PSEUDOGAP IN $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ HTSC MATERIAL

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Analysis of the excess conductivity of the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ sample within the framework of the local pair model made it possible to determine the temperature dependences of the pseudogap (T). For sample $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$, the maximum pseudogap value was set.

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1. INTRODUCTION

The number of works devoted to pseudogap effects in HTSC materials is extremely large (see, for example, [1–8]). As noted in these works, the pseudogap is a unique phenomenon observed in HTSCs. It manifests itself when studying the phenomena of tunneling, photoemission, heat capacity and other properties of HTSC [8].

It is believed that at a certain temperature $T^*>T_c$ the density of states on the Fermi surface is redistributed: on part of this surface the density of states decreases. Below temperature T* the connection is in a state with a pseudogap. In [9], it is assumed that the value of T* at a low doping level can reach values of 300–600 K for different HTSC systems. However, this issue is still highly controversial. The works listed above discuss possible mechanisms of conductivity within the framework of models of normal, superconducting and pseudogap states of HTSC, which, strictly speaking, are also not completely clear [10].

The study of a pseudogap (PG) continues to be one of the most relevant areas in the physics of high-temperature superconductors (HTSC) [11–13]. Despite the large number of accumulated results, both the nature of the PG and the question of its role in the formation of the superconducting state in HTSCs still remain unclear.

Note that the reason for the high superconducting transition temperature T_c still remains an unsolved problem. The pseudogap phase in HTSC turned out to be as difficult a problem as high-temperature superconductivity itself. Only key experimental works are discussed and an attempt is made based on their results related to the nature of this unique phenomenon.

One of the most interesting materials for studying the PG are the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ compounds, which is due to the possibility of widely varying their composition by replacing yttrium with its isoelectronic analogues or changing the degree of oxygen nonstoichiometry [5]. In this regard, we consider the study of the pseudogap state of the superconducting $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ HTSC material to be relevant.

The purpose of the presented work is to analyze the magnitude and temperature dependence of the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ HTSC material pseudogap on today's existing research models [11, 14].

2. ANALYSIS OF THE MAGNITUDE AND TEMPERATURE DEPENDENCE OF THE PSEUDOGAP

To calculate the value of the temperature dependence of the pseudogap, we used the data obtained as a result of the calculation of the fluctuation conductivity of $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ HTSC material [15] and are reflected in Table 1.

An analysis of the magnitude and behavior of the temperature dependence of the pseudogap was presented in the local pair model [14] and further refined in [11] based on the possibility of transition from Bose-Einstein condensation (BEC) to the BCS regime with decreasing temperature in the interval $T^*<T<T$.

Table 1.

Parameters of the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ sample obtained from the analysis of fluctuation conductivity [15]

YBCO (Cd)	ρ(300K), mkOhm·cm	ρ(100K), mkOhm·cm	T_c,K	T_c^{mf}, K	T_G,K	T^*, K	$\xi_c(0)$, Å
$Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$	918,3	999,5	84	84,8	85	116,4	1,74

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Note that excess conductivity exists precisely in this temperature range, where fermions presumably form pairs - the so-called strongly coupled bosons (CBBs) [16]. These SSBs are transformed into FCPs as T approaches Tc (BEC-BCS transition), which is favored by the low value of the coherence length ξ(T) in cuprates.

Based on the results of our studies of the temperature dependence of excess conductivity in $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ in the temperature range from T* to T_c, we estimated the value, as well as the temperature dependence of the PG, according to [17]:

$$\Delta\sigma(\varepsilon) = \left\{ \frac{A(1-T/T^*)[\exp(-\Delta^*/T)]e^2}{16\hbar\xi_c(0)\sqrt{2\varepsilon_0^{\ *}\cdot sh(2\varepsilon/\varepsilon^*{}_0)}} \right\} \tag{1}$$

where (1-T/T*) determines the number of pairs formed at T ≤ T*; and exp(-Δ*/T) is the number of pairs destroyed by thermal fluctuations below the temperature of the BEC-BCS transition.

In equation (1), ε and ε_0^* are calculated respectively using the formula (T/T_c^{mf}1) and (T^*/T_c^{mf}-1).
Solving equation (1) gives the value of Δ*:

$$\Delta^*(T) = T\cdot\ln\left\{ \frac{A(1-T/T^*)e^2}{\Delta\sigma(T)16\hbar\xi_c(0)\sqrt{2\varepsilon_0^*\cdot sh(2\varepsilon/\varepsilon^*{}_0)}} \right\} \tag{2}$$

where Δσ(T) is the allocated excess conductivity.

Equations (1) and (2) include a number of parameters that, within the framework of the LP model, are determined from experiment [18]. In addition to T_c, $\xi_c(0)$ and ε, which are obtained from resistive measurements and FLP analysis, both equations include the coefficient A, which has the same meaning as the C-factor in the FLP theory, and the theoretical parameter ε_0* [19].

The temperature dependence and the value of the pseudogap parameter Δ*(T) (Fig. 1) were calculated on the basis of equation (2) with the parameters given in Table 1. The value of coefficient A was selected from the condition that the temperature dependence Δσ (equation 1) coincides with the experimental data in the region of 3D fluctuations near T_c.

