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A quantum dynamical approach to various scattering mechanisms and their influences on thermal conductivity of Sr- and Zn-doped La_2CuO_4 high temperature superconductor cuprate

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Despite enormous experimental and theoretical accomplishments over the last thirty years, the nature of the cuprates' superconducting fluctuation domain remains highly contentious. One of the major challenges in condensed matter physics is the mechanism of superconductivity in cuprates. Although numerous theories (many of which have flaws) have been proposed to analyse the thermal conductivity of HTS, beginning with the pioneering work of Bardeen, Rickayzen, and Tewordt and continuing to the present, a viable answer has yet to be established [1]. When impurities and electrons are the dominant scatterers, these theories provided a method for determining the electronic contribution to thermal conductivity (which is similar to the numerically approachable model of Callaway [2]). It was later expanded to account for phonon scattering, resulting in phonon thermal conductivity in HTS below the strong coupling limit for both s-wave and d-wave pairing processes [3, 4]. Meanwhile, heat carriers in materials, such as phonons or electrons, are collided often (scatterings). Despite the fact that numerous scattering events such as boundary, dislocation, point, phonon-phonon, electron-phonon and so on have previously been reported to explain the phenomena, the curves above the conductivity maximum could not be properly described. While the Callaway theory is useful for predicting the thermal conductivity of various HTS, it has numerous significant complications, notably the accumulation of inverse relaxation periods when Matthiessen's rule may be applied to separate scattering events. It also does not include phonon polarisation or phonon dispersion relations. Even at very low temperatures, however, the effects of anharmonicities, defects, and other variables on various scattering events of HTS cannot be ignored, and hence a violation of Matthiessen's criteria is inescapable. Fortunately, the violation of Matthiessen's rule may be avoided by substituting interaction life times or linewidths for the relaxation time [5]. In this study, a quantum dynamical based analytical model is developed to analyse the thermal conductivity of Sr- and Zn-doped La_2CuO_4 by taking into consideration various phonon scattering mechanisms. The proposed formulation expands the idea of relaxation times from frequency (energy) line widths for multiple scattering processes and eliminates the shortcomings of the Matthiessen's rule employed in the Callaway theory. A theoretical calculation of the thermal conductivity of Sr- and Zn-doped La_2CuO_4 below and above the transition temperature demonstrates reasonable agreement with experimental observations.

In comparison to the standard Callaway model, Fig. 1 shows good agreement between experimental findings and theoretical calculations based on the current model. Indeed, at low doping concentrations ($x < 5\,\%$), Sr doping results in hole doping, whereas Zn doping results in electron doping in lanthanum cuprate superconductor, $La_{2-x}CuO_4$ (LCO). Because of increased phonon scattering, the phonon peak in thermal conductivity along the c-axis declines quicker with Sr doping than with Zn doping. The phonon peak in thermal conductivity along the ab-plane, on the other hand, decreases somewhat quicker with Zn doping than with Sr doping. Based on the specific doping dependence of the steep damping of the low temperature phonon peak, it is possible to deduce that phonon scattering is much stronger along the c-axis heat transfer than along the in-plane (ab-plane) phonon scattering. It is worth noting that, despite the fact that lanthanum cuprate is not a ferromagnetic insulator, recent neutron scattering investigations on LSCO superconductors revealed better

