Temperature stability and linear magnetic field response of the magnetoresistance in Ag$_{0.07}$–La$_{0.67}$Sr$_{0.13}$Ag$_{0.08}$MnO$_3$ composite

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Composite bulk polycrystalline samples of Ag$_{1-x}$La$_{0.67}$Sr$_{0.33}$–Ag$_{0.08}$MnO$_3$ ($x = 0.00, 0.15, 0.20, y = 0.00$; and $x = 0.15, y = 0.03, 0.05$, with $\Delta$ representing cation vacancy at La site) were successfully synthesized using the sol–gel method. It is found that there are two phases in the samples, a cubic structure Ag phase and a perovskite phase. An experimental method for estimating the Ag phase content $\delta$ in the samples is presented. The Ag content $x - \delta$ and the cation vacancy $y + \delta$ were calculated. The Ag phase content and the lattice parameters of the two phases were also investigated using the Rietveld refinement method. The Ag phase contents obtained from the two methods are very close. The influences of $x - \delta$ and $y + \delta$ on the lattice parameters of the perovskite phase, the Curie temperature ($T_C$), the metallic–semiconductor transition temperature ($T_{MI}$), the magnetoresistance (MR), the peak temperature ($T_{MR}$) of the MR, and the temperature stability of the MR of the samples were examined. The Mn–O bond length $L_B$ of the perovskite phase increases with increasing $x - \delta$. However $T_C$, $T_{MI}$, and $T_{MR}$ decrease with increasing $L_B$. For the sample Ag$_{0.07}$La$_{0.67}$Sr$_{0.13}$Ag$_{0.08}$MnO$_3$, under an applied magnetic field of 1.8 T, the MR is stable (9.41 ± 0.32%) in the temperature range 275–305 K; the MR increases linearly with magnetic field up to 1.5 T; and the change of MR with magnetic field, $S_{MR} = d(MR)/d(\mu_0H)$, is as high as about 5.2%/T.
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1 Introduction

The manganite R$_{1-x}$TMnO$_3$ with ABO$_3$ perovskite structure, where R and T are rare earth and alkaline earth ions, respectively, has been extensively studied due to its abundant physics related to colossal magnetoresistance (CMR) and its potential applications in magnetic devices [1–4]. In general, the MR of a perovskite manganite reaches a maximum only at the Curie temperature ($T_C$), which is generally beyond the room temperature region. Also, the MR changes abruptly as the temperature approaches the Curie temperature. These properties severely limit the practical applications of these materials [5–8].

The Curie temperature of the perovskite manganite R$_{1-x}$TMnO$_3$ is related to the average size $\langle r_A \rangle$ of cations in the A positions and the mean manganese valence $\langle V_{Mn} \rangle$. The vacancy concentration in the A-site will influence the value of $\langle V_{Mn} \rangle$, thereby having an effect on the electronic and magnetic properties. Some investigations concerning vacancy doping at the A-site in perovskite manganites are described in Refs. [9–11].
For practical utilization, low-field MR (LFMR) around room temperature is necessary. Therefore, several studies have been concentrated on synthesizing new material systems that provide LFMR around room temperature [12–15]. Ye et al. [16] reported the structural, magnetic, and electronic properties of polycrystalline LaMnO$_3$ with Ag doping. Its MR can reach 14% under a relatively low field of 0.4 T at 288 K. Here MR = [(ρ$_0$ - ρ$\delta$)/ρ$_0$] × 100%, where ρ$_0$ and ρ$\delta$ are the resistivities without and with magnetic field. However, the MR decreases to 5.2% at 300 K. Wu et al. reported the microstructure, magnetic, and transport properties of the heterogeneous system with a nominal composition of (1/4)Ag$_2$O–La$_{0.833}$K$_{0.167}$MnO$_3$. Its MR value is as high as 64% with a magnetic field of 5.5 T at 300 K. However, it decreases to 50 and 52% at 283 and 322 K, respectively [17, 18]. Pal et al. reported the magnetization and transport properties of the La$_{0.8}$Pb$_{0.2}$MnO$_3$ + x wt% Ag (x = 0–20) system. For samples with x = 2.5 and 5%, the MR temperature stability is better than that reported previously, but the stable MR is only about 4% under a magnetic field of 1.5 T in the temperature range 288–318 K [19].

