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Inhomogeneous phase separation and domain wall dynamics in orthorhombically distorted $La_{0.87}MnO_x$

K De, S Majumdar and S Giri

Department of Solid State Physics, Indian Association for the Cultivation of Science, Jadavpur, Kolkata 700 032, India

E-mail: sspsg2@iacs.res.in (S Giri)

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Abstract

We observe interesting magnetization and resistivity results in the orthorhombically distorted self-doped manganite, $La_{0.87}MnO_x$. A significant irreversibility between zero-field-cooled and field-cooled resistivities as well as magnetization data is clearly observed up to a temperature which is well above the both paramagnetic to ferromagnetic (T_c) and metal to insulator (T_{MI}) transition temperatures. In the ferromagnetically ordered and metallic states the magnetotransport results suggest the influence of domain wall dynamics. An interesting scenario of memory effects through the domain wall dynamics is strikingly observed in the relaxation of resistivity in a limited temperature region. The characteristic features of magnetotransport behaviour are suggested to be due to the coexistence of structurally driven inhomogeneous phase separation and domain wall dynamics.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Investigation of the hole-doped manganites still demands special attention because of the wide range of intriguing magnetic and transport properties [1, 2]. Recently, the self-doped manganites with composition $La_{1-\delta}MnO_x$ have also been shown to exhibit structural, magnetic and transport properties that are very similar to those of the hole-doped manganites. As a result of La deficiency, the oxidation state of Mn changes partially from Mn^{3+} to Mn^{4+} in association with the spectacular changes in the physical properties like the hole doping in manganites. Systematic studies in $La_{1-\delta}MnO_x$ show that the structural, electronic transport and magnetic properties strongly depend on δ and x [3–7]. The maximum La deficiency in the single-phase perovskite has been noticed in $La_{0.87}MnO_x$, where physical properties are found to be highly sensitive to x. In the case of the most reduced sample, a paramagnetic to orbitally ordered antiferromagnetic (AFM) transition is observed like in stoichiometric $LaMnO_3$, where the

orthorhombic phase is noticed at room temperature. The gradual transition from the orbitally ordered orthorhombic to the orbitally disordered ferromagnetic (FM) state has been observed with the increase of oxygen stoichiometry. With the further increase of oxygen stoichiometry a structural change from the orbitally disordered orthorhombic phase to the monoclinic phase is observed at room temperature, where the dynamic orbital correlations favour the FM state. Recently, examples of metastabilities in the self-doped manganites have been reported based on low-field dc and ac susceptibility measurements, which are mainly suggested due to the domain wall dynamics in the system [7–9]. Because of the interplay among transport, magnetic, orbital, and structural degrees of freedom, the self-hole-doped manganites attract considerable attention, which has not yet focused widely like that on hole-doped and charge-ordered (CO) manganites.

In this paper, we report on the magnetic and electrical transport properties of $La_{0.87}MnO_x$ under different conditions of applied magnetic field and thermal cycling. The results exhibit the evidence of metastable states over a wide temperature range; these states are found even at much higher temperature than the paramagnetic (PM) to FM and metal to insulator (MI) transitions. The metastabilities in the magnetotransport behaviour are found to be strongly influenced by the structurally driven inhomogeneous phase separation (PS) and domain wall dynamics in the FM ordered state. In addition, an interesting feature of a memory effect is observed over a limited temperature range in the dynamics of resistivity for the orthorhombically distorted oxygen-deficient compound.

2. Experimental details

A polycrystalline sample with nominal composition $La_{0.87}MnO_x$ was prepared by a chemical route as described in the literature [10]. The final heat treatment was performed at 1200 °C for 12 h in air; the samples were then cooled down to room temperature by furnace cooling. A portion of the sample annealed in air was further annealed in the presence of oxygen at 1000 °C for ≈6 h. The single phase of the sample was characterized by an x-ray diffractometer (Seifert XRD 3000P) using Cu Kα radiation. The powder x-ray diffraction analysis confirms the single phase of the compound, which could be indexed to the orthorhombic structure ($Pnma$). In accordance with the reported results, the crystal structure of the oxygen-annealed sample was indexed to the monoclinic structure ($I2/a$) [5]. For simplicity, we denote the oxygen-annealed sample as $La_{0.87}MnO_x(O_2)$. The magnetoresistance (MR) was measured by the standard four-probe technique; the equipment was fitted with an electromagnet and a commercial closed-cycle refrigerator operating down to 10 K (Janis Research Inc.). The magnetization (M) was measured using a commercial superconducting quantum interference device (SQUID) magnetometer (MPMS, XL). In zero-field-cooled (ZFC) measurements of resistivity (ρ) and M, the sample was cooled down to the desired temperature at zero magnetic field and the measurements were performed in the heating cycle just after the application of applied magnetic field. For the field-cooled (FC) condition, the sample was cooled down to the desired temperature with a magnetic field and the measurements were performed while heating.

