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$La_{0.7}Sr_{0.3}MnO_3$ Thin-Film Grain-Boundary Junctions on a Bi-Crystal Substrate

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Transport properties of 10 μm to 30 μm wide grain-boundary junctions ion-etched in thin colossal magnetoresistance $La_{0.7}Sr_{0.3}MnO_3$ films deposited on a $SrTiO_3$ bi-crystal were investigated. We have measured the current–voltage characteristics in the temperature range from 4.2 K to 300 K without applied magnetic field, as well as the magnetoresistance at magnetic fields up to $\pm$10 kOe directed parallel to the film surface, both perpendicular and parallel to the direction of current flow through the junctions. The investigated junctions have nonlinear current–voltage characteristics in this temperature range and consist of several magnetic domains. The maximum magnetoresistance $(R(H) - R_{\max})/R_{\max}$, measured at 1 kOe was –17.6% at 4.1 K.

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1. Introduction

The properties of doped manganese oxides (manganites) with the general formula $Ln_{1-x}Me_xMnO_3$, where Ln is a rare-earth element and Me stands for Ca, Sr or Ba, have been widely studied during the last decade, mainly because of the

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colossal magnetoresistance (CMR) exhibited by these compounds [1, 2]. Grain--boundary junctions made out of manganite thin films display also unique transport properties in magnetic fields [3].

2. Results and discussion

70 nm thick $La_{0.7}Sr_{0.3}MnO_3$ films were deposited by r.f. magnetron sputtering on (001) $SrTiO_3$ bi-crystals with a 24° boundary. As-grown films were c-axis oriented, their Curie temperature T_C was approximately 360 K, and their resistivity was equal to 121 mΩcm at 5 K. Further preparation details and information on thin film properties can be found in [4]. The films were patterned into bridges using 500 eV Ar ion-beam milling applying AZ 1350J photoresist, cooled down to 80 K, as a mask. The bridges were between 10 and 30 μm wide and 50 μm long close to the junction (see the inset of Fig. 1). In contrast to the preparation details described in [5] and [6], we did not anneal our samples after the ion-etching process.

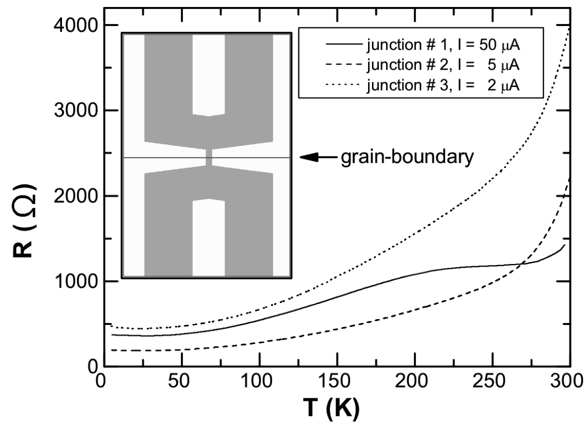

Fig. 1. Temperature dependence of the resistance for three grain-boundary junctions of different widths: Junction #1 — 30 μm, #2 — 20 μm, #3 — 10 μm. The junction geometry is shown in the inset.

All resistance measurements and current–voltage ($I-V$) characteristics were recorded in a liquid helium-dewar using a Keithley 236 source-measure unit and a sensitive digital voltmeter (Keithley 182) for voltages below 1000 mV. Typical resistance vs. temperature curves of three different junctions are shown in Fig. 1. We did not observe any maximum of the $R(T)$ curves below the Curie temperature for our junctions, in contrast to the results described in papers [5] and [6]. Our grain-boundary junctions had quite low resistivities at room temperature, with $R_J A$ values around 3×10^{-5} Ωcm^2 (A is the junction cross-section). Due to the high Curie temperature of our films, all $I-V$ curves were nonlinear at all temperatures below room temperature as well as at room temperature. At low temperatures the curves can be easily fitted by polynomial functions described in the paper by Glazman and Matveev [7], confirming a multi-step tunnelling mechanism through an insulating oxide barrier with localized states.