In the work reported in this paper, we studied the phase structure and magnetic and MR properties of the composite Ag$_x$–La$_{0.6}$Sr$_{0.33}$–Ag$_{y}$–MnO$_3$ using X-ray diffraction, magnetization, and resistivity measurements. It was found that, for the sample Ag$_{0.07}$–La$_{0.67}$Sr$_{0.13}$Ag$_{0.08}$MnO$_3$, under an applied field of 1.8 T, the MR is stable (9.41 ± 0.32%) in the temperature range 275–305 K; the MR increases linearly with magnetic field up to 1.5 T; and the change of MR with magnetic field, SMR = d(MR)/d(µH), is as high as about 5.2%/T. These three good properties have been obtained for one sample, which are important for the potential applications of this MR material as a magnetic field sensor.

2 Experimental

Composite samples of Ag$_x$–La$_{0.6}$Sr$_{0.33}$–Ag$_{y}$–MnO$_3$ (x = 0.00, 0.15, 0.20, y = 0.00; and x = 0.15, y = 0.03, 0.05, with A representing cation vacancy at La site) were prepared by the sol–gel method [10]. This method has the advantage of using a low-temperature synthesis, which not only results in smaller grains but also produces high-purity and homogeneous samples. Stoichiometric quantities of La$_2$O$_3$, Sr(NO$_3$)$_2$, AgNO$_3$, and Mn(NO$_3$)$_2$ were dissolved in dilute HNO$_3$ solution; suitable amounts of citric acid and ethylene glycol as complexing agents were added, until a completely homogeneous transparent solution was obtained. This solution was subjected to slow evaporation at 360 K until a highly viscous residue was formed. Finally a gel was developed on heating at 473 K for 24 h. The gel was thermally treated at 873 K for 5 h for the purpose of organic precursor decomposition. After grinding, the samples were calcined in air at 1073 K for 10 h and furnace cooled. These powder samples were pressed into pellets and then sintered in air at 1673 K for 14 h followed by furnace cooling. Finally the bulk samples were obtained.

Phase identification of the samples was performed using X-ray diffraction (XRD) with an 18 kW Rigaku max-RB diffractometer with Cu K$_\alpha$ radiation. Magnetization measurements were carried out using a Lake Shore vibrating sample magnetometer (VSM) in the temperature range 300–400 K. In order to determine the Curie temperature, we plotted a curve of dM/dT along the curve of magnetization versus temperature. The temperature for which dM/dT tends to zero with increasing temperature indicated the Curie temperature ($T_C$). All Curie temperature measurements were performed at a field of 0.05 T. The morphologies of the powder samples were investigated using an S-570 scanning electron microscopy (SEM) instrument. The temperature and magnetic field dependences of the resistivity were measured with an Oxford Maglab Exa Measurement System using the standard dc four-probe method with the applied field parallel to the direction of the current.

