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Magneto-transport properties of $La_{0.7}Ca_{0.3}MnO_3$/ $SrTiO_3$/$La_{0.7}Ce_{0.3}MnO_3$ tunnel junction

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Abstract. Hole-doped rare-earth manganite $La_{0.7}Ca_{0.3}MnO_3$ and the electron-doped manganite $La_{0.7}Ce_{0.3}MnO_3$ both show a metal–insulator transition around 250 K associated with a ferromagnetic transition and colossal magnetoresistance. In an earlier publication we have reported the rectifying characteristic of $La_{0.7}Ca_{0.3}MnO_3$/$SrTiO_3$/$La_{0.7}Ce_{0.3}MnO_3$ tunnel junction at room temperature, showing that it is possible to fabricate a diode out of the polaronic insulator regime of doped manganites. Here we report the magneto-transport properties of such a tunnel junction above and below the metal–insulator transition. We show, from the large positive magnetoresistance of the tunnel junction at low temperature, that $La_{0.7}Ce_{0.3}MnO_3$ could be a minority spin carrier ferromagnet. The implication of this observation is discussed.

Keywords. $La_{0.7}Ce_{0.3}MnO_3$/$SrTiO_3$/$La_{0.7}Ce_{0.3}MnO_3$ tunnel junction; magneto-transport properties; magnetoresistance.

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1. Introduction

Hole-doped rare-earth manganites, where Mn is in the Mn^{3+}/Mn^{4+} mixed valence state, have been a topic of intense research because of the colossal magnetoresistance (CMR) observed in these compounds close to the ferromagnetic transition temperature. More recently, it has been shown that it is also possible to obtain CMR by driving the manganese to a mixture of Mn^{3+} and Mn^{2+} valence states [1,2]. The electron-doped compound $La_{0.7}Ce_{0.3}MnO_3$, where Ce is in the Ce^{4+} valence state, has been shown to exhibit the generic behavior of CMR, namely, a sharp metal–insulator transition associated with a ferromagnetic transition around 250 K, associated with CMR [3]. Recently, we have shown that tunnel junctions made of $La_{0.7}Ca_{0.3}MnO_3$ and $La_{0.7}Ce_{0.3}MnO_3$ separated by a thin insulating spacer layer, exhibit strong rectifying characteristics at room temperatures (where both the compounds behave as polaronic insulators) confirming the electron-doped nature of $La_{0.7}Ce_{0.3}MnO_3$ [4]. However, a detailed study of the transport properties of the tunnel junction with and without magnetic field is required to gain insight regarding the electronic structure of the compound. In this paper we report the magneto-transport properties of a tunnel junction made of $La_{0.7}Ca_{0.3}MnO_3$ and $La_{0.7}Ce_{0.3}MnO_3$ layers with a 50 Å thick $SrTiO_3$ as the spacer layer.

2. Experimental

The sample was prepared by off-axis pulsed layer deposition on 0.5% Nb-doped $SrTiO_3$ (Nb-STO) conducting substrate. Details regarding sample preparation and characterization have been reported elsewhere [4]. The two current and voltage leads were attached one at the bottom of the conducting substrate and the other on the top layer ($La_{0.7}Ca_{0.3}MnO_3$). Current vs. voltage (I–V) characteristics of the tunnel junction were measured from 300 K down to 48 K with and without magnetic field. To avoid any artifact arising from the junction between Nb-STO and $La_{0.7}Ca_{0.3}MnO_3$ the I–V characteristics of the interface were measured separately. They were found to be Ohmic with a voltage contribution three orders of magnitude lower than that across the tunnel junction.

3. Results and discussion

Figure 1 shows the I–V characteristics of the tunnel junction below and above the metal–insulator transition with and without magnetic field. At 300 K where both $La_{0.7}Ca_{0.3}MnO_3$ and $La_{0.7}Ce_{0.3}MnO_3$ are paramagnetic insulators, the I–V curves at zero field and in a field of 7.5 T coincide with each other showing that the tunnel junction has no magnetoresistance at this temperature. This is quite expected. However, this also demonstrates that we are indeed measuring the I–V curves for the tunnel junction and not for the individual layers or pinholes within the insulating layer since the individual layers have considerable negative magnetoresistance (MR) at this temperature. On the other hand, at 48 K the I–V curves with and without field show a large positive MR at an applied field of 2 T. At 100 K the behavior is roughly similar to that at 48 K except in a narrow region at low bias voltage where the MR is negative.

