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Nanotechnology and Quantum Devices

MAGNETOTRANSPORT PROPERTIES OF LA-CA-MN-O MULTILAYERS.

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Compositionally modulated structures consisting of FM $La_{1-x}Ca_xMnO_3$ layers (x=0.33, 0.4, 0.48) and $La_{1-y}Ca_yMnO_3$ antiferromagnetic (AF) layers (y=0.52, 0.67, 0.75) were grown on (001)$LaAlO_3$ by pulsed laser deposition. The effect of interfacial Ca composition on the magneto-transport properties of FM/AF multilayers is examined between 4.2 and 300 K.

Spin-engineered structures with large magnetoresistance at room temperature open up new possibilities for applications in the emerging field of magneto-electronic devices. Such devices are magnetic tunnel junctions (MTJ) that consist of a ferromagnetic (FM) top and a FM bottom electrode separated by a thin oxide (insulator) layer that defines [1] two metal-oxide interfaces (FM-I-FM). The conduction is due to quantum tunneling through the insulator. When the electrodes are FM, the tunneling of electrons across the insulating barrier is spin-polarised, and this polarization reflects that of the density of states (DOS) at the Fermi level (E_F) of the electrodes. Spin-polarized tunneling gives rise to tunnelling magnetoresistance (TMR) because the resistance of the junction depends on whether the electrodes have parallel or antiparallel magnetization: $TMR=(\Delta R)/R=(R_{AP}-R_P)/R_{AP}=(2P_1P_2)/(1+P_1P_2)$, where R_{AP} and R_P are the resistances with magnetizations of the electrodes antiparallel and parallel. The spin polarization P of tunneling electrons from a given FM electrode reflects a characteristic intrinsic spin polarisation of the DOS in the FM: $P = [N_\uparrow(E_F)-N_\downarrow(E_F)]/[N_\uparrow(E_F)+N_\downarrow(E_F)]$.

The recent interest in magnetoresistance in doped perovskite manganites was initiated by the discovery of colossal magnetoresistance (CMR) in epitaxial $La_{0.67}Ca_{0.33}MnO_3$ thin films [2]. Of great technological importance are the half-metallic $La_{2/3}A_{1/3}MnO_3$ (A=Ca, Sr) FM films where all the mobile carriers have identical spin states and the conduction band is 100% spin-polarized [3]. The full (100%) polarization of the conduction band in these FM manganites means that TMR can reach its optimum value. To test this approach several groups have prepared MTJ structures consisting of an insulating $SrTiO_3$ layer sandwiched between two layers of FM $La_{2/3}Sr_{1/3}MnO_3$. A record value of 450% TMR was observed in fields below 100 Oe at 4.2 K, corresponding to an electrode polarization of about 85% at low temperatures. However, the TMR falls with increasing temperature and becomes vanishingly small at room temperature. Since the magnetic polarization in the surface of a $La_{2/3}Sr_{1/3}MnO_3$ thin film decreases more rapidly with temperature than the bulk polarization [3], the rapid loss of TMR could

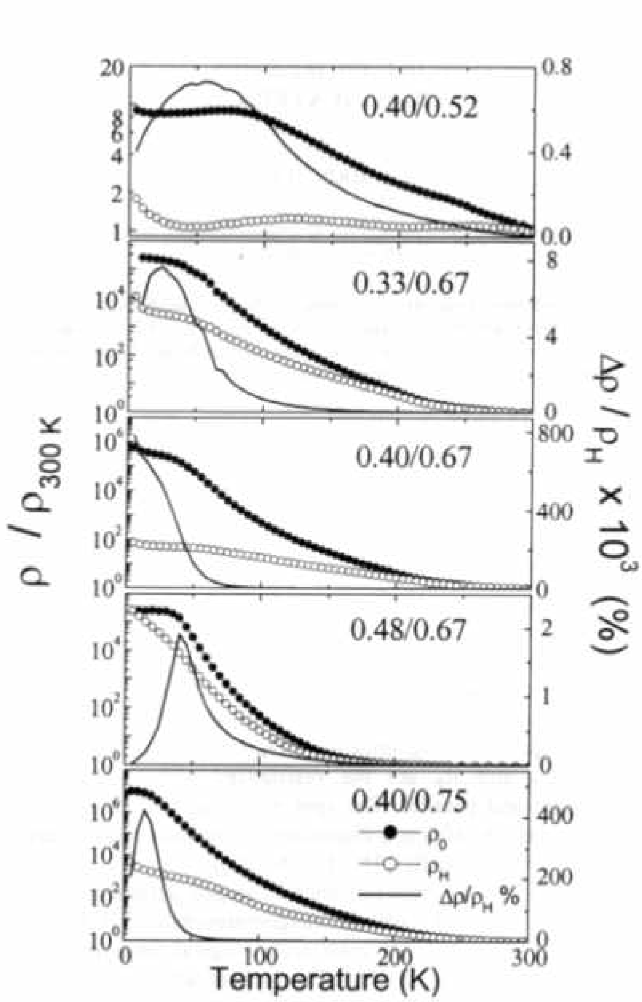

Figure 1. Resistivity, normalized to the 300 K value, as a function of temperature, measured in 50 kOe (ρ_H) and in zero applied field (ρ_0) for a series of $LaAlO_3$/AF(40 nm)/[FM(Λ/2)/AF(Λ/2)$]_{15}$multilayers. The CMR ratio $\Delta\rho/\rho_H=[\rho_0-\rho_H]/\rho_H$ is plotted as a solid line.

be caused by charge carriers losing their spin-polarization as they cross the FM-I-FM interfaces.