3. Experimental results

3.1. Magnetic properties

The temperature dependence of M measured at 1 kOe is shown in the top panel of figure 1, indicating a PM to FM transition (T_c) at 130 K, which was obtained from the minimum of the dM/dT against T plot. The transition is not sharp like a typical PM to FM transition, but

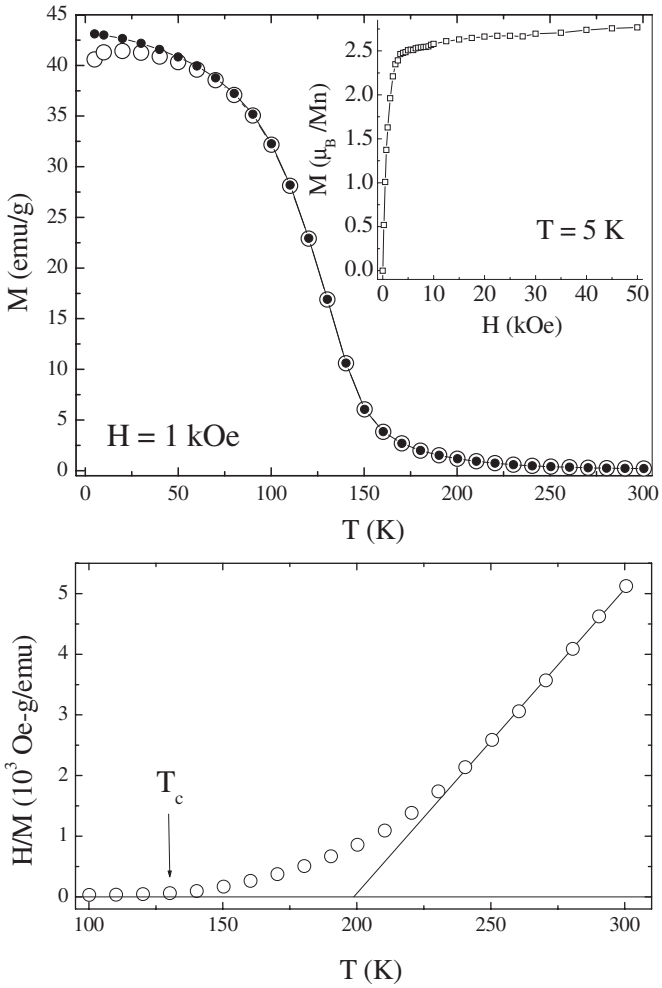

Figure 1. The top panel shows the temperature dependence of magnetization under zero-field-cooled (open circle) and field-cooled (closed circle) conditions measured at 1 kOe. The inset shows the magnetization curve at 5 K. The bottom panel exhibits the inverse susceptibility. The solid line indicates Curie–Weiss behaviour. The arrow indicates T_c.

is rather spread over a wide temperature region. At low temperature the ZFC magnetization (M_{ZFC}) indicates a decreasing trend with a broad peak I_P around 15 K, while M_{ZFC} deviates from the FC magnetization (M_{FC}) around ∼85 K. The inset of the top panel of figure 1 exhibits the magnetization curve at 5 K, which does not saturate even at 50 kOe. The value of the moment at 50 kOe is found to be 2.77 μ_B/Mn, which is less than that of the effective moment, $\mu_{eff} = 5.91\ \mu_B$/Mn, obtained from the linearity of the inverse susceptibility with paramagnetic Curie temperature, $\theta \approx 200$ K. Note that the value of μ_{eff} is much larger than the spin-only value for $S = 2$, $\mu_{theo} = 4.90\ \mu_B$, suggesting the existence of FM clusters in accordance with the reported results [3, 5, 10]. The inverse susceptibility deviates from the Curie–Weiss behaviour around ∼240 K, which is much higher than T_c as seen in the bottom panel of figure 1. The orthorhombic crystal structure at room temperature and the value of the moment at 5 K suggest the oxygen stoichiometry $x \sim 2.87$, in consistence with the reported results [5].

