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Non-local spin injection effects in coplanar $La_{0.7}Sr_{0.3}MnO_3/Bi_2Sr_2CaCu_2O_8$/ $La_{0.7}Sr_{0.3}MnO_3$ tri-layer

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NON-LOCAL SPIN INJECTION EFFECTS IN COPLANAR $La_{0.7}Sr_{0.3}MnO_3/Bi_2Sr_2CaCu_2O_8/La_{0.7}Sr_{0.3}MnO_3$ TRI-LAYER

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Abstract. Non-local electrical properties of pulsed laser deposited $La_{0.7}Sr_{0.3}MnO_3/Bi_2Sr_2CaCu_2O_8/La_{0.7}Sr_{0.3}MnO_3$ (L-B-L) coplanar tri-layer is investigated under different wiring configurations. Long range super-current of Bi-2212 penetrating into LSMO is dependent on geometry of spin injection. From qualitative analysis of structural, magnetic and electrical data, long range super-current is suggested to pass through domain walls and/or grain boundaries of LSMO.

Keywords: Spin injection, half-metallic LSMO, superconducting Bi-2212, grain boundary, domain wall, pair breaking
PACS: 72.25.Hg, 72.25.Mk, 85.75.-d, 85.25.-j, 74.25.F-, 75.70.-i

INTRODUCTION

Spin polarized cooper pairs entering ferromagnet 'F' from a high transition temperature (T_C) superconductor 'S' are de-phased due to exchange field 'h_{ex}', exhibiting phenomena such as depression and/or oscillation of T_C [1], domain wall superconductivity, [2] etc. Few reports exist on 'S' and 'F' in coplanar geometry [3] deposited 'side by side' for studying 'spin injection' effect [1]. Coplanar geometry minimizes pin-holes and electrical shorts between the electrodes. Half-metallic $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) show excellent electrical and magnetic properties [4] with high Curie temperature, T_{Curie}=370 K. The $Bi_2Sr_2CaCu_2O_8$ (Bi-2212) compound (T_C=80 K) has been less explored for spin injection effects [1]. Here, we deposit and investigate the coplanar $La_{0.7}Sr_{0.3}MnO_3/Bi_2Sr_2CaCu_2O_8/La_{0.7}Sr_{0.3}MnO_3$ (L-B-L) film by varying the geometry of applied current.

DEPOSITION OF TRI-LAYER FILM

Thin films were pulsed laser deposited on LAO (100) substrate as in Ref. 5. The LSMO is grown first at 800 °C in 100 mtorr of oxygen (O_2) pressure after masking the middle part with 'Si' substrate, followed by insitu annealing at 400 °C/1h in 300 torr of O_2. The 'Si' mask is then removed and the LSMO regions are masked exposing uncoated region. The Bi-2212 is deposited at 750 °C in 150 mtorr of O_2. Deposition rate [6] is optimized such that Bi-2212 and LSMO are 80 nm and 75 nm thick respectively after final deposition (Inset of Fig. 1). The edges of L-B-L film are trimmed to eliminate the electrical shorts, and then annealed at 800 °C/2h in air to release strain and to attain optimal carrier concentration [6].

RESULTS AND DISCUSSION

The X-ray diffraction (XRD) peaks of L-B-L film (Fig. 1) is indexed to orthorhombic structure of Bi-2212 and LSMO [5, 6]. Bi-2212 is (00ℓ) textured, while LSMO is polycrystalline. Both LAO/Bi-2212 and LAO/LSMO interfaces have tensile stress [5]. Left bottom inset of Fig. 2 is the HR-SEM image of an L-B-L junction. The LSMO is smooth; while Bi-2212 has nano-sized outgrowths by strain relaxation [5].

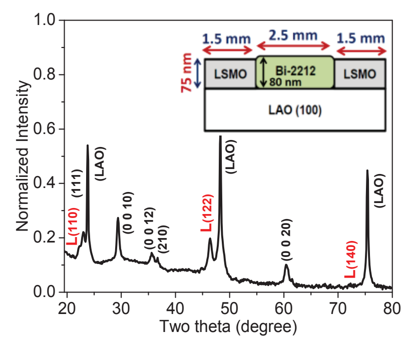

Fig. 1. The XRD patterns of L-B-L film, '*L*' are planes of LSMO layer. Inset is the schematics of coplanar geometry.

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The 'In-plane' M(H) curves measured in a SQUID magnetometer at 75 K and 10 K show coercivity (H_C) of 1000 Oe (Right bottom inset of Fig. 2) due to ferromagnetism of LSMO. The zero-field cooled temperature dependent magnetization ZFC-M(T) curve shows superimposed ferromagnetic and weak superconducting behavior (Top inset of Fig. 2). The T_{Curie} is clearly seen around 300 K. Below the metal insulator transition (T_{MI}) around 190 K, M(T) is negative signifying weak Meissner transition around 100 K due to transition onset (T_{con}) of Bi-2212.

