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LETTER TO THE EDITOR

A comparison of the ultrasonic evidence for mode softening in $La_{1.8}Sr_{0.2}CuO_4$ and the electron-doped superconductor $Nd_{1.85}Ce_{0.15}CuO_{4-y}$

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Abstract. Measurements of sound velocity show strong evidence for mode softening in $La_{1.8}Sr_{0.2}CuO_4$ but not in $Nd_{1.85}Ce_{0.15}CuO_{4-y}$. The results for $La_{1.8}Sr_{0.2}CuO_4$ are in agreement with a new recently reported phase diagram.

A softening of elastic constants was found to produce a significant enhancement of the electron–phonon coupling responsible for superconductivity in the A15 compounds. The nature of this softening was elucidated by a series of careful ultrasonic studies of these compounds (Testardi 1973). Following their discovery, the new ceramic high-temperature superconductors quickly became the subject of ultrasonic studies. Ultrasonic measurements of the first of these, $La_{2-x}Sr_xCuO_4$ (LSCO) (Bishop *et al* 1987, Horie *et al* 1987, Luthi *et al* 1987), showed remarkably similar characteristics to those found for the A15 compounds. Large decreases in elastic constants were found on cooling followed by a modest stiffening below the transition temperature, T_c. These results were not fully explained and have been rather bypassed because the higher-T_c superconductor $YBa_2Cu_3O_7$ did not exhibit similar effects. The recent discovery of an electron-doped superconductor (Tokura *et al* 1989) $Nd_{1.85}Ce_{0.15}CuO_{4-y}$ (NCCO) has prompted a number of comparisons with the properties of the original hole-doped superconductors. The purpose of this brief paper is to present a comparison of the first ultrasonic measurements of the electron-doped superconductor NCCO with some of LSCO and to point out that details of the latter must be related to the very recently reported lower-temperature tetragonal transformation (Axe *et al* 1989).

Samples of the two superconductors were produced by the conventional mixed-powder route and sintered to form pellets, 13 mm in diameter and about 4 mm thick. The resulting NCCO sample was subsequently annealed in an argon atmosphere at 1000 °C (Tokura *et al* 1989). Superconducting transitions were observed in both samples using the four-lead resistance technique; x-ray diffraction measurements were made to confirm structures. The faces of the samples were polished flat and ultrasonic waves were generated by quartz transducers bonded to these flat surfaces. Measurements were made of the velocity of ultrasound with a precision of at least 1 in 10^4 in the temperature range 4.2 to 290 K. Warming and cooling rates of less than 1 K min^{-1} were employed throughout.

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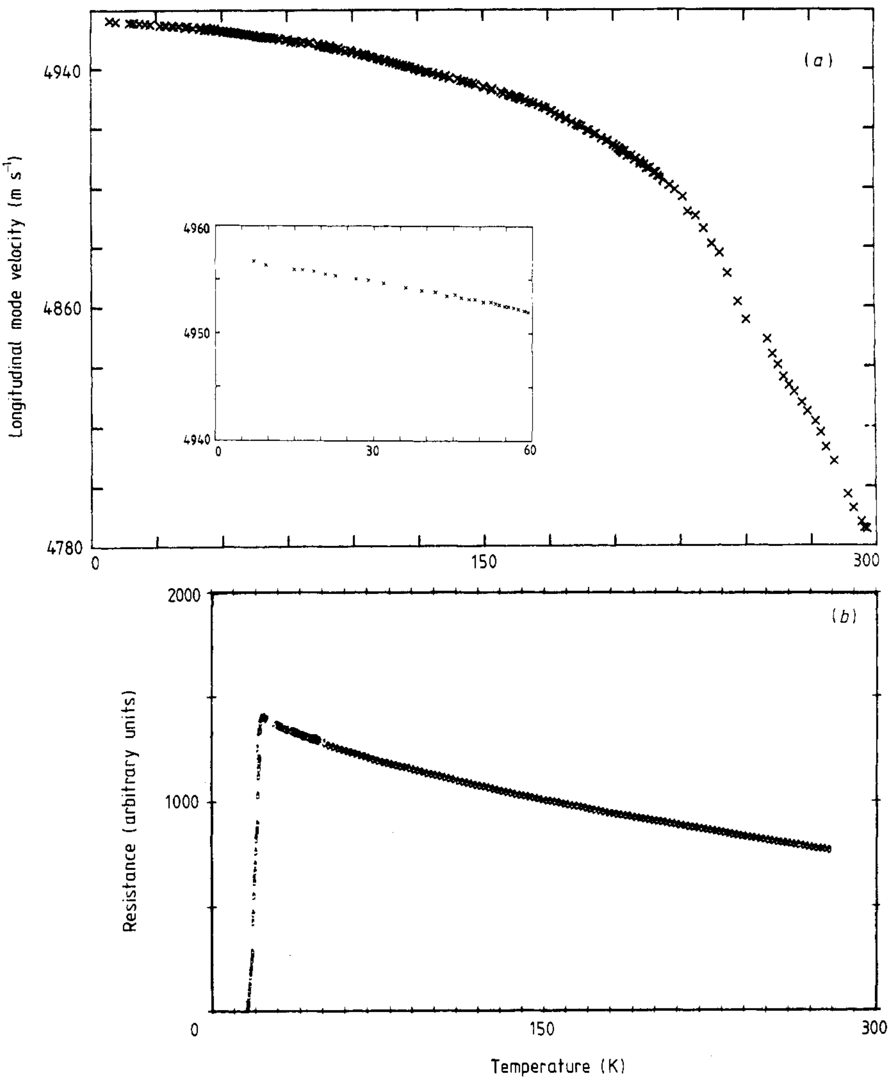

