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Metal–insulator transition and phonon scattering mechanisms in $La_{1-x}Sr_xCoO_3$

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Abstract

The thermal conductivity $\kappa(T)$ and electrical resistivity $\rho(T)$ have been measured for $La_{1-X}Sr_XCoO_3$ ($0 \leqslant X \leqslant 0.50$). The phonon scattering is drastically enhanced with the initial hole doping as a result of the appearance of powerful phonon scattering by localized Co^{4+}. The strong scattering due to the Jahn–Teller active Co^{4+} intermediate spin is reduced in the metallic region $X \geqslant 0.20$ as the doped holes become itinerant. However, the phonon scattering due to band carriers becomes dominant for $X \geqslant 0.40$. $\kappa(T)$ of metallic $La_{1-X}Sr_XCoO_3$ ($0.20 \leqslant X \leqslant 0.50$) shows an enhancement at the magnetic ordering temperature T_c, which is attributable to the electronic contribution κ_e.

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Keywords: $La_{1-X}Sr_XCoO_3$; Thermal conductivity; Phonon scattering; Jahn–Teller ions

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1. Introduction

$LaCoO_3$ has attracted renewed interest recently mainly owing to the peculiar Co^{3+} spin-state transitions. The thermally driven transition from the low spin Co^{3+} (LS) ($S = 0$, t_{2g}^6) to the Jahn–Teller active intermediate spin Co^{3+} (IS) ($S = 1$, $t_{2g}^5 e_g^1$) results in a strong phonon-scattering enhancement in $LaCoO_3$ [1]. The phonon-scattering enhancement is even more drastically displayed by rightly doping divalent cations [2]. In this note, we study and analyze the thermal conductivity $\kappa(T)$ of single phase and stoichiometric $La_{1-X}Sr_XCoO_3$ (LSCO) over a wide range of Sr concentration X ($X \leqslant 0.50$).

2. Results and discussion

The polycrystalline LSCO samples were prepared by a solid-state reaction method. $\kappa(T)$ was measured by a steady heat flow method. X-ray diffraction confirmed a single-phase rhombohedral structure and iodine titration guaranteed the oxygen stoichiometry for $X \leqslant 0.50$.

Fig. 1 shows the electrical resistivity $\rho(T)$. The insulator–metal (I–M) transition takes place between the Sr concentration $X = 0.15$ and $X = 0.20$, concomitant with the appearance of ferromagnetic (FM) order in LSCO ($X = 0.20$).

Fig. 2 displays $\kappa(T)$ of very lightly doped LSCO ($X \leqslant 0.02$). For $X \leqslant 0.10$, the electrical resistivity $\rho(T)$ is very large and $\kappa(T)$ can be regarded entirely as the phonon contribution κ_{ph}. The characteristic peak of pristine $LaCoO_3$, which originates from the spin-state transition $Co^{3+}(LS) \rightarrow Co^{3+}(IS)$ [1], completely disappears by only 1% Sr^{2+}-doping. The very strong phonon scattering ability of the strain field around the Jahn–Teller active Co^{4+} (IS) ($S = 3/2$, $t_{2g}^4 e_g^1$) introduced by Sr^{2+}-doping wipes out the $\kappa(T)$ peak [2].

Fig. 3 shows $\kappa(T)$ of heavily doped LSCO ($X \geqslant 0.10$). The magnetic behavior of insulating LSCO ($X = 0.10$) is that of spin-glass, while LSCO is FM metal for $X \geqslant 0.20$.

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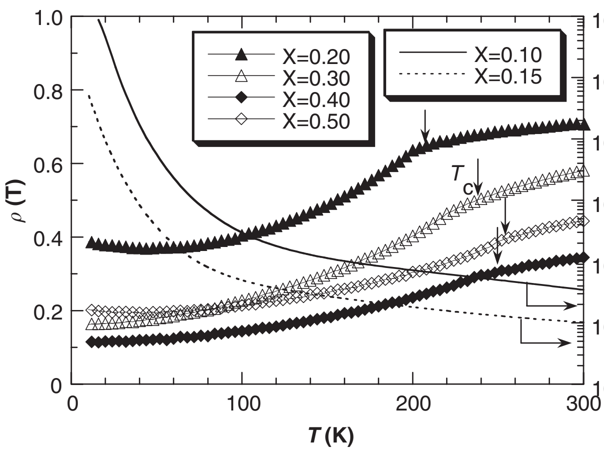

Fig. 1. $\rho(T)$ of the LSCO specimens ($0.10 \leqslant X \leqslant 0.50$).

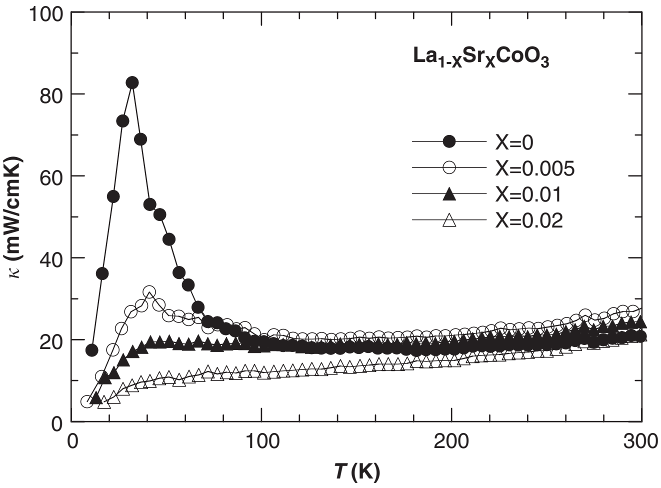

Fig. 2. $\kappa(T)$ of lightly doped LSCO ($X \leqslant 0.02$).