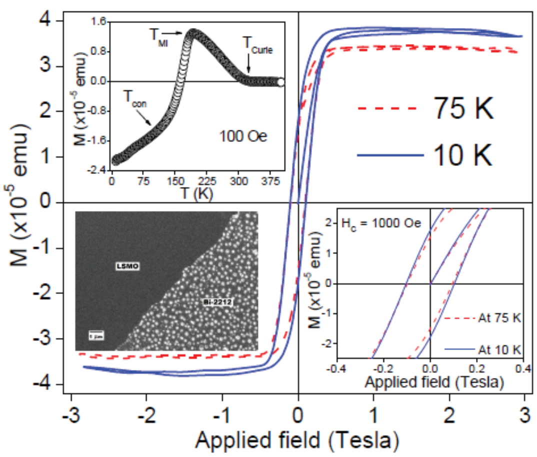

Fig. 2. The M(H) of L-B-L film at 75 K and at 10 K. Right bottom inset is the coercivity (H_C) loop, top inset is the M(T) and left bottom inset is the HR-SEM image.

Prior to non-local measurements, four probe temperature dependent resistance, R(T) of individual Bi-2212 and LSMO regions were measured to ensure superconducting and metallic behaviors respectively (Fig. 3). The T_{con} around 94 K with R(T) ≈ 50 Ω at 300 K and zero resistance state (T_{coff}) around 46 K are witnessed. Similarly, R(T) of LSMO has metallic behavior varying from ≈ 350 Ω to ≈ 25 Ω from 300 K to 30 K respectively (Fig. 3).

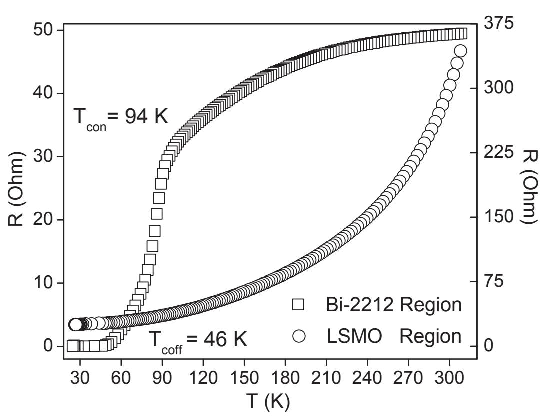

Fig. 3. The R(T) of individual Bi-2212 and LSMO regions.

The electrical measurements are 'non-local' [7] in the sense that 'V' is measured in a region where there is no drive current 'I' and sometimes 'I' is applied and 'V' is measured on different type of materials. Wiring configuration with 'I' and 'V' probes on LSMO regions across Bi-2212 in a parallel and diagonal geometry show insulating behavior with R(T) around $9x10^4$ Ω from 300 K to 30 K without superconducting drop (Fig. 4). This geometry has longest current path encompassing three layers and two junctions. Quasi particles injected into Bi-2212 undergo a competition of spin exchange interaction with the cooper pairs. Spin flip and scattering occurring at the junctions result in higher R(T) value with insulating behavior leading to ohmic current instead of super-current below 90 K. However, a hump observed around 89 K corresponds to T_{con} of Bi-2212 due to surviving cooper pairs in LSMO region.

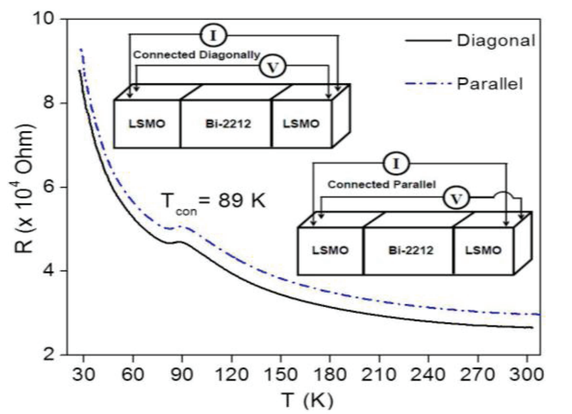

Fig. 4. The R(T) with 'I' and 'V' probes on two LSMO regions in diagonal and parallel configuration across Bi-2212. Wiring configurations are shown schematically.

In linear four probe geometry (Fig. 5), 'I' is on two LSMO regions and the spin polarized quasi particles injected from LSMO into Bi-2212 are measured by 'V' probes. Metallic behavior with T_{con} at 92 K and T_{coff} around 31 K is seen with R(T) value ≈ 193 Ω at 300 K. If 'I' is applied on Bi-2212 and 'V' is measured on LSMO (by interchanging 'I' and 'V' in Fig. 5), we observe a similar behavior except for T_{coff} reduced to 27 K and a marginal increase in R(T) at 300 K (Dotted line in Fig. 5). Here, cooper pairs from Bi-2212 may diffuse into LSMO.

To elucidate junction behavior, 'I' and 'V' probes with one end on LSMO and the other on Bi-2212 is adapted (Fig. 6A). The R(T) is a semiconducting behavior from 300 K to 91 K with value ≈ 12 Ω at 300 K. Below T_{con} (91 K), R(T) drops to zero at T_{coff} ≈ 39 K (Fig. 6A). In other mode, probes are fixed away from junction (Fig. 6B) with one of the 'V' leads on Bi-2212 positioned in-between the 'I' probes.