Figure 1. The temperature dependence of (*a*) the 5 MHz longitudinal wave velocity and (*b*) the electrical resistance in $Nd_{1.85}Ce_{0.15}CuO_{4-y}$.

Measurements of the longitudinal wave velocity in NCCO and LSCO, $x = 0.2$, are shown in figures 1 and 2 respectively. The appropriate resistance temperature characteristics are also shown in the figures. The ultrasonic characteristics of the two compounds are clearly quite different. Whereas LSCO exhibits a large fall in sound velocity on cooling below about 170 K, the electron superconductor, NCCO, shows a conventional increase. The insets in the figures amplify the behaviour near T_c. Again the difference is striking: LSCO exhibits a distinctive minimum in sound velocity—and hence elastic constants—at T_c, whereas the NCCO data are featureless at the superconducting transition. One unusual feature in the NCCO data, however, is the pronounced change in slope at about 225 K.

The first conclusion that can be drawn from the ultrasonic data is that in LSCO one or more of the elastic constants become soft at the zone centre and that the same zone-centre softening is not present in NCCO. Hence, if there is a lattice-mediated contribution

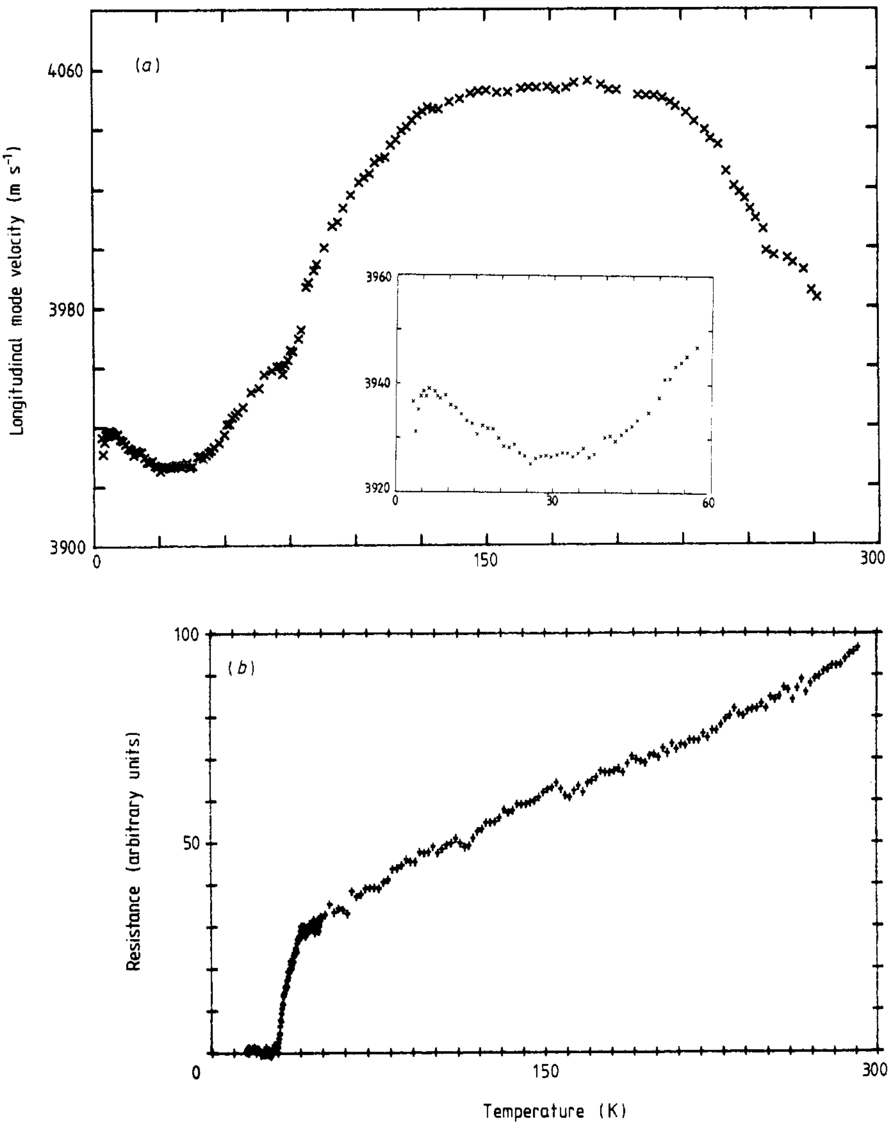

Figure 2. The temperature dependence of (*a*) the 5 MHz longitudinal wave velocity and (*b*) the electrical resistance in $La_{1.8}Sr_{0.2}CuO_4$.

to electron coupling in these materials, it appears not to be of the same type in these two cases. The decrease in the velocity–temperature slope in NCCO at 225 K might be indicative of a modest reduction in elastic stiffness caused by softening of optic or zone-boundary acoustic phonons, but since ultrasonics is strictly a zone-centre probe we can do no more than suggest this as a possibility.

