AIP Journal of Applied Physics

Thickness dependent spin-injection effects in Nd 0.7 Ca 0.3 Mn O 3 ∕ Y Ba 2 Cu 3 O 7 bilayers

Daniel Hsu, J. G. Lin, C. P. Chang, C. H. Chen, C. H. Chiang, W. C. Chan, and W. F. Wu

Citation: Journal of Applied Physics **103**, 07C710 (2008); doi: 10.1063/1.2833819
View online: http://dx.doi.org/10.1063/1.2833819
View Table of Contents: http://scitation.aip.org/content/aip/journal/jap/103/7?ver=pdfcov
Published by the AIP Publishing

Thickness dependent spin-injection effects in $Nd_{0.7}Ca_{0.3}MnO_3/YBa_2Cu_3O_7$ bilayers

Daniel Hsu,[1,2] J. G. Lin,[1,2,a)] C. P. Chang,[1] C. H. Chen,[1] C. H. Chiang,[3] W. C. Chan,[3] and W. F. Wu[4]
[1]*Center for Condensed Matter Sciences, National Taiwan University, Taipei 106, Taiwan, Republic of China*
[2]*Center for Nanostorage Research, National Taiwan University, Taipei 106, Taiwan, Republic of China*
[3]*Department of Physics, Tamkang University, Tamsui, Taipei 251, Taiwan, Republic of China*
[4]*Department of Mechanical Engineering, National Taiwan University, Taipei 106, Taiwan, Republic of China*

(Presented on 9 November 2007; received 10 September 2007; accepted 26 October 2007; published online 8 February 2008)

Two $Nd_{0.7}Ca_{0.3}MnO_3/YBa_2Cu_3O_7$ (NCMO/YBCO) bilayers with different thickness ratios are fabricated and the spin-injection effects are investigated. The NCMO/YBCO samples have thicknesses of 100 nm/200 nm and 200 nm/200 nm, which are denoted as N/Y(1) and N/Y(2), respectively. It is shown that the current-induced suppression rate of superconducting transition temperature (dT_c/dI) in YBCO is enhanced by four to six times of magnitude in N/Y(1) and N/Y(2) compared with that in pure YBCO. Furthermore, dT_c/dI in N/Y(2) is larger than that in N/Y(1), which suggests that the thickness of NCMO has influence on the pair breaking in YBCO.
 [DOI: 10.1063/1.2833819]

I. INTRODUCTION

The subject of superconducting systems incorporating polarized spins has attracted considerable attention in both the academic societies and intustries.[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[7–13] are under extensive study. The investigations of pair breaking in superconductors by injection/diffusion of spin-polarized quasiparticles from ferromagnetic materials have generated many interesting and important results.[10–14] One of them is the experimental work of neutron reflectivity in multilayer $YBa_2Cu_3O_7/La_{0.7}Ca_{0.3}MnO_3$.[13] The data of this experiment suggested that an induced magnetic layer within $YBa_2Cu_3O_7$ may be a region where the superconducting pairs are broken by the exchange field. Recently, our experimental results of current-dependent magnetic proximity in bilayer $Nd_{0.7}Ca_{0.3}MnO_3/YBa_2Cu_3O_7$ (NCMO/YBCO) (Refs. 12 and 15) further showed that the charge-ordered half metals $Nd_{0.7}Ca_{0.3}MnO_3$ could be effective spin injectors. Therefore, extended studies are carried out in this work to understand the influence of film thickness of NCMO on the efficiency of spin injector. We prepare two NCMO/YBCO bilayers with different thickness ratios of NCMO to YBCO, and the current-dependent resistivity is investigated. It is found that the influence of thickness of NCMO is not only on the superconducting transition temperature T_c of YBCO but also on the current-induced T_c-suppresion rate.

II. EXPERIMENT

The NCMO and YBCO single layers and NCMO/YBCO bilayers were deposited on $LaAlO_3$ (LAO) single crystal substrate by a commercial pulsed laser deposition system (Neocera Pioneer 180) with a KrF (248 nm) laser. The detailed synthesis conditions were described in Ref. 12. Scanning electron microscope and x-ray diffraction were utilized to determine the thickness of the sample and the phase purity, respectively. The samples of NCMO(100 nm)/YBCO(200 nm) and NCMO(200 nm)/YBCO(200 nm) are denoted as N/Y(1) and N/Y(2), respectively. The image of high resolution transmission electron microscope (TEM) was taken at the interface of NCMO/YBCO, along with a profile of energy dispersive spectroscopy (EDS) across the interface, to determine the distribution of chemical elements. On the top of NCMO, four Pt leads were attached to the surface with indium. Temperature dependent resistivity measurements with different applying currents were carried out with a standard four-probe configuration in a closed-cycle refrigerator system. Keithley 220 and 182 were used as the current source and the voltage meter, respectively.

