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MAGNETORESISTANCE IN RAMP-EDGE TUNNELING
JUNCTIONS BASED ON DOPED MANGANITE
FERROMAGNETIC ELECTRODES AND A SRTIO₃
INSULATOR

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Author(s):

C. Kwon , MST-STC
Q. X. Jia , MST-STC
Y. Fan , MST-STC
M. F. Hundley , MST-10
D. W. Reagor , MST-STC
M. E. Hawley , MST-8
D. E. Peterson, MST-STC

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Observation of Large Low Field Magnetoresistance in Ramp-Edge Tunneling Junctions Based on Doped Manganite Ferromagnetic Electrodes and A SrTiO₃ Insulator

C. Kwon, Q. X. Jia, Y. Fan, M. F. Hundley, D. W. Reagor, M. E. Hawley,
and D. E. Peterson

Materials Science and Technology Division, Mail Stop K763
Los Alamos National Laboratory, Los Alamos, NM 87545

ABSTRACT

We report the fabrication of ferromagnet-insulator-ferromagnet junction devices using a ramp-edge geometry based on (La_{0.7}Sr_{0.3})MnO₃ ferromagnetic electrodes and a SrTiO₃ insulator. The multilayer thin films were deposited using pulsed laser deposition and the devices were patterned using photolithography and ion milling. As expected from the spin-dependent tunneling, the junction magnetoresistance depends on the relative orientation of the magnetization in the electrodes. The maximum junction magnetoresistance (JMR) of 30 % is observed below 300 Oe at low temperatures (T < 100 K).

INTRODUCTION

There has been a great deal of interest in spintronic devices, in which the spin-dependent transports are utilized to generate a large magnetoresistance in conventional ferromagnetic metal thin films and multilayers. For example, the large junction magnetoresistance (JMR) in magnetic tunnel junctions is observed at room temperature [1]. Due to the uneven spin distribution of conduction electrons at the Fermi level in the ferromagnets, one can expect tunneling probability to be dependent on the relative magnetization orientation of the ferromagnet electrodes. By assuming that spin is conserved in the tunneling process and tunneling current is dependent on the density of states at Fermi level of two electrodes, Jullier showed the maximum change in the tunneling resistance (ΔR) as [2]

$$\Delta R/R_A = (R_A - R_p)/R_A = 2P_1P_2/(1 + P_1P_2),$$

where R_A and R_p are the junction resistances when the magnetizations are antiparallel and parallel, respectively, and P_1 and P_2 are the spin polarizations of the two electrodes.

Doped manganites, (R_xM_{1-x})MnO₃ where R is a rare earth element such as La, Pr, and Nd and M is believed to be a half-metallic material due to the strong Hund's coupling and a relatively narrow conduction band [3]. The half-metallic characteristics in La_{0.7}Sr_{0.3}MnO₃ have been observed in spin-resolved photoemission measurements well below the Curie temperature, T_c [4]. Half-metallic systems are characterized by the coexistence of metallic behavior for one electron spin and insulating behavior for the other. Hence, the density of states has 100 % spin polarization at the Fermi level and the conductivity is completely dominated by the metallic single-spin charge carriers. Since a half-metallic ferromagnet has 100% spin polarization for conduction electrons, it offers potential as a ferromagnetic metal electrode in devices based on spin-dependent transport effects. Compared to the tunneling junctions based on the conventional ferromagnetic metal electrodes, MR in the tunneling junctions made of the manganites is expected to be larger. Sun *et al.* have demonstrated the existence of large magnetoresistance at low fields and low temperatures in the trilayer sandwich junctions using doped manganites [5].

In this paper, we report on the fabrication of ramp-edge ferromagnet-insulator-ferromagnet junction devices using (La_{0.7}Sr_{0.3})MnO₃ (LSMO) and SrTiO₃ (STO) as the ferromagnet and insulator layers, respectively. As we have learned from the study of thin-film high temperature superconductor applications that the control of interfaces in metal-oxide heterostructures is quite difficult. A ramp-edge structure has technical advantages in metal-oxide based junction devices due to a small junction area by nature of the design. Spin dependent tunneling transport

characteristics are observed. A large junction magnetoresistance of 30 % ($JMR = [(R_j(H) - R_j(1000 \text{ Oe})/R_j(1000 \text{ Oe})]$) in fields less than 300 Oe is obtained at low temperatures.