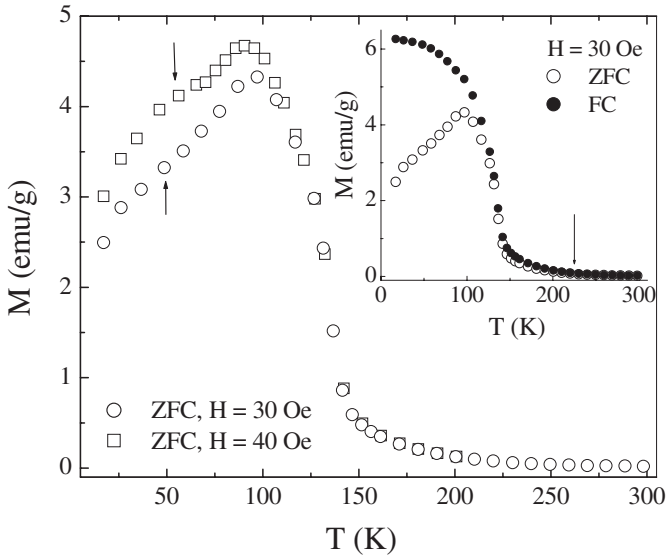

Figure 2. Temperature dependence of magnetization measured at 30 and 40 Oe in zero-field-cooled (ZFC) conditions. The arrows indicate the anomalies below the broadened peak. The inset exhibits the field-cooled effect of magnetization, where the arrow indicates the temperature of bifurcation between ZFC and FC magnetizations.

We also measured the temperature variation of M in low dc magnetic field; this is shown in figure 2. The temperature dependence of M at 30 and 40 Oe exhibits different characteristic features compared to the measurement at 1 kOe. In the inset of figure 2, the strong ZFC–FC effect of magnetization, measured at 30 Oe, is shown. The M_{FC} curve surprisingly deviates from that of M_{ZFC} around ∼230 K, which is consistent with the deviation of the inverse susceptibility from the Curie–Weiss law around the same temperature region. In the case of low-field measurement, T_{c} obtained from the minimum of the $\mathrm{d}M/\mathrm{d}T$ against T plot was found to be close to that of the high-field measurements. The external magnetic field does not practically change the phase transition at T_{c}. A peak in M_{ZFC}, T_{p}, is noticed around 97 and 90 K for the magnetic field at 30 and 40 Oe, respectively, which is consistent with the T_{p} at 1 kOe, indicating that T_{p} shifts towards low temperature with increasing magnetic field (see table 1). In addition to T_{p}, an anomaly, $T_{\mathrm{a}}(M)$, is noticed in M_{ZFC} around ∼65 and ∼48 K for 40 and 30 Oe, respectively, as seen in table 1. In contrast to the field dependence of T_{p}, $T_{\mathrm{a}}(M)$ is shifted towards higher temperature with magnetic field. Note that similar results were also reported in M_{ZFC} for $\mathrm{La}_{1-\delta}\mathrm{MnO}_3$ ($1/16 \leqslant \delta \leqslant 1/8$), where the anomaly in the M_{ZFC} was, in fact, suggested to be due to the domain wall pinning effects [7].

3.2. Transport properties

The temperature dependence of ρ for $\mathrm{La}_{0.87}\mathrm{MnO}_x$ is shown in the top panel of figure 3; these values were measured in zero magnetic field and 2 kOe magnetic field under both ZFC and FC conditions. The temperature dependence of ρ in zero field exhibits a peak at around 144 K (T_{MI}), which is found to be much larger than T_{c}. The nature of the broadened peak at 144 K looks different in contrast to the sharp peak at the temperature of the metal–insulator transition for hole-doped compounds. In between 35 and 153 K the typical metallic behaviour

Table 1. Metal–insulator transition (T_{MI}) and the anomaly in $d\rho/dT$, $T_a(\rho)$, under different field-cooled conditions (FCC), and peak, T_p, and anomaly in ZFC magnetization, $T_a(M)$, in different magnetic fields (H).

		Transport		Magnetic		
Sample	FCC	T_{MI} (K)	$T_a(\rho)$ (K)	H (Oe)	T_p (K)	$T_a(M)$ (K)
$La_{0.87}MnO_x$	$H = 0$	144	56	30	97	48
	ZFC (2 kOe)	149	56	40	90	65
	FC (2 kOe)	153	55	1000	15	—
$La_{0.87}MnO_x(O_2)$	$H = 0$	260	—	—	—	—

($d\rho/dT > 0$) is noticed. The small increase of ρ is clearly observed with a minimum in ρ at 35 K, which is more pronounced in the temperature dependence of the low-field MR. The effect of the grain boundary contribution to ρ might have dominant role in the low-field MR for the polycrystalline sample. The effect of MR is noticed below ∼230 K, while the maximum of MR is observed near T_c, as seen in figure 3. The bottom panel of figure 3 shows the plot of $d\rho/dT$ against T in the selected temperature region under different conditions of applied magnetic field. An anomaly, $T_a(\rho)$, is consistently noticed around 56 K in zero magnetic field, which does not change noticeably under ZFC conditions. The anomaly is slightly shifted to 55 K under FC conditions in accordance with the effect of external magnetic field dependence of $T_a(M)$ observed in the low-field magnetization study (figure 2), as seen in table 1. It is interesting to point out that the present resistivity result is sensitive to the effect of domain wall movement even at zero magnetic field, if we believe the anomaly noticed in the magnetization study to be ascribed to the effect of domain wall pinning [7].