III. RESULTS AND DISCUSSION

High resolution TEM image of N/Y(2) is shown in Fig. 1(a) (upper left panel). It shows that the interface is pretty sharp and the two layers are grown epitaxially. The high angle angular dark field (HAADF) image was taken at the interface of NCMO/YBCO by TEM, as shown in Fig. 1(b) (upper right panel). The solid line marks the range of line scan by EDS across the NCMO/YBCO interface. The data of element distribution along the scanning line are shown in Fig. 1(c), confirming that the chemical diffusion at the interface is insignificant.

Resistivity ρ versus temperature T for NCMO, YBCO, NY(1), and N/Y(2) 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} of around 87.9 K

[a)]Author to whom correspondence should be addressed. Electronic mail: jglin@ntu.edu.tw.

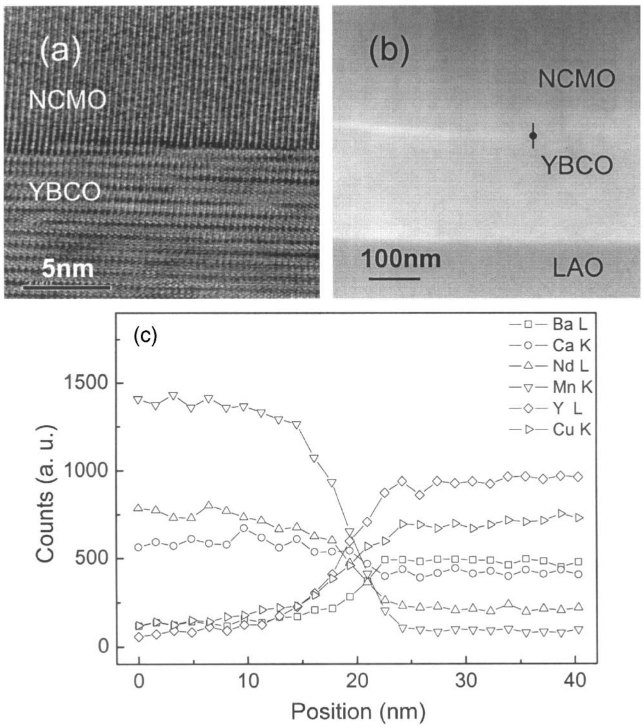

FIG. 1. (a) High resolution TEM image of N/Y(2) at the interface, (b) image of HAADF of NCMO/YBCO/LAO cross section, and (c) profile of EDS across the NCMO/YBCO interface. The vertical line indicates the path of scanning within 40 nm.

and its offset temperature is around 86.0 K. The onset of transition temperature T_{con} is defined as the crossing point of an extended line from the precipitous slope of transition and an extracted line of the normal state; the offset temperature T_{coff} is the crossing point of the extended line and x axis; both are indicated in the inset of 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 width is, 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/LAO thin film. For NCMO film, an insulatinglike behavior is observed within the measurable range. The behaviors of $\rho(T)$ in N/Y(1) and N/Y(2) are different from that of pure YBCO, and T_{con} is suppressed more with increasing thickness of NCMO.

Figure 3 displays $\rho(T)$ curves for N/Y(1) with $I = 1-60$ mA. For $I=0.1-1$ mA, the $\rho(T)$ behavior is not affected by current through the whole measured temperature range; therefore, it is not shown here. At $I=1$ mA, $d\rho/dT$ changes slightly at 200 K, which corresponds to the charge ordering in NCMO.[16] With increasing current from 1 to 60 mA, the normal state resistivity decreases above 200 K but increases below 200 K. T_{con}/T_{coff} reduces from 84.3 K/80.1 K down to 62.2 K/57.6 K with ΔT_c remaining at around 4 K. Figure 4 displays $\rho(T)$ curves for N/Y(2) with $I=1-40$ mA. At $I=1$ mA, $d\rho/dT$ changes from negative to positive at around 200 K and becomes linear below 100 K. T_{con}/T_{coff} becomes 54.2 K/48.8 K, and ΔT_c is around 6.4 K. With increasing current from 1 to 40 mA, the normal state resistivity decreases at above 120 K, but increases below 120 K. T_{con}/T_{coff} reduces down to 28.9 K/21.9 K. It is interesting to note that the crossing points of $\rho(T)$ curves are different in N/Y(1) and N/Y(2).

