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High-Temperature Superconductor Based Composites: Large Magnetoresistance in Weak Magnetic Fields

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Abstract—It was found that high-temperature superconductor (HTSC) based composites of the 1–2–3 (YBCO) + dielectric and YBCO + normal metal types exhibit large magnetoresistances in weak magnetic fields in a broad temperature range. This behavior is qualitatively explained using the concept of the irreversibility line in HTSCs and the mechanism of thermal fluctuations in the network of weak bonds of the Josephson type realized in HTSC composites. The HTSC-based composites exhibit a much higher sensitivity (as compared to that in the usual HTSC ceramics) to weak magnetic fields (below 300 Oe) at liquid-nitrogen temperatures, which is important for practical applications. © *2001 MAIK "Nauka/Interperiodica".*

The resistivity ρ of polycrystalline high-temperature superconductors (HTSCs) at temperatures below the superconducting transition temperature T_c is highly sensitive to weak magnetic fields [1, 2]. This sensitivity is explained by dependence of the resistive state of such HTSCs on the state of grain boundaries representing weak bonds of the Josephson type [1–3] known to be very sensitive to external magnetic fields [4]. However, the temperature interval in which the HTSC ceramics exhibit a large magnetoresistance in weak magnetic fields is very narrow, typically amounting to several degrees (e.g., 85–90 K for the yttrium ceramics and 90–100 K for the bismuth ceramics [2]). This circumstance probably accounts for the fact that the above magnetoresistance effect in HTSC ceramics is insufficiently studied from the standpoint of practical applications. At the same time, extensively studied are the related materials such as the HTSC-based composites (see, e.g., [5–12]). These materials exhibit interesting transport [5, 6, 10, 12] and magnetic [9] properties. Below, we report on the results of our investigation of the magnetoresistance effect in weak magnetic fields in bulk composites of the HTSC + normal metal and HTSC + dielectric types.

The samples of composites were synthesized as follows. The 1–2–3 HTSC composition $Y_{3/4}Lu_{1/4}Ba_2Cu_3O_7$ (referred to below as YBCO) was prepared using a standard technology.[1] In the YBCO + dielectric composites, the dielectric component was CuO of a special purity grade [13]. $BaPbO_3$ oxide obtained by solid-state synthesis from BaO_2 and PbO was used as the normal metal [14]. The mixtures of powdered components taken in stoichiometric proportions were thoroughly mixed in an agate mortar and pressed into tablets. The tablets were annealed according to the following schedule: 5min at 930°C and 6 h at 400°C for the composites with $BaPbO_3$; 2 min at 910°C and 3 h at 350°C for the composites with CuO. After the final annealing stage at 350–400°C, the samples were cooled down to room temperature with the furnace (for detail, see [10, 11]).

The X-ray diffraction investigation of HTSC-based composites showed only the reflections due to phases of the initial components, which was evidence of the absence of chemical interactions between these components. The electron-microscopic observation of HTSC-normal metal composites showed that an average size of the YBCO grains in this material was ~1.5 μm. The transport properties (resistivity below T_c, critical current, current–voltage characteristics) of the composites were reported in detail elsewhere [10–12]. The experimental data on the effect of a magnetic field on the resistivity of these materials are presented for the first time.

The ρ(T) curves were measured using a standard four-point-probe method in the sample heating mode, with a magnetic field H applied perpendicularly to the current direction. The samples were cooled in the Earth magnetic field. Figures 1 and 2 show the ρ(T) curves of the composites measured at a constant value of the probing transport current (indicated in the legends to

[1] We selected the yttrium ceramics with lutetium because this base composition was employed for the preparation of HTSC- based composites in [10–12]. The character of the experimental data is generally the same for pure $YBa_2Cu_3O_7$ based composites.

