Giant room-temperature magnetoresistance in $La_{0.8}Tb_{0.2}MnO_3$ under the low magnetic fields

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ABSTRACT

Polycrystalline perovskite $La_{0.8}Tb_{0.2}MnO_3$ (LTMO) with an orthorhombic phase was synthesized by conventional solid-state reaction. The magnetic and electric properties of $La_{0.8}Tb_{0.2}MnO_3$ were examined. The striking finding is that the material exhibits giant magnetoresistance at room temperature as high as −31.8% and −35.7% under the low magnetic fields of 100 and 1000 Oe, respectively. This result suggests that $La_{0.8}Tb_{0.2}MnO_3$ has a promising potential in future device developments.

1. Introduction

Manganese oxides with the general formula of $La_{1-x}A_xMnO_3$ series (where A is a divalent metal such as Ca, Sr, Ba, or Pb) [1–8] have attracted considerable attention due to their unusual magnetic and electronic properties [9–11]. For example, in these materials magnetic fields can drive insulator-to-metal transition where both the conductivity and magnetization change dramatically resulting in the so-called colossal magnetoresistance (CMR). The parent compound, $LaMnO_3$, is an antiferromagnetic insulator with a distorted perovskite structure. When doped with divalent cations, such as Ca^{2+}, Sr^{2+}, or Ba^{2+}, it undergoes a phase transition to the metallic state and becomes ferromagnetic. Zener [12] explained these simultaneous metallic and magnetic phase transitions in doped $LaMnO_3$ in terms of the double exchange mechanism. Recently the electron-doped compounds in which A was substituted by tetravalent or pentavalent ion such as Ce^{4+}, Te^{4+}, Sb^{4+}, Zr^{4+}, etc., have been reported by some research groups [13,14]. The discovery of CMR in perovskite manganites derived from $LaMnO_3$ has renewed interest in these and related materials for possible technological applications [15–17].

But the high magnetic fields and low-temperature windows where the large magnetoresistance responses are observed present daunting limitations. A possible avenue for overcoming these limitations is to improve the low-field and room-temperature ranges response by modifying the manganites. Until now,

there were few reports on the feature that A in $La_{1-x}A_xMnO_3$ was substituted by Tb^{3+} and Tb^{4+}. In this work, we reported that the MR ratio of $La_{0.8}Tb_{0.2}MnO_3$ can reach giant values as −31.8% at 100 Oe and −35.7% at 1000 Oe at room temperature. These values are much higher than those reported in literatures. For example, $La_{2/3}Sr_{1/3}MnO_3$ [18] at $T = 120 K$ and $Tl_2Mn_2O_7$ [19] at $T = 280 K$ show MR ratios less than 10% under a magnetic field about 1000 Oe. Sr_2FeMoO_6 [20] shows MR ratio about 10% under 7 T at 300 K.

2. Experimental

$La_{0.8}Tb_{0.2}MnO_3$ polycrystalline samples were made by the conventional solid-state reaction method. The stoichiometric amounts of Tb_4O_7, La_2O_3 and MnO_2 powders with high purity (99.99%) were thoroughly mixed, and then fired at 1200–1300 °C for 20 h repeatedly. Finally, the obtained powders were palletized and fired at 1500 °C in air for another 20 h followed by furnace cooling. The crystalline structure of the samples was examined by X-ray diffraction (XRD) measurement with Cu/K radiation ($\lambda = 1.5406$ Å). The electrical and magnetic properties of the LTMO are measured at room temperature. The magnetic field is applied perpendicularly to the interface and parallel to the current. The measurement was carried out with a pulse-modulated current source.

3. Results and discussion

Fig. 1 shows the XRD pattern of $La_{0.8}Tb_{0.2}MnO_3$. All diffraction peaks can be perfectly indexed by an orthorhombic phase with

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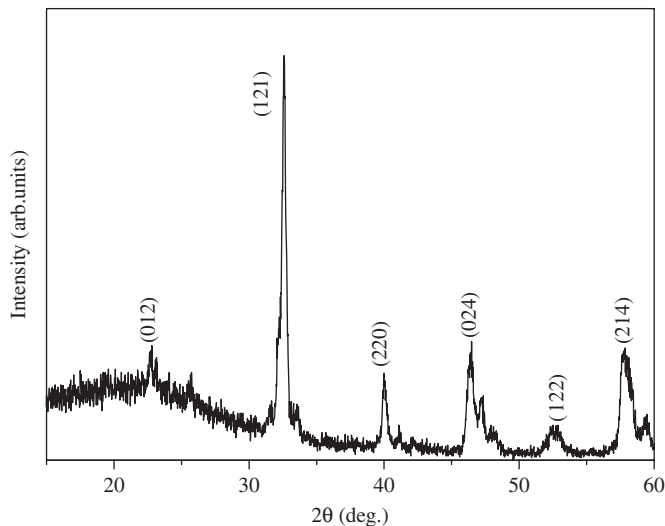
Fig. 1. X-ray diffraction pattern of $La_{0.8}Tb_{0.2}MnO_3$ sample.

Fig. 2. Current versus voltage of $La_{0.8}Tb_{0.2}MnO_3$ under various magnetic fields at 300 K.