3 Results and discussion

3.1 Phase structure of powder samples

The structural characterization of the powder samples used to prepare the bulk samples was carried out by means of XRD. The powder samples were thermally treated at 873 K for 5 h and at 1073 K for 10 h. The XRD patterns obtained for samples with x = 0.00, 0.15, 0.20, y = 0.00 and x = 0.15, y = 0.00, 0.03,
0.05 are shown in Fig. 1. The results indicate that our samples are composites composed of an R3c perovskite phase and a nonmagnetic Ag metal phase of space group Fm3m. The compositions can therefore be written as Ag$_{\delta}$−La$_{0.67}$Sr$_{0.33}$−$x$−$y$Ag$_x$−$\delta$δ$\Delta$y+δMnO$_3$. It is indicated that there are vacancies with mole content $\delta$ in the perovskite phase of the samples even for $y = 0.00$, and that the ratio of the Ag metal phase mole content to the perovskite phase is $\delta$:1. From Fig. 1, the intensity ratio, $R = I_A/I_P$, between main peaks of the Ag and La$_{0.67}$Sr$_{0.33}$−$x$−$y$Ag$_x$−$\delta$δ$\Delta$y+δMnO$_3$ phases, can be determined as shown in Table 1. In addition, there is very little MnO$_3$ phase in samples 3, 4, and 5, indicated by XRD diffraction peaks at $2\theta = 28.88^\circ$ and $36.12^\circ$.

In order to estimate the mole content of Ag phase in the samples, $\delta$, based on the intensity ratio $R = I_A/I_P$ between the main peaks of the Ag and perovskite phases in Fig. 1, another group of samples (La$_{0.67}$Sr$_{0.33}$MnO$_3$)$_{1-r}$+(Ag)$_r$ ($r = 0.1, 0.2, 0.3$) were studied. AgNO$_3$ was mixed with the La$_{0.67}$Sr$_{0.33}$MnO$_3$ powder prepared by the method described above. After grinding, the mixture was thermally treated at

Table 1 XRD measurement results for Ag$_{\delta}$−La$_{0.67}$Sr$_{0.33}$−$x$−$y$Ag$_x$−$\delta$δ$\Delta$y+δMnO$_3$ powder composite samples. Here $R = I_A/I_P$ is the intensity ratio between main peaks of the Ag and perovskite phases in Fig. 1, another group of samples (La$_{0.67}$Sr$_{0.33}$MnO$_3$)$_{1-r}$+(Ag)$_r$ ($r = 0.1, 0.2, 0.3$) were studied. AgNO$_3$ was mixed with the La$_{0.67}$Sr$_{0.33}$MnO$_3$ powder prepared by the method described above. After grinding, the mixture was thermally treated at

<table>
<thead>
<tr>
<th>no.</th>
<th>$x$ (mol)</th>
<th>$y$ (mol)</th>
<th>$2\theta$</th>
<th>$I_p$</th>
<th>$2\theta$</th>
<th>$I_{\Lambda}$</th>
<th>$R$</th>
<th>$\delta$ (mol)</th>
<th>$x - \delta$ (mol)</th>
<th>$y + \delta$ (mol)</th>
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<td>2698</td>
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<td>0.069</td>
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<td>0.088</td>
<td>0.112</td>
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<td>32.64</td>
<td>35880</td>
<td>38.08</td>
<td>2698</td>
<td>0.075</td>
<td>0.069</td>
<td>0.081</td>
<td>0.069</td>
</tr>
<tr>
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<td>0.05</td>
<td>32.64</td>
<td>26471</td>
<td>38.06</td>
<td>1902</td>
<td>0.072</td>
<td>0.066</td>
<td>0.084</td>
<td>0.116</td>
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</tbody>
</table>
873 K for 5 h. After grinding again, the samples were calcined in air at 1073 K for 10 h and furnace cooled. The XRD patterns are shown in Fig. 2a. According to Fig. 2a, we can obtain the dependence of the mole ratio \( r/(1 - r) \) between the Ag and La\(_{0.67}\)Sr\(_{0.33}\)MnO\(_3\) phases on their diffraction intensity ratio \( R \), as shown in Fig. 2b.

