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Review

Critical behavior near the ferromagnetic–paramagnetic phase transition temperature of $Pr_{0.67}Ba_{0.33}Mn_{1-x}Fe_xO_3$ ($x=0$ and 0.05) manganite

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ABSTRACT

Critical behavior of $Pr_{0.67}Ba_{0.33}Mn_{1-x}Fe_xO_3$ ($x=0$ and 0.05) perovskite-manganites is studied around their Curie temperatures (T_C). Results reveal that the two samples undergo a second-order phase transition. The estimated critical exponents obtained for $x=0$ sample are close to the tricritical mean-field model ($\beta=0.246\pm0.002$, $\gamma=1.030\pm0.018$ and $\delta=5.069$ at $T_C=201$ K). Whereas for $x=0.05$ sample, these exponents are close to the mean-field model ($\beta=0.501\pm0.026$, $\gamma=1.007\pm0.002$ and $\delta=2.920$ at $T_C=128$ K). These critical exponents fulfill the Widom scaling relation $\delta=1+\gamma/\beta$, implying the reliability of our values. Based on the critical exponents, the magnetization–field–temperature (M–H–T) data around T_C collapses into two curves obeying the single scaling equation $M(H,\varepsilon)=|\varepsilon|^{\beta}f_{\pm}(H/|\varepsilon|^{\beta+\gamma})$ with $\varepsilon=(T-T_C)/T_C$ is the reduced temperature.

1. Introduction

In the last decades, intensive research has been focused on the perovskite colossal magnetoresistance (CMR) manganites with the general formula $R_{1-x}A_xMnO_3$ (R=rare earth elements; A=divalent ions) [1–3]. Many theories, such as double-exchange DE interaction [4], polaronic effects [5], and phase separation combined with percolation [6], have been proposed to understand the underlying physics of the CMR effects. To understand better the metal–insulator transition and the CMR, it is important to fully understand the nature of the paramagnetic (PM)-ferromagnetic (FM) transition. One approach is to study in detail the critical exponents associated with the transition. Many experimental studies of critical behavior have been made on some manganites [7–20]. Previous studies have reported the ordering of cations in the A sublattice of the perovskite structure, in particular, in the Ba-doped manganites [21,22]. The Ln–Ba cations ordering in A-sublattice of perovskite structure phenomena can vary greatly as the phase transition order [23] well as well as the Curie temperature at the same chemical composition. In the case of $L^{3+}=Pr^{3+}$, the Curie temperature increases from ~140 to ~320 K [24]. Moreover, the different degree of A-site order [21–25] also strongly affect the Curie point. The A-site ordering is observed for the samples from wide range of the solid solutions [26]. Numerous works have been focused on the study of the critical phenomena of La-based manganite [8–17]. For example, the values of the critical exponents for $La_{0.7}Sr_{0.3}MnO_3$ single crystal and $La_{0.67}Ba_{0.33}MnO_3$ polycrystalline are in good agreement with those predicted by the 3D-Heisenberg model [9,10]. In the samples $La_{0.7}Ca_{0.3-x}Mn_{1-x}Ti_xO_3$ ($x=0$, 0.03, 0.05, 0.07 and 0.1), Xuebin Zhu et al. showed that at low doping level the critical exponents are close to the parameters predicted by the mean-field theory, however, at higher doping level the critical exponents are satisfied with the 3D-Heisenberg model [14]. Currently, four kinds of different theoretical models, mean field, three-dimensional (3D) Heisenberg, 3D Ising, and tricritical mean field were used to explain the critical properties in manganite.

The effect of Fe doping on structural, magnetic and magnetocaloric properties of $Pr_{0.67}Ba_{0.33}Mn_{1-x}Fe_xO_3$ ($x=0$ and 0.05) manganite are reported elsewhere [27,28]. We have shown that our samples crystallize in the orthormbic space groupe Imma and we have shown that our samples exhibit a transition from a paramagnetic (PM) to a ferromagnetic (FM) states at the Curie temperature T_C (~ 201 K for $x=0$ and 128 K for $x=0.05$). The maximum magnetic entropy change and the relative cooling power (RCP) are respectively 4.37 and 3.09 J Kg^{-1} K^{-1} and 230 and 287 J Kg^{-1} at a field change of 5 T, for $x=0$ and 0.05 samples. These values are compared favorably with those of some others

