ANALYSIS OF FLUCTUATION CONDUCTIVITY IN $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$

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A study was made of the influence of substitution of up to 50% of yttrium for cadmium in $YBa_2Cu_3O_{7-\delta}$ polycrystals on the mechanism of formation of excess conductivity. It has been established that such a substitution led to a significant increase in the resistivity of $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ and the value of the critical transition temperature T_c to the superconducting state decreases. The mechanism of formation of fluctuation conductivity (T) near T_c is considered within the framework of the Aslamazov-Larkin theory. The Ginzburg temperature, the critical temperature in the mean field approximation, and the 3D-2D crossover temperature were determined. In is shown that the doping of $YBa_2Cu_3O_{7-\delta}$ with cadmium leads to the coherence length along the *c* axis by a factor of 1,96. An 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 and its maximum value.

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In recent years, the group of works [1–5] devoted to the analysis of pseudogap effects in HTSC compounds has appeared. Pseudogap (PG) is a unique phenomenon characteristic of HTSC with an active CuO_2 plane (cuprates) in the doping region less than optimal. It manifests itself in studies of the phenomena of tunneling, photoemission, heat capacity [2, 4] and other properties of HTSC. It is assumed that at a certain temperature T * >> T_c (T_c is the critical temperature of the superconducting transition) the density of states on the Fermi surface is redistributed: on a part of this surface the density of states decreases. Below the temperature T *, the compound is in a pseudogap state. In these works, possible conduction mechanisms in the modes of the normal, superconducting, and pseudogap states in HTSC are also discussed.

Recently, the work [6], devoted to the study of the pseudogap state in $Pb_{0.55}Bi_{1.5}Sr_{1.6}La_{0.4}CuO_{6+\delta}$ (Pb-Bi2201) appeared. A series of Pb-Bi2201 single crystals was obtained, on which a wide range of investigations were conducted to identify the pseudogap state. The results of studies on three different experimental methods indicate that the appearance of a pseudogap at T≅132 K should be perceived only as a phase transition. Thus, the authors confirmed the assumption that at the temperature decreasing, the HESC material must undergo two phase transitions: first the appearance of a pseudogap, and then a transition to the superconducting state.

However, as noted by A.Abrikosov [7], the pseudogap state cannot really be considered as some kind of new phase state of matter, since the PG is not separated from the normal state by a phase transition. So the question of a possible phase transition at T = T * also remains open. At the same time, it can be said that a crossover occurs at T = T * [1]. Below this temperature, due to reasons not yet established to date, the density of quasiparticle states at the Fermi level begins to decrease. Actually for this reason, this phenomenon is called "pseudogap". For the first time, this result was obtained in experiments on the study of NMR in a weakly doped Y123 system, in which an anomalous decrease of the Knight shift [2] during cooling, which is directly related to the density of states at the Fermi level in the Landau theory, was observed. Note that earlier in [8] we analyzed the fluctuation conductivity $Y_{1-x}Cd_xBa_2Cu_3O_{7-\delta}$ (x=0÷0,4).

Thus, the aim of this work is to study the normal state of $YBa_2Cu_3O_{7-\delta}$ (sampb. Y1) and $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ (sampb. Y2) in the temperature range T *> T> T_c, to determine their physical characteristics, as well as to study the possibility of the occurrence of the PG states in these compounds. The analysis was carried out on the basis of the study of excess conductivity above T_c in the framework of the local pair (LP) model [3,4] taking into account the Aslamazov – Larkin fluctuation theory [8] near T_c.

EXPERIMENTAL RESULTS AND THEIR PROCESSING

The method for obtaining $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ is described in [9].

The temperature dependences of the specific resistivity ρ of the samples Y1 and Y2 are showed in Fig.1. The critical temperatures of the SC transition T_c were determined from the maximum obtained by differentiating the curve ρ(T). Critical temperature of investigated samples is T_{c1} = 92.63K (Y1) and T_{c2} = 89.23 (Y2), respectively (Fig.1). In this case, the resistivity of the sample $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ in the normal phase at 300 K increases almost 15 times compared to $YBa_2Cu_3O_{7-\delta}$.

