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Ultrasound attenuation and velocity in $Bi_2Sr_{2-x}Ca_{1+x}Cu_2O_{8-\delta}$

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Abstract

We report preliminary results of measurements of ultrasound velocity and attenuation in polycrystalline samples of $Bi_2Sr_{2-x}Ca_{1+x}Cu_2O_{8-\delta}$ with $x=0$, 0.25, 0.50, 0.75 and 1.00. We have found different dependences of sound velocity on temperature in the samples investigated. The attenuation exhibits a maximum near 230 K.

1. Introduction

We wanted to distinguish the relation between elastic properties and the structure and the critical temperature of high T_c superconductors. Therefore we have chosen to investigate $Bi_2Sr_{2-x}Ca_{1+x}Cu_2O_{8-\delta}$ samples with x ranging from 0 to 1. These samples have the same crystallographic structure, but their critical temperature varies by more than 40 K.

2. Sample preparation and measurement

A series of polycrystalline $Bi_2Sr_{2-x}Ca_{1+x}Cu_2O_{8-\delta}$ samples ($x=0$, 0.25, 0.50, 0.75 and 1.00) was prepared by the common powder metallurgical method from Bi and Cu oxides and Sr and Ca carbonates. These samples will be denoted as A0, A25, A50, A75 and A100, respectively. After calcination at 800–840 °C for 64 h in air, the powders were compacted and sintered at 840–845 °C for 96 h in air. Sintering was interrupted twice and samples were isostatically cold pressed at 0.5 GPa.

Oxygen desorption of $Bi_2Sr_{2-x}Ca_{1+x}Cu_2O_{8-\delta}$ ($x=0$–1) oxides is known to change the critical temperature (originally about 80 K for all the compositions) into a critical temperature that is strongly dependent on x [1]. Therefore the samples were finally heat treated at 600 °C in an N_2 atmosphere.

The resulting pellets were about 11 mm in diameter, 6 mm in height and 5.2–5.5 g cm^{-3} in density. X-ray diffraction analysis revealed that the prepared samples were nearly single phase, isostructural to the 2212 phase; the edge compositions contained a small amount of other phases.

The d.c. and a.c. magnetic susceptibilities were measured using a miniature susceptometer based on a SQUID system. The measurements were performed in a magnetic field at about 30 μT in the FC regime. The critical temperature T_c (determined as the onset temperature of the diamagnetic shift) decreases with increasing concentration of Ca (Fig. 1).

The ultrasound measurements were performed with the pulse-echo method using the Matec apparatus. The frequency of the longitudinal and of the shear ultrasound waves was 5 MHz. We measured the attenuation and the velocity on both the cooling and the heating runs to eliminate any possible influence of thermal hysteresis. We found that the difference between the runs was not significant.

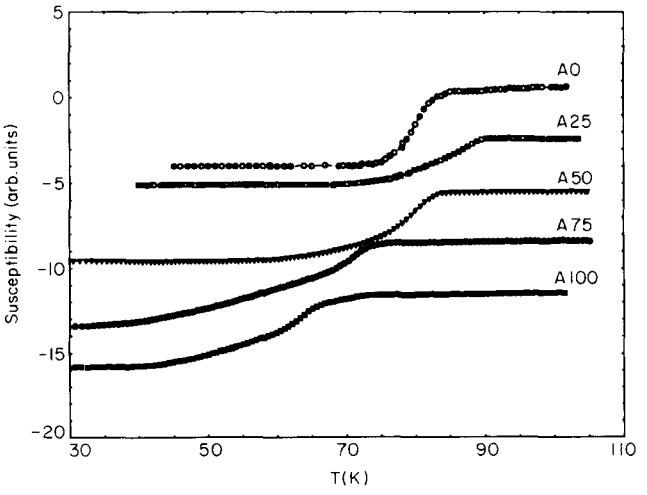

Fig. 1. The d.c. susceptibility of the investigated samples.

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3. Results

The results of the attenuation measurement of longitudinal and shear waves are plotted in Figs. 2 and 3 respectively. The curves are smooth, with an attenuation maximum in samples A0, A25, A75.