The bifurcation of ZFC and FC resistivities is clearly observed below ∼190 K (top panel of figure 3), which is noticed to be much higher than T_c and T_{MI}. The values of T_{MI} are found to be 149 and 153 K under ZFC and FC conditions, respectively, as seen in table 1. The bifurcation of ZFC and FC data has commonly been found in the temperature dependence of M, either due to metastability from the glassy component or from domain wall pinning [11]. The evidence of the ZFC–FC effect in ρ is rather a rare example among transition metal oxides, but it has recently been reported in a few manganites [12, 13]. A strong ZFC–FC effect in ρ was observed in phase-separated $(La_{0.8}Gd_{0.2})_{1.4}Sr_{1.6}Mn_2O_7$ below the spin glass (SG) temperature (T_{SG}), where glassy behaviour was ascribed to the competing magnetic interactions between FM and AFM states [12]. The other example of ZFC–FC effect in ρ was observed in CO compounds, where the CO state was destroyed by the application of a strong magnetic field, resulting in the different T-dependence between FC and ZFC resistivities below the charge-ordering temperature (T_{CO}) [13]. In the present case, the origin of the FC effect in ρ is different from the above cases: it shows another kind of example of the FC effect in ρ in the orthorhombically distorted self-doped manganites. In order to understand the origin, we incorporated the above experimental protocol for $La_{0.87}MnO_x(O_2)$ as seen in figure 4. In contrast to the oxygen-deficient sample, the bifurcation between ZFC and FC resistivities disappears. In place of a broadened peak for the oxygen-deficient sample a sharp peak is observed at 260 K in association with a broad hump around 240 K. The features of the temperature dependence is similar to the reported results [5], though the sharp peak in the present observation is 10 K higher than the sample with $x = 2.95$. The temperature dependence of $[\rho(0) - \rho(2\text{ kOe})]$ clearly indicates a sharp peak at 258 K, where T_c is expected, indicating $x \geqslant 2.96$ for $La_{0.87}MnO_x(O_2)$. The temperature dependence of ρ for $La_{0.87}MnO_x(O_2)$ exhibits

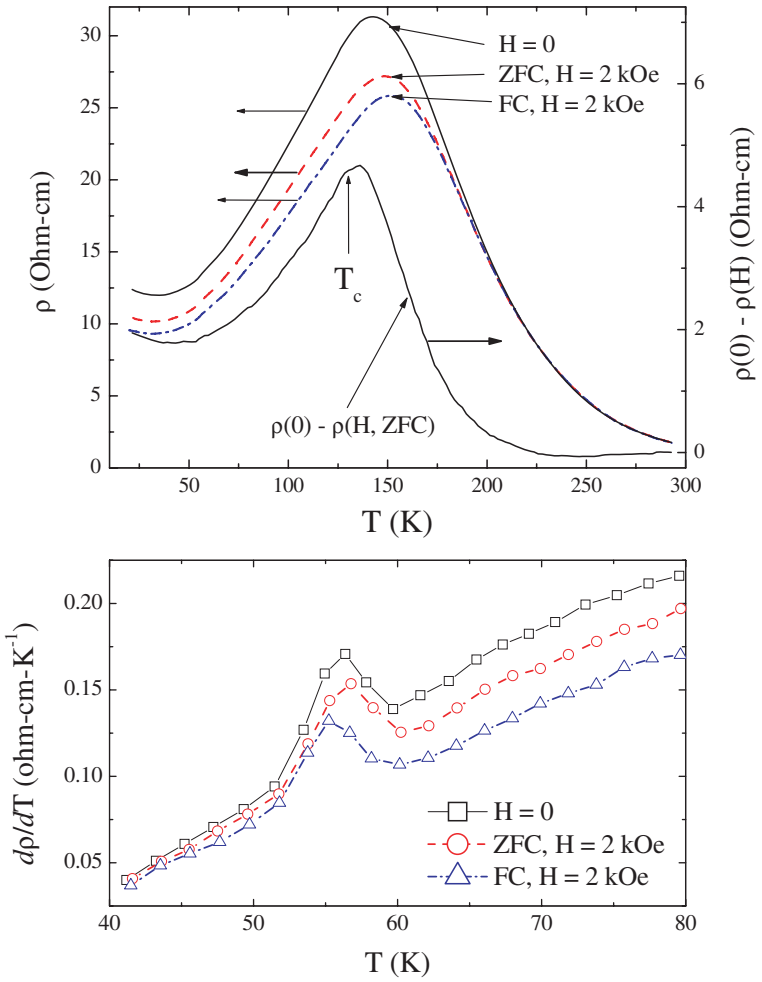

Figure 3. In the top panel, the temperature dependence of resistivity in zero magnetic field, zero-field-cooled (ZFC) and field-cooled (FC) conditions with 2 kOe field, and the temperature dependence of the magnetoresistance, $\rho(0) - \rho(H)$, where $\rho(0)$ is the resistivity in zero field and $\rho(H)$ is the resistivity with 2 kOe field. In the bottom panel, the temperature dependence of $\mathrm{d}\rho/\mathrm{d}T$ in a selective temperature region indicating the anomalies in zero magnetic field, ZFC and FC conditions.

