The nanosecond studies of granular carbon nanostructures based on high temperature superconductors

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Abstract. The peculiarities of current percolation in two-component structures (HTSC- MWNTs) depending on the concentration of components are established. It is established that at 20% nanopowder content there is an increase in the critical temperature of the TC transition to the superconducting state. Discusses the mechanism of destruction of the percolation cluster with changing concentration of the nanopowder.

Introduction

Studies of multicomponent systems with reduced dimensionality are interest because their properties dependence of the composition, the size of the components particle, and their interaction with each other. The kinetic phenomena in such structures are well described by percolation theories [1].

The investigation of the effect of morphological factors on the capture of magnetic flux and critical currents in the superconducting structure, which is a percolation superconductor with pinning centers, is presented in [2]. The results of this studies show that the clusters of the normal phase in the superconductor increase pinning of the magnetic field and slow down the superconductivity destruction. It was established in [3,4] that when the nanoparticles BaTiO$_3$ [3] and BaHfO$_3$ [4] are added to YBa$_2$Cu$_3$O$_{7-\delta}$ (YBCO), the superconducting transition temperature increases to 103 and 107 K, respectively. The introduction of nanoparticles of other elements in YBCO, as a rule, reduces the critical temperature of the transition to the superconducting state $T_C$ [5-7], whereas for our nanostructured materials, $T_C$ increases.

In this paper are presented the new investigation results of the transport characteristics of HTSC materials based on YBa$_2$Cu$_3$O$_{7-\delta}$ which are modified with multi-walled carbon nanotubes (MWNTs) in the nanosecond voltage duration interval.

Experimental details

The measurements were carried out on samples consisting of a microcrystalline powder YBa$_2$Cu$_3$O$_{7-\delta}$ obtained by solid-phase sintering and a nanocrystalline powder YBa$_2$Cu$_3$O$_{7-\delta}$ obtained by the glycine-nitrate method [8, 9]. MWNTs with a diameter of 20-70 nm and a length of more than 150 nm [10].

The modified structures were obtained by mixing the two powdered components in a weight ratio that
were not sintered to avoid mutual diffusion and chemical reactions of the components. We consider a model system—a mixture of powders with artificially created Josephson weak bonds formed at natural intergranular boundaries. In order to evaluate the transport characteristics, the temperature dependences of the resistance in the ns-interval (1-20 ns) of voltage durations up to amplitude of 1 V at a frequency of 100 Hz were investigated [11]. The nanosecond experiment was chosen because it gives the possibility to manage the thermal overheat control percolation channel. It allows to identify the percolation characteristics in heterogeneous systems without destroying them.

Results

It is known that in the multicomponent percolation systems the transport characteristics are dependent on the impurity concentration and its threshold value ($N_c$—critical concentration at which the percolation threshold is observed). In the investigated structures the nanodispersed component (MWNTs and YBCO nanocrystalline powder) acts as a binding substance, forming a grid of weak Josephson-type junction in microcrystalline HTSC. Being located between the microparticles of HTSC, the nanodispersed filling mixture, provides the formation of a superconducting percolation cluster in an heterogeneous medium as well as the formation of a non-superconducting percolation cluster based on MWNTs.

Actually, the performed researches of the samples at room temperature made it possible to establish that at the threshold value of the nanotube concentration $N = 10\%$, the main percolation cluster begins to “break down” in the HTSC—MWNTs system and the conductivity is switch over the second non-superconducting component up to 20% (Figure 1a, curve 3). We can assume that starting from $N = 20\%$, a quench to a percolation cluster on the basis of MWNTs occurs within $N = 20-100\%$.

It should be noted that in the system HTSC—nanocrystalline powder at room temperature is observed a minimum resistance at 20%. [11]

![Figure 1](image_url)

Figure 1 The resistance dependence on the concentration of nanopowder at room(1) and nitrogen(2) temperatures, MWNTs at room(3) and nitrogen(4) temperatures
The results of measurements at a nitrogen temperature showed that the state of superconductivity in the HTSC-MWNTs system changes continuously and disappears at \( N = 20\% \) (Figure 1, curve 4). In this case, the system switch over to the percolation cluster based on the MWNTs, as we can observe it at room temperatures (Figure 1, curve 3). By adding of nanopowder \( \text{YBa}_2\text{Cu}_3\text{O}_{7-\delta} \) to the microcrystalline HTSC medium, the "destruction" of the percolation cluster can be seen in the changing of the width (\( \Delta T \)) of superconducting transition and superconducting critical temperature.

The results of the investigation of the dependence of the critical temperature (\( T_c, K \)), the width of the superconducting transition (\( \Delta T, K \)), and the slope of the resistance-temperature curve (\( B, K^{-1} \)) for samples with different nanopowder content are presented in Table 1.

Table 1. Parameters of the superconducting transition (\( T_c, \Delta T, B \)) for the modified \( \text{YBa}_2\text{Cu}_3\text{O}_{7-\delta} \) samples with different content of nanopowder \( N \).

| N, \%   | 0     | 10    | 20    | 30    | 100   |
|---------|-------|-------|-------|-------|-------|
| \( T_c, K \) | 94,7  | 96    | 99    | 95    | 93    |
| \( \Delta T, K \) | 14    | 14    | 10    | 12    | 13    |
| \( B, K^{-1} \) | 0,064 | 0,064 | 0,09  | 0,07  | 0,071 |

According to percolation theory, the conductivity in inhomogeneous media depends on the impurity concentration in the initial sample and its threshold value (\( N_c \)- the critical concentration at which the percolation threshold is observed). In the structures studied by us, the nanodispersed powder acts as a binder, forming a network of weak Josephson-type bonds in the microcrystalline HTSC. The nanodispersed filler, located between the microparticles of HTSC, provides the formation of a superconducting percolation cluster in an inhomogeneous medium.

Thus, the study of transport characteristics for nanosecond voltage durations made it possible to reveal new features of the conductivity mechanism when components were changed:

- under normal conditions, when is not appear superconductivity, it is established that the switch over of mechanism conductivity in the HTSC-MWNTs system starts at 10%; by adding of nanopowder the maximum value of current percolation in the system is carried out at a concentration of 20%;
- at temperatures within the limits of the existence of \( T_c \), it is established that by addition of a nanocrystalline powder can control the width and critical temperature of the superconducting quench.

We assume that the modification of HTSC by means of carbon nanotubes will make it possible to obtain modified materials with predetermined performance characteristics in the nanosecond voltage duration interval and, accordingly, in the microwave interval.
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