EXPERIMENT

A schematic diagram of a ramp-edge junction fabrication process is shown in Fig. 1. At first, a bottom electrode (LSMO) and a thick insulation layer (STO) were deposited on a LaAlO_3 substrate using pulsed laser deposition. A 308 nm XeCl excimer laser was used with an energy density of 2 J/cm^2 and a repetition rate of 10 Hz. The oxygen background pressure was 400 mTorr and the heater block temperature was 700°C . Using conventional photolithography and ion milling with Ar ions, a bottom electrode was defined (Fig. 1(b)) and the ramp-edge was created (Fig. 1(c)). After removing the photoresist, a thin insulating barrier of STO and a top electrode of LSMO were deposited using *in situ* pulsed laser deposition under 400 mTorr oxygen and at 700°C (Fig. 1(d)). The insulating barrier and the top electrode were patterned to form a junction (Fig. 1(e) and (f)). The contact pads were defined by photolithography and gold was sputtered (Fig. 1(g)). After the lift-off process, gold formed the contact pads (Fig. 1(f)). For this work, the thicknesses of a bottom electrode of LSMO and a top electrode of LSMO were 1100 and 900 Å, respectively. The junction area is determined by the length, about $0.4 \mu\text{m}$ as estimated from the ramp-angle and the thickness of the bottom electrode, and the width of the junction.

Figure 2 shows an atomic force microscope image of a ramp-edge after the Ar ion milling of the bottom electrode. It shows the ramp-angle is $(13 \pm 1)^\circ$.

As-grown LSMO films under the above growth conditions have a Curie temperature, T_c , of 350 K and a sharp decrease of resistance at the same temperature (LSMO has paramagnetic metal-to-ferromagnetic metal transition near T_c [6]). The resistive transitions of both top and bottom electrodes were measured after the device fabrication process and showed the same temperature dependence as the as-grown films.

The JMR was measured with a four-terminal ac resistance bridge in fields up to $\pm 1 \text{ T}$ in the temperature range of 16 - 300 K. The measurements performed using a dc current source gave the same results. The current was flowing across the insulating barrier layer similar to the current-perpendicular-to-plane (CPP) geometry in a trilayer sandwich junction. The magnetic field was applied in the plane either parallel or perpendicular to the current. No significant difference was observed in the field dependence of JMR.

RESULTS

The field dependent junction resistance, $R_j(H)$, and JMR, $\Delta R_j/R_j(1000 \text{ Oe})$ of a device at 15.7 K is shown in Fig. 3. JMR values as large as 30 % are observed at low fields (between 180 Oe and 220 Oe). The shape of JMR versus field is similar to that of metal-electrode-based tunnel junctions [1]. At high fields, the junction resistance is low because the magnetization in both electrodes is parallel. When H is between the coercive fields of the top and bottom electrodes (i.e., the electrode magnetization vectors are antiparallel), the junction resistance reaches a maximum value. Generally the JMR increases nearly linearly with decreasing temperature and saturates at values as large as 30 % below 100 K.

In order to study the effect of the insulating barrier, we have made two devices using the same fabrication process with and without the STO insulating barrier layer. Figure 4 shows the temperature dependent junction resistance, $R_j(T)$, of $5 \mu\text{m}$ wide ramp-edge junction devices. The device with a STO barrier has much larger junction resistance indicating the junction resistance is dominated by the barrier layer not by the interfaces. The device without the STO barrier layer exhibits similar $R(T)$ as an as-grown LSMO film. The junction resistance for the device with a barrier layer decreases with temperature, however, the change is much smaller than that in the device without a barrier. Unlike the trilayer sandwich junction devices, the ramp-edge junction devices does not show any sign of variable range hopping behavior.