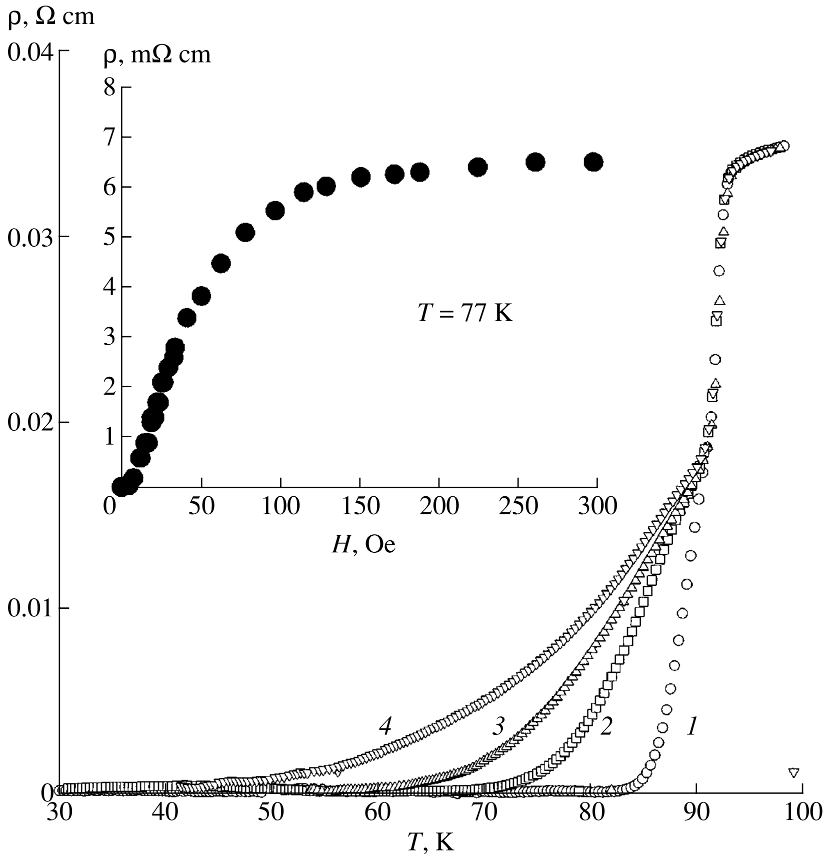

Fig. 1. Temperature dependences of the resistivity ρ of a 85 vol % YBCO + 15 vol % $BaPbO_3$ composite measured at various values of the applied magnetic field strength $H = 0$ (*1*), 38 (*2*), 79 (*3*), and 270 Oe (*4*) using a probing current density of 50 mA/cm^2. The inset gives the plot of ρ versus H at $T = 77$ K.

figures) and variable magnetic field. The jump in ρ at $T = 93.5$ K corresponds to a transition to the superconducting state in HTSC grains. This temperature coincides with T_c of the composites and the initial YBCO determined from the results of magnetic measurements. The relative magnitude of the resistivity jump depends neither on the transport current (as established in [10, 11]) nor on the applied magnetic field (see Figs. 1, 2) and varies only with the bulk ratio of the components. The transition of a composite sample into the state with "zero" resistance (measured with an accuracy of ~10^{-6} Ω cm) is manifested by an extended ρ(T) branch ("tail"). Such behavior of ρ(T) reflects the influence of the grain boundaries, the role of which in the composite is played by the non-HTSC component. This branch of the ρ(T) curve of the composite exhibits a strong dependence on the transport current [10, 11] and the magnetic field strength.

The insets to Figs. 1 and 2 show the plots of ρ(H) measured at $T = 77$ K. Below the magnetic field strength of $H \approx 40$ Oe, the initial (forward) and reverse branches of the ρ(H) dependence coincide. For $H > 40$ Oe, the reverse branch of ρ(H) is lying below the initial curve. When the external field strength is decreased down to $H \approx 0$ (the Earth's magnetic field was not shielded), the resistance is greater than that before switching the field on (these data are not depicted in the figures). Such a behavior of the ρ(H) is related to the effect of vortex pinning in the HTSC grains. The results of a detailed investigation of ρ(H) at various temperatures will be reported separately. Here, we would like only to emphasize that ρ is highly sensitive to relatively weak magnetic fields (below ~300 Oe) at 77 K. As the H value is increased further, the ρ(H) value at 77 K grows rather weakly, as can be seen from the plots of ρ(H) measured at $H = 1$, 10, and 60 kOe for the sample of 70 vol % YBCO + 30 vol % CuO (Fig. 2). Note that the resistivity transition in HTSC grains also exhibits smearing when the field increases to $H \sim 10$–60 kOe (Fig. 2), the magnitude of this effect in the composite at ~10 K for $H = 60$ kOe being comparable to that in YBCO single crystals [15].

Using the concept of the irreversibility line in HTSCs and the mechanism of thermally activated phase slippage [16] in the Josephson junction, Tinkham [15] theoretically derived an expression for the resistivity transition width as a function of the applied magnetic field strength: $\Delta T_c(R = 0) = CH^{2/3}$ and indicated that this result is applicable both to HTSC single

