Kinetic properties of the HTSC compound Ag–Bi2223

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Thermal conductivity $\lambda(T)$ and resistivity $\rho(T)$ of the HTSC compound Ag–Bi2223 ($T_c \simeq 107$ K; $\Delta T_c \simeq 2$ K) produced by the Intermagnetics General Corporation (USA) were measured in the temperature intervals 4.2–300 K and T_c–300 K respectively. Away from the SC transition, the values of $\lambda(T)$ and $\rho(T)$ are determined by the silver content. For $T > 60$ K, irregular thermal conductivity oscillations are observed in the vicinity of the superconducting transition against the background of the dependence $\lambda(T)$ typical of silver. The position and amplitude of the oscillations are not affected by temperature cycling. A sharp minimum on the $\lambda(T)$ dependence, whose depth is much larger than the estimated contribution of thermal conductivity of Bi2223 to the thermal conductivity of the system, is observed at T_c. © *1999 American Institute of Physics.* [S1063-777X(99)01406-1]

Temperature dependences of thermal conductivity λ and resistivity ρ of the superconducting composite material Ag–HTSC are studied.

The investigated material was in the form of a ribbon of cross-section 3.68×0.206 mm^2 produced by the Intermagnetics General Corporation (USA). A mixture of silver powder and the HTSC compound Bi2223 having volume fractions of 70 and 30% respectively were packed in a silver casing. The initial purity of silver was 99.95%. The sample was about 5 cm long. The resistivity $\rho(T)$ was measured by the four-probe method, while the thermal conductivity $\lambda(T)$ was measured by using the *steady axial heat* flow technique. The charge and thermal fluxes were directed along the ribbon. The thermometers were attached to the sample for $\lambda(T)$ measurement at the same points as the potential leads for $\rho(T)$ measurement, and hence the geometrical factors coincide in both cases. The temperature dependence of ρ was measured in the interval between T_c and 300 K with an average error not exceeding 0.5%. The dependence $\lambda(T)$ was measured in the interval 4.2–300 K with an average error 2%.

The superconducting transition temperature T_c, determined from the position of the $d\rho/dT$ peak, was found to be 107 K with a transition width of about 2 K. The $\rho(T)$ dependence of the composite is a linear function of temperature in the interval 108–300 K, and $\rho(300\,\mathrm{K}) = 3.87 \times 10^{-8}$ $\Omega \cdot$m, which is about twice as large as the data available in literature for pure silver.[1]

The $\lambda(T)$ dependence of the composite in the investigated temperature range is typical for the thermal conductivity of pure silver (Fig. 1). The thermal conductivity peak lies at 15 K, which is in accord with the data obtained in Refs. 2 and 3, but the thermal conductivity at the peak is about half the value given in these works. Above 100 K, the thermal conductivity of the composite depends weakly on temperature and amounts to about 210 W/(m·K). In this region, the thermal conductivity of silver samples with different degrees of purity is close to 430 W/(m·K) (see, for example, Ref. 4), which is almost double the value obtained by us. Thus, the characteristic values of $1/\rho$ and λ are about half the values given in the literature for pure silver. The measured values of conductivity indicate that the outer silver shell occupies about half the cross-sectional area of the ribbon. The remaining silver is in the form of interlayers between HTSC particles.

The obtained results can be discussed conveniently by using the Lorentz function

$$L(T) = \lambda(T)\rho(T)/T. \tag{1}$$

Figure 2 shows the values of $L(T)$ for silver having various degrees of purity, calculated by using the data presented in Refs. 1–4, as well as for the composite material studied in this work. It can be seen that the $L(T)$ curves for silver with different degrees of purity are close to each other and tend to the Sommerfeld value $L_0 = 2.45 \times 10^{-8}$ WΩ/K^2 upon an increase in temperature, which is typical of metallic

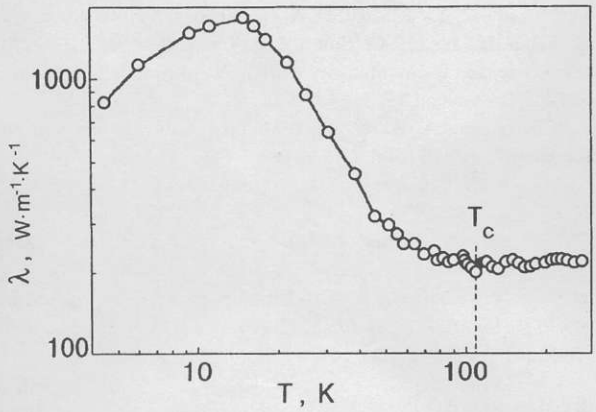

FIG. 1. Temperature dependence of the thermal conductivity of the composite Ag–Bi2223.