Figure 5 is a plot of T_{con}/T_{coff} versus current for YBCO single layer and NCMO/YBCO bilayers. It indicates that the

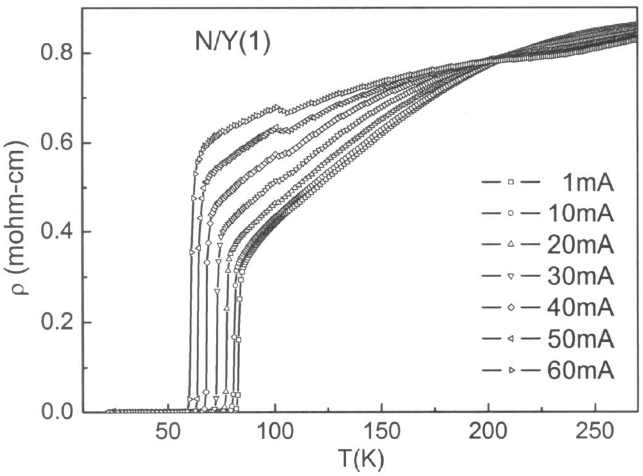

FIG. 3. ρ vs T for N/Y(1) with various currents from 1 to 60 mA.

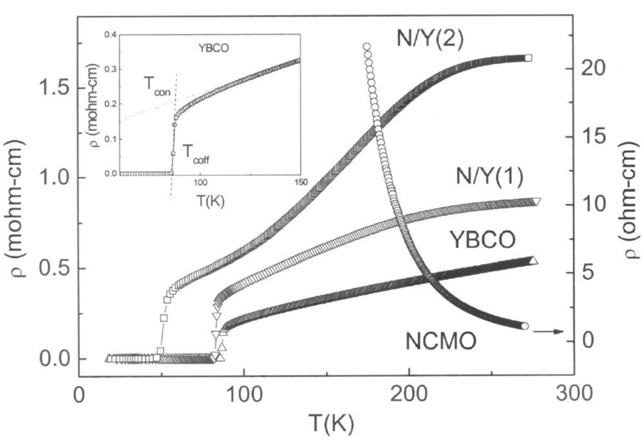

FIG. 2. Resistivity (ρ) vs temperature (T) for NCMO with the right scale and YBCO, N/Y(1), and N/Y(2) with left scale. The arrows indicate the positions of T_{con} and T_{coff} in the inset.

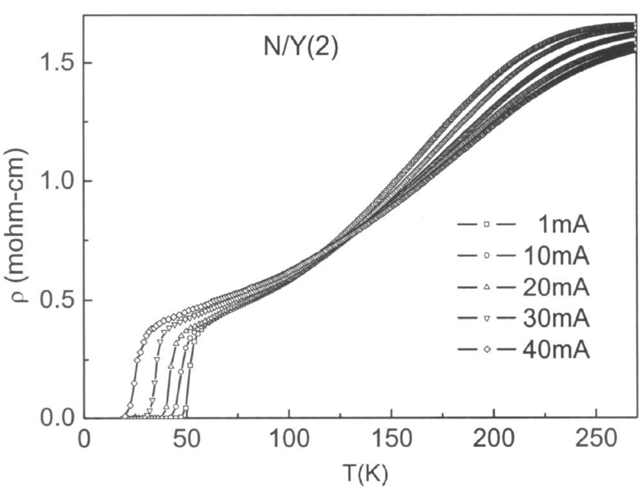

FIG. 4. ρ vs T for N/Y(2) with various currents from 1 to 40 mA.

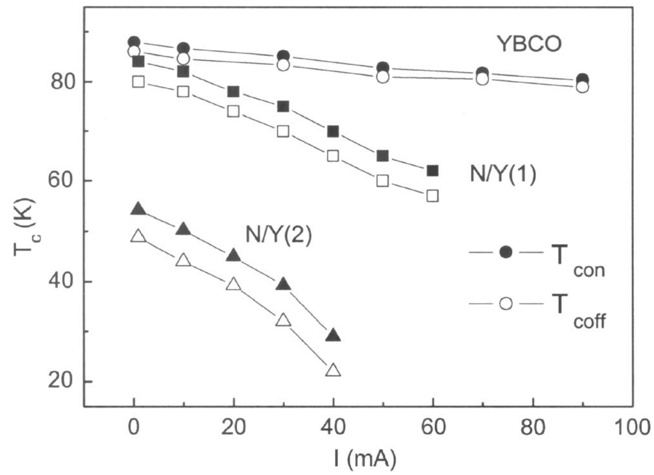

FIG. 5. T_{con} and T_{coff} vs current for YBCO, N/Y(1), and N/Y(2).