The magnetoresitance was measured with the four-point probe method by means of a Physical Property Measurement System made by Quantum Design. A dc current of up to 30 μA was passed through the junctions in a helium-gas atmosphere. The measurements were done in the magnetic field aligned always parallel to the film surface, for two configurations, perpendicular and parallel to the current direction. The magnetoresistance for the perpendicular case (the magnetic field is parallel to the grain boundary) is presented in Fig. 2. At each temperature the magnetic field was swept between 0 and 0.1 T, 0.1 T and –0.1 T, and –0.1 T and 0.1 T. The profile of the measured curves clearly indicates the appearance of a spin-dependent current flow across the grain boundary. Please note that the magnetoresistance maximum appears at a magnetic field as low as 50 Oe.

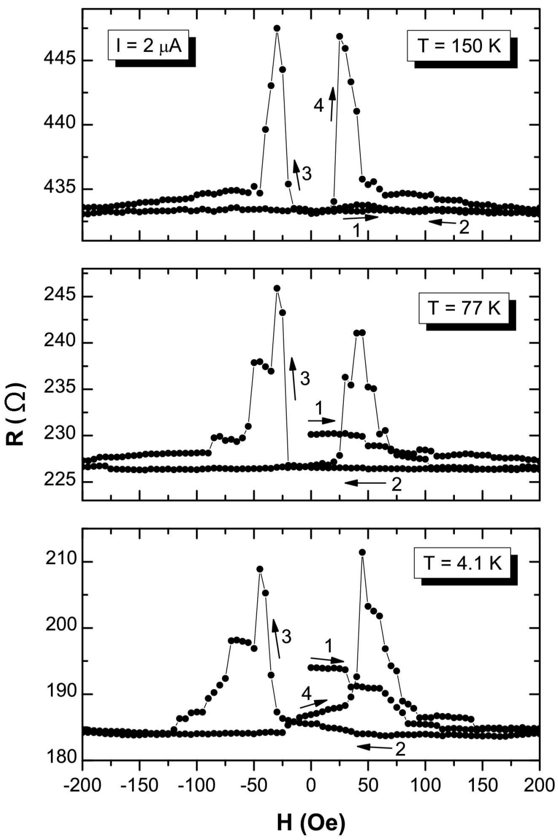

Fig. 2. Magnetoresistance of junction #2 at 4.1 K, 77 K, and 150 K, respectively. The measurement sequence is indicated by arrows and numbers.

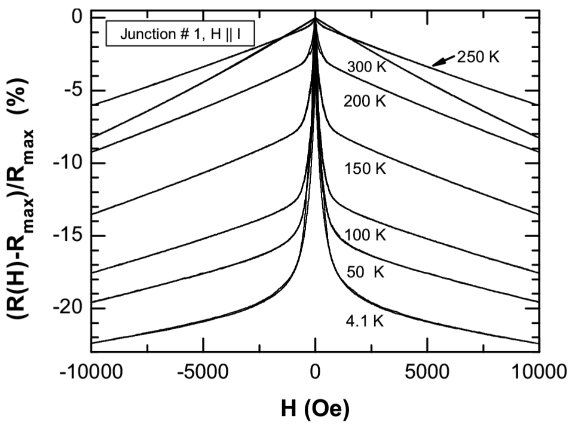

Fig. 3. Magnetoresistance of junction #1 at various temperatures.

The disappearance of steps or jumps with increasing temperature, resulting in more regular curve shapes, can be explained by thermal fluctuations. Our junctions were composed of several magnetic domains, with a maximum spin polarization of approx. 0.35 at 4.1 K, which was calculated based on Julliere's equation [8], assuming equal spin polarizations on both sides of the grain boundary.

A typical result for the magnetic field oriented parallel to the current direction is shown in Fig. 3. At each temperature, the magnetic field was swept between 0 and 1 T, 1 T and –1 T, and –1 T and 0. The steeper slope of the curve measured at 300 K is due to the dominance of the intrinsic magnetoresistance of the manganite film over the junction resistance at temperatures approaching T_C.

3. Conclusion

In conclusion, we have fabricated and characterized low-resistivity, $La_{0.7}Sr_{0.3}MnO_3$ thin-film grain-boundary junctions, consisting of several magnetic domains, displaying spin-dependent tunnelling, with a maximum spin polarization of 0.35 at low temperature.

Acknowledgment

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