Anomalous Damping of Phonon Thermal Transport in Lightly Y- or Eu-doped La_2CuO_4 Single Crystals

X. F. Sun [a,1], Seiki Komiya [a], Yoichi Ando [a]

[a] *Central Research Institute of Electric Power Industry, Komae, Tokyo 201-8511, Japan*

Abstract

We present the measurements of the in-plane thermal conductivity κ_{ab} of single crystals La_2CuO_4 and lightly doped $La_{1.98}Y_{0.02}CuO_4$ and $La_{1.98}Eu_{0.02}CuO_4$. It is found that such slight doping strongly suppresses the phonon peak (at $\sim$ 25 K) in $\kappa_{ab}(T)$ of La_2CuO_4 and this suppression is much stronger than that observed in $La_{1.98}Sr_{0.02}CuO_4$. This anomalously strong suppression of phonon transport is attributed to the structural distortion induced by Y- or Eu-doping, which also brings on some changes in the magnetic properties.

Key words: thermal conductivity; phonon; lightly-doped cuprates

It has recently been discussed that the holes in the high-T_c cuprates self-organize into quasi-one-dimensional stripes. However, the static charge stripes were only observed in rare-earth (RE) doped $La_{2-x}Sr_xCuO_4$ [1], where RE-doping transforms the structure from orthorhombic (LTO) to tetragonal (LTT) phase at low temperatures and the LTT phase can stabilize the charge stripes. It was proposed that the phonon heat transport is released from strong phonon scattering of dynamical stripes when the static stripe phase is formed in RE-doped $La_{2-x}Sr_xCuO_4$ [2]. On the other hand, RE-doping introduces the structural distortions, which are expected to damp the phonon transport [3]. To investigate the RE-doping effect on the phonon transport, we measure the thermal conductivity of lightly Y- or Eu-doped La_2CuO_4 (LCO) single crystals.

The single crystals are grown by the traveling-solvent floating-zone method and are carefully annealed in flowing pure He gas to remove excess oxygen. The crystals are cut into rectangular thin platelets with the typical sizes of $2.5\times0.5\times0.15$ mm^3, where the c-axis is perpendicular to the platelet within an accuracy of 1°. The thermal conductivity κ_{ab} is measured using a conventional steady-state technique below 150 K and a modified steady-state technique above 150 K [4]. The temperature difference ΔT in the sample is measured by a differential Chromel-Constantan thermocouple, which is glued to the sample using GE vanish. Magnetization measurements are carried out using a Quantum Design SQUID magnetometer.

Figure 1 shows the temperature dependence of κ_{ab} for LCO, $La_{1.98}Y_{0.02}CuO_4$ (LYCO) and $La_{1.98}Eu_{0.02}CuO_4$ (LECO) single crystals. The undoped LCO shows a sharp phonon peak at low temperature ($\sim$ 25 K) and a broad magnon peak at high temperature ($\sim$ 270 K) [4]. It can be seen that the high-T peak does not change so much upon Y- or Eu-doping, which means the doping has little effect on the high-T magnetic properties, whereas the low-T phonon peak is strongly suppressed upon doping of only 0.02 concentration. There is still a small peak in the LYCO sample, while the phonon peak completely disappears in LECO; instead, the LECO sample shows a glass-like transport behavior at low temperatures. Such suppression of phonon transport by Y- or Eu-doping is much stronger than that in $La_{1.98}Sr_{0.02}CuO_4$ (LSCO) with the same doping level, as shown in Fig. 1, which means that the impurity atoms themselves are not the main source of phonon scattering. Measurements of

