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Direct injection of spin-polarized carriers across $YBa_2Cu_3O_{7-\delta}$–$La_{0.3}Ca_{0.7}MnO_3$ interface at 77 K

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Abstract. We report here injection of spin-polarized carriers from a half-metallic $La_{0.3}$-$Ca_{0.7}MnO_3$ (LCMO) colossal magnetoresistive (CMR) thin film into a high-temperature superconducting $YBa_2Cu_3O_{7-\delta}$ (YBCO) thin film studied using a micro-bridge. The LCMO and YBCO films were grown on ⟨100⟩ $LaAlO_3$ (LAO) substrate sequentially using pulsed laser deposition (PLD). I–V measurements carried out at 77 K show that while normal critical current, I_c^n, of the micro-bridge is 80 mA, the critical current, I_c^p, through the micro-bridge when injected from the CMR layer is 38 mA. This clearly shows that spin-polarized quasiparticles injected from the CMR layer into the YBCO layer suppress the critical current of the superconductor via the pair-breaking phenomena.

Keywords. Superconducting devices; colossal magnetoresistance; spin injection.

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1. Introduction

There has been a lot of research going on recently in the field of *Spintronics*, which makes use of the electron spin as well as the electronic charge. The half-metallic nature of the hole-doped rare-earth manganites of the form $R_{1-x}A_xMnO_3$ (R = rare-earth, A = bivalent cation) provides a reservoir of spin-polarized electrons whose charge as well as spin can be utilized by integrating them into unconventional devices [1,2]. There are reports of suppression of the critical current in a superconductor by spin-polarized quasiparticles [3–7] due to the breaking of the time reversal symmetry of the Cooper pairs. Most of the studies done so far are on heterostructures of a ferromagnet and a superconductor with an insulating layer in between where the focus was more on the study of spin-polarized tunneling rather than spin-injection. Here we report the first observation of the suppression of superconductivity by *direct* injection of spin-polarized quasiparticles from a ferromagnet into a high-temperature superconductor (without any insulating barrier).

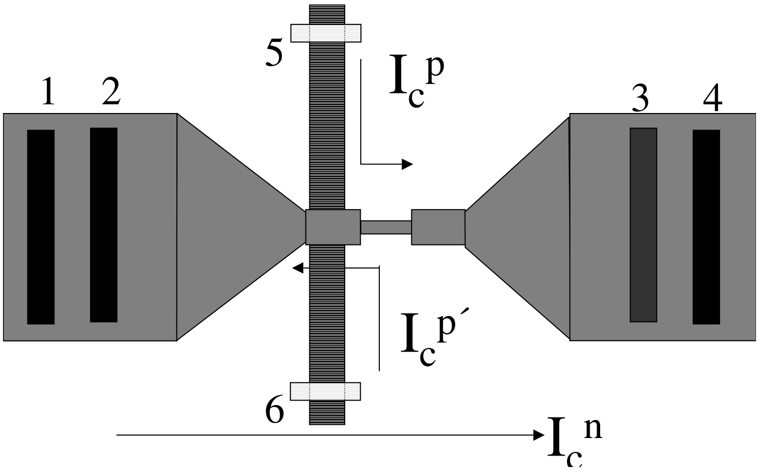

Figure 1. Device structure and electrical contact configurations for measurements of I_c. Contacts 1(5) and 4 were used as current contacts and 2 and 3 were used as voltage contacts for measuring I_c^n (I_c^p) of micro-bridge. Contacts 1 and 6 were used as current contacts and 2 and 3 were used as voltage contacts for measuring $I_c^{p'}$. Note that contacts 5 and 6 are on LCMO and the remaining four on YBCO layer.

2. Experimental

The device was fabricated by first depositing a LCMO layer (500 Å thick) in the form of a thin line (500 μm wide) on a single crystalline (100) oriented LAO substrate using pulsed laser deposition (PLD) technique. The line was defined by using two other LAO substrates to cover the substrate as a mask. The mask was then dropped *in situ* by a mechanical arrangement and a YBCO layer (2000 Å thick) was deposited *in situ* on the enitre LAO substrate. A micro-bridge (20 μm wide) was patterned on the YBCO film using photolithography (see figure 1) from a 200 μm wide strip. The micro-bridge was positioned 100 μm away from the LCMO line so as to eliminate the possibility of the proximity effect of the LCMO layer on the critical current of the superconductor. Six gold pads – two on LCMO and four on YBCO – were deposited on the film (as shown in figure 1) by PLD using a metal mask for I–V measurements. Gold pads were made large in size to ensure minimum contact resistance and all measurements were carried out at 77 K by dipping the device into liquid nitrogen dewar. Critical current (I_c^n) of the superconductor was measured by standard four-probe technique (1 and 4 for current, and 2 and 3 for voltage). The critical current with spin-polarized injection (I_c^p) was measured by injecting the current through 5 and 4 (instead of 1 and 4) and measuring voltage across 2 and 3. Note that this current passed through the micro-bridge. The critical current with spin-polarized injection ($I_c^{p'}$) was measured by injecting current through 6 and 1 and measuring voltage across 2 and 3. Note that this current *does not pass through* the micro-bridge. The criterion used for the measurement of critical current was 1 μV/mm.

3. Results and discussion

The transition temperature, T_c, of the superconducting film as measured using the ac-susceptibility set up before doing photolithography was found to be 90 K. The normal critical current density, J_c, of the micro-bridge (cross-sectional area of $4\mu m^2$) was found to be 2×10^6 A/cm^2 at 77 K (with a critical current $I_c^n = 80$ mA). This was measured when current source was connected between terminals 1 and 4.

I–V measurements carried out at 77 K (by dipping the device into liquid nitrogen) have shown that while normal critical current, I_c^n, of the micro-bridge (measured using 1 μV/mm criterion) is 80 mA, the critical current, I_c^p (cross sectional area $\sim$ 4 μm^2) through the micro-bridge when injected from the CMR layer is as low as 38 mA. On the other hand, the critical current, $I_c^{p'}$, through the 200 μm wide YBCO strip (cross sectional area $\sim$ 40 μm^2) injected from the CMR layer has been found to be only 63 mA.

The Joule heating in this case can be neglected since there is no insulating layer between the LCMO and the YBCO layers and also since the device is kept dipped into liquid nitrogen. The fact that $I_c^n > I_c^p$ clearly shows that the spin-polarized quasiparticles when injected into the superconductor, suppress the critical current of the superconductor. The huge disparity between the I_c^n and the $I_c^{p'}$ may be ascribed to various effects including the proximity effect due to the ferromagnetic layer, or to the self-injection of spin-polarized quasiparticles as explained by Yeh *et al* [6].

4. Conclusion

In summary, we have shown that the direct injection of spin-polarized carriers from LCMO into YBCO suppresses the critical current of the YBCO layer due to the breaking of the time reversal symmetry of the Cooper pairs. Further, our experiments show that when the ferromagnetic LCMO layer is in direct contact with YBCO, the proximity effect at this injecting contact greatly determines the current injection, and hence, the critical current in a superconducting strip.

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