Fig. 3. MR ratio versus magnetic field of $La_{0.8}Tb_{0.2}MnO_3$ at 300 K. Inset: MR–V curves of $La_{0.8}Tb_{0.2}MnO_3$ under various magnetic fields.

space group Pbnm. Lattice parameters deduced from the diffraction angles 2θ of the (0 1 2), (1 2 1), (2 2 0) reflection by using Bragg's equation ($\lambda = 0.15418$ nm) were found to be $a = 5.560$ Å, $b = 7.692$ Å, and $c = 5.513$ Å. These values are somewhat smaller than those of $LaMnO_3$ ($a = 5.537$ Å, $b = 7.695$ Å, and $c = 5.743$ Å). This indicates that the larger ion of La^{3+} was partially replaced by smaller ion Tb^{3+}, leading to the reduction in parameter of the doped sample.

The current versus voltage (I–V) characteristics of the $La_{0.8}Tb_{0.2}MnO_3$ (0.6 cm × 0.35 cm × 0.1 cm) under various magnetic fields, measured with a pulse-modulated current source, are shown in Fig. 2. The measurements were taken by a constant current with a step of 0.2 mA at room temperature. It is seen that the I–V curve undergoes a large change in response to the applied magnetic fields, and then saturates at above 1000 Oe. This indicates that the sample exhibits large MR ratio at low fields. We define the MR ratio as $\Delta R/R_0 = (R_H - R_0)/R_0$, where R_H is the resistance under an applied magnetic field and R_0 is the resistance at zero field. The behavior of MR as a function of applied field was plotted in Fig. 3, from which we can see that the MR ratio increases drastically in the low magnetic-field range. The MR ratio at 200 Oe reaches −14.2%, and −21.8% at 700 Oe. With further increasing the applied fields, the MR ratio saturates at a value of −22.3%. The MR ratio as a function of the applied voltage was displayed in the inset of Fig. 3. The ratios are found to be −15.8% at 100 Oe, −31.8% at 500 Oe, and −35.7% at 1000 Oe under an applied voltage of 0.5 V. From the point of view of applications, the giant MR ratio at room temperature and at the low field is extremely interesting. In general, the rapid increase of the MR ratio in the low magnetic-field range, followed by a slow increase at high fields reflects a typical external effect. In perovskite manganites, the surface magnetism will be quite different from that of the bulk, owing to the lower effective magnetic coupling, the tendency of spin canting as well as the disorder due to the surface termination of the crystal structure. Another important fact is the influence of the Jahn–Teller lattice disorder [21]. Therefore, the possible reasons responsible for the observed results might attribute to the grain boundary transport and the disorder region. This implies that the low magnetic-field MR ratio at room temperature can be achieved conveniently by doping to tune the resistance of the grain boundary and the disorder region with respect to the bulk material's resistivity.
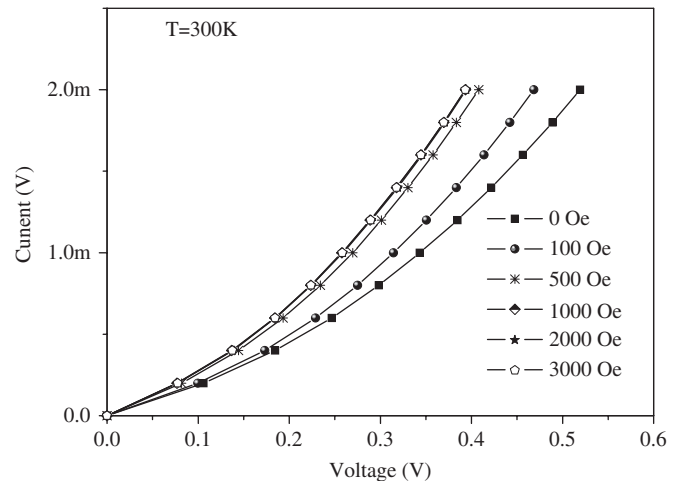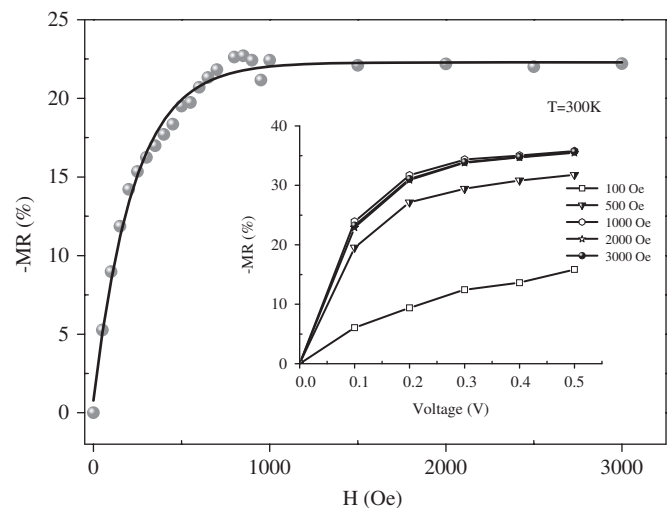
4. Conclusion

In summary, we found giant MR ratio at the low magnetic field and room temperature in polycrystalline $La_{0.8}Tb_{0.2}MnO_3$ materials. Besides, the MR ratio can be easily tuned by an applied electric field. Saturated MR ratio can be achieved at a low voltage of 0.5 V at room temperature. These results indicate that the Tb-doped $LaMnO_3$ has excellent low-field-magnetoresistance properties and the potential application in future device developments.

Acknowledgements

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