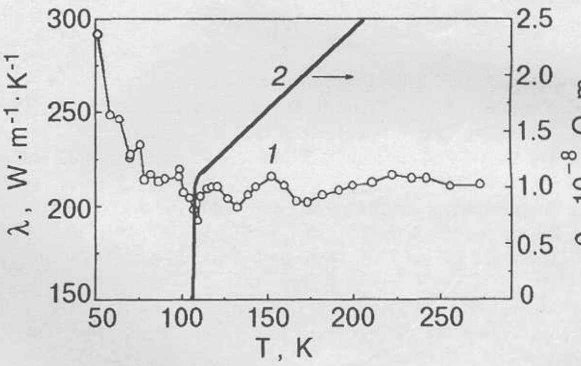

FIG. 3. Thermal conductivity (curve *1*) and electric resistivity (curve *2*) of the composite Ag–Bi2223 in the vicinity of the superconducting transition.

conductivity at temperatures higher than the Debye temperature. For the composite, $L(T) > L_0$, and increases with temperature. This is probably due to the additional contribution to $\rho(T)$ (1) associated with the presence of two components, especially with the scattering at interfaces.

At low temperatures, the thermal conductivity of quite pure metals is described by the Wilson formula[5]

$$T/\lambda(T) = \rho_0 / L_0 a T^3, \tag{2}$$

which is also applicable to the composite investigated by us in the temperature range 4.2–46 K. Here, ρ_0 is the residual resistivity of the composite and a is a constant. The value of ρ_0 in formula (2) is equal to $1.14\times 10^{10}\,\Omega\cdot$m. Thus, the ratio $\rho(300\,\mathrm{K})/\rho(4.2\,\mathrm{K})$ characterizing the purity of the silver matrix is close to 300.

At $T > 60$ K, irregular oscillations of thermal conductivity of the composite are observed against the background of the $\lambda(T)$ dependence typical of pure metals in this temperature range (Fig. 3). The oscillation amplitude is about 10% of the thermal conductivity in this temperature range, i.e., several times larger than the characteristic values of the thermal conductivity of bismuth-based HTSC (see, for example, Refs. 6 and 7). Multiple temperature cycling (from 4.2 to 300 K) does not affect the obtained results.

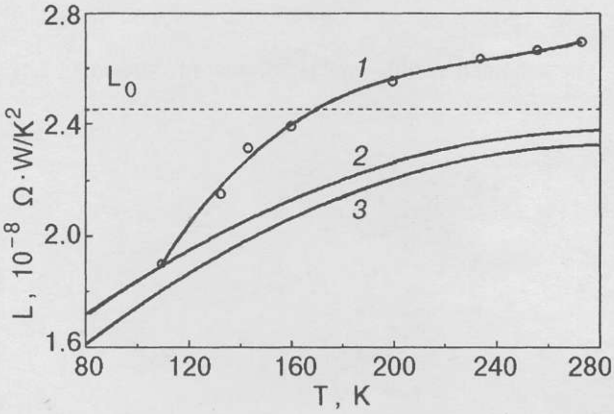

FIG. 2. Temperature dependence of the Lorentz function of composite Ag–Bi2223 (curve *1*) and silver of different purities (curves *2, 3*).[1,3]

It can be assumed that such a behavior of thermal conductivity is associated with the emergence of the effect of Andreev reflection of quasiparticles in a mesoscopic system of nonsuperconductor–superconductor junctions in the investigated heterophase system.

On the temperature scale, the deepest and sharpest thermal conductivity minimum coincides with T_c. Such a sharp decrease in thermal conductivity and electrical resistivity indicates the elimination of superconducting electrons from the heat transport process. Such a behavior of $\lambda(T)$ and $\rho(T)$ in the vicinity of T_c was indicated by us earlier.[8]

Analogous behavior of some physical characteristics was also observed in several superconducting composites, including HTSC. In Refs. 9 and 10, such a behavior of heat capacity, linear expansion coefficient, and thermal conductivity of Y-based HTSC was attributed by the authors to lattice instability caused by migration of superstoichiometric oxygen. For the superconducting composite Nb–Cu, such a behavior of thermal conductivity was observed at 50–60 K,[11] i.e., far from the superconducting transition ($T_c = 9.1$ K). Simultaneously, a decrease in the internal friction and a splitting of the natural frequency of flexural vibrations of the sample into three components was observed upon a decrease in temperature.

Apparently, such structural instabilities are characteristic of spatially inhomogeneous materials including high-temperature superconductors and composites, and may be manifested near the superconducting transition or away from it.

Note that the thermal expansion of Bi-based HTSC has a considerable anisotropy[12,13] while the thermal expansion coefficient is about half its value for silver. The data presented in Refs. 12–15 can provide a very rough estimate of the stresses emerging in the composite sample upon cooling from 300 to 100 K. Such an estimate leads to a value of the order of 10^8 Pa. Such anisotropic stresses may stimulate the emergence of structural instabilities in the investigated two-phase composite, which may also lead to the observed nonmonotonic behavior of thermal conductivity.