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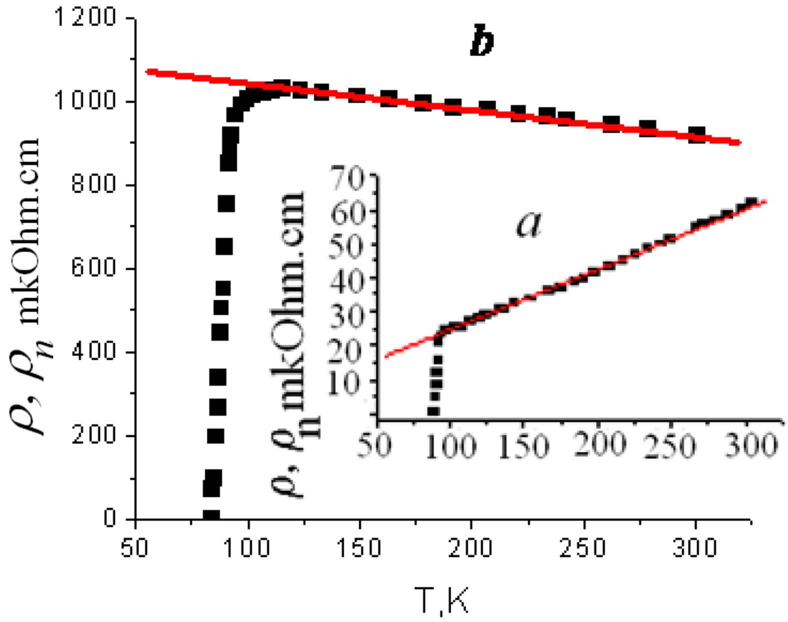

Fig. 1. Temperature dependences of the resistivity ρ of the samples: a- YBa2Cu3O7-δ (Y1) [8] and b- Y0,3Cd0,7Ba2Cu3O7-δ (Y2). Direct represent dependences ρn(T) extrapolated to the region of low temperatures.

FLUCTUATION CONDUCTIVITY

The linear course of the temperature dependence of the specific resistance of samples Y1 and Y2 in the normal phase is well extrapolated by the expressions $\rho_n(T) = (D + \kappa T + BT^2)$ and $\rho_n(T) = (\rho_0 + \kappa T + BT^2)$ (here D, B and k are some constants). This linear relationship, extrapolated to the low temperature range, was used to determine excess conductivity $\Delta\sigma(T)$ according to:

$$\Delta\sigma(T) = \rho^{-1}(T) - \rho_n^{-1}(T). \qquad (1)$$

The analysis of the behavior of excess conductivities was carried out in the framework of the local pair model [4, 11].

Assuming the possibility of the formation of local pairs [3,4] in the Y2 sample at a temperature below T*=116,39K (Y2), the experimental results near T_c are obtained and analyzed taking into account the appearance of fluctuation Cooper pairs (FCP) above T_c in the framework of the Aslamazov-Larkin theory (AL) [9].

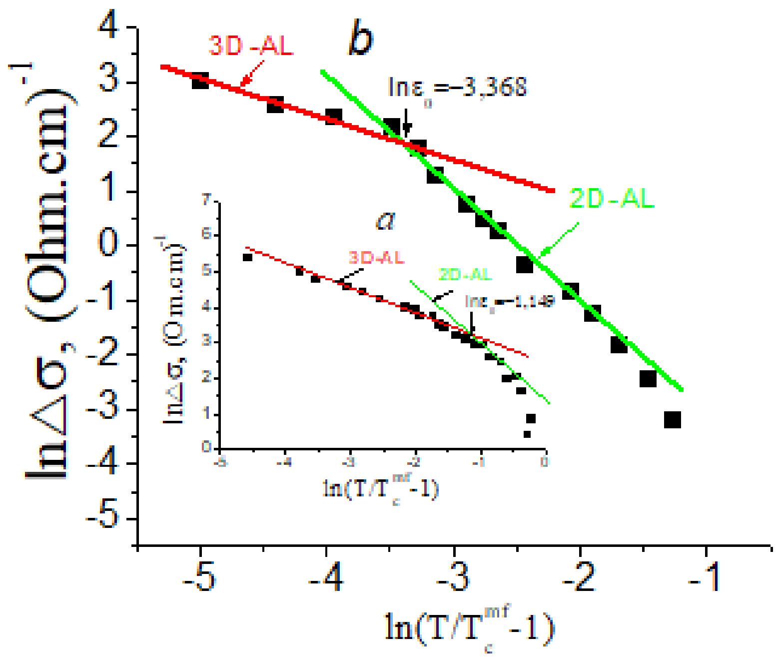

Fig.2. Dependences of the logarithm of excess conductivity on $\ln(T/T_c^{mf}-1)$ of samples Y1[8] and Y2. Solid lines – calculation within the framework of the Aslamazov-Larkin theory.

