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Thermal diffusivity and critical behavior of $Nd_{1-x}Sr_xMnO_3$

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Abstract

Thermal diffusivity measurements on $Nd_{1-x}Sr_xMnO_3$ ($0 \leqslant x < 0.5$) single crystals have been performed by means of a photopyroelectric technique in the temperature range 78–320 K. The critical exponents of the antiferromagnetic–paramagnetic transition in the undoped sample, as well as those of the ferromagnetic–paramagnetic transition in $Nd_{0.6}Sr_{0.4}MnO_3$, have been obtained through the analysis of the inverse of the thermal diffusivity. For $x = 0$, the results agree with the Heisenberg model ($\alpha_{Heisenberg} = -0.115$), while for $x = 0.4$, they point to the Ising model ($\alpha_{Ising} = +0.110$).

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Perovskite manganites $R_{1-x}A_xMnO_3$ (R = lanthanide, A = alkaline earth) have attracted great attention in the last years due to their colossal magnetoresistance [1]. In this study, we focus our attention on the $Nd_{1-x}Sr_xMnO_3$ family with $x < 0.5$. We have previously studied the dynamical thermal properties of $La_{1-x}Sr_xMnO_3$ ($x \leqslant 0.35$) in order to obtain information about the critical behavior of the system at the magnetic transitions [2]. Our interest is to see whether there are similarities between the two families, though they present very different phase diagrams as hole doping is increased [3,4]. We have performed thermal diffusivity measurements, through which the critical exponent α can be obtained, on a set of high quality single crystals of $Nd_{1-x}Sr_xMnO_3$ ($x = 0$, 0.15, 0.3 and 0.4). The details of the technique can be found elsewhere [5].

First, room temperature thermal diffusivity has been measured for all samples. The values obtained are $1.67 \pm 0.04\,mm^2/s$ for $x = 0$, $0.59 \pm 0.02\,mm^2/s$ for $x = 0.15$, $0.49 \pm 0.02\,mm^2/s$ for $x = 0.3$ and $0.64 \pm 0.02\,mm^2/s$ for $x = 0.4$. These values are similar to the ones previously obtained for $La_{1-x}Sr_xMnO_3$ [6]. As thermal conduction in manganites is mainly governed by phonons [2], the presence of strontium in the crystal reduces the phonon mean-free path, thus reducing the thermal diffusivity in the doped samples with respect to the undoped sample.

Secondly, the temperature dependence of the thermal diffusivity around the antiferromagnetic ($x = 0$) or ferromagnetic ($x = 0.15$, 0.3, 0.4) to paramagnetic transition is shown in Fig. 1. In the case of $x = 0$ and 0.4 there is a well-defined dip, which is the expected curve for a magnetic transition. For $x = 0.15$ there is no evidence of the magnetic transition (which after the phase diagram must be at about 120 K). A similar behaviour has been observed for the case of $La_{1-x}Sr_xMnO_3$ in the lightly doped region, due to the superposition of different transitions, as well as the presence of dynamic segregation into hole-rich and hole-poor phases. $Nd_{0.85}Sr_{0.15}MnO_3$ has been so scarcely studied that there is no information whatsoever about this region.

At $x = 0.3$ there is only a step, with the usual change of slope in thermal diffusivity before and after the magnetic transition. In this case, at the same time that the magnetic transition takes place, there is also a metallic–insulator transition with the steepest change in resistivity of about two orders of magnitude [7]. This seriously affects the shape of the thermal diffusivity curves. At $x = 0.4$, there is

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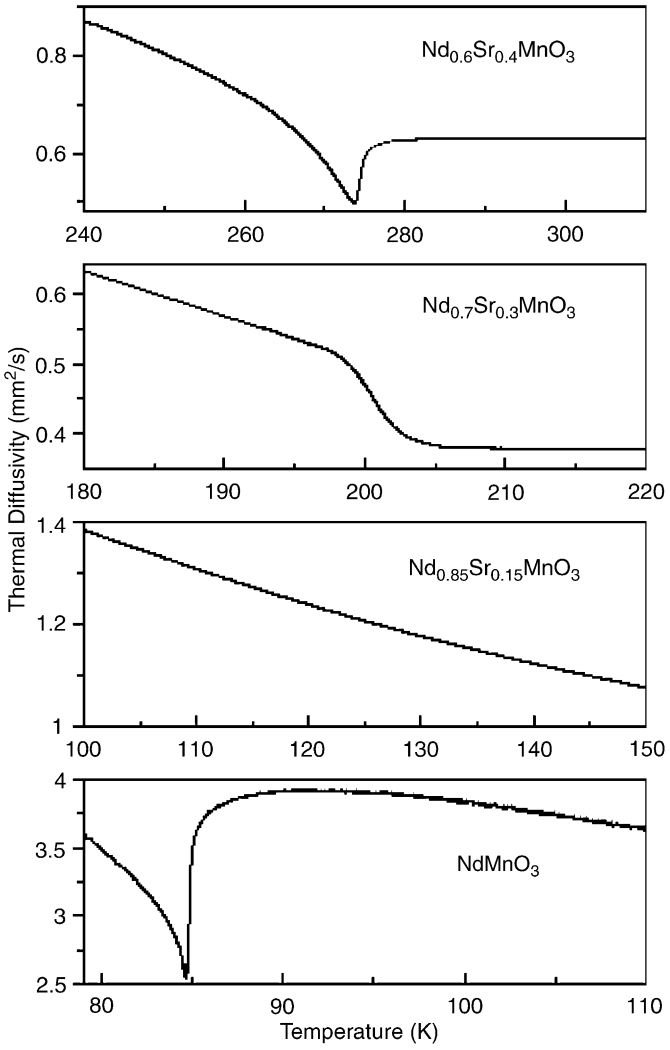

Fig. 1. Thermal diffusivity D as a function of temperature showing the magnetic transition for $Nd_{1-x}Sr_xMnO_3$.

