Enhancement of room-temperature magnetoresistance in La$_{0.6}$Dy$_{0.1}$Sr$_{0.3}$MnO$_3$/Ag$_x$

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Abstract

The samples of La$_{0.6}$Dy$_{0.1}$Sr$_{0.3}$MnO$_3$/Ag$_x$ ($x = 0.00, 0.02, 0.04, 0.06, 0.08, 0.10, 0.20, 0.25, \text{and} 0.30$) were prepared by using the solid-state reaction method. Their magnetic property, transport behavior, transport mechanism and magnetoresistance effect were studied through the measurements of magnetization-temperature ($M$-$T$) curves, $\rho$-$T$ curves and the fitting of $\rho$-$T$ curves. The results indicated that Ag could take part in the reaction when the doping amount is small. However, when the doping amount is comparatively large, Ag as metallic state mainly deposits on the grain boundary of La$_{0.6}$Dy$_{0.1}$Sr$_{0.3}$MnO$_3$, and then the system forms a two-phase composite. When the Ag doping amount is 30% mole ratio, the resistivity of the sample is one order of magnitude smaller than that of low doped samples, and its peak of magnetoresistance at 292 K and in the magnetic field of 0.2 T strengthens apparently and reaches 16.3%, which is over 7 times as large as 2.2% of La$_{0.6}$Dy$_{0.1}$Sr$_{0.3}$MnO$_3$. The two-phase composite system of magnetoresistance based on perovskite manganite consists of two parts: intrinsic magnetoresistance and extrinsic magnetoresistance. However, extrinsic magnetoresistance comes from spin-dependent scattering (SDS) and spin-polarized tunneling (SPT). Magnetoresistance near $T_C$ increases due to the contribution of intrinsic magnetoresistance and extrinsic magnetoresistance formed by SDS, and magnetoresistance at low temperature is extrinsic magnetoresistance formed by SPT.

Keywords: room temperature; low-field magnetoresistance; two-phase composite; perovskite manganite

1. Introduction

In recent years, the discovery of colossal magnetoresistance (CMR) effect has inspired people’s research enthusiasm for manganites with perovskite structure because CMR effect has potential application value in magnetic sensors, magnetic records, magnetic refrigeration, etc. [1-4]. However, two external conditions are needed for the appearance of CMR effect in manganites: one is that the temperature $T$ is near Curie temperature $T_C$, which usually deviates from room temperature and the other is that the applied magnetic field should be as large as several Tesla. Therefore, it is difficult for CMR effect to obtain the favor of practical application, and besides, the mechanism of magnetoresistance has not been fully explained at present. Thus, the purpose of the relevant investigations is to explore magnetoresistance enhancement at room temperature and in low magnetic field for perovskite manganite.

In 1996, Gupta et al. and Hwang et al. found that manganite single crystal and its epitaxial film hardly exhibit magnetoresistance effect in low magnetic field $H$ under low temperature $T$ (far below $T_C$), but its polycrystalline ceramics and film show apparent magnetoresistance (MR, $\sim 20\%$ in the magnetic field of several hundred Gauss), and is called low-field magnetoresistance (LFMR) effect [5-6]. The discovery of LFMR has drawn widespread attention not only because LFMR needs only the magnetic field of several hundreds and even several tens of Gauss and has application prospect in practical spintronic devices but also because its physical mechanism is different from that of CMR. The mechanism is called spin-polarized tunneling (SPT) or spin-dependent scattering (SDS).

To enhance low-field magnetoresistance, a spin disordering area is usually introduced to the material microstructure. According to the thought, investigators introduced holes at A site, doped tungsten (W), chromium (Cr) and so on at B site in crystal lattices, introduced artificial grain boundaries [7], adopted the composite material of sintered...
perovskite manganite/insulator [8] or sintered perovskite manganite/metal [9] and created magnetic domain walls and so on in the manganites, which could obtain room-temperature and low-field magnetoresistance as large as possible to meet the needs of practical application.

In this paper, La$_{0.6}$Dy$_{0.1}$Sr$_{0.3}$MnO$_3$ with $T_C = 308$ K and with a magnetoresistance of 75% in the magnetic field of 6 T is chosen as the host material, and a two-phase composite was prepared together with the metal Ag. The transport mechanism of the two-phase system and the physical mechanism of low-field magnetoresistance were further discussed.

2. Experimental

The samples were prepared by the following two steps. First, the host material of La$_{0.6}$Dy$_{0.1}$Sr$_{0.3}$MnO$_3$ powder was fabricated by the solid-state reaction method. La$_2$O$_3$ of high purity was dewatered at 600°C for 6 h because it is extremely easy to absorb moisture, then it was matched with the chemical reagents Dy$_2$O$_3$, Sr$_2$O$_3$, and MnO$_2$ of high purity in nominal composition. The mixture was sufficiently ground and prefired at 900°C for 12 h. After cooling naturally, the material was taken out and ground carefully, then sintered at 1100°C for 12 h, and it was processed at 1200°C for 12 h as before to get good crystallinity. Second, the prepared powder and Ag$_2$O powder were mixed in a proper mole ratio and ground, and then pressed into pellets with a diameter of 13 mm and with a thickness of about 1 mm, sintered at 1100°C for 6 h in air, and cooled in the furnace. Thus, a series of doped materials La$_{0.6}$Dy$_{0.1}$Sr$_{0.3}$MnO$_3$/Ag$_x$ (Ag$_x$O$_{2x}$) were obtained, $x$ is the mole ratio between the doped Ag and the host material ($x = 0.00, 0.02, 0.04, 0.06, 0.08, 0.10, 0.20, 0.25$, and $0.30$). Finally, the materials were cut into bulk samples in a long strip shape.

The microstructure of the powder samples was detected by an X-ray diffractometer with Cu K$_\alpha$ radiation made in Dandong, China. M-T curves were measured by M-9300 vibrating sample magnetometer (VSM) made by Lake Shore Company. The samples were cooled to 5 K in zero magnetic field and in the magnetic field of 0.01 T, respectively, and measured in warming condition. The resistivity in zero magnetic field and in the magnetic field of 0.2 T was measured by the standard four-probe method, the applied magnetic field was perpendicular to the current, and the measuring current was kept at 1-10 mA.

3. Results and discussion

Fig. 1 is X-ray diffraction patterns of part samples. It can be seen that the samples with $x = 0.00$ and 0.02 are in good single-phase structure without mixed phase, and their diffraction peaks can be demarcated by the perovskite structure with rhombohedral symmetry. The samples with $x \geq 0.04$ exhibit apparent diffraction peaks of Ag in cubic structure, and the peaks are located at $2\theta = 38.122^\circ$, $44.299^\circ$, $64.601^\circ$, and $77.603^\circ$, respectively. The result indicates that a part of Ag can take part in reaction during sintering process, and Ag ions enter into A site, but the reaction is limited. When $x = 0.04$, the excess Ag deposits and accumulates at the grain surface of the host material, therefore the system becomes a two-phase composite. From Jade6.5 software analysis, it was found that the diameter of the grain is 35 nm.

3.1. Macro-magnetic properties of La$_{0.6}$Dy$_{0.1}$Sr$_{0.3}$MnO$_3$/Ag$_x$

Fig. 2 is the zero-field-cooling (ZFC) and field-cooling (FC) magnetization-temperature ($M$-$T$) curves of three samples with $x = 0.00, 0.04$, and 0.30, respectively. As shown in Fig. 2, the magnetic properties of the three samples are basically the same. When the temperature decreases, the samples transform from paramagnetism to ferromagnetic clusters, and the Curie temperature $T_C$ (defined as the temperature