different characteristic features than the cases for $La_{0.87}MnO_x$, where the broad hump does not correspond to $T_a(\rho)$. Note that the crystal structure for oxygen-annealed $La_{0.87}MnO_x(O_2)$ is different (monoclinic) from that of the as-prepared $La_{0.87}MnO_x$ (orthorhombic). In addition, we did not observe any time dependence of ρ around this broad hump at any field-cooled condition, which clearly distinguishes the different conduction mechanism for $La_{0.87}MnO_x(O_2)$.

The weak thermal hysteresis in ρ was strikingly observed in the metallic temperature region, when the measurement was performed in presence of a magnetic field of 2 kOe under FC conditions, as seen in figure 5. The above scheme of measurements was performed both in the absence and the presence of magnetic field. The thermal hysteresis in ρ was not observed in zero magnetic field. The irreversibility between cooling and heating curves starts around ∼155 K, which is well above T_C and T_{MI}, and they join up around ∼55 K, where anomaly

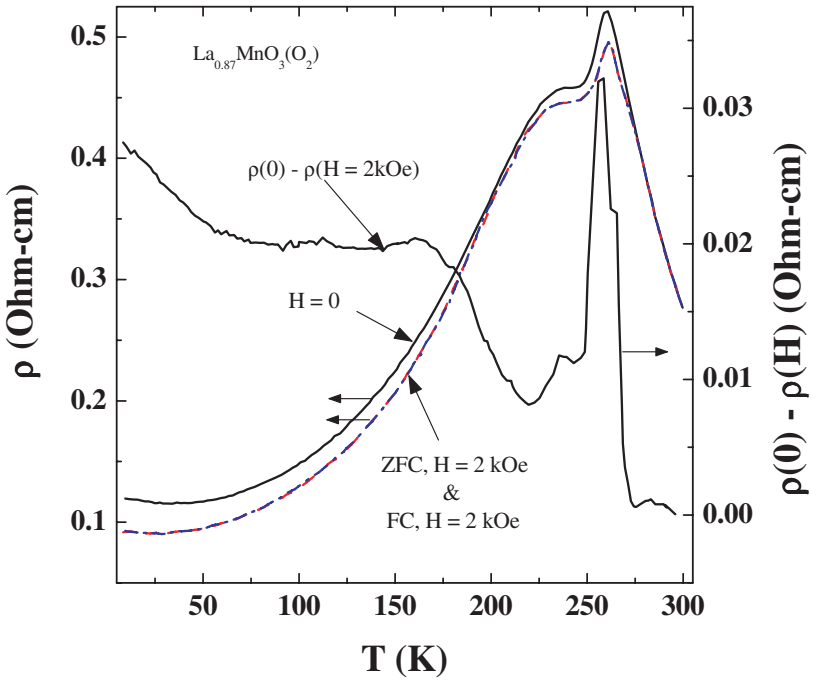

Figure 4. The temperature dependence of resistivity in zero magnetic field, zero-field cooled (ZFC) and field-cooled (FC) conditions with 2 kOe field for $La_{0.87}MnO_x(O_2)$. The temperature dependence of magnetoresistance, $\rho(0)$–$\rho(H)$, where $\rho(0)$ is the resistivity in zero field and $\rho(H)$ is the resistivity with 2 kOe field.

in $d\rho/dT$ was noticed (bottom panel of figure 3) under FC conditions. We performed several successive cycles of heating and cooling under FC conditions and observed that the thermal hysteresis was reproducible. Since the measurements are performed using an electromagnet, the question of experimental artefacts due to persistent current in the superconducting magnet can be ruled out. Note that Troyanchuk *et al* [5] suggested the probability of a first-order phase transition at T_c, which was indicated indirectly by the analysis of magnetization curves around T_c for the monoclinic phase of oxygen-rich samples. We measured the resistivity for monoclinic $La_{0.87}MnO_x(O_2)$ under FC conditions both in the heating and cooling cycles: it does not show any thermal hysteresis. However, the thermal hysteresis of resistivity was clearly noticed for the monoclinic $La_{0.87}Mn_{0.98}Fe_{0.02}O_x$ under FC conditions [14]. Since the ionic radii of Fe^{3+} and Mn^{3+} are the same, the inhomogeneity in the lattice is introduced by the random substitution of Fe^{3+}, which might be responsible for the thermal irreversibility in the resistivity under FC conditions. Note that the existence of thermal hysteresis of M as well as in ρ was noticed for CO manganites, indicating the first-order transition below T_{CO}, which has been observed even in the absence of magnetic field [13]. In addition to the mixed valent manganites and cobaltites, the existence of thermal hysteresis in ρ and M, indicating the first-order phase transition, has also been noticed in the intermetallics [15, 16].