This kind of dependence is relatively common in "high temperature" superconductors (HTSC); its origin is usually ascribed to reordering of oxygen atoms.

The apparent absence of the maximum in sample A50 may be due to the high basic level of the attenuation (more than twice that in the other samples), which can cover the possible maximum in this sample.

The velocity (both of longitudinal and of shear waves) shows an increase ("stiffening") upon cooling, with a tendency to saturation at low temperatures. Such a behaviour is shared by most solids. The differing behaviour of the investigated samples appears, however, when the velocities are normalized (Figs. 4 and 5). The differences are subtle for shear waves, but clearly visible for longitudinal waves.

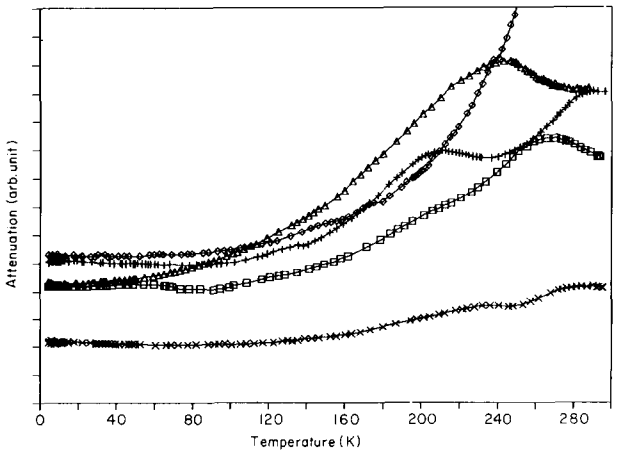

Fig. 2. Ultrasonic attenuation of longitudinal waves in the investigated samples. □, A0; +, A25; ◇, A50; △, A75; ×, A100.

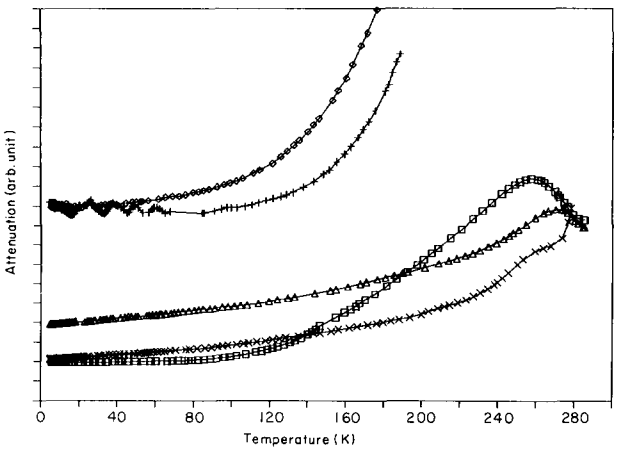

Fig. 3. Ultrasonic attenuation of shear waves in the investigated samples. □, A0; +, A25; ◇, A50; △, A75; ×, A100.

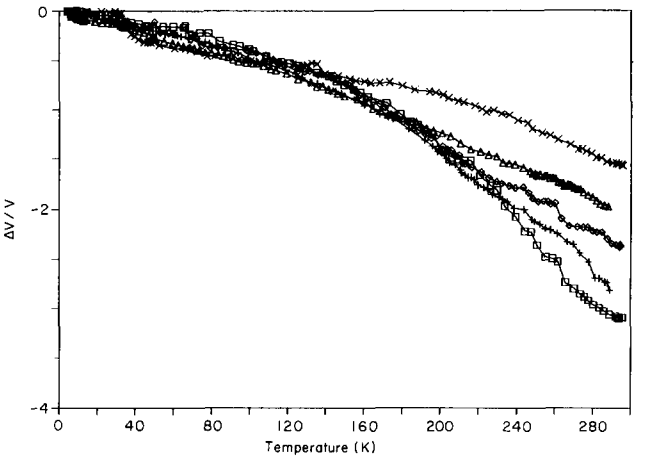

Fig. 4. Relative change (%) of longitudinal velocity in the investigated samples. The velocities are normalized to $v(T=4\ \mathrm{K})$ in each sample. □, A0; +, A25; ◇, A50; △, A75; ×, A100.

