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Heat transport in T*-phase $(Nd_{1-x-y}Ce_xSr_y)_2CuO_4$ superconductors

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Abstract

The thermal conductivity κ of $(Nd_{1-x-y}Ce_xSr_y)_2CuO_4$ (NCSCO) with T*-structure have been measured and compared with those of $La_{2-x}Sr_xCuO_4$ (LSCO) with T-structure and of $Nd_{2-x}Ce_xCuO_4$ (NCCO) with T′-structure. The phonon scattering mechanisms effective in NCSCO have been analyzed. © 2000 Elsevier Science B.V. All rights reserved.

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Among the so-called (214) oxide superconductors, there are three closely related tetragonal structures which are named as T-phase with Cu–O octahedra ($La_{2-x}Sr_xCuO_4$ (LSCO)), T′-phase with Cu–O squares ($Nd_{2-x}Ce_xCuO_4$ (NCCO)) and T*-phase with Cu–O pyramids ($(Nd_{1-x-y}Ce_xSr_y)_2CuO_4$ (NCSCO)). The magnitude of the thermal conductivity κ and its temperature dependence are quite different between T- and T′-phase [1,2]. The existence of two apical oxygen atoms above and below the unit Cu–O square may explain the reduce of κ in the T-phase system. Although there are many investigations about the structure and superconductivity for T*-phase system, there have been no reported data for thermal transport properties. We fabricated the single-phase sintered T*-phase superconductors, $(Nd_{1-x-y}Ce_xSr_y)_2CuO_4$ ($x = 0.0875, y = 0.2$), and measured the thermal conductivity. T*-phase materials have an intermediate structure between T- and T′-phase with one apical oxygen above the Cu–O square.

$(Nd_{1-x-y}Ce_xSr_y)_2CuO_4$ ($x = 0.0875, y = 0.2$) polycrystals were prepared from stoichiometric mixtures of Nd_2O_3, CeO_2, $SrCO_3$ and CuO raw powders. The mixtures were calcined twice at 900°C for 12 h in air. They were pressed into pellets and sintered at 1150°C for 18 h in air and furnace-cooled. Finally, the samples were heat-treated at various temperatures T_{HT} from 1000°C to 1210°C for 24 h in flowing oxygen and furnace-cooled. The thermal conductivity was measured between 10 and 150 K by a continuous heat-flow method using an automated measuring system [1]. The electrical resistivity $\rho(T)$ of the samples decreased with increasing T_{HT}. The $T_{HT} = 1210$°C sample with single-phase T* structure has a small and metallic $\rho(T)$, and exhibits the highest T_c ($T_{c(onset)} = 23$ K, $T_{c(end)} = 16$ K).

Fig. 1 shows the temperature dependence of the thermal conductivity $\kappa(T)$ of $(Nd_{1-x-y}Ce_xSr_y)_2CuO_4$ (T*-phase, $T_{c(end)} = 16$ K), $La_{2-x}Sr_x$ CuO_4 (T-phase: $x = 0.15$: $T_c = 38$ K) and $Nd_{2-x}Ce_x$ CuO_4 (T′-phase: $x = 0.15$: $T_c = 20$ K). In contrast to T′-phase, the magnitude of κ is comparatively small for T- and T*-phase samples. There is some difference in $\kappa(T)$ behavior between T- and T*-phase. In T-phase, $\kappa(T)$ is reduced at lower temperatures more heavily than that in T*-phase.

We assume that electron component $\kappa_{en}(T)$ follows the Wiedemann–Franz law and calculate $\kappa_{ph}(T)$ on the basis of the relaxation time approximation [3,4], where the total phonon scattering rate τ_{ph}^{-1} is given by

$$\tau_{ph}^{-1} = \tau_b^{-1} + Ux\exp(-\Theta_D/aT) + S(Tx)^2 + P(Tx)^4 + E(Tx)g(x,y) + K(Tx). \quad (1)$$

Here, x is the reduced phonon frequency, τ_b is the phonon relaxation time due to grain boundaries and P, S, E and $Ux\exp(-\Theta_D/aT)$ ($\Theta_D = 400$ K, $a = 1.8$) refer to

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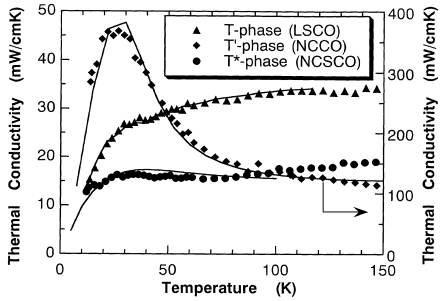

Fig. 1. Temperature dependence of the thermal conductivity $\kappa(T)$ of the $La_{2-x}Sr_xCuO_4$ ($x = 0.15$: T-phase), $Nd_{2-x}Ce_xCuO_4$ ($x = 0.15$: T′-phase) and $(Nd_{1-x-y}Ce_xSr_y)_2CuO_4$ ($x = 0.0875$, $y = 0.2$: T*-phase) samples. The fitting curves of κ_{ph} for the T-, T*- and T′-phase are also shown.

Table 1
Fitting parameters determined by κ_{ph} analyses for T-, T*- and T′-phase

	T-phase [1]	T*-phase	T′-phase [2]
$\tau_b^{-1}(s^{-1})$	6.4×10^8	6.7×10^8	3.6×10^8
$U(s^{-1})$	0	3.7×10^{11}	6.9×10^{11}
$S(K^{-2}s^{-1})$	5.5×10^6	1.4×10^7	0
$P(K^{-4}s^{-1})$	1.5×10^4	3.0×10^4	4.3×10^2
$E(K^{-1}s^{-1})$	2.5×10^8	0	0
$K(K^{-1}s^{-1})$	2.5×10^8	1.3×10^8	0

the strength of the scattering by point defects, sheet-like faults, electrons and other phonons, respectively. The fitting curves for the thermal conductivity κ of T-, T′- and T*-phase samples are also shown in Fig. 1. The determined parameters are summarized in Table 1. The phonon scattering strengths by point defects (P), sheet-like faults (S) and umklapp process (U) for T*-phase are larger than those for T-phase. However, a steeper reduction in $\kappa(T)$ of LSCO (T-phase) at low temperatures can be reproduced only by a larger KTx term than that for T*-phase. We have proposed that a larger KTx term of T-phase comes from the tunneling-like motion of the apical oxygens related to the structural instability between LTO phase and HTT phase, because the structural transformation is provoked most directly by the change of apical oxygen sites [4,5]. For T*-phase, K term is about a half of that for T-phase, which might reflect the relative number of apical oxygens in both structures. The phonon scattering by two-level-like tunneling of apical oxygen may reduce the phonon transport also in T*-phase NCSCO, though not so strongly as in T-phase LSCO.

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