PERCOLATION EFFECTS IN Ag–YBaCuO COMPOSITES

V. Yu. Tarenkov, A. I. D'yachenko, O. I. Chernyak, A. V. Vasilenko, V. M. Svistunov

Physico-Technical Institute, Ukrainian Academy of Sciences, 72, R. Luxemburg str., 340114 Donetsk, Ukraine

J. Leszczynski, J. Jackewicz

Institute of Principles of Electrical Power Engineering I–12, Technical University of Lodz, 18/22, B. Stefanowskiego str., 90-924 Lodz, Poland

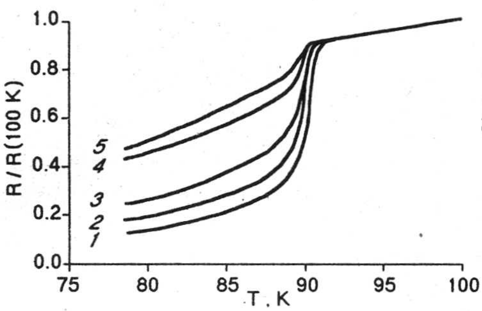
The system of YBaCuO–Ag *with different (from 5 to 30 vol.%) content of* Ag *was the subject of investigation. The value of ceramics-metal contact resistance and appearance of phase coherence between the grains through metallic layer due to the proximity effect were of interest. The samples were prepared by mixing powders of ceramics and fine-disperse argentum followed by compaction and annealing of the mixture. The annealing temperature* ~ 650 °C *was taken so as to achieve a low contact resistance at ceramics-metal boundary and high resistance between the grains. Preservation of the percolation threshold at the same concentrations below the temperature of the grain transition to superconducting state and the linear character of current-voltage characteristics of samples point to absence of appreciable proximity effect in the studied system.*

In this work we made an attempt to realize the situation when composite material is a system of granular ceramics bound by metal inclusions. The most suitable couple of materials for these experiments are the YBaCuO-ceramics and silver. Though this composite is rather well studied the properties of the percolation cluster below the superconducting transition temperature of the ceramics grains are not quite known.

It is known [1–3] that small (up to 10 %) additions of silver to the yttrium metal oxide matrix can improve its superconducting properties considerably. In most cases experiments show a decrease in the width of the *R(T)*-transition, grows of the critical current, improvement of mechanical properties. Some investigators associate these changes with a technological factor, e.g. improvement in stoichiometry with respect to oxygen stabilizes the critical temperature, presence of highly conducting microinclusions hinders the creep thus increasing effective critical current [4]. On the other hand, some attempts have been made to interpret these results as a formation of a new percolation structure where natural week links in intergranular space are replaced with metallic inclusions. For this situation the effect of ceramics-metal proximity should be of great importance.

The percolation effects for the Ag–YBaCuO system were studied in [5]. However, since at the temperature below the critical one for the YBaCuO the percolation channel formed by the YBaCuO–Ag–YBaCuO chains is shunted by the YBaCuO–YBaCuO cluster, the most interesting information about the properties of the *S–N–S*-type contacts formed by the ceramics grains and metallic inclusions was unaccessible for a study. To obtain composite samples we used the specific technological process thanks to which the conductivity in the sample appeared only in the Ag–YBaCuO–Ag chain but it was almost absent directly between the ceramics grains. This gave the possibility to study the characteristics of the Ag–YBaCuO links in detail.

Samples for these investigations were prepared in the following way. Powder of single phase ceramics 123 was thoroughly mixed with fine silver powder. Then the above mixture was compacted under 20–30 kbar pressure to form $10\times1\times0.1$ mm^3 plates which were annealed for 10 min at 650 °C and up to 2 hours at 420 °C in oxygen atmosphere. Those annealing conditions provided small contact resistance between silver inclusions and YBaCuO. Measurements showed that the temperature dependence of resistance $R(T)$ for a reference sample free from Ag-inclusions had a semiconducting nature. Big magnitude $\rho_{300} \sim 10^{-2}$ Ohm·cm and absence of a noticeable singularity in the $R(T)$ transition at $T = T_c$ of grains indicate that the sample resistance is mostly due to the resistance of intergranular boundaries.