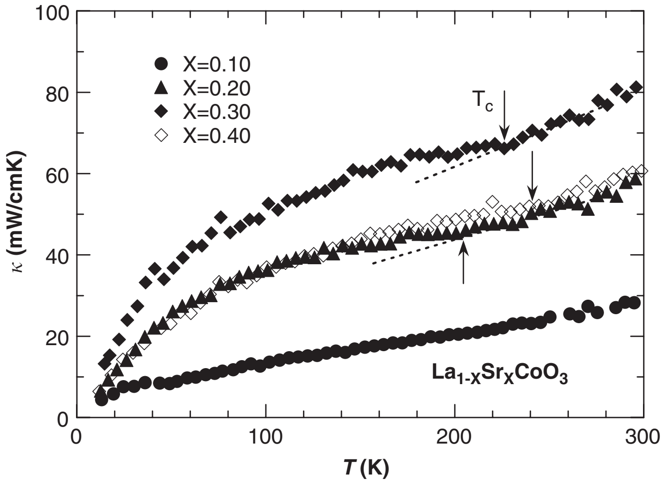

Fig. 3. $\kappa(T)$ of LSCO ($0.10 \leqslant X \leqslant 0.40$). The arrows indicate the FM transition temperature T_c.

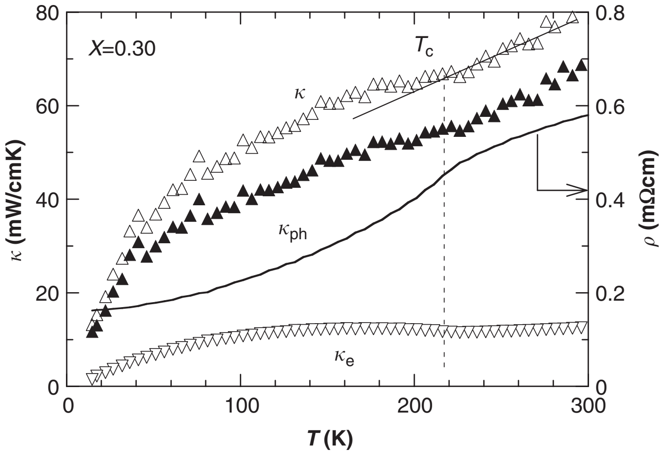

Fig. 4. Separation of the phonon component κ_{ph} and the electron component κ_e for LSCO ($X = 0.30$). The electrical resistivity $\rho(T)$ is also presented.

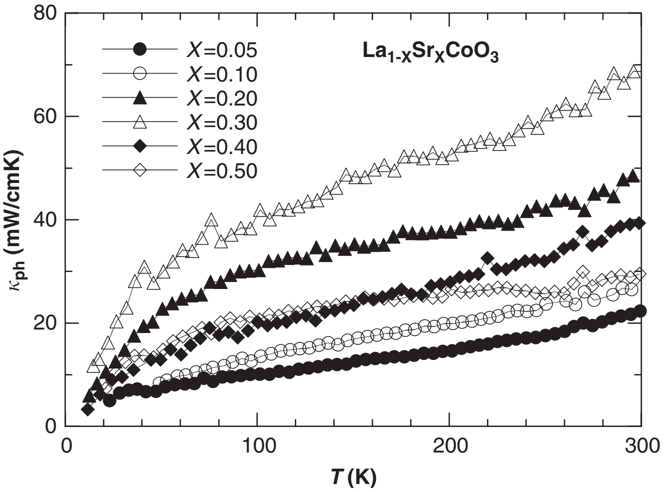

Fig. 5. Phonon thermal conductivity $\kappa_{ph}(T)$ for various Sr^{2+} concentration X.

$\kappa(T)$ is enhanced from $X = 0.10$ to $X = 0.30$, taking the maximum for $X = 0.30$.

Fig. 4 presents the separation of κ_{ph} and the electronic component κ_e on the basis of the Wiedemann-Franz law. As we can see, the $\kappa(T)$ is enhanced by κ_e, which is the main origin of the slight enhancement of $\kappa(T)$ at the FM transition temperature T_c observed for $X \geqslant 0.20$.

Fig. 5 summarizes the phonon contribution $\kappa_{ph}(T)$. For $X \geqslant 0.05$, $\kappa_{ph}(T)$ is enhanced with increasing X up to $X = 0.30$ because the strain field around the hole ($= Co^{4+}$(IS)) is reduced with increasing mobility of the holes. Above $X = 0.30$, however, the increasing number of doped holes make the phonon scattering by band carriers dominant and κ_{ph} decreases.

In summary, with increasing Sr^{2+} concentration X, κ_{ph} of $La_{1-X}Sr_XCoO_3$ is at first drastically reduced by the strain field around the localized holes ($X \leqslant 0.05$). Then κ_{ph}

is gradually enhanced with further increase of X ($0.05 \leqslant X \leqslant 0.30$) owing to the reduction of the strain field caused by the hole mobility increase and, finally, κ_{ph} is again reduced as the phonon scattering by band carriers dominates. The $\kappa(T)$ enhancement observed at the FM transition temperature T_{c} is of electronic origin.

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