The Fig. 2 shows dependence of the logarithm of the excess conductivity of the samples Y1 (1) and Y2 (2) on the logarithm of the reduced temperature $\varepsilon = (T / T_c - 1)$. According to the theory of AL, as well as Hikami – Larkin (HL) developed for HTSC [10], in the region of T>Tc (but near T_c), the fluctuation coupling of charge carriers occurs, leading to the appearance of fluctuation conductivity (FC). In this region, the temperature dependence of excess conductivity on temperature is described by the expressions:

$$\Delta\sigma_{АЛ3D} = C_{3D}\ \{e^2/[32\hbar\xi_c(0)]\}\varepsilon^{-1/2}, \qquad (2)$$

$$\Delta\sigma_{АЛ2D} = C_{2D}\ \{e^2/[16\hbar d]\}\varepsilon^{-1}, \qquad (3)$$

respectively for three-dimensional (3D) and two-dimensional (2D) region. The scaling coefficients C are used to combine the theory with experiment [4].

Thus, by the angle of inclination α of dependences ln (Δσ) as a function of ε = ln (T / T_c-1) (see Fig. 3), we can distinguish 2D (tgα = -1) and 3D (tgα = - 1/2) regions of phase transition. It can also determine the crossover temperature T_0 (the transition temperature from $\Delta\sigma_{2D}$ to σ_{3D}) and the tangents of the slopes of the dependences Δσ(T) corresponding to the exponents ε in equations (2) and (3). The corresponding values of the parameters 2D and 3D regions determined from the experiment for sample Y1 are 2D (tgα = -1.04) and 3D (tgα = -0.44) and for Y2 2D (tgα = -1.1) and 3D (tgα = -0.49).

On basis of value the temperature of the crossover T_0, which corresponds to $\ln\varepsilon_0$, according to Fig. 2, it can determine the coherence length of local pairs along the c axis [12,13]:

$$\xi_c(0) = d\sqrt{\varepsilon_0}\ , \qquad (4)$$

here d ≈ 11.7Å is the distance between the inner conducting planes in Y-Ba-Cu-O [13]. The values of ξ_c (0) = 1,1 Å ($\ln\varepsilon_0 \approx$ -1.149) for Y1 and ξ_c (0) = 2,16 ($\ln\varepsilon_0 \approx$ -3.368) for Y2 was obtained, accordingly.

The parameters of the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ and $YBa_2Cu_3O_{7-\delta}$ samples obtained from fluctuation conductivity analysis are given in Table 1.

Table 1.

Parameters of $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ and $YBa_2Cu_3O_{7-\delta}$ samples obtained from fluctuation conductivity analysis

YBCO (Cd)	ρ(300K), мкОм·см	ρ(100K), мкОм·см	T_c, K	T_c^{mf}, K	T_G, K	T_0, K	$\xi_c(0)$,Å	Лит.
Y1 (x=0)	60	24	90,2	91,99	92,1	92,8	1,1	[8]
Y2(x=0,7)	923	1051	84,6	87,1	88	89,6	2,16	-

ANALYSIS OF THE MAGNITUDE AND TEMPERATURE DEPENDENCE OF THE PSEUDOGAP

As noted above, in the cuprates at T<T *, the density of electron states of quasiparticles on the Fermi level decreases [14] (the cause of this phenomenon is not yet fully elucidated), which creates conditions for the formation of a pseudogap in the excitation spectrum and it leads ultimately to the formation of an excess conductivity. The magnitude and temperature dependence of the pseudogap in the investigated samples was analyzed using the local pair model, taking into account the transition from Bose-Einstein condensation (SCB) to the BCS mode predicted by the theory [10] for HTSC when the temperature decreases in the interval T * <T <T_c. Note that excess conductivity exists precisely in this temperature range, where fermions supposedly form pairs - the so-called strongly coupled bosons (PRS). The pseudogap is characterized by a certain value of the binding energy $\varepsilon_b \sim 1/\xi^2(T)$, causing the creation of such pairs [10,13], which decreases with temperature, because the coherence length of the Cooper pairs $\xi(T)=\xi(0)(T/T_c-1)^{-1/2}$, on the contrary, increases with decreasing temperatures. Therefore, according to the LP model, the SCB are transformed into the FCP when the temperature approaches T_c (BEC-BCS transition), which becomes possible due to the extremely small coherence length ξ (T) in cuprates.