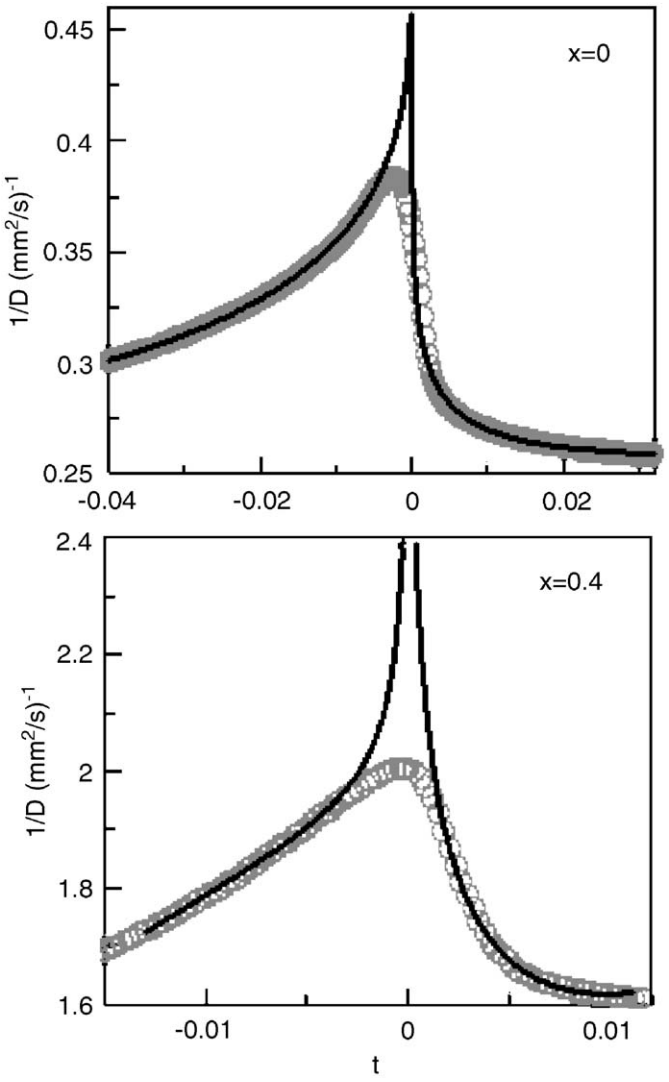

Fig. 2. Inverse of the thermal diffusivity as a function of the reduced temperature t. The circles represent the experimental points, the continuous lines the fitted functions.

also a metallic–insulator transition but with a smaller and not so sharp change in resistivity as in the case of $x = 0.3$ [8], so the shape of the dip is affected in a lesser way. Nevertheless, it is not as sharp as in the undoped sample.

Concerning the fitting procedures, the inverse of the thermal diffusivity D has been fitted to the function which is generally used for specific heat [9].

$$1/D = B + Ct + A|t|^{-\alpha}\left(1 + F|t|^{0.5}\right), \quad (1)$$

where $t = (T - T_C)/T_C$ is the reduced temperature and A, B, C, and F are adjustable parameters for $T > T_C$. Similar equations are used for $T < T_C$ with prime parameters. The details of the fitting process are reported elsewhere [2].

In order to obtain the critical parameters, detailed measurements of D have been performed in the near vicinity of T_N for $x = 0$ and T_C for $x = 0.4$. These results are shown by circles in Fig. 2, where $1/D$ is depicted as a function of the reduced temperature t. The continuous lines represent the fitted functions. The critical behavior of the undoped sample is well described by the 3D-Heisenberg model (with $\alpha = -0.11$, $A/A' = 1.8$ as experimental values), which means that the interactions among spins are short-ranged, ruling out other possible descriptions based on mean-field models, which is consistent with our previous results on $LaMnO_3$ [2].

On the other hand, for $x = 0.4$ the result of the fitting gave $\alpha = +0.12$ and $A/A' = 1.16$. The value of α points to an Ising model, though the ratio A/A' is far from 0.5, which is the theoretical value. We observed a similar behavior in $La_{1-x}Sr_xMnO_3$ in the concentration range in which, together with the ferromagnetic–paramagnetic transition, there is also a metallic–insulator one [2]. The deviation from universality in these samples can be explained by the fact that the transition is not purely magnetic. Since the electrical properties vary at the same time, the shape of the thermal diffusivity dip should be modified with respect to a

pure magnetic transition and therefore the fitting and the values of the critical exponents should be altered.

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