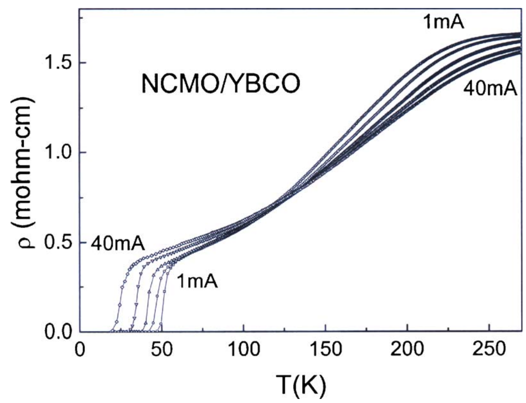

FIG. 3. ρ vs T for a NCMO/YBCO bilayer with various currents from 1, 10, 20, 30, to 40 mA.

observed within the measurable range. Figure 3 displays $\rho(T)$ curves for the NCMO/YBCO bilayers with $I=1$, 10, 20, 30 to 40 mA. With $I=0.1-1$ mA, the $\rho(T)$ behavior is not affected by current trough the whole measured temperature range, therefore it is not shown here. At $I=1$ mA, $d\rho/dT$ changes from negative to positive at around 200 K and becomes linear below 100 K. Then ρ drops with $T_{con}=54.2$ K and $T_{coff}=48.8$ K, and ΔT_c is around 6.4 K, suggesting that the degree of oxygen inhomogeneity is higher in the NCMO/YBCO bilayer sample. It is note worthy that the behavior of $\rho(T)$ in NCMO/YBCO is very different from that of pure YBCO and pure NCMO, implying that NCMO/YBCO has its unique electronic characteristic. With increasing current from 1 to 40 mA, the normal state resistivity decreases above 100 K, but increases below 100 K; both T_{con} and T_{coff} are reduced down to 28.9 and 21.9 K, respectively. The result of current dependent normal state in Fig. 3 suggests that the carrier concentration as well as the scattering centers increase with increasing current. Figure 4 is a plot of T_{con} and T_{coff} vs current for an YBCO single layer (the upper two curves) and a NCMO/YBCO bilayer (the lower two curves). It can be seen in Fig. 4 that the current-induced suppression of superconducting temperature in YBCO is linear with respect to the magnitude of current with a rate around 0.1 K/mA, while that in NCMO/YBCO is nonlinear and much larger (24 K by 40 mA) than that in YBCO. It is noted that the transition width ΔT_c in both pure YBCO and

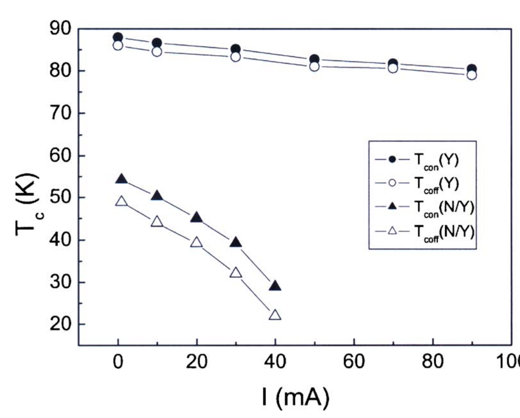

FIG. 4. T_{con} and T_{coff} vs current for an YBCO single layer (the upper two curves) and a NCMO/YBCO bilayer (the lower two curves).

NCMO/YBCO bilayer does not change with increasing current, indicating that the current has no significant effect on the oxygen distribution. For pure YBCO the current flows from Ag electrode to YBCO, thus, the current-generated quasiparticles in YBCO are ordinary quasiparticles. In principle, the mechanism of T_c suppresion by quasiparticles shall be a simple pair breaking due to the perturbation of superconducting order parameter.[13] On the other hand, when the current flows through NCMO to YBCO, quasiparticles are polarized. The polarized quasiparticles could prolong the recombination time of superconducting pairs, resulting in an enhancement of pair breaking. Therefore, with increasing current the suppression of T_c in NCMO/YBCO bilayer is much larger than that in pure YBCO. Furthermore, it is very likely that the proximity effect of NCMO on YBCO is different from that of $La_{0.7}Ca_{0.3}MnO_3$, which will be discussed in a separate paper.

IV. CONCLUSION

In conclusion, the temperature and current dependences of resistivity for an YBCO/NCMO bilayer are investigated and the results are compared with that of pure YBCO. The current-induced suppression of the superconducting transition temperature in NCMO/YBCO bilayer is much larger than that in YBCO single layer, suggesting a significant effect of pair breaking by the polarized quasiparticles.

ACKNOWLEDGMENTS

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