The high field JMR, $\Delta R_j(H)/R_j(1 \text{ T})$, is presented in Fig. 5 for both devices. The device without a barrier shows small JMR ($< 0.5\%$) while the device with a barrier exhibits large JMR

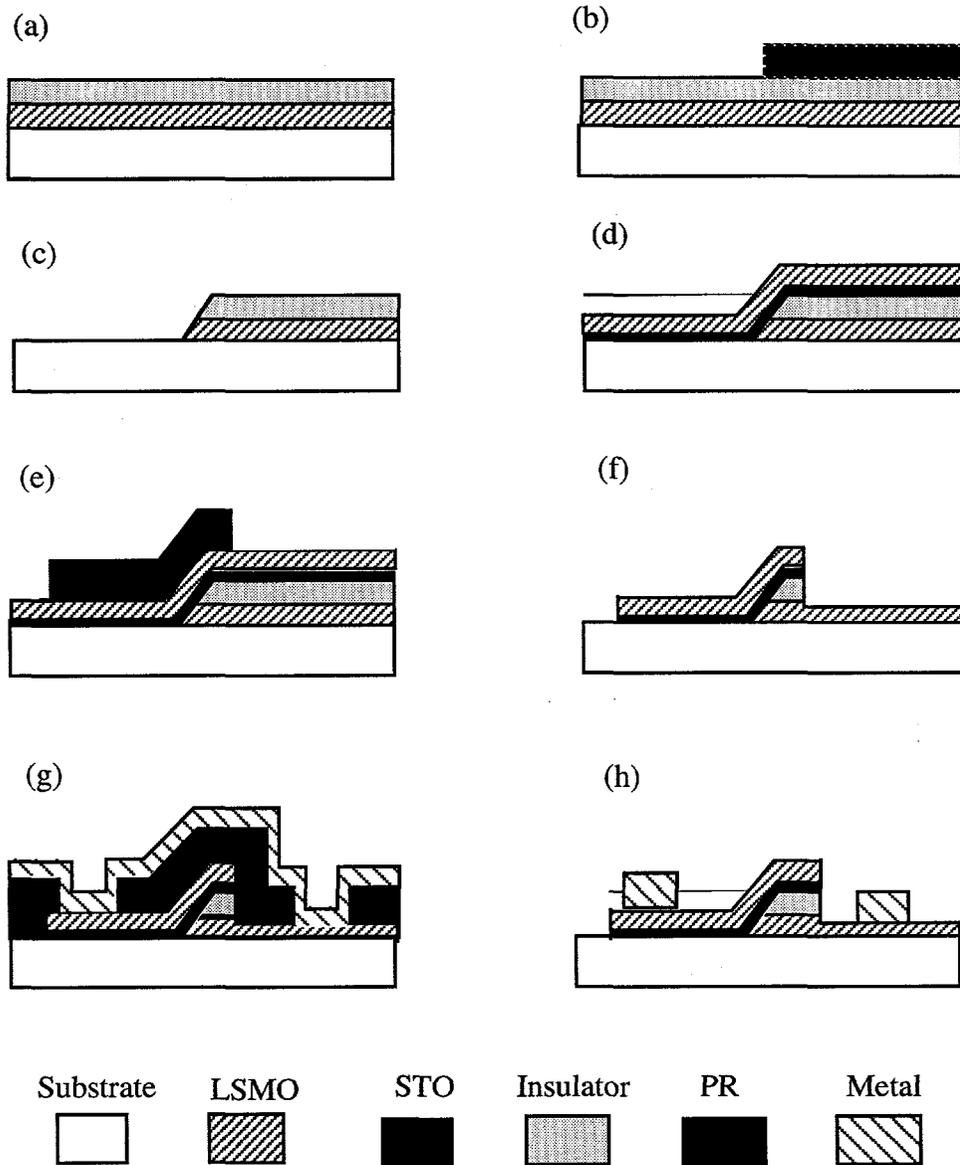


Figure 1. A schematic diagram of a ramp-dege junction fabrication process.