We measured the MR by varying the low magnetic field; this is shown in figure 6. The low-field MR curves were measured at selected temperatures under ZFC and FC conditions as shown in the top panel of figure 6. The nonlinearity of the MR curves was noticed at 10, 55, 100 and 150 K; the nonlinearity decreases with increasing temperature. Similar to the temperature-dependent behaviour, a large difference between MR curves is clearly noticed

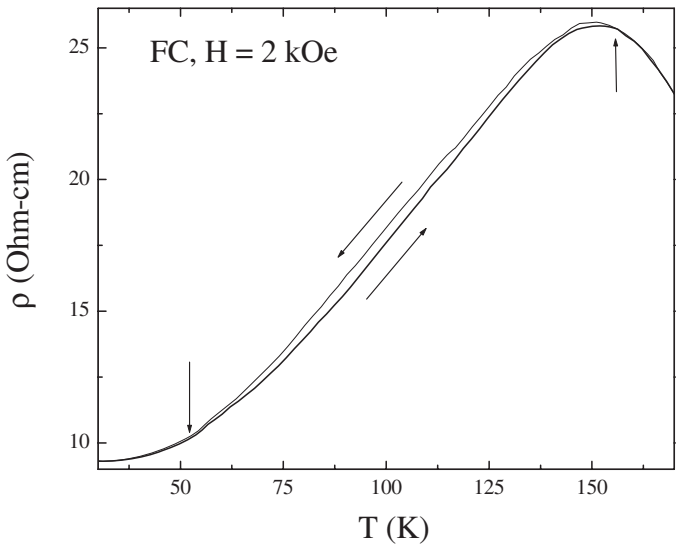

Figure 5. Thermal hysteresis of resistivity under field-cooled conditions in between 155 and 55 K, as indicated by the arrows. The other arrows indicate the mode of thermal cycling.

under ZFC and FC conditions at 10 K, while the difference decreases at 55 K. At 100 and 150 K, the difference between ZFC and FC MR curves was not distinguishable. The values of MR, defined as $[\rho(0) - \rho(H)]/\rho(0)$, are ∼23, 22, 19 and 22% at 5 kOe for 150, 100, 55 and 10 K, respectively under ZFC conditions, where $\rho(0)$ and $\rho(H)$ are the resistivities in zero field and in field. We did not observe any significant change of magnetization curves in the increasing and decreasing cycles of magnetic field at 100 and 150 K under ZFC and FC conditions. However, a clear evidence of hysteresis in the increasing and decreasing cycles was observed at 55 K under ZFC conditions, which enhances considerably at 10 K, as seen in the bottom panel of figure 6. Note that Sankar *et al* [7] also reported the considerable increase of coercivity from the hysteresis of magnetization below T_a. Here, the anomaly in $d\rho/dT$ is observed around 55 K, where the hysteresis in MR curves are noticed for $T \leqslant 55$ K, consistent with the magnetization results.

The dynamics of ρ was measured under different conditions. We found that the values of ρ do not change with time in the absence of external magnetic field in all the measured temperature range. An interesting scenario in the relaxation of ρ was surprisingly observed only in a very limited temperature region. The sample was first cooled down to 55 K under FC conditions with 2 kOe magnetic field from room temperature, kept there for $t_w = 1$ and 1.5 h, and then ρ was measured with time just after switching off the field. Striking evidence of the sharp change of ρ with t_w in the relaxation of ρ is found, as seen in figure 7. The relaxation path for $t_w = 1$ h does not follow the relaxation path for $t_w = 1.5$ h. The above features are similar to the ageing in M, which has been commonly observed for SG compounds, indicating cooperative relaxation processes. In addition, the ageing effect in M is commonly observed below T_{SG}, where the relaxation rate of magnetization, $S = 1/H(dM/d\ln t)$, is found to be maximum around $t = t_w$ [11]. The evidence for such an effect in ρ is rather a rare example even in mixed-valent manganites. Recently, the sharp change in ρ at t_w was also reported by Wu *et al* in cobaltite, where the origin of such unusual features was not explained [17]. In accordance with this results, the sharp change in ρ is directly observed in the ρ versus t plot