The positive MR observed at low temperatures is significant to gain an insight regarding the possible electronic structure of $La_{0.7}Ce_{0.3}MnO_3$. In a ferromagnetic tunnel junction involving dissimilar ferromagnets a positive tunneling MR implies that the spin character of the two layers at Fermi energy (E_F) are opposite with respect to their respective magnetization. In zero field the dipolar interaction dominates and the magnetization of the two layers align antiparallel to each other. Thus if a tunnel junction is fabricated with one majority spin carrier ferromagnet and one minority spin carrier ferromagnet, in zero field the spin of the electrons at E_F are parallel. Since tunneling is a spin-conserving process this favors the interlayer tunneling of electrons. At high fields, on the other hand, the magnetization are parallel to each other and the spin of the electrons at E_F are antiparallel. This inhibits the interlayer tunneling causing the resistance of the tunnel junction to increase. This process has been earlier observed in $Fe_3O_4/SrTiO_3/La_{0.7}Sr_{0.3}MnO_3$ tunnel junctions [5]. The observation of positive MR at low temperature implies that $La_{0.7}Ce_{0.3}MnO_3$ may be a minority spin-carrier ferromagnet, which in turn suggests that all the manganese is not in a high spin state.

The bias dependent MR at 100 K is more complicated and is at present not completely understood. In doped manganites the Jahn–Teller and exchange splitting energies are of

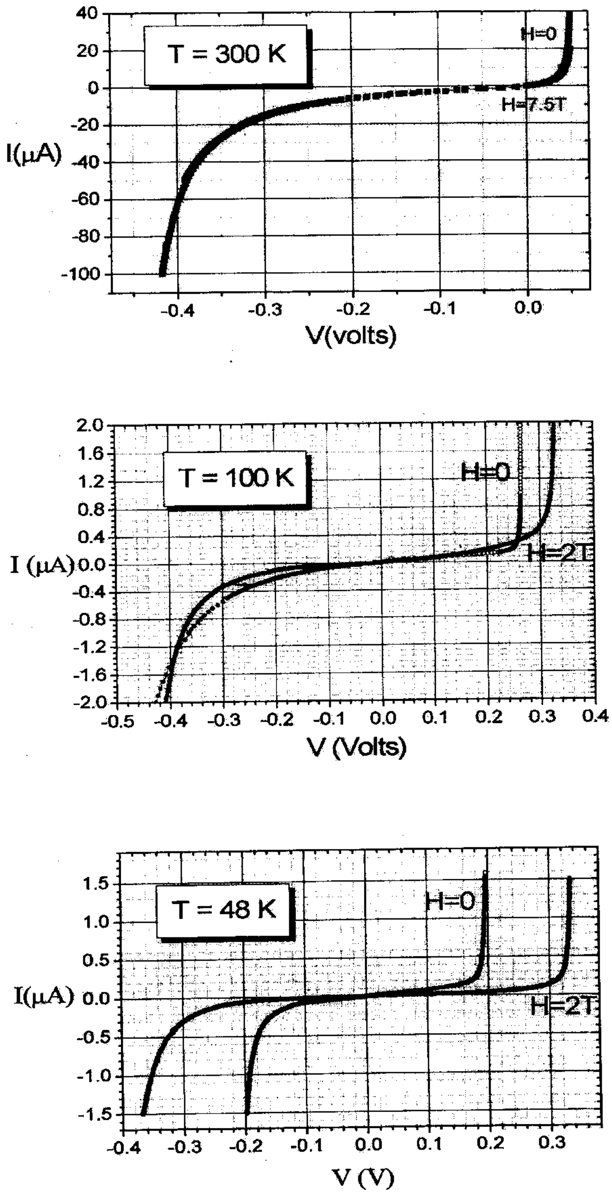

Figure 1. I–V curves for the $La_{0.7}Ca_{0.3}MnO_3/SrTiO_3/La_{0.7}Ce_{0.3}MnO_3$ tunnel junction with and without magnetic field at three temperatures: 300 K, 100 K and 48 K.

the same order of magnitudes, and therefore, a crossover from minority to majority spin-carrier ferromagnet with temperature and electric field (bias voltages) cannot be ruled out. It has to be also noted that the fringe electric field on the layer is of the order of magnitude at which a large electro-resistance is observed in these materials [6]. Therefore, an effect due to the electric field on the layers on the tunneling characteristics also cannot be ruled out. Further careful studies on the tunnel junction are required to establish this.

4. Conclusion

In summary, we have fabricated tunnel junctions with electron- and hole-doped manganites and reported their I–V characteristics with and without magnetic field. The large positive MR observed at low temperatures suggest that $La_{0.7}Ce_{0.3}MnO_3$ is a minority spin-carrier ferromagnet. This observation is interesting since conventionally manganese is believed to be in the high-spin state due to the large Hund's rule coupling in Mn. Further studies on this and other tunnel junctions made of electron-doped manganites and other ferromagnets will be useful to establish the electronic structure of this compound.

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