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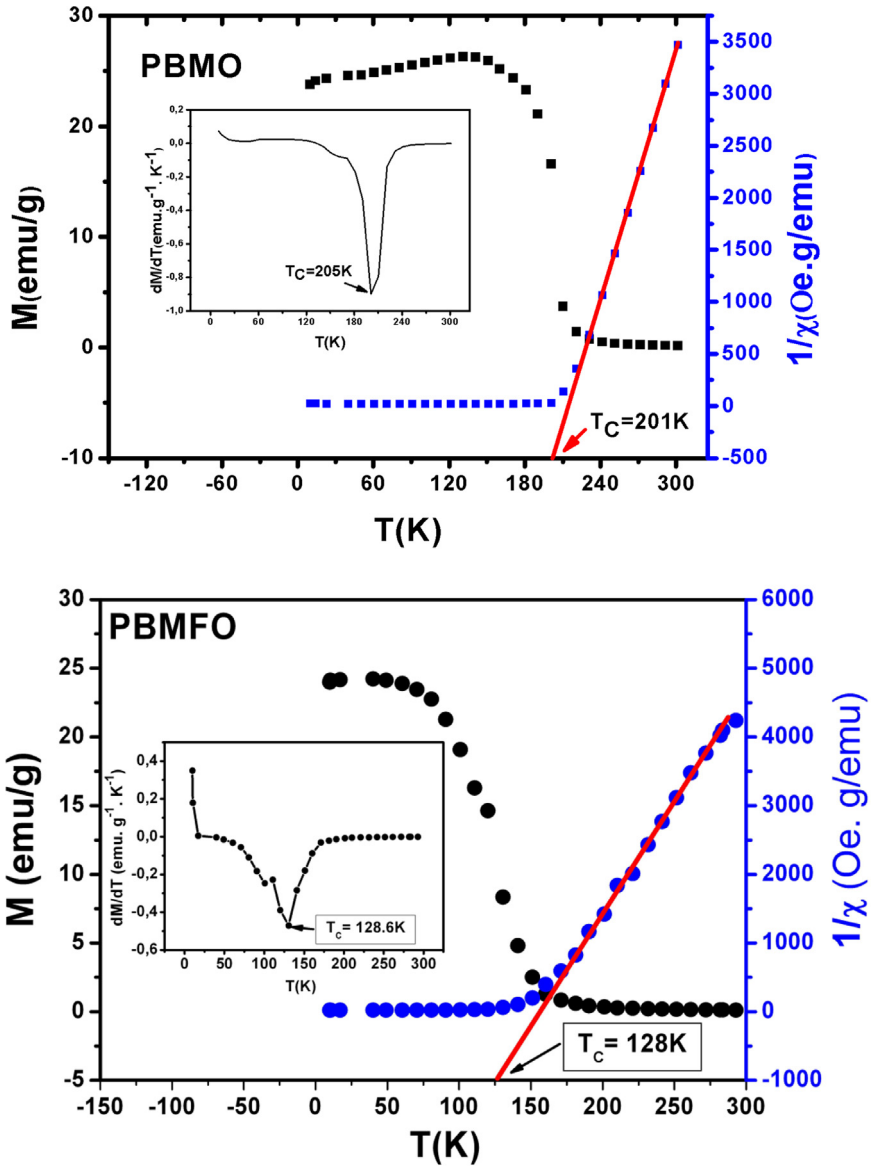

Fig. 1. Temperature dependence of magnetization $M(T)$ at $H=500$ Oe in the field cooled mode for PBMO and PBMFO samples. The inset shows the plot of dM/dT as a function of temperature.

reported manganite, making our samples promising candidates for the magnetic refrigeration.

Because of the lack of investigation on the critical behavior for Pr-based manganite, the aim of this work is to study the critical behavior, based on the M (H, T) curves presented by us elsewhere [27,28], in the vicinity of the PM–FM phase transition for $Pr_{0.67}Ba_{0.33}Mn_{1-x}Fe_xO_3$ ($x=0$ and 0.05) manganite by analyzing the critical exponents through various techniques, such as the modified Arrott plot and the Kouvel–Fisher method.

2. Results and discussions

The temperature dependence of magnetization $M(T)$ for $Pr_{0.67}Ba_{0.33}Mn_{1-x}Fe_xO_3$ ($x=0$ and 0.05) under a magnetic field of 500 Oe is shown in Fig. 1. An abrupt PM–FM phase transition happens at T_C. The Curie temperature T_C can be determined from peak of dM/dT vs. T curve, as shown in the inset of Fig. 1. An estimation of the Curie temperature T_C can be also obtained in the paramagnetic region by a linear fit of the Curie Weiss Law:

$$1/\chi = (T - \Theta)/C \quad (1)$$

(See the inset of Fig. 1), where Θ is the Curie Weiss temperature and C is the Curie constant defined as:

$$C = (1/3k_B)(N_a/M_m)(\mu_{eff}^{meas})^2\mu_B^2 \quad (2)$$

k_B is the Boltzmann constant and μ_{eff}^{meas} is the measured effective moment expressed in Bohr magneton.

The obtained values of T_C determined by the two methods mentioned above are practically the same. The obtained values of T_C are respectively 205 K and 201 K for $x=0$ and 128.6 K and 128 K for $x=0.05$. These results, allows us to choose the temperature range in the vicinity of 201 K and 128 K for isothermal $M(H, T)$ data measurement. To analyze the nature of the magnetic phase transition in detail, we have carried from the isothermal $M(H, T)$ data measured in different temperature ranges (see Fig. 2), a study of the critical exponents near T_C for $Pr_{0.67}Ba_{0.33}Mn_{1-x}Fe_xO_3$ ($x=0$ and 0.05) samples. According to the scaling hypothesis [29], for a second-order phase transition around T_C, critical exponents β (associated with the spontaneous magnetization $M_s(H=0)$ below