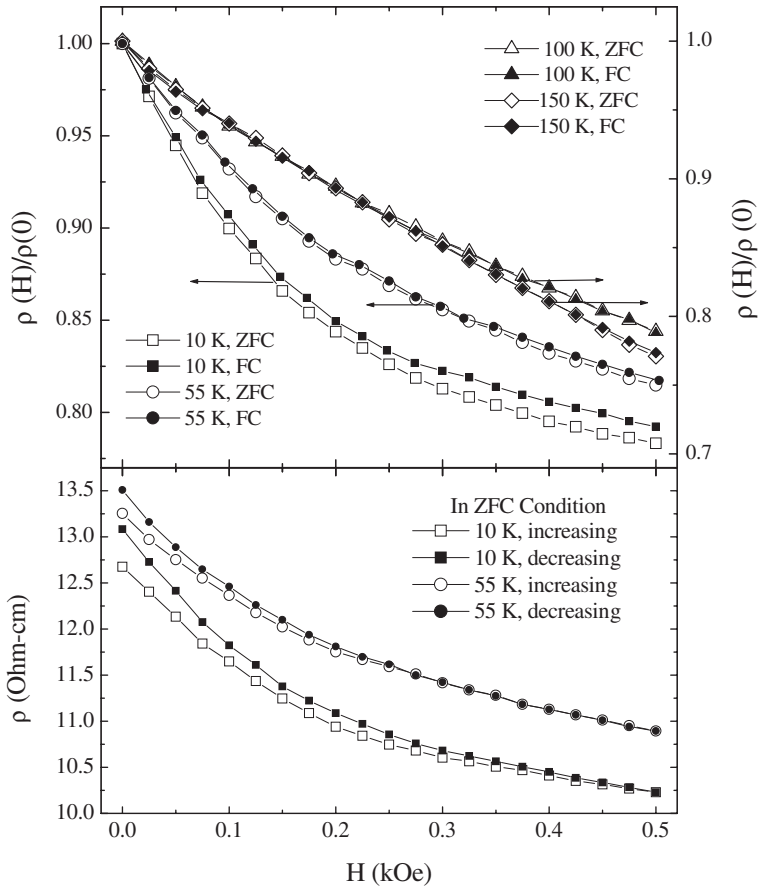

Figure 6. The top panel shows the field dependence of resistivity, $\rho(H)$, scaled by the resistivity in zero field, $\rho(0)$, under zero-field-cooled (ZFC) and field-cooled (FC) conditions at 150, 100, 55 and 10 K. The bottom panel shows the field dependence of resistivity under ZFC conditions in the increasing and decreasing cycles of low magnetic field at 10 and 55 K.

at $t = t_w$, not in the relaxation rate of ρ. Note that the relaxation of ρ was noticed only in the limited temperature region around the anomaly in $d\rho/dT$ (bottom panel of figure 3), where the relaxation in magnetization was also reported by Sankar *et al*, suggesting the effect of domain wall dynamics [7]. We also measured the time dependence of ρ for $La_{0.87}MnO_x(O_2)$ both in the presence and the absence of magnetic field at different temperatures; no noticeable time dependence in ρ was observed.

4. Discussions

The influence of domain wall dynamics has been reported in different manganites, mainly based on low-field magnetization studies. The evidence of domain wall dynamics has also been reported in $La_{1-x}MnO_3$, which was characterized by the temperature dependence and relaxation studies of dc and ac susceptibilities [7–9]. The influence of domain wall dynamics on ρ also has a significant role in different FM materials, namely, epitaxial thin film [18], (Ga, Mn)As [19], nanocontacts of polycrystalline Fe_3O_4 [20]. The influence of domain wall

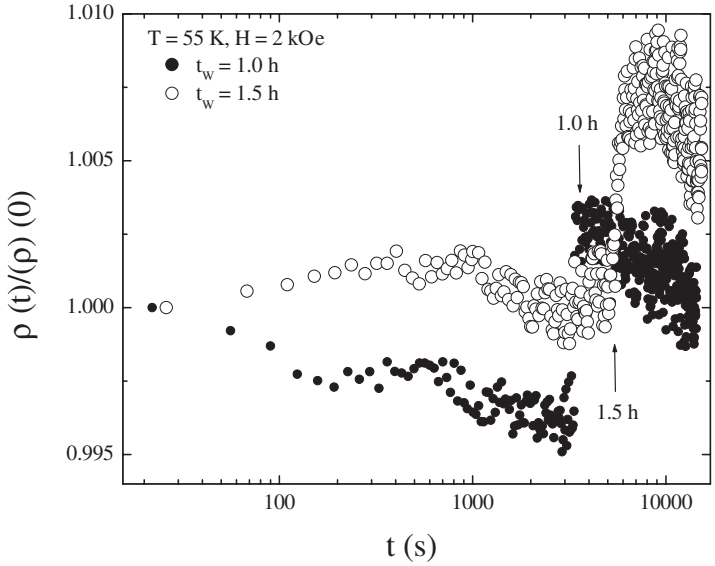

Figure 7. Time dependence of resistivity measured in zero magnetic field at 55 K, while the sample was cooled down to 55 K under field-cooled conditions of 2 kOe field, indicating the sharp change in resistivity around different t_w. Arrows indicate the time at t_w.