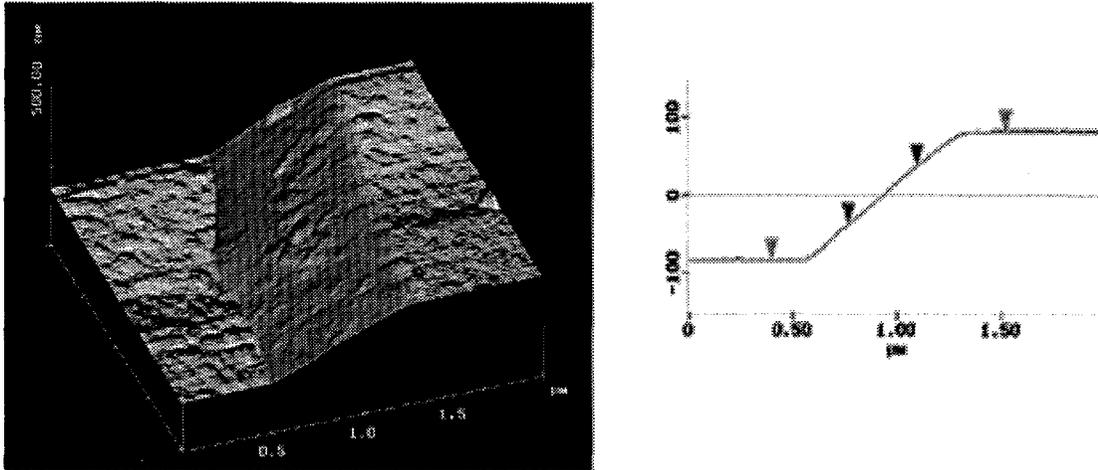


Figure 2. (Left) An atomic force microscope image of a ramp-edge after the Ar ion milling of the bottom electrode. (Right) A line scan along the ramp-edge.

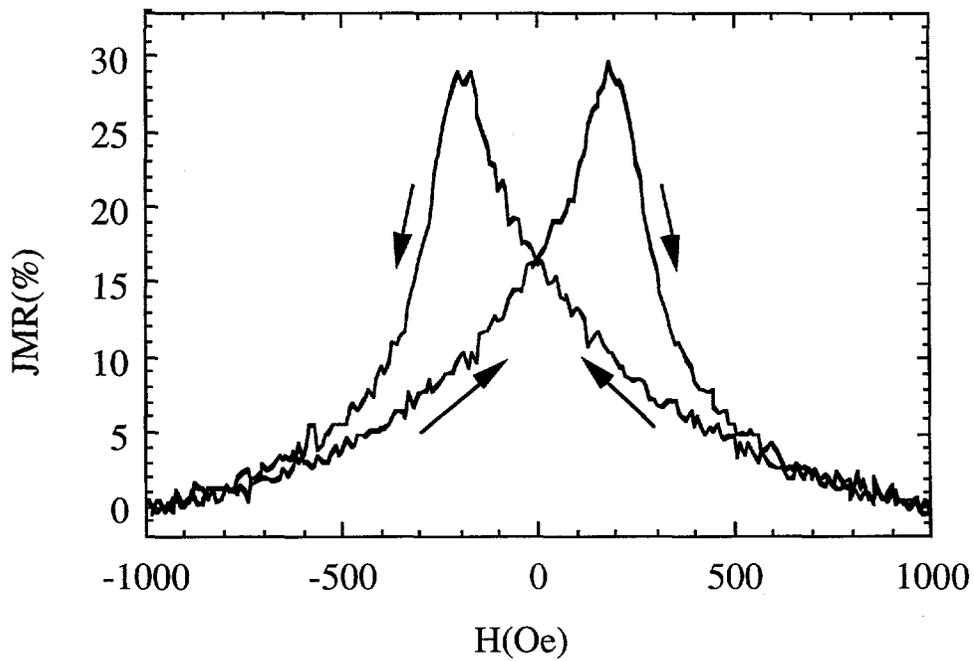


Figure 3. The field dependent junction magnetoresistance, $JMR = \Delta R_j / R(1000 \text{ Oe})$, of a device at 15.7 K.