By means of Fig. 2b, the mole content of the Ag phase, \( \delta \), in the Ag\(_x\)-La\(_{0.67}\)Sr\(_{0.33}\)-\( x \)-\( y \)-Ag\(_{y}\)-\( \delta \)-La\(_{0.67}\)Sr\(_{0.33}\)MnO\(_3\) samples was estimated. Subsequently, the Ag content and the cation vacancy at La site in the La\(_{0.67}\)Sr\(_{0.33}\)-\( x \)-\( y \)-Ag\(_{y}\)-\( \delta \)-La\(_{0.67}\)Sr\(_{0.33}\)MnO\(_3\) phase, \( x - \delta \) and \( y + \delta \), respectively, were calculated, as shown in Table 1.

It can be seen from Table 1 that when \( x = 0.00 \), both \( x - \delta \) and \( y + \delta \) increase with increasing \( x \); when \( x = 0.15 \), \( y + \delta \) increases with increasing \( y \), and \( x - \delta \) decreases at first and then increases with increasing \( y \). It will be seen from the discussion below that \( x - \delta \) and \( y + \delta \) are important factors influencing the lattice parameters of the perovskite and the magnetic and electrical properties of the samples.

A Rietveld refinement of the XRD patterns shown in Fig. 1 was also carried out. The fitted results are shown in Fig. 3 and Tables 2 and 3 (where Pha.1 (wt%) and Pha.2 (wt%) are the content of the R3c perovskite phase and the nonmagnetic Fm3m Ag phase, respectively). It can be seen from Table 2 that the mole content \( \delta \) of nonmagnetic Fm3m Ag phase obtained by fitting is very close to the value of \( \delta \) in Table 1 estimated from Fig. 2b. It can also be seen from Table 2 that there are very few Mn ion vacancies in the perovskite phase of samples 3, 4, and 5. If these Mn ions separated from perovskite phase exist in MnO\(_3\) phase, as shown in Fig. 1, the contents \( \delta (\text{MnO}_3) \) of MnO\(_3\) phases in samples 3, 4, and 5 are 0.0118, 0.0084, and 0.0104 mol, about 1 mol% of the samples, which are far less than the mole content of Ag phase as shown in Table 2.

The lattice parameters \( a \) and \( c \) and the crystal cell volume \( V \) calculated by means of the Rietveld refinement are shown in Table 3. The following can be seen from Fig. 1 and Table 3: for the three samples \( x = 0.00 \), 0.15, or 0.20 and \( y = 0.00 \), Mn–O–Mn bond angle \( \theta \) = 167.05, 164.15, 161.79, and the cell parameter ratio \( c/a = 2.4632, 2.4313, 2.4274 \) decrease with increasing \( x - \delta \); Mn–O bond length \( L_a = 1.9494, 1.9556, 1.9648 \) increases with increasing \( x - \delta \). For the three samples \( x = 0.15, y = 0.00 \), 0.03, 0.05, \( \Delta \theta = 164.15, 162.20, 162.26 \), and the ratio \( c/a = 2.4313, 2.4268, 2.4274 \) decrease at first and then increase with increasing and then decreasing \( x - \delta \) at first and then decreases with increasing and then decreasing \( x - \delta \). In summary, the tendencies of \( \Delta \theta \) and \( c/a \) change inversely with \( x - \delta \), and the tendency of \( L_a \) changes similarly to \( x - \delta \). These changes are the description of the lattice distortion. The decrease of \( A_{4p} \) and increase of \( L_a \) result in an enhancement of the lattice distortion, thus weakening the double-exchange interaction [1] in Mn\(^{3+}\)–O–Mn\(^{4+}\). It will be seen in the discussion below that the magnetic and electrical properties of the samples are related to these changes.
Table 2  Data for the Rietveld refinement and the computed results. The mole content of La$^{3+}$, Sr$^{2+}$, Ag$^+$, Mn$^{3+}$, Mn$^{4+}$, O$^{2-}$ ions, the refined factors $R_p$, $R_{wp}$, and $s$, the computed content Pha.1 of perovskite phase, the content Pha.2 and $\delta_C$ of metal Ag phase, and content $\delta$(MnO$_4$) of MnO$_4$ phase.