[1] Corresponding author. E-mail: ko-xfsun@criepi.denken.or.jp

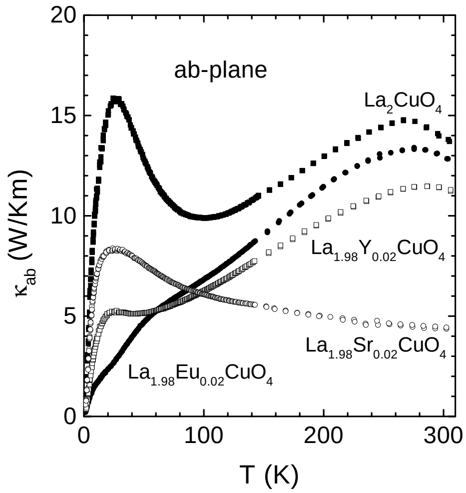

Fig. 1. In-plane thermal conductivity of undoped La_2CuO_4 and Y-, Eu-doped La_2CuO_4 single crystals. Data for $La_{1,98}Sr_{0.02}CuO_4$ is also shown for comparison.

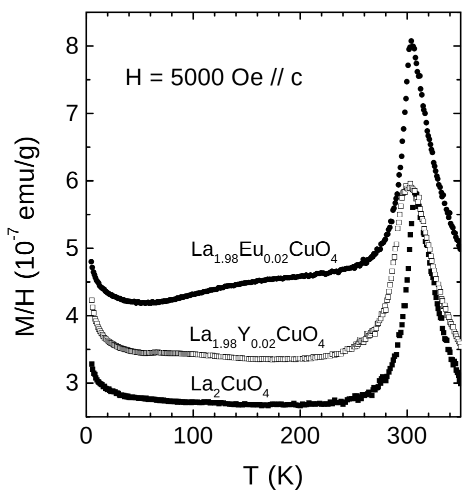

Fig. 2. Magnetic susceptibility of undoped La_2CuO_4 and Y-, Eu-doped La_2CuO_4 single crystals measured in 5000 Oe field applied along the c axis.

κ_{ab} in magnetic field for LECO at 12.5 K and 18.5 K find no field dependence up to 6 T, which rules out the possibility of magnetic origin for the strong phonon scattering. Thus, the possible reason for such strong suppression of phonon peak is the phonon scattering by the structural distortion. Reasonably strong lattice distortion occurs in LYCO because of the difference in the ion size between Y^{3+} and La^{3+}. It is known that Eu-doping can induce the LTO to LTT phase transition. When the doping level is too small to induce structural transition, the LTT-like titling of the CuO_6 octahedra exists locally around rare-earth ions in the background of LTO phase, which induces very strong lattice distortion.

It is helpful for understanding the doping effect on local structure by studying the magnetic properties, since the Cu^{2+} canted moments are very sensitive to the titling of CuO_6 octahedra. Figure 2 shows the magnetic susceptibility data of these single crystals measured with 5000 Oe field applied along the c axis. The LCO sample shows a sharp Néel transition at 307 K, which originates from the canted moments due to the Dzyaloshinski-Moriya interaction [5,6]. Upon Y- or Eu-doping, the Néel transition remains unchange except for a slight broadening of the transition in LYCO. Therefore, the high temperature magnetic properties do not show any dramatic change upon Y- or Eu-doping; this is consistent with the weak change of the high-T magnon peak. In contrast, the magnon peak disappears in LSCO, in which the Néel transition also disappears. One obvious change in the magnetic data is that the susceptibility is shifted up upon Y- or Eu-doping. The additional moment may come from the local lattice distortion in LYCO (which causes incomplete cancellation of the antiparallel Cu^{2+} canted moments) or from the magnetic Eu^{3+} ions in LECO, respectively. Moreover, the susceptibility of LECO decreases with deceasing temperature from 150 K to 50 K. This also indicates that Eu-doping induces local LTT regions in the LTO background, which eliminates the number of Cu^{2+} canted moments since the canted moments are caused by the orthorhombic distortion and disappear in tetragonal structure [7].

In summary, the Y- or Eu-doping cause very strong damping of phonon heat transport in LCO, which is likely due to the local structural distortion.

Acknowledgements

We thank A. N. Lavrov and I. Tsukada for helpful discussions, and J. Takeya for technical assistance. X.F.S. acknowledges support from JISTEC.

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