current-induced suppression rates of T_c (dT_c/dI) are around 0.1 K/mA in YBCO, 0.4 K/mA in N/Y(1), and 0.6 K/mA in N/Y(2). It is found that the T_c-suppressing rate in N/Y(2) is more severe than that in N/Y(1), suggesting that the efficiency of spin injection depends on the thickness of NCMO. In principle, when the current flows through ferromagnetic materials, quasiparticles are polarized and prolong the recombination time of superconducting pairs, resulting in an enhancement of pair breaking. Since the reduction of normal state resistivity is related to the current-induced melting of charge ordering state in NCMO, the large T_c suppression is attributed to the generation of spin-polarized quasiparticles via the ferromagnetic clusters. Therefore, the number of polarized quasiparticles should be proportional to the suppression rate of T_c. Namely, dT_c/dI should be the same for N/Y(1) and N/Y(2). However, the transport path for the superconducting pairs through NCMO is longer in N/Y(2) than that in N/Y(1), which adds another parameter to be considered.

IV. CONCLUSION

The current dependences of resistivity for YBCO/NCMO bilayers are investigated and the effect of NCMO thickness is observed. Our results show not only that the superconducting state of YBCO is affected by the thickness of NCMO layer but also that the current-induced T_c-suppression rates are higher in NCMO/YBCO with thicker NCMO layer. It implies that the efficiency of spin injection depends on not only the number of polarized quasiparticles but also the length of electrical path in NCMO.

ACKNOWLEDGMENTS

This work is supported by the Ministry of Economics Affair (No. 95-EC-17-A-08-S1-0006) and the National Science Counsel of R. O. C. (Nos. NSC-95-2120-M-002-0108 and NSC 95-2752-M-002-006-PAE).

[1] S. A. Wolf, D. D. Awschalom, R. A. Buhrman, J. M. Daughton, S. von Molnár, M. L. Roukes, A. Y. Chtchelkanova, and D. M. Treger, Science **294**, 1488 (2001).
[2] G. Sun, D. Y. Xing, and J. Dong, Phys. Rev. B **65**, 174508 (2002).
[3] T. Kontos, M. Aprili, J. Lesueur, and X. Grison, Phys. Rev. Lett. **86**, 304 (2001).
[4] V. A. Vas'ko, V. A. Larkin, P. A. Kraus, K. R. Nikolaev, D. E. Grupp, C. A. Nordman, and A. M. Goldman, Phys. Rev. Lett. **78**, 1134 (1997).
[5] N. C. Yeh, R. P. Vasque, C. C. Fu, A. V. Samoilov, Y. Li, and K. Valiki, Phys. Rev. B **60**, 10522 (1999).
[6] P. Mikheenko, M. S. Colclough, C. Severac, R. Chakalov, F. Welhoffer, and C. M. Muirhead, Appl. Phys. Lett. **78**, 356 (2001).
[7] J. Y. T. Wei, J. Supercond. **15**, 67 (2002).
[8] Z. Sefrioui, D. Arias, V. Pena, J. E. Villegas, M. Varela, P. Prieto, C. Leon, J. L. Martinez, and J. Santamaria, , Phys. Rev. B **67**, 214511 (2003).
[9] T. Holden, H.-U. Habermeier, G. Cristiani, A. Boris, A. Pimenov, J. Humlicek, O. I. Lebedev, G. V. Tendeloo, B. Keimer, and C. Bernhard, Phys. Rev. B **69**, 064505 (2004).
[10] S. Soltan, J. Albrecht, and H.-U. Habermeier, Phys. Rev. B **70**, 144517 (2004).
[11] J. G. Lin, S. L. Cheng, C. R. Chang, and D. Y. Xing, J. Appl. Phys. **97**, 113528 (2005).
[12] J. G. Lin, D. Hsu, W. F. Wu, C. H. Chiang, and W. C. Chan, J. Appl. Phys. **101**, 09G106 (2007).
[13] J. Stahn, J. Chakhalian, Ch. Niedermayer, J. Hoppler, T. Gutberlet, J. Voigt, F. Treubel, H.-U. Habermeier, G. Cristiani, B. Keimer, and C. Bernhard, Phys. Rev. B **71**, 140509(R) (2005).
[14] Y. Gim, A. W. Kleinsasser, and J. B. Barner, J. Appl. Phys. **90**, 4063 (2001).
[15] D. Hsu, J. G. Lin, C. P. Chang, C. H. Chen, W. F. Wu, C. H. Chiang, and W. C. Chan, Appl. Phys. Lett. **90**, 162504 (2007).
[16] D. Hsu, J. G. Lin, and W. F. Wu, Appl. Phys. Lett. **88**, 222507 (2006).