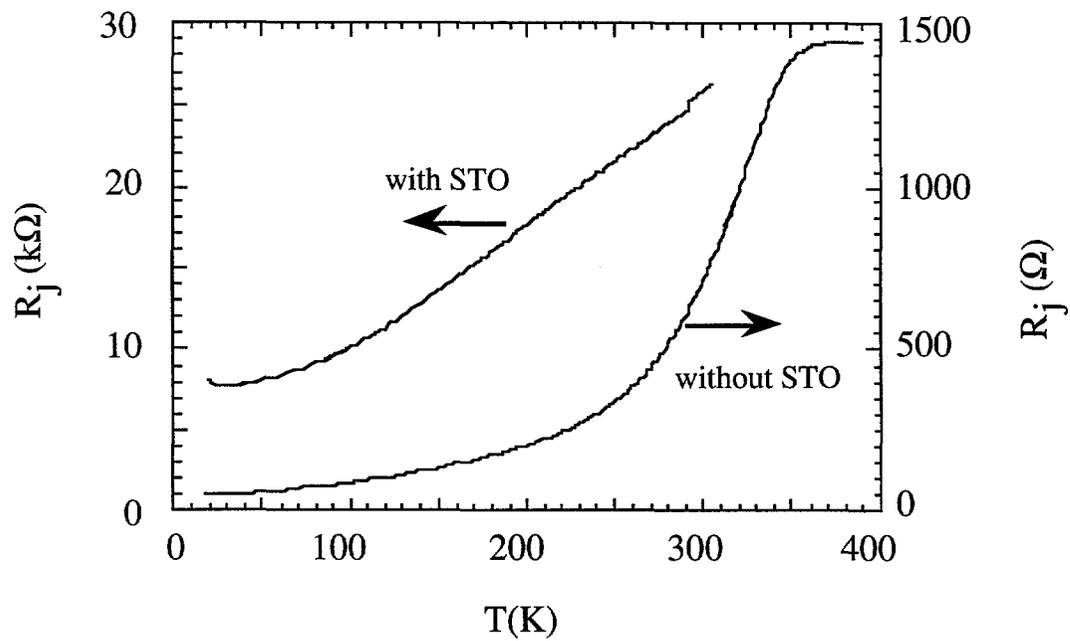


Figure 4. The temperature dependent junction resistance, R_j , of two ramp-edge devices with and without the STO barrier layer.

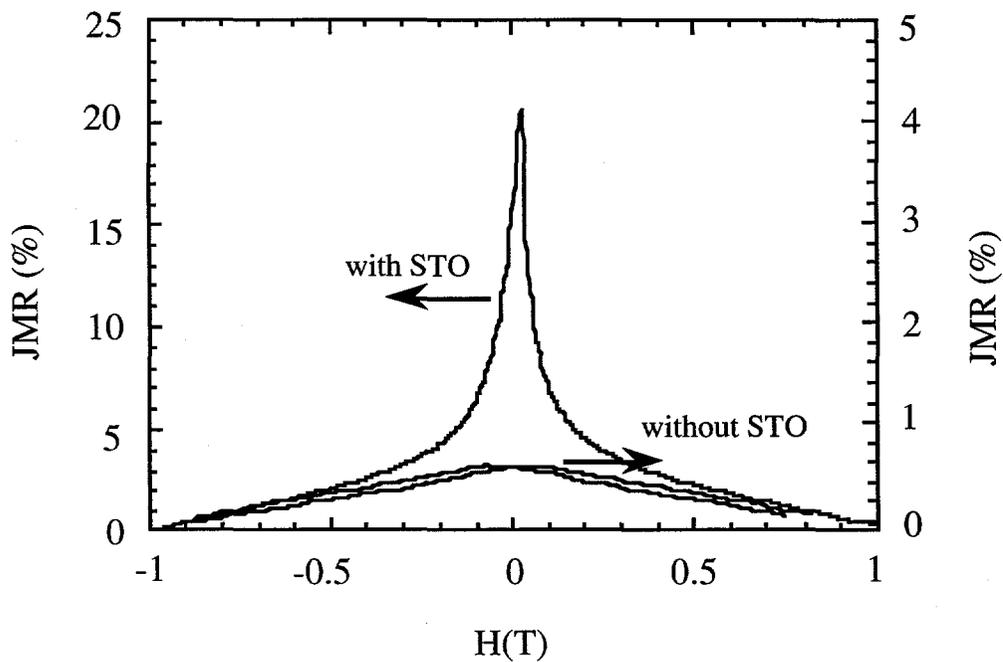


Figure 5. The high field JMR, $\Delta R_j(H)/R_j(1T)$, for two ramp-edge devices with and without the STO barrier layer.

(21 %). There have been reports of a large low field magnetoresistance in samples with grain boundaries [3,7]. A small JMR in the device without a barrier indicates relatively clean interfaces in the ramp-edge. The large JMR in the device with a barrier is indeed from spin-dependent tunneling.

CONCLUSIONS

We have successfully fabricated LSMO/STO/LSMO junction devices using a ramp-edge geometry. The junction magnetoresistance depends on the relative orientation of the magnetization in the electrodes as expected from the spin-dependent tunneling. The maximum junction magnetoresistance (JMR) of 30 % is observed below 300 Oe at low temperatures. Comparison between ramp-edge devices with and without a STO barrier layer demonstrates that the transport characteristics in LSMO/STO/LSMO junction devices is dominated by the barrier and the large JMR is from the spin-dependent tunneling.

Acknowledgments

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