<table>
<thead>
<tr>
<th>no.</th>
<th>content of ions in perovskite phase</th>
<th>$R_p$ (%)</th>
<th>$R_{wp}$ (%)</th>
<th>$s$</th>
<th>Pha.1 (wt%)</th>
<th>Pha.2 (wt%)</th>
<th>$\delta_C$ (mol)</th>
<th>$\delta$(MnO$_4$) (mol)</th>
</tr>
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<td>13.8 16.6 3.42</td>
<td>100.0 0.00 0.000 0.0000</td>
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</tr>
<tr>
<td>2</td>
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<td>6.62 8.67 2.16</td>
<td>96.74 3.26 0.069 0.0000</td>
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</tr>
<tr>
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<tr>
<td>4</td>
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<tr>
<td>5</td>
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<td>9.39 13.0 2.81</td>
<td>96.95 3.05 0.063 0.0104</td>
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</table>

Fig. 3 (online colour at: www.pss-a.com) Rietveld refinement results of XRD patterns of powder samples: a) sample 1, b) sample 2, c) sample 3, d) sample 4, e) sample 5.
Table 3  Refined structural parameters, calculated Mn–O bond lengths $L_B$, Mn–O–Mn bond angles $A_B$, and the lattice parameter ratio $c/a$ of the perovskite phase. $a$(Ag) is the crystal lattice constant of Ag phase.

<table>
<thead>
<tr>
<th>no.</th>
<th>coordinates of ions in the perovskite cell ($u$, $v$, $w$)</th>
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<th>lattice parameters of the perovskite cell</th>
<th>$a$ ($\text{Å}$)</th>
<th>$c$ ($\text{Å}$)</th>
<th>$V$ ($\text{Å}^3$)</th>
<th>$L_B$ ($\text{Å}$)</th>
<th>$A_B$ ($^\circ$)</th>
<th>$c/a$</th>
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</table>

3.2 Morphology of the powder sample

Figure 4 shows the SEM morphology of a powder sample (no. 2) of $\text{Ag}_{0.07}\text{La}_{0.67}\text{Sr}_{0.18}\text{Ag}_{0.08}\Delta_{0.07}\text{MnO}_3$ after heat processing first at 873 K for 5 h then at 1073 K for 10 h in air. From Fig. 4 it can be seen that the sample prepared by the sol–gel method possesses homogeneous globular-shaped grains. The grain size is about 100 nm, with the larger grains consisting of smaller grains joined together.

3.3 Magnetization versus temperature of bulk samples

The upper panel of Fig. 5 shows the magnetization $M$ versus temperature $T$ for the bulk samples, under an applied magnetic field of 0.05 T. The lower panel shows $dM/dT$ versus temperature, for which the

Fig. 4  SEM morphology of powder sample 2.

Fig. 5  Magnetization $M$ and $dM/dT$ versus temperature for composite bulk samples 1 ($x = 0.00$, $y = 0.00$), 2 ($x = 0.15$, $y = 0.00$), 3 ($x = 0.20$, $y = 0.00$), 4 ($x = 0.15$, $y = 0.03$), and 5 ($x = 0.15$, $y = 0.05$) with an applied field $\mu H = 0.05$ T.
Table 4  Curie temperature $T_c$, metal–semiconducting transition temperature $T_{MI}$, maximum value $MR_{\text{max}}$ of the MR, and corresponding temperature $T_{MR}$ for the bulk samples $\text{Ag}_{x} \text{La}_{0.67} \text{Sr}_{0.33} \text{Ag}_{\delta-\text{MnO}_3}$.

