Measurement of the spin polarization of LaSrMnO

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A new method for determining the transport spin polarization, point contact tunneling from a low temperature superconductor into a ferromagnet, is used to determine the spin polarization of several LaSrMnO thin films and crystals. The Andreev process and its utility in measurements of spin-polarization are described. Preliminary results for the spin polarization of LSMO are presented.
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I. INTRODUCTION

The doped manganates have generated a great deal of interest recently due to their peculiar magnetic and transport properties. Specifically, when appropriately doped and annealed there exists a Curie temperature where the samples undergo a paramagnetic to ferromagnetic transition which is nearly coincident with a transformation from activated to metallic or nearly metallic resistivity. Furthermore, the resistance transformation is strongly modified by the application of moderate magnetic fields (on the order of a few Teslas), i.e., the activated resistance peak is reduced. This so-called colossal magnetoresistance (CMR) has been demonstrated to have values of dR/dH of many orders of magnitude. One of the most studied of these materials is $La_{0.7}Sr_{0.3}MnO_3$ (LSMO).

It is generally believed that below the Curie temperature these materials are double exchange ferromagnets[1,2] which implies that the conduction electrons may be 100% spin polarized. Such materials are thus of considerable interest for fundamental studies of spin polarized transport and as critical components in ''spintronics,'' a new class of electronic devices.[3]

A new technique,[4,5] based on the suppression of Andreev scattering, has been developed for determining the spin polarization of a ferromagnet. Soulen *et al.*[4] have shown that a modified Blonder–Tinkham–Klapwijk (BTK)[6] analysis of point-contact tunneling conductance data of a low temperature superconductor into a ferromagnet (or vice versa) can be used to determine the ferromagnet's transport spin polarization. This method has the advantage of being versatile, allowing the study of films, foils, or crystals of virtually any metallic material without the necessity of forming planar tunnel junctions. The results for conventional ferromagnets have been confirmed by Upadhyay *et al.*[5] who observed the suppression of Andreev reflection in microlithographically fashioned SF junctions.

II. ANDREEV REFLECTION

Andreev reflection is a process that occurs at a normal metal/superconductor interface in which normal current converts into supercurrent.[7] Figure 1 illustrates the process at an unpolarized metal/superconductor interface. In Fig. 1(a) an ''up'' electron approaches the interface. The simplified energy diagram shows an electron at the Fermi energy in the up band in the normal metal. Since the superconductor has a gap, Δ, there are no available single particle states within Δ of the Fermi energy and the electron cannot enter the superconducting condensate. The only way for the ''up''electron to enter is as part of a Cooper pair [Fig. 1(b)]. This can happen only if a ''down'' electron also enters the superconductor from the normal metal. For this to occur, a hole with momentum and spin opposite that of the down electron must be reflected back into the normal metal. These holes add to the transport current and thus double the conductance, dI/dV, for voltages less than Δ.

In the 100% spin-polarized case (Fig. 2) the Andreev process is suppressed by the lack of states near the Fermi energy in the ''down'' band. In Fig. 2(a) the normal metal electron again approaches the interface. In this case, a pair cannot form [Fig. 2(b)] because there are no ''down'' states near the Fermi energy. Thus the conductance is suppressed to zero for $V<\Delta$. The expected normalized conductance spectra at $T=0$ K are shown in Fig. 3. The curves broaden at higher temperatures.

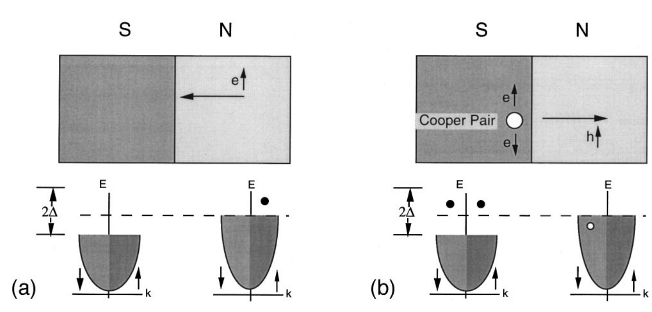

FIG. 1. Andreev reflection at an unpolarized normal metal/superconductor interface. (a) An ''up'' electron propagates towards the interface. (b) After reflection a Cooper pair is created in the superconductor and an ''up'' hole (in the ''down'' band) is reflected into the normal metal.