Surprisingly, semiconducting behavior vanish and a metallic behavior with R(T) ≈ 200 Ω at 300 K and T_{coff} ≈ 26 K is observed (Fig. 6B) due to longer current path. The different trend of Fig. 6 A and B implies that in vicinity of the junction, structural in-homogeneity and current non-uniformity are larger showing a semiconducting behavior [6, 8] which tend to decrease appreciably away from the junction.

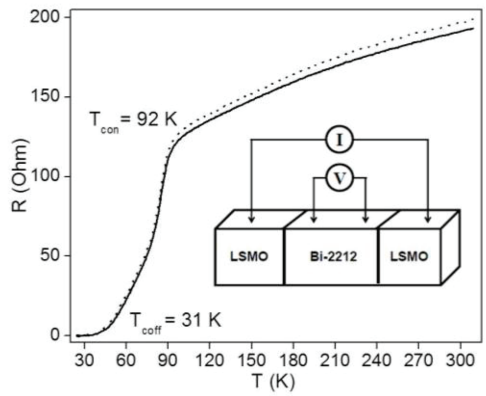

Fig. 5. Linear geometry R(T) with 'I' on LSMO and 'V' on Bi-2212. Dotted line is for 'I' on Bi-2212 and 'V' on LSMO.

The observed T_{con} of Bi-2212 in LSMO regions (Figs. 4 to 6) are evidence for percolating long range super-current. This is not due to pin-holes and electrical micro shorts unlike 'stacked' geometry since coplanar structure minimizes them. Polycrystalline nature of LSMO (Fig.1) in tri-layer may play a role in transport of cooper pairs along the grain boundaries.

From these data, following trends are deduced,

a) Spin polarized quasi particles injected into Bi-2212 are possibly converted into a measurable super-current after spin flipping and scattering mechanism.

b) Cooper pairs could appreciably percolate along domain wall region and/or along grain boundaries of LSMO constituting a measurable long range super-current despite presence of 'h_{ex}'.

CONCLUSION

Observation of T_{con} of Bi-2212 inside LSMO is a signature of long range diffusion of cooper pairs by virtue of in-homogeneity threading along the grain boundaries [9]. Local spin structure near the domain walls may provide pathways for cooper pairs in addition to grain boundaries. Numerous domains in LSMO may lead to domain-wall superconducting mechanism [2]. The domain-walls have relatively lower 'h_{ex}' than domain interior, thereby aiding cooper pairs to survive along the domain-walls constituting a measurable long range super-current inside LSMO.

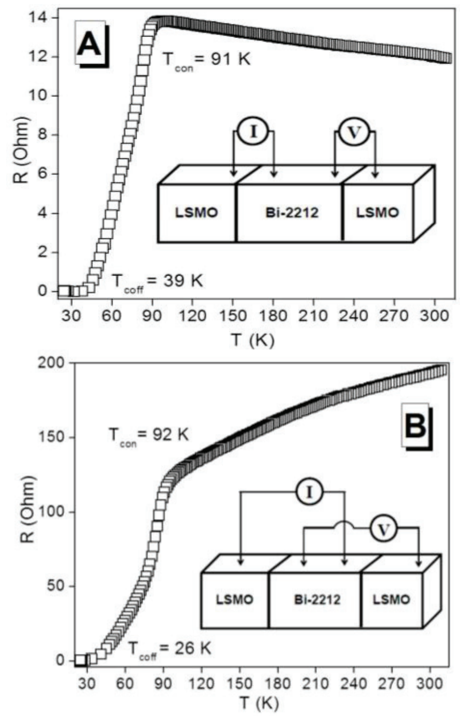

Fig. 6. 'I' and 'V' at two junctions (A); 'I' and 'V' across the junction with leads at middle of LSMO and Bi-2212 (B).

In conclusion, choice of wiring configuration unfolds interesting and intriguing features of non-local spin injection effects in coplanar L-B-L film providing opportunities for new type of experiments. Presently no 'model' or 'mechanism' exists for explaining all observed features. Further studies may elucidate the physics behind the novel long-ranged penetration of cooper pairs into LSMO.

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REFERENCES

1. V. Pena *et al*, *Phys. Rev. B* **69**, 224502 (2004).
2. Z. Yang *et al*, *Nat. Mater.* **3**,793 (2004).
3. U. Schoop *et al*, *Physica C* **350**, 237 (2001).
4. R. Mahendiran, *et al*, *Solid State Comm.*. **99**, 149 (1996).
5. D. Paul Joseph and J. G. Lin, *J. Am. Ceram. Soc.* **96** [2], 481 (2013).
6. D. Paul Joseph and J. G. Lin, *Supercond. Sci. and Technol.* **26**, 075004 (2013).
7. T. Nurgaliev *et al*, 9th Euro. Conf. on Appl. Supercond., *J. of Phys.: Conf. Series* **234**, 012029 (2010).
8. U. Topal *et al*, *J. Alloys and Compds.* **492**, 8 (2010).
9. P. Przyslupski *et al*, *Acta Physica Polonica A* **118** (2), 313 (2010).