<table>
<thead>
<tr>
<th>no.</th>
<th>$x$ (mol)</th>
<th>$y$ (mol)</th>
<th>$L_B$ (Å)</th>
<th>$A_B$ (°)</th>
<th>$T_C$ (K)</th>
<th>$T_{MI}$ (K)</th>
<th>$T_{MR}$ (K)</th>
<th>$MR_{\text{max}}$ (%)</th>
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<td>320</td>
<td>302</td>
<td>26</td>
</tr>
<tr>
<td>2</td>
<td>0.15</td>
<td>0.00</td>
<td>1.9556</td>
<td>164.15</td>
<td>346</td>
<td>349</td>
<td>330</td>
<td>35</td>
</tr>
<tr>
<td>4</td>
<td>0.15</td>
<td>0.03</td>
<td>1.9638</td>
<td>162.20</td>
<td>335</td>
<td>339</td>
<td>316</td>
<td>35</td>
</tr>
<tr>
<td>5</td>
<td>0.15</td>
<td>0.05</td>
<td>1.9632</td>
<td>162.26</td>
<td>346</td>
<td>353</td>
<td>333</td>
<td>40</td>
</tr>
</tbody>
</table>

Curie temperatures ($T_c$) of the samples are determined for $dM/dT$ tending to zero. Values of $T_c = 380$, 346, 324, 335, and 346 K for samples 1 ($x = 0.00$, $y = 0.00$), 2 ($x = 0.15$, $y = 0.00$), 3 ($x = 0.20$, $y = 0.00$), 4 ($x = 0.15$, $y = 0.03$), and 5 ($x = 0.15$, $y = 0.05$) are obtained, as shown in Table 4. Comparing the data of Table 4 with those of Table 3, we can see that $A_B$ and $L_B$ of the samples are the important factors in determining $T_c$: it decreases with increasing $L_B$ and decreasing $A_B$. According to Ref. [1], there is a maximum value of the Curie temperature in $\text{La}_{1-z} \text{Sr}_z \text{MnO}_3$ when $z = 0.33$. This suggests that the most stable crystal structure and the strongest double-exchange interaction in $\text{Mn}^{3+}$–$\text{O}$–$\text{Mn}^{4+}$ in $\text{La}_{0.67} \text{Sr}_{0.33} \text{MnO}_3$ are found with a certain Mn–O bond length ($L_B$). The variation of $L_B$ corresponding to ($L_B$)$_0$ due to changing Sr content, affects the stability of the crystal structure and results in a weakening of the double-exchange interaction in $\text{Mn}^{3+}$–$\text{O}$–$\text{Mn}^{4+}$, and a decreasing value of $T_c$. This may be one of the important reasons for the variation of $T_c$ for our samples.

3.4 Temperature dependence of the resistivity and MR of the bulk samples

The temperature dependences of the resistivity measured at zero field and in an applied field ($\mu_0 H = 1.8T$) for the samples are plotted in Figs. 6 and 7. It can be seen that resistivity of these samples is very small, of the order of about $10^{-4}$ Ω m. The samples show metallic conductivity at low temperature and semiconducting conductivity at high temperature. The transition is characterized by a maximum of resistivity at the metallic–semiconducting transition temperature $T_{\text{MR}}$. For samples 2, 3, 4, and 5, their $T_{\text{MR}}$
values are 349, 320, 339, and 353 K, respectively, and the change of $T_{\text{MI}}$ with Mn–O–Mn bond angle $A_B$ and Mn–O bond length $L_B$ is similar to that of the corresponding Curie temperature ($T_C$) of the samples, as shown in Fig. 8 and Table 4.

The MR is defined as $\text{MR} = \left(\frac{\rho_0 - \rho_H}{\rho_0}\right) \times 100\%$, where $\rho_0$ and $\rho_H$ are the resistivities without and with magnetic field. Application of a magnetic field considerably reduces the resistivity over the whole temperature range measured. Negative MR is therefore seen for all the samples. We also obtained the MR of the samples as a function of temperature. The results are plotted in Figs. 6 and 7. It can be seen that there is a maximum value MR$_{\text{max}}$ of the MR at a certain temperature $T_{\text{MR}}$ for each sample. For samples 2, 3, 4, and 5, the MR$_{\text{max}}$ values are 35, 26, 35, and 40%, and the corresponding $T_{\text{MR}}$ are 330, 302, 316, and 333 K, respectively. The change in $T_{\text{MR}}$ with Mn–O–Mn bond angle $A_B$ and Mn–O bond length $L_B$ is similar to those of $T_C$ and $T_{\text{MI}}$, as shown in Fig. 8 and Table 4.