movement on the resistivity behaviour of ferromagnetic manganite is not unlikely, because the transport properties are strongly dependent on the magnetic states in manganites. The effect of domain wall movement on the resistivity has been reported in cases of thin film [21]. However, reports on the electron scattering correlated to the domain wall dynamics, which is reflected in the resistivity behaviour, are very rare for polycrystalline samples of manganites [22]. Here, we observe the effect of domain wall movement in the temperature, magnetic field and time dependence of ρ. An anomaly in $d\rho/dT$ is noticed around 55 K. The hysteresis of MR curves is clearly observed for $T \leqslant 55$ K. In the case of relaxation of ρ, the sample was first cooled to 40 K from room temperature with magnetic field of 2 kOe, kept there for t_w, and then the relaxation was measured just after switching off the magnetic field. In this experimental condition the following features may take place: the system can memorize the tracks of domain wall movements and the effect of the switching off the magnetic field at t_w, which is reflected in the dynamics of ρ by the discontinuous change at t_w. The above experimental results show an interesting feature of memory effects in the relaxation of ρ, which is ascribed to the domain wall dynamics.

The values of T_p in the low-field magnetization shift towards lower temperature with increasing magnetic field. The paramagnetic to FM transition is spread over a wide temperature range. A large difference between the ZFC and FC magnetization is observed in addition to the slow decreasing trend with temperature up to the lowest measured temperature, even for the measurement at 1 kOe. The magnetization curve at 5 K does not indicate a saturating tendency even up to 50 kOe magnetic field. The above features are the necessary ingredients of SG features in the system. In fact, the competition between orbitally ordered AFM and orbitally disordered FM states may lead to the SG phase, which has been observed in different cases of manganites. Note that the positive values of $d\rho/dT$ below T_c exhibits metallic states, which does not fit well with the SG state. The neutron diffraction results confirm the long-range FM ordering below T_c [5], which rules out the possibility of real SG state at low temperature. In

such a case, the explanation of the existence of domain wall movement below T_c is justified rather than the glassy states.

The crystal structure, magnetic and transport properties of the present self-doped oxygen-deficient compound exhibits an FM metallic state at low temperature, where the characteristic features do not reflect the normal features of a typical ferromagnet. Weak thermal hysteresis is noted below 155 K, which indicates the features of a first-order transition. The thermal hysteresis in ρ does not appear in the case of the monoclinic phase of the oxygen-annealed sample. Note that the thermal hysteresis again appears convincingly in the case of low Fe substitution with the monoclinic structure, where the random substitution of Fe introduces inhomogeneities into the lattice. Recently, the existence of local clustering and structural disorder were suggested by Troyanchuk *et al* to establish an intrinsic chemical and structural inhomogeneity in the orthorhombically distorted $La_{0.88}MnO_x$ ($2.86 \leqslant x \leqslant 2.91$) [5]. However, they discussed such a possibility based on the value of the moment, which is less than the value of the full spin arrangement in the ferromagnetically ordered state. The structural and magnetic properties of the present compound characterize the oxygen stoichiometry within the above limit, where the thermal hysteresis in ρ directly shows evidence of structural disorder-induced phase separation in the oxygen-deficient self-doped manganites. In fact, the recent theoretical model [1] supported by the experimental observation in low hole-doped $La(Sr)MnO_3$ also exhibits the existence of intrinsic structural inhomogeneity in manganites [23]. Here, the MI transition at 144 K is broadened in contrast to the sharp MI transition observed for hole-doped manganites and the oxygen-annealed self-doped $La_{0.87}MnO_x(O_2)$. The temperature dependences of ρ and M surprisingly exhibit clear evidence of a ZFC–FC effect much higher than T_c, which suggests that the short-range FM clusters are developed well above T_c. In addition, the inverse of the susceptibility deviates from Curie–Weiss behaviour around $\sim$240 K, which is much higher than T_c at $\sim$130 K. The above results are consistent with the existence of inhomogeneous phase separation, which is originated partially due to the growth of short-range FM clusters with a distribution of sizes above T_c. In addition to the orbitally disordered FM clusters, the orbitally ordered AFM phase may coexist, which might be responsible for the structural inhomogeneities. However, a detailed microscopic experiment, namely, neutron diffraction, is suggested to confirm the origin of the structural inhomogeneities.

5. Conclusion

The magnetization and resistivity results exhibit interesting features in orthorhombically distorted $La_{0.87}MnO_x$. The strong ZFC–FC effects of magnetization and low-field MR in the temperature and magnetic field dependence are clearly noticed at much higher temperature than T_c, which is suggested to be due to inhomogeneous phase separation. On the other hand, the characteristic features of magnetization and MR suggest the strong influence of domain wall dynamics in the ferromagnetically ordered state. An interesting scenario of memory effects through the domain wall dynamics is strikingly observed in the relaxation of ρ in a limited temperature region. The magnetotransport behaviours of the oxygen-deficient compound are suggested to be due to the coexistence of structurally driven inhomogeneous phase separation and domain wall dynamics.

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