Anomalies in the velocity of sound and in the elastic moduli near the superconducting transition of the ceramic $YBa_2Cu_3O_7$

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The velocity of the longitudinal and transverse ultrasonic waves (2.4 MHz) in a superconducting ceramic $YBa_2Cu_3O_7$ is measured over the temperature interval 4.2–300 K. The ultrasonic velocity of the longitudinal and transverse waves was found to behave anomalously in the neighborhood of the superconducting transition (93 K). The velocity of the longitudinal waves was also found to increase as the temperature was raised from 40 K to 65 K. The results of the measurements are used to calculate the temperature dependences of the elastic moduli and the Debye temperature.

The study of elastic properties is important in determining the mechanism responsible for the superconductivity of high-temperature ceramics and for the anomalous behavior of their characteristics near the transition to the superconducting state. We have measured the temperature dependence of the ultrasound velocity in single-

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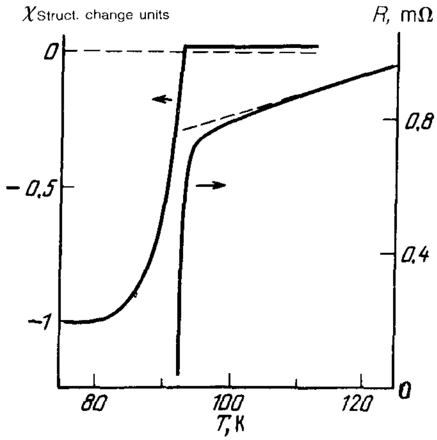

FIG. 1. Temperature dependence of the magnetic susceptibility $\chi(T)$ in a 5-Oe field and of the sample's resistance $R(T)$.

phase ceramic samples $YBa_2Cu_3O_7$ and calculated various elastic characteristics of these samples.

The samples were fabricated using the technology described in Ref. 1. As basic components we used finely ground Y_2O_3, BaO, and CuO powders. The original mixture of the required composition was pressed into pellets at a pressure of 2–5 kbar and then annealed in an oxygen stream at a temperature of 900 °C for 12 h with intermediate grinding. The use of this method enabled us to eliminate carbon impurities in the material. The samples used for the study of the elastic characteristics were 15-mm-diameter cylinders of various heights. The density of the samples was 5.3 g/cm^3. X-ray analysis revealed the presence of only one phase: $YBa_2Cu_3O_7$.

Figure 1 shows the temperature dependences of the susceptibility $\chi(T)$ and of the

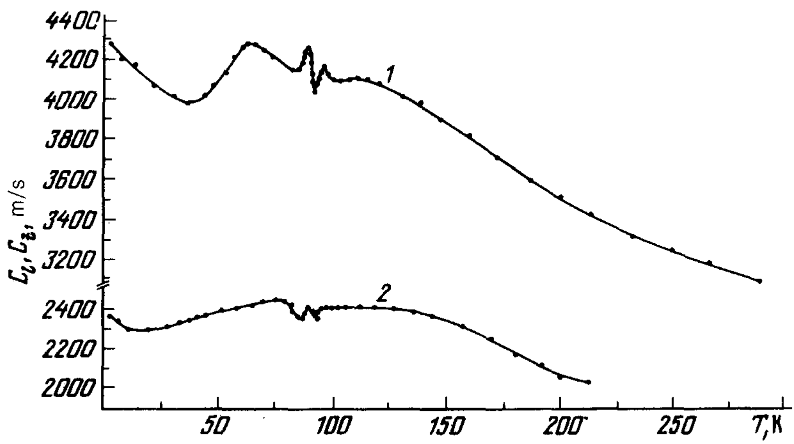

FIG. 2. Temperature dependences of the ultrasonic velocity of the longitudinal waves (1) and shear waves (2).

resistance $R(T)$ of one of the $YBa_2Cu_3O_7$ samples near the transition to the superconducting state. At $T = 77.4$ K the value of χ is nearly -1 (in units of structural change). The temperature at which the transition to the superconducting state occurs is $T_c = 93$ K (measured at the transition midpoint). The sample became completely superconducting at $T = 92$ K. The $R(T)$ curve begins to diverge from linear behavior at $T = 113$ K.

The velocities of longitudinal ultrasonic waves and transverse ultrasonic waves were measured at a frequency of 2.4 MHz using a setup described in Ref. 2. As piezoelectric transducers we used $LiNbO_3$ plates. The measurement accuracy of the velocity of ultrasound was better than 1%. The measurements were carried out in the temperature interval between 4.2 K and 300 K. The sample was held at a temperature within 0.1 K.

Figure 2 shows the temperature dependences of C_l and C_t. The value of C_l increases by approximately 30% as the temperature is lowered from room temperature to 120 K. Such an increase in the velocity of sound with decreasing temperature is unusual. At 100–115 K the value of C_l is essentially constant. Near T_c we see an interesting peculiarity in the behavior of both C_l and C_t. The oscillation in the sound velocity, anomalously large (5%), in this region is much larger than the measurement error. At low temperatures ($T < 65$ K) we see another anomaly: a nonmonotonic behavior of $C_l(T)$. In the case of shear waves the velocity does not increase as markedly as the temperature is lowered from room temperature to 130 K. We see a plateau at $T = 130$ K.