It is worth noting that samples 3 and 5 both have good temperature stability of MR and high $S_{\text{MR}}$. Here $S_{\text{MR}} = \frac{d(\text{MR})}{d(\mu_0 H)}$.

In Fig. 7b, it can be seen there is a stable MR of 9.41 ± 0.32% in the temperature range between 275 and 305 K under an applied magnetic field of $\mu_0 H = 1.8$ T for sample 5. The applied field dependence of
the MR measured at 295 K for sample 5 is shown in Fig. 9, which clearly indicates that there is a linear dependence of MR on field up to $\mu H = 1.5$ T, the change of MR with magnetic field being $S_{MR} = 5.2$%/T. It can be seen that the MR increases linearly with increasing field, and reaches 7.7% when $\mu H = 1.5$ T.

In Fig. 6b, there is almost a plateau-type maximum of MR = 25.0 ± 0.6% over a wide temperature range between 295 and 315 K for sample 3. The applied field dependence of the MR measured at 300 K is shown in Fig. 10. It can be seen that the MR increases with increasing field, and reaches 49% when $\mu H = 6$ T. The inset in Fig. 10 clearly indicates that there is a linear dependence of MR on temperature up to $\mu H < 1.2$ T, the change of MR with magnetic field being $S_{MR} = 16.9$%/T.

Therefore, a good MR temperature stability and high $S_{MR}$ for perovskite-type manganese oxides in the region of room temperature have been obtained simultaneously for some of the samples investigated. This is important for the potential applications of these MR materials.

4 Conclusions

Composite polycrystalline samples of $\text{Ag}_{x}\text{La}_{0.67}\text{Sr}_{0.33-x}\text{Ag}_{y}\text{MnO}_3$ have been successfully synthesized by the sol–gel method. XRD analyses of the samples have revealed that there are two phases of cubic structure Ag and rhombohedral structure perovskite. It is found that the Ag content $x$ and the cation vacancy $y + \delta$ in the perovskite phase can influence the Mn–O–Mn bond angle $A_{B}$ and Mn–O bond length $L_{B}$. $A_{B}$ decreases with increasing $x - \delta$ and $L_{B}$ increases with increasing $x - \delta$. Measurement of the magnetic and conductive properties indicates that $A_{B}$ and $L_{B}$ can influence the Curie temperature ($T_{C}$), the metallic–semiconducting transition temperature ($T_{MI}$), and the temperature ($T_{MR}$) at MR peak value. As to the factors influencing the MR and temperature stability of MR, except for $x - \delta$ and $y + \delta$, there might be other ones, such as the existence of few of Ag phase and MnO$_2$, and so on. There is a Mn–O bond length ($L_{B}$) corresponding to $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$. The variation of the Mn–O bond length corresponding to ($L_{B}$) will reduce the stability of the perovskite structure, thus resulting in $T_{C}$, $T_{MI}$, and $T_{MR}$ all decreasing. For sample $\text{Ag}_{0.07}\text{La}_{0.67}\text{Sr}_{0.33}\text{Ag}_{0.08}\text{MnO}_3$, under an applied field of 1.8 T, there is a MR with a maximum of 40% at 333 K, a stable MR of 9.41 ± 0.32% in the temperature range 275–305 K, and a linear increase of MR with magnetic field up to 1.5 T, which is as high as about 5.2%/T. These properties are important for the potential applications of this MR material.
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References