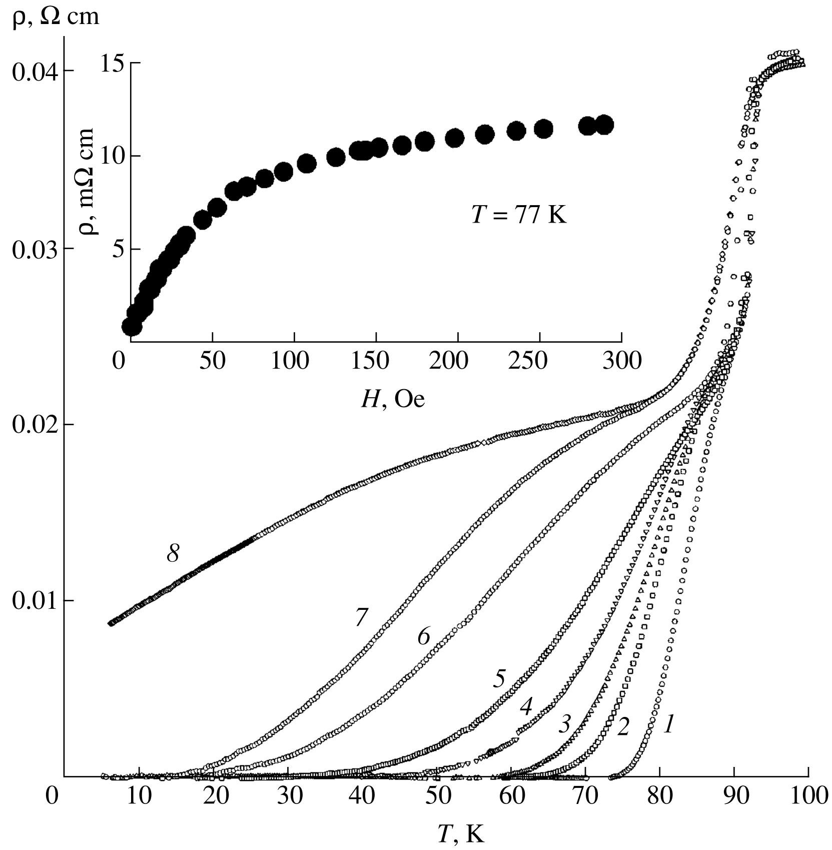

Fig. 2. Temperature dependences of the resistivity ρ of a 70 vol % YBCO + 30 vol % CuO composite measured at various values of the applied magnetic field strength $H = 0$ (*1*), 38 Oe (*2*), 79 Oe (*3*), 183 Oe (*4*), 1 kOe (*5*), 10 kOe (*6*), 60 kOe (*7*) using a probing current density of 50 mA/cm^2 and $H = 60$ kOe (*8*) using a probing current density of 0.5 A/cm^2. The inset gives the plot of ρ versus *H* at $T = 77$ K.

crystals and to a network of weak contacts of the Josephson type realized in polycrystalline HTSCs. However, the constant factor *C* in the latter case must be greater than that for the single crystal, which implies that the magnetoresistance effect will be manifested in weak magnetic fields.

Figure 3 shows the plots of $\Delta T_c = T_c(H, R = 0) - T_c(H = 0, R = 0)$ versus $H^{2/3}$. As can be seen, the experimental points fit well to the straight lines constructed in the coordinates of the Tinkham relationship for the field strengths below $H \sim 300$ Oe. The temperatures of zero resistance at $H = 1$, 10, or 60 kOe do not obey this relationship: the experimental curves of $R(H)$ and $R(T, H)$ differ from those calculated by the model proposed in [15]. This can be related to the fact that this mechanism is applicable only in the case of low resistivity and small field strengths. In our composites, it is probably necessary to take into account the distribution of grain boundaries with respect to thickness. It must be noted that the $\rho(T)$ curves for HTSC + CuO composites [10] at various values of the transport current were successfully described within the framework of a mechanism [16] based on the thermoactivated phase slip in the Josephson junction. The behavior of the $\rho(T, H)$ function in a range of both weak and strong magnetic fields will be considered in a special publication.

Thus, the YBCO + CuO and YBCO + $BaPbO_3$ bulk composites exhibit a greater magnetoresistance effect

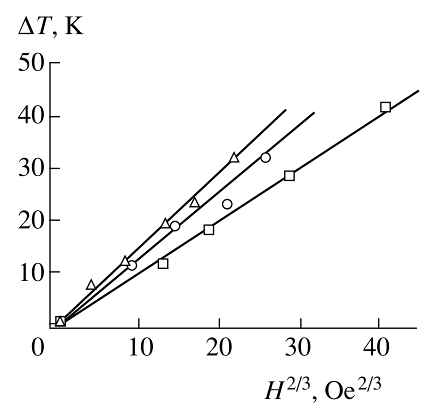

Fig. 3. The plots of $\Delta T_c = T_c(H, R = 0) - T_c(H = 0, R = 0)$ versus $H^{2/3}$ for various HTSC composites: (squares) 85 vol % YBCO + 15 vol % $BaPbO_3$; (triangles) 85 vol % YBCO + 15 vol % CuO; (circles) 70 vol % YBCO + 30 vol % CuO.

than HTSC ceramics in weak magnetic fields (below 300 Oe) at liquid nitrogen temperature. This behavior is of interest for practical applications.

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