The temperature dependences of the following dynamic moduli were calculated (in the constant-density approximation) by Perepechko[3] from the experimental data

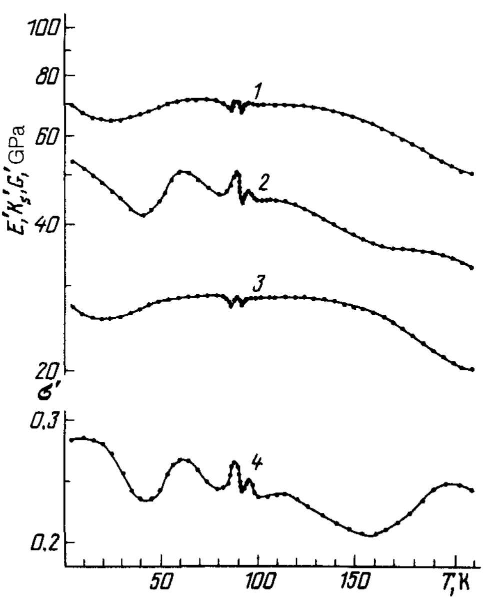

FIG. 3. Temperature dependences of the following dynamic moduli: Young's modulus (1), bulk modulus (2), shear modulus (3), Poisson's ratio (4).

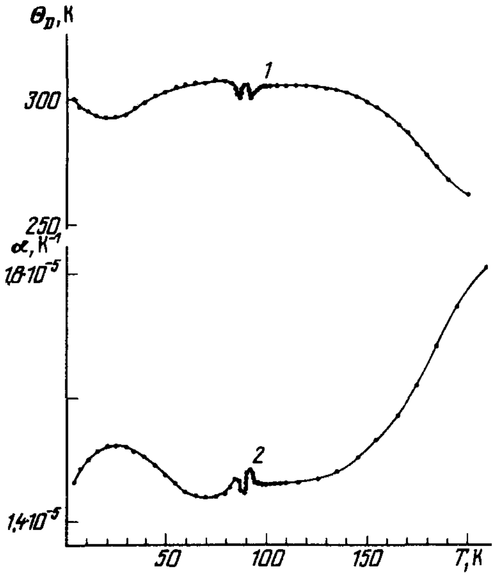

FIG. 4. Temperature dependences of the Debye temperature Θ_D (1) and of the linear expansion coefficient α (2).

on the ultrasound velocities: Young's modulus E', bulk modulus K'_s, shear modulus G', and Poisson's brackets σ' (Fig. 3). Some of these curves (K'_s and σ') reveal several additional peculiarities at $T \simeq 200$ K, for example.

The results obtained allowed us to calculate the Debye temperature Θ_D and the linear expansion coefficient α (Fig. 4). The Debye temperature, which turned out to be $\Theta_D \approx 300$ K, varies slightly with the temperature, increasing by 10–15% as T is lowered from room temperature to 100 K. The value of α was calculated on the basis of Barker's empirical formula, $\alpha^2 =$ const. Near T_c the value of α and the functional dependence $\alpha(T)$ are in agreement with the independent direct measurements of the expansion coefficient.

The results obtained by us show that the transition to the superconducting state of the yttrium ceramic $YBa_2Cu_3O_7$ is accompanied by a series of anomalies in the behavior of elastic, structural, and other characteristics. The variation of the corresponding parameters over a narrow temperature interval exceeds by several orders of magnitude a similar variation in ordinary superconductors. The observed anomalies in the elastic characteristics near the transition reflect, in our view, the structural changes of the system. These changes suggest that the crystal lattice of the compound has a definite instability near T_c which is lifted by virtue of the superconducting transition. The structural changes which set in near 100 K put the system in a peculiar state (in which a nonphonon type of electron-electron interaction likely occurs), which accounts for the high-temperature superconductivity. A metal-insulator transition, in which sets of four particles, rather than electron-electron or electron-hole pairs, are formed near the Fermi surface, is a possible mechanism which could bring about such a change in the structure and in the electronic spectrum.[4]

[1]M. K. Wu, J. G. Ashburn, C. J. Torng, P. H. Hor, R. L. Meng, L. Gao, L. J. Huang, Y. Q. Wang, and C. W. Chu, Phys. Rev. **58**, 908 (1987).
[2]I. I. Perepechko and P. D. Golub', Prib. Tekh. Eksp., No. 6, 216 (1972).
[3]I. I. Perepechko, Properties of Polymers at Low Temperatures, Khimiya, Moscow, 1977.
[4]Yu. V. Kopaev, Trudy FIAN **86**, 3 (1986) (Proceedings of the Lebedev Physics Institute).

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