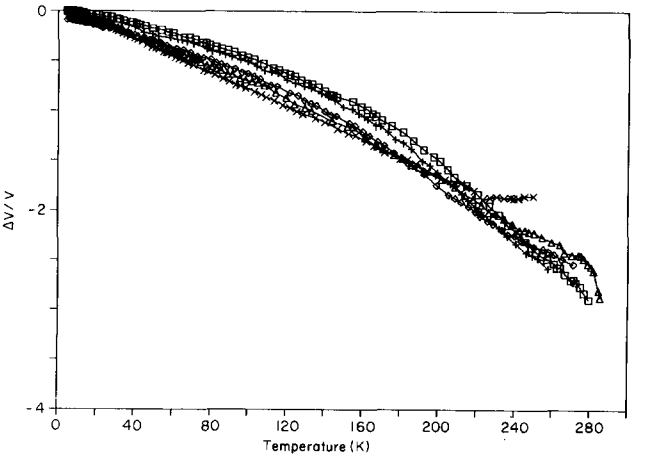

Fig. 5. Relative change (%) of shear velocity in the investigated samples. The velocities are normalized to $v(T=4\ \mathrm{K})$ in each sample. □, A0; +, A25; ◇, A50; △, A75; ×, A100.

We have not made any corrections for the thermal dilatation. We expect that these corrections would not influence the results significantly. The relative change of sample length in HTSC is about a tenth of the relative change of sound velocity [2]. Furthermore, the velocity and the lattice parameters should change with temperature in a similar way [3].

We also did not recalculate the results for the void-free values. This approach is allowed by the fact that we are interested not in the absolute values but in the differences between the samples. Because the densities of the samples did not differ by more than 6%, this cannot explain the observed difference in $\Delta v/v$.

4. Discussion

It should be stated at first that the observed differences between longitudinal velocities are not due to exper-

imental error, as the relative position of the curves for individual samples fits Sr/Ca content.

The temperature dependence of sound velocity v has been described by Maris [5]:

$$\frac{\Delta v}{v} = -\frac{TC_v\gamma_{\text{eff}}^2}{2\rho v^2} \quad (1)$$

where C_v is the specific heat per unit volume, ρ is the density, v is the sound velocity, and γ_{eff} is a thermal average of the first- and second-order Grüneisen tensors.

We are, however, not interested in the general dependence of sound velocity but rather in differences between the investigated samples. In eqn. (1), we know T, v and ρ. C_v can be calculated, if we know the Debye temperature.

We used estimated values of the following quantities from review papers: longitudinal velocity $v_l = 2800$ m s^{-2}, shear velocity $v_s = 1800$ m s^{-2} [2], $\rho = 6450$ kg m^{-3}, Debye temperature $\Theta = 240$ K [2, 5].

From $\Delta v/v$ at 240 K we obtained $\gamma_{\text{eff}} = 9.4$ for shear waves (almost equal for all the samples), and 13.9, 12.8, 12.0, 11.2 and 10.3 for longitudinal waves for samples A0, A25, A50, A75 and A100, respectively.

The reasons why the observed effects cannot be significantly influenced by different porosities can be summarized as follows:

1. The samples were prepared in a similar way and their porosities do not differ much.

2. The dependence of porosities on the Ca content is not monotonic, compared with the dependence of γ_{eff}.

3. The influence of porosity cannot explain the different behaviour of shear and longitudinal waves.

The data found are influenced by all the approximations taken during the calculation. Furthermore we cannot distinguish how much the individual phonon mode/modes contribute to γ_{eff}. We have shown, however, that a relation exists between γ_{eff} and the Sr/Ca ratio or the critical temperature (*i.e.* oxygen content). We suppose the latter more probable. We also see that the electron–phonon interaction for longitudinal waves does depend on Sr–Ca or O content, while electron–phonon interaction for shear waves does not.

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