According to [20], the optimal approximation for a HTSC material is achieved at values of $2\Delta^*(T)/\kappa_B T \approx 5 \div 7$. For the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ sample, the value $2\Delta^*(T)/\kappa_B T = 5$ was determined, this made it possible to establish the value of $\Delta^*(T_c)$ for the studied sample. The determined values of the parameters Δ*(T) are presented in the table 2.

Table 2.

Pseudo-gap analysis parameters in the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ sample

YBCO (Cd)	A*	T_m, K	D*, K	$\Delta^*(T_m)$, K	$\Delta^*(T_G)$, K
$Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$	0,8	112,4	2,5	793,8	268,6

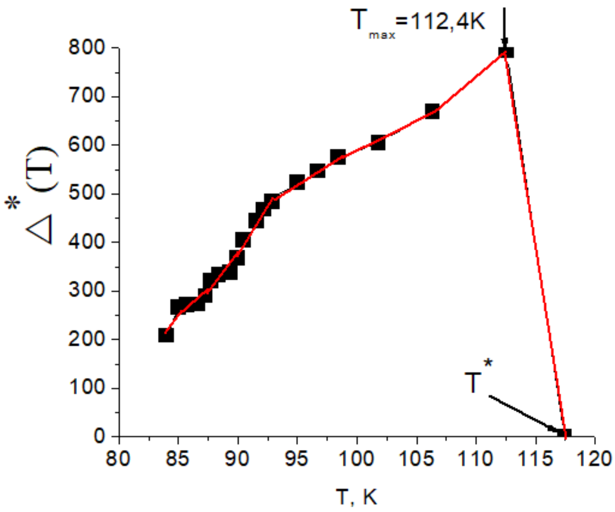

Fig.1. Temperature dependence of the calculated pseudogap value of the sample $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ with parameters given in the text. Arrows show the maximum values of the pseudogap value.

Analysis of Fig. 1 shows that with decreasing temperature the value of the pseudogap first increases, then, having passed through a maximum, decreases. This decrease is due to the transformation of SSB into FCP as a result of the BEC-BCS transition, accompanied by an increase in excess conductivity at $T \rightarrow Tc$. This behavior of Δ^* with decreasing temperature was first discovered on YBCO films [21] with different oxygen contents, which is apparently typical for cuprate HTSCs.

In Fig. Figure 2 shows the dependence of the logarithm of the excess conductivity of the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ sample on the inverse temperature. The choice of such coordinates is due to the strong sensitivity of the linear section $\ln\Delta\sigma(1/T)$ on the value of$\Delta^*(T_c)$ in equation (2), which makes it possible to estimate the coefficient A. The $\ln\Delta\sigma(1/T)$dependences were calculated according to the method tested in [19].

Based on the obtained parameters of the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$sample, the $\Delta\sigma(\varepsilon)$ dependences were calculated using equation (2). A comparison of theory with experiment in the region of 3D–AL fluctuations near T_c showed good agreement between equation (1) and experiment in the temperature range from T* to T_G. This feature is one of the main properties of most HTSCs. It can be assumed that equation (2) gives reliable values for the magnitude and temperature dependence of the PG.

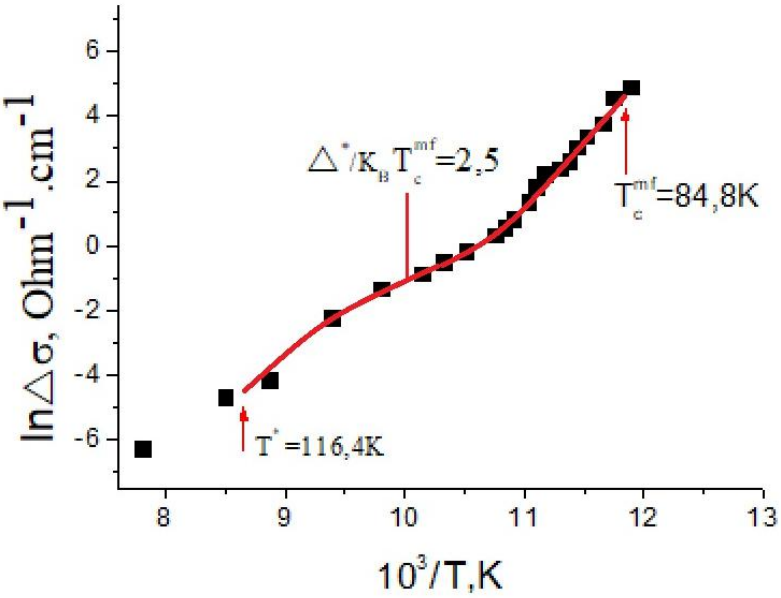

Fig.2. Dependence of the logarithm of excess conductivity on its inverse temperature $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$, solid lines – approximation level 1 with the parameters given in the text.

CONCLUSION

Thus, we can come to the conclusion that in the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ we studied, there is the possibility of the formation of local pairs of charge carriers at $T>>T_c$, which creates conditions for the formation of a pseudogap with the subsequent establishment of phase coherence of fluctuation Cooper pairs at $T<Tc$.

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