The intent of this study is to investigate the effect of interfacial composition on the magneto-transport properties of FM/I manganite multilayers between 4.2 and 300 K. Two series of $[(FM)La_{1-x}Ca_xMnO_3(\Lambda/2)/(AF)La_{1-y}Ca_yMnO_3(\Lambda/2)]_{15}$ multilayers (Λ=8.2 nm is the bilayer thickness) were used to investigate the effect of Mn^{3+}:Mn^{4+} interface ratio (2-x-y)/(x+y) in the temperature dependence of the magnetoresistance (fig.1). One series is grown [4] with constant y=0.67 while x=0.33, 0.4, 0.48, and the other with constant x=0.4 while y=0.52, 0.67, 0.75. For brevity, we named the samples by the Ca^{2+} concentration ratio x/y used (fig.1).

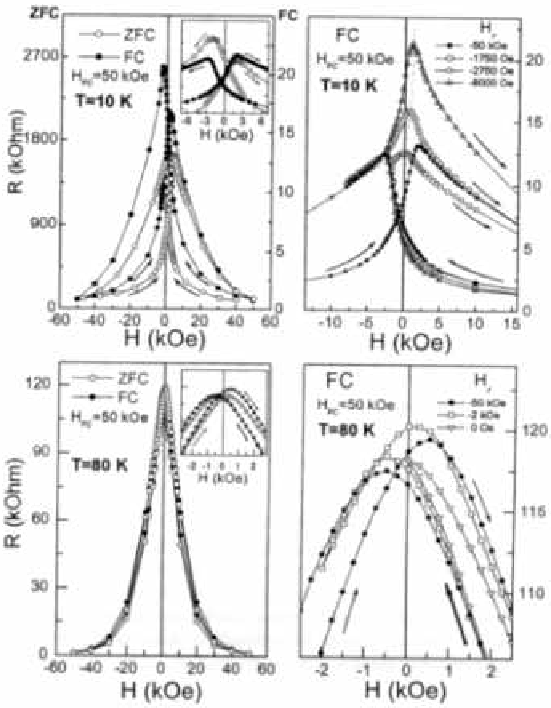

Figure 2. The magnetoresistance of the 0.40/0.67 sample at 10 K and 80 K. *Left side*: R-H loops measured at 10 K (above) and 80 K (below) after FC in 50 kOe (solid circles) and ZFC (open circles) from 300 K. The inset shows in detail the observed peaks. Arrows indicate the direction of field change. *Right side*: R-H loops measured at 10 K (above) and 80 K (below) after FC in 50 kOe from 300 K. Incomplete loops (open symbols) measured by varying the field from 50 kOe to H$_r$ and reverse to 50 kOe.

Figure 1 shows the variation of the normalized resistivity as a function of temperature, measured in 50 kOe (FC, ρ_H) and in zero applied field (ZFC, ρ_0). The resistivity increases drastically as we cool down from 300 K, spanning almost four orders of magnitude. Also, the CMR ratio becomes maximum in the temperature range below a blocking temperature [5,6] T_B ($\approx$70 K). To answer why T_B remains more or less the same it is reasonable to consider that interfacial spin ordering is confined within a few atomic planes near the AF/FM interfaces, defining an *active* film volume V_{int}. Since T_B results from a thermally activated process, its value depends on the active volume at the interfaces ($T_B \propto V_{int}$) which emerges to be similar in the examined multilayers [6,7]. The observed thermal decay of resistivity at low-T can be due to the tunneling of holes from the FM (hole-type carriers) layers [5] to AF (electron-type carriers) layers when the hopping rate between the FM and AF layer is varied [4] with temperature.

Figure 2 shows magnetoresistance loops for the 0.40/0.67 sample at 10 and 80 K. The left-plot shows saturation zero-field-cooling (ZFC) and field-cooling (FC) loops whereas the right-plot shows irreversible FC loops where the reversal (H_r) field is much lower than the saturation field of -50 kOe. Both saturation loops exhibit a large assymetry between the two branches whereas the R-maximum is shifted from the negative (ZFC) to positive field range (FC). The irreversible FC loops exhibit an R-maximum in the positive field branch. This R-maximum scales down with the magnitude of H_r, depending on whether the H_r is in the descending or ascending part of the negative field branch. Remarkably, the loop-assymetry and the irreversible behavior disappear above the T_B of about 70 K. Qualitatively similar results were observed in all the examined samples. These magnetic history depended effects indicate that the interfacial resistance becomes dominant at low-T due to [4] exchange-coupling of the AF/FM interfaces. The large magnetic irreversibilities (Fig. 2) show that [4] the origin of exchange-coupling below 80 K is interfacial magnetic disorder (like partial domain walls).

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