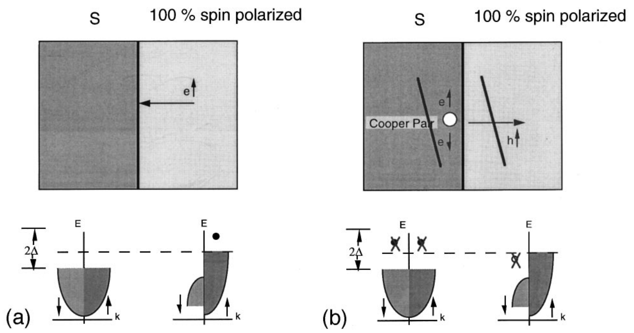

FIG. 2. Andreev reflection at a 100% polarized normal metal/superconductor interface. (a) An ''up'' electron approaches the interface. (b) A Cooper pair can't be created because there are no ''up'' holes available in the normal metal.

III. CONDUCTANCE MEASUREMENTS

The probes for this study were fabricated by mechanically polishing a Nb rod to a sharp point using sandpaper. The tip was attached to a drive shaft which was vertically positioned above the sample. The shaft was driven by a micrometer mechanism capable of moving the point linearly by 100 μm per revolution. The measurements were made using a conventional four-terminal arrangement while the point contact and sample were immersed in a liquid helium bath at either 4.2 or 1.5 K. The dI/dV data were obtained by standard ac lock-in techniques at a frequency of 2 kHz.[4] The point contacts were formed by forcing the superconducting Nb tip into the LSMO samples. Details of the point contact conductance measurements are presented elsewhere.[4]

Several thin film and crystal manganates were studied. Crystals of $La_{0.7}Sr_{0.3}MnO_3$ were grown by a floating zone technique. The process has been described in a previous report.[8] Thin films of $La_{0.7}Sr_{0.3}MnO_3$ were grown by off-axis sputtering using composite targets of LSMO material mounted in a copper cup. The substrates were (100)-oriented neodymium gallate ($NdGaO_3$) silver pasted onto a stainless-steel substrate holder that was radiatively heated from behind by quartz lamps. Although there was no direct measurement of the holder temperature for the samples prepared for this study, previous runs (under nominally the same conditions) using a thermocouple clamped onto the front surface of the holder indicated a temperature of 670 °C. The LSMO target was dc sputtered in a sputter gas composed of 80% Ar and 20% O_2 (as measured by flow meters) and at a total pressure of 100 mTorr. These conditions gave deposition rates of approximately 17–50 nm/h, with film thicknesses being typically 100 nm. After deposition, the samples were cooled in 100 Torr of oxygen. Similar growth conditions have been reported for LCMO films.[9]

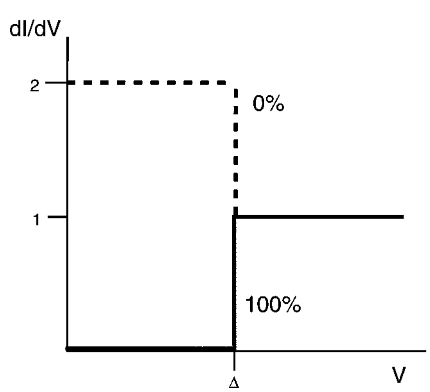

FIG. 3. Expected normalized conductance for unpolarized and 100% spin-polarized normal metals at $T=0$ K.