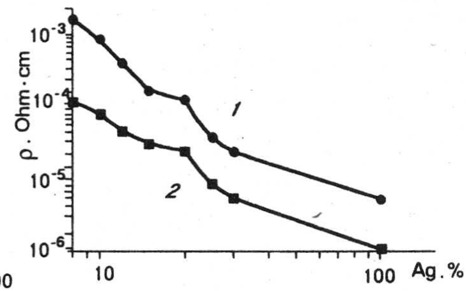


Fig. 1. $R(T)$ characteristics of Ag–YBaCuO composites with different volume concentration of Ag: *1* — 8%; *2* — 10%; *3* — 12%; *4* — 15%; *5* — 20%

Fig. 2. Dependencies of resistivity ρ of samples on silver concentration p : *1* — T = 300 K; *2* — T = 77 K

Another case is ceramics with silver impurity. Fig. 1 shows $R(T)$ characteristics of Ag–YBaCuO composites. We observe a jump in resistance at 91 K which corresponds to the superconducting transition temperature of ceramic grains. Magnitude of jumps in $R(T)$ and known concentrations of metallic inclusions p can be used as an estimate of the contact resistance R_C acting as a fit parameter in the relationship for conductivity of the Ag–YBCO system obtained in the effective medium model

$$\sigma_{\text{Ag-YBCO}} = \left[(B^2 + 4\beta\sigma_1\sigma_2)^{1/2} - \beta\right]/2\beta ,$$

where $B(T) = p(\sigma_2 - \beta\sigma_1) - q(\beta\sigma_2 - \sigma_1)$;

$$\sigma_1(T) = \sigma_{\text{Ag}}/\left[1 + \alpha_{\text{Ag}}(T - T_0)\right]$$

is the silver inclusion conductivity;

$$\sigma_2(T) = \left[\rho_{\text{Y}}(T) + R_C/a_0\right]^{-1}$$

is the effective conductivity of YBaCuO grains with the account of the transient resistance R_C of the Ag–YBaCuO contacts; $\rho_{\text{Y}}(T)$ is the resistivity of the YBaCuO grains whose temperature dependence is calculated using the following expressions

$$\rho_{\text{Y}}(T) = \left[1 + \alpha_{\text{YBCO}}(T - T_0)\right]\cdot\rho_{\text{YBCO}}(T_0)\, f\,(T/T_C) , \quad f(x) = x^N/(1 + x^N) .$$

Here $\beta = Z/2 - 1$ is the coordinate number, $Z = 6$ is the number of the nearest neighbors of the grain in ceramics; $q = 1 - p$, p is the volume concentration of Ag; $a_0 = 5 \cdot 10^{-4}$ cm is the average radius of the granule; $\rho_{Ag} = 10^{-6}$ Ohm·cm and $\rho_{YBCO} = 2 \cdot 10^{-4}$ Ohm·cm is the resistivity at $T = 300$ K of bulk silver and YBCO ceramics, respectively; $N = 200$ is the power function $f(x)$ exponent chosen for the analytical approximation of the $R(T)$ dependence of the superconducting transition of YBaCuO; $\alpha_{Ag} = 5 \cdot 10^{-2}\ K^{-1}$ and $\alpha_{YBCO} = 10^{-2}\ K^{-1}$ is the temperature coefficient of resistance of Ag and YBaCuO, respectively; $T_0 = 300$ K.

The magnitude of $R_C \sim 10^{-9}$ Ohm·cm^2 obtained by fitting to experimental $R(T)$ curves at different concentration of Ag coincides with the magnitude of the transient resistance of a single contact prepared by high-temperature annealing. Thus we can investigate the characteristics of the Ag–YBaCuO cluster having the same contact resistance as that of the materials obtained by the high-temperature annealing. Fig. 2 shows the dependence of the samples resistivity ρ at $T = 300$ K on silver inclusion concentrations p. The $\rho(p)$ curve exhibits singularity in the vicinity of 19 % Ag. The position of this singularity is connected with the percolation threshold in the three-dimensional cluster of silver. The same dependence is constructed for $T = 77$ K.

The manifestation of the proximity effect in the structure of contacts Ag–YBaCuO–Ag must be expressed in the difference between the character of the $\rho(p)$ dependence below and above the superconducting transition temperature T_c of ceramics grains. If a part of the cluster passes into the superconducting state the percolation threshold point at the $\rho(p)$ dependence should shift. In the $\rho_{300}(p)$ and $\rho_{77}(p)$ dependencies the silver concentrations corresponding to the percolation threshold coincide amounting $P = 19$ %. The absence of changes at the transition via T_c indicates that the proximity effect has no influence on the conductivity of the structure. The $I - V$ characteristics recorded at $T = 77$ K also appeared to be linear. Thus the Ag–YBaCuO contacts at transient resistance $R_C \sim 10^{-9}$ Ohm·cm^2 and $T = 77$ K are normal and cannot transport dissipationless current.

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