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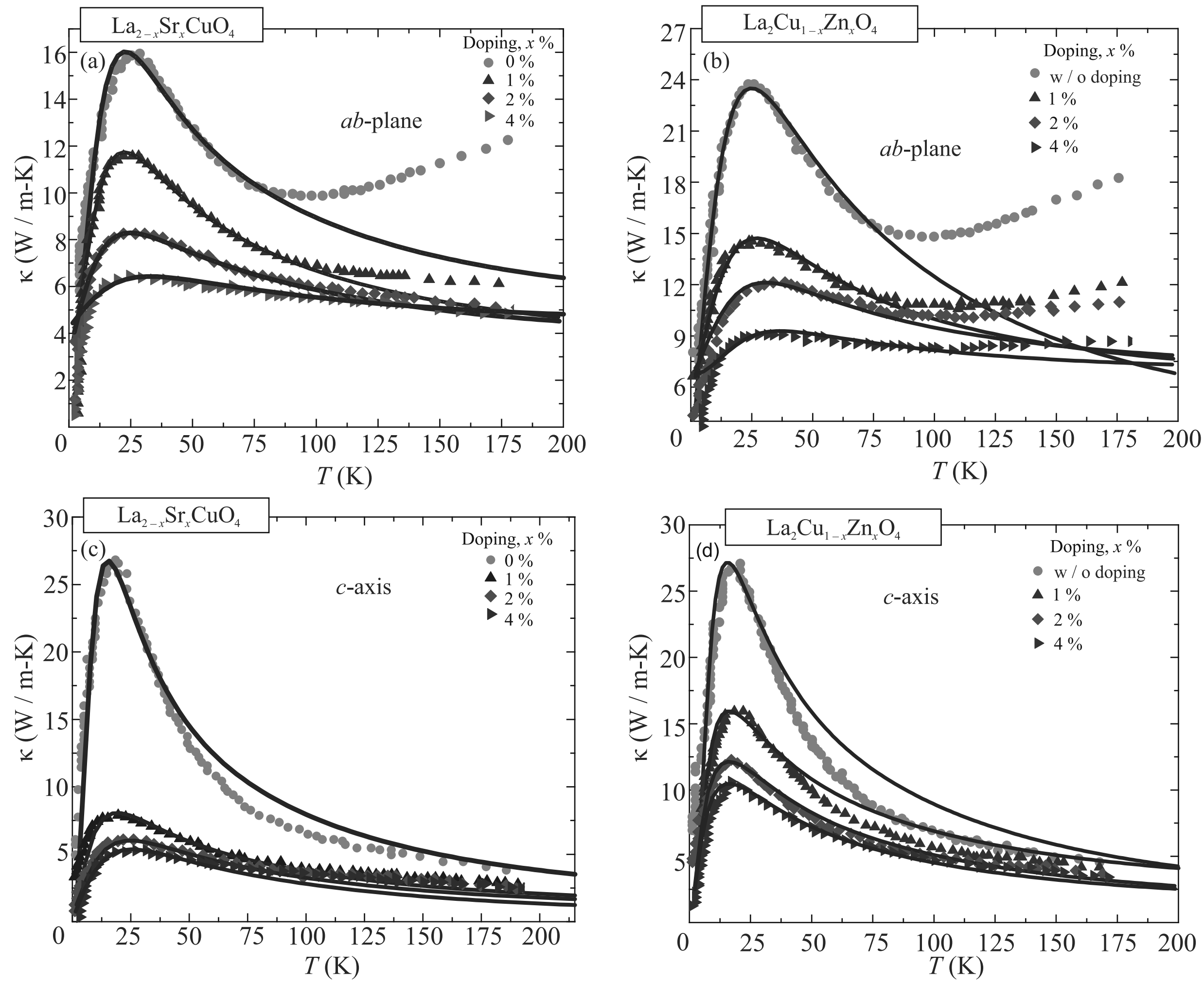

Fig. 1. (Color online) Theoretical investigation on thermal conductivity of Sr-doped $La_{2-x}Sr_xCuO_4$ (LSCO) and Zn-doped $La_2Cu_{1-x}Zn_xO_4$ (LCZO) along the *ab*-plane and *c*-axis. The experimental data were taken from Sun et al. [8]

antiferromagnetic order in the vortex state. As a result, at low doping levels, LCO will display aniferromagnetic behaviour at low temperatures, and the phonon-magnon contribution to thermal conductivity might eventually play a major role at low temperatures [6, 7]. Indeed, theoretical fitting has revealed that for both Sr and Zn doped LCO, phonon-magnon scattering below 25 K contributes more to heat transport in the *ab*-plane than in the *c*-axis. The proposed analytical model explains the experimental findings of Sr- and Zn-doped La_2CuO_4 thermal conductivity data in the temperature range 0–200 K adequately.

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1. J. Bardeen, G. Rickayazen, and L. Tewordt, Phys. Rev. **113**, 982 (1959).
2. J. Callaway, Phys. Rev. **113**, 1046 (1959).
3. G. P. Srivastava, *The Physics of Phonons*, 1st ed., Taylor and Francis, N.Y. (1990).
4. L. Tewordt and Th. Wolkhausen, Solid State Commun. **75**, 515 (1990).
5. P. G. Klemens, Proc. Phys. Soc. A **68**, 1113 (1955).
6. G. B. Teitel'baum, V. E. Kataev, E. L. Vavilova, P. L. Kuhns, A. P. Yeyes, and W. G. Moulton, JETP Lett. **78**, 1242 (2003).
7. P. D. Grigoriev and T. Ziman, JETP Lett. **106**, 349 (2022).
8. X. F. Sun, J. Takea, S. Komia, and Y. Ando, Phys. Rev. B **67**, 104503 (2003).