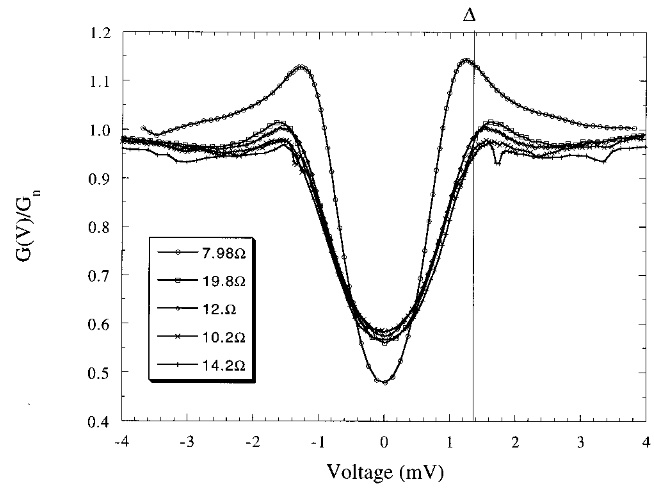

FIG. 4. Nb point into $La_{0.7}Sr_{0.3}MnO_3$ crystal at 1.5 K for several junction resistances. The energy gap of Nb, 1.4 mV, is indicated by Δ.

Figures 4 and 5 show the results for the Nb point into a $La_{0.7}Sr_{0.3}MnO_3$ crystal and thin film taken respectively at 1.5 K. The spin polarization can be calculated from the conductance curves using a modified BTK[6] theory.[4] At $T=0$, this theory yields

$$\frac{1}{G_n}\frac{dI}{dV}=2(1-P_c) \tag{1}$$

for $V<\Delta$, where G_n is the normal conductance (for $V>\Delta$) and

$$P_c=\frac{N_\uparrow(E_F)\nu_{F\uparrow}-N_\downarrow(E_F)\nu_{F\downarrow}}{N_\uparrow(E_F)\nu_{F\uparrow}+N_\downarrow(E_F)\nu_{F\downarrow}}, \tag{2}$$

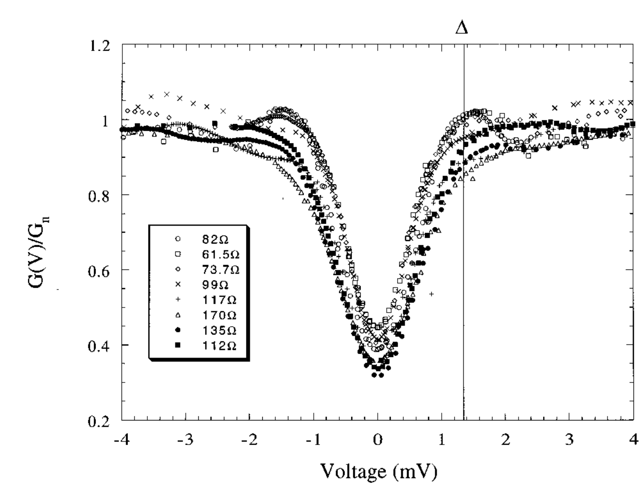

FIG. 5. Nb point into $La_{0.7}Sr_{0.3}MnO_3$ thin film at 1.5 K for several junction resistances. The energy gap of Nb, 1.4 mV, is indicated by Δ.

where $N_{\uparrow}(E_F)$ and $N_{\downarrow}(E_F)$ are the density of states of the up and down bands respectively and $\nu_{F\uparrow}$ and $\nu_{F\downarrow}$ are the Fermi velocities for the up and down bands, respectively.

The transport polarization P_c of the samples can be estimated from the conductance values at $V=0$ using Eq. (1). This analysis shows that the spin polarizations of the crystal and film are approximately 70% and 80%, respectively.

These results show that LSMO is highly polarized. The disagreement in the values obtained for the thin film and the crystal suggest that these measurements represent lower bounds for the intrinsic value of the material. Factors such as surface morphology and paramagnetic impurities could be responsible for the lower values of spin polarization that were obtained.

ACKNOWLEDGMENTS

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