From our studies, we can estimate the magnitude and temperature dependence of PG, based on the temperature dependence of excess conductivity in the entire temperature range from T * to T_c according to [3,13]:

$$\Delta\sigma(\varepsilon) = \left\{ \frac{A(1 - T/T^*)[\exp(-\Delta^*/T)]e^2}{16\hbar\xi_c(0)\sqrt{2\varepsilon_0{}^* \cdot sh(2\varepsilon/\varepsilon^*{}_0)}} \right\} \qquad (5)$$

where the (1-T / T *) determines the number of pairs formed at T ≤ T *: and the exp (-Δ */T) determines the number of pairs destroyed by thermal fluctuations below the BEC-BCS transition temperature. The coefficient A has the same meaning as the coefficients C_{3D} and C_{2D} in (2) and (3).
The solution of equation (5) gives the value of Δ *:

$$\Delta^*(T) = T \cdot \ln\left\{ \frac{A(1-T/T^*)e^2}{\Delta\sigma(T) 16\hbar\xi_c(0)\sqrt{2\varepsilon_0^* \cdot sh(2\varepsilon/\varepsilon^*_0)}} \right\} \tag{6}$$

where Δσ (T) is the experimentally determined excess conductivity.

On fig. Figure 3 shows the dependences of the logarithm of the excess conductivity of the sample Y2 on the reciprocal temperature. The choice of such coordinates is due to the strong sensitivity of the linear section lnΔσ(1/T) to the value $\Delta^*(T_c)$ in equation (5), which allows you to estimate this parameter with high accuracy (this is necessary to find the coefficient A) [3,14,16]. Dependences lnΔσ(1/T) were calculated according to the method tested in [12]. As can be seen from fig. 3, the lnΔσ(1/T) values calculated for sample Y2 with parameters:

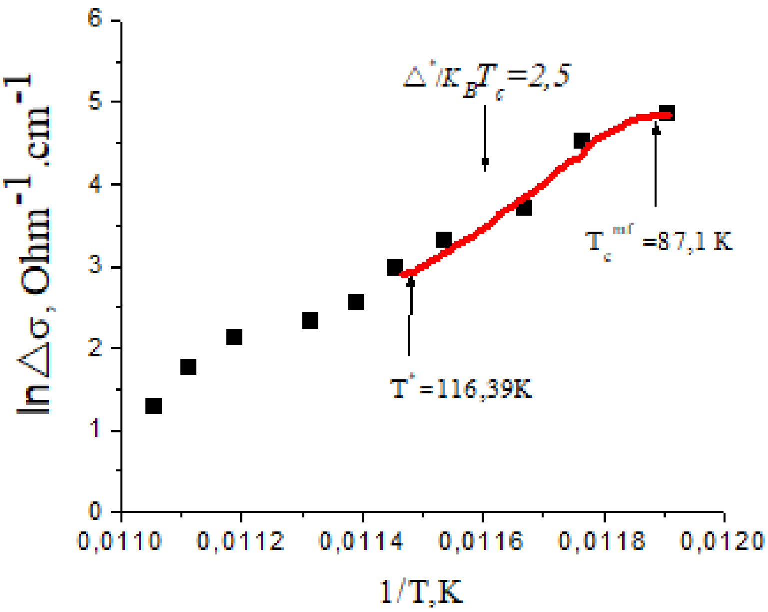

Fig.3. Dependences of the logarithm of excess conductivity on the reciprocal temperature polycrystal $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ solid lines – approximation eq. 6 with parameters given in the text.

A=1,847 ±0,1, T^*=116,39K, $\zeta_c(0)$=2,16 Ǻ are in good agreement with the experimental data.

The temperature dependence and the value of the pseudogap parