Reply to "Comment on 'Low-temperature phonon thermal conductivity of single-crystalline Nd_2CuO_4: Effects of sample size and surface roughness' "

S. Y. Li,[1] J.-B. Bonnemaison,[1] A. Payeur,[1] P. Fournier,[1,2] C. H. Wang,[3] X. H. Chen,[3] and Louis Taillefer[1,2,*]
[1]*Département de Physique and RQMP, Université de Sherbrooke, Sherbrooke, Canada J1K 2R1*
[2]*Canadian Institute for Advanced Research, Toronto, Canada M5G 1Z8*
[3]*Hefei National Laboratory for Physical Science at Microscale and Department of Physics, University of Science and Technology of China, Hefei, Anhui 230026, People's Republic of China*
(Received 20 November 2008; published 1 May 2009)

In their comment [X. F. Sun and Yoichi Ando, preceding paper, Phys. Rev. B **79**, 176501 (2009)] on our study of phonon heat transport in Nd_2CuO_4 [S. Y. Li, J.-B. Bonnemaison, A. Payeur, P. Fournier, C. H. Wang, X. H. Chen, and Louis Taillefer, Phys. Rev. B **77**, 134501 (2008)], Sun and Ando estimate that the phonon mean free path at low temperature is roughly half the width of the single crystal used in our study, from which they argue that phonon scattering cannot be dominated by sample boundaries. Here we show that their use of specific-heat data on Nd_2CuO_4, which contains a large magnetic contribution at low temperature that is difficult to reliably extract, leads to an underestimate of the mean free path by a factor 2 compared to an estimate based on the specific-heat data of the nonmagnetic isostructural analog Pr_2CuO_4. This removes the apparent contradiction raised by Sun and Ando.

DOI: 10.1103/PhysRevB.79.176502 PACS number(s): 74.72.−h, 72.15.Eb

Recently, we reported the effect of sample size and surface roughness on the phonon thermal conductivity κ_p of Nd_2CuO_4 single crystals down to 50 mK.[1] At 0.5 K, κ_p was shown to be proportional to $\sqrt{A}$, where A is the cross-sectional area of the sample. This clearly demonstrates that κ_p is dominated by boundary scattering at and below 0.5 K.

In their Comment, Sun and Ando (SA) (Ref. 2) calculated the phonon mean free path l from our thermal conductivity data using the formula $\kappa_p = C\langle v\rangle l/3$, where $C=\beta T^3$ is the phonon specific heat and $\langle v\rangle$ is a suitable average of the three acoustic sound velocities. Using $\beta=0.42$ mJ/mol K^4 for Nd_2CuO_4, they arrived at an estimate of l which is about 50% of the average sample width $W \equiv 2\sqrt{A/\pi}$. Because $l < W$, they concluded that phonons in our Nd_2CuO_4 single crystals did not reach the boundary scattering regime at low temperature.

Because their criticism is based entirely on a quantitative estimate of l, it would seem important to know the uncertainty in the parameters β and $\langle v\rangle$ used to arrive at this estimate. SA provided no indication of the uncertainty on their numbers. More problematic, however, is their use of specific-heat data on Nd_2CuO_4 to estimate β. Indeed, because of the large magnetic contribution to $C(T)$ at low temperature coming from Nd^{3+} moments, SA had to make some assumptions to extract the phonon component from that low-temperature data. An alternate and standard approach is to use the nonmagnetic isostructural analog Pr_2CuO_4, for which there is no such magnetic contribution. The specific heat of Pr_2CuO_4 below 10 K readily yields $\beta=0.19$ mJ/mol K^4.[3]

If we use that value for β, which is half that used by SA for their estimate of l, we arrive at an estimated phonon mean free path which is twice as large. This removes the discrepancy which is the basis for their Comment. Note also that $\beta=0.19$ mJ/mol K^4 is in excellent agreement with the value of $\beta=0.20$ mJ/mol K^4 calculated by SA using the standard expression based on sound velocities [Eq. (2) in their Comment].

We conclude that as best as one can estimate it, the phonon mean free path in Nd_2CuO_4 at $T=0.5$ K works out to be roughly equal to the average sample width so that one can expect phonons to be scattered by boundaries below 0.5 K. In as-grown crystals with smooth, mirrorlike faces, it is then reasonable to expect some specular reflection as the phonon wavelength gets longer and longer with decreasing temperature. The best way to verify this is to deliberately roughen those surfaces and see whether the thermal conductivity is reduced. The purpose of our article[1] was to show that it clearly does.

*louis.taillefer@physique.usherbrooke.ca

[1] S. Y. Li, J.-B. Bonnemaison, A. Payeur, P. Fournier, C. H. Wang, X. H. Chen, and L. Taillefer, Phys. Rev. B **77**, 134501 (2008).
[2] X. F. Sun and Y. Ando, preceding paper, Phys. Rev. B **79**, 176501 (2009).
[3] S. Ghamaty, B. W. Lee, J. T. Markert, E. A. Early, T. Bjornholm, C. L. Seaman, and M. B. Maple, Physica C **160**, 217 (1989).