The physical origins of the striking ultrasonic effects found solely in the hole-doped La_2CuO_4 superconductors have recently emerged from a clarification of the structural phase transformations in $La_{2-x}Ba_xCuO_4$ (Axe *et al* 1989). It is reported that in addition to the already known (Paul *et al* 1987) higher-temperature orthorhombic–tetragonal phase transformation, a further transformation to a second tetragonal phase occurs at lowest temperatures. An examination of the reported phase diagram shows that the substantial softening below room temperature measured in $La_{2-x}Ba_xCuO_4$, $x = 0.15$, by Fossheim *et al* (1987) is associated with the higher-temperature orthorhombic–tetragonal transformation, whilst the modulus hardening occurs at lower temperatures where the low-temperature tetragonal phase develops. For the $x = 0.2$ composition, the two phase transition temperatures coincide with each other and also with the superconducting transition temperature T_c, eliminating the intermediate orthorhombic state. A sample of this composition is in a condition of maximum overall elastic softening at T_c. This is just the composition studied here, explaining (assuming that the phase diagrams for Sr- and Ba-doped La_2CuO_4 are similar) the simple minimum (see figure 2) in sound velocity at T_c.

There is a marked similarity between the ultrasonic behaviour of the hole-doped La_2CuO_4 superconductors and that of the A15 compounds. In both groups of materials structural phase transitions and consequent elastic mode softening occur at temperatures near T_c. There is now, we believe, an urgent need for single-crystal ultrasonic measurements to elucidate the elastic constant softening. By contrast, the electron-doped superconductor, and the higher-T_c superconductors $YBa_2Cu_3O_7$ and $GdBa_2Cu_3O_7$ (Almond *et al* 1989), exhibit no effects that might be associated with softening of the long-wavelength acoustic phonon modes; in this respect the original ceramic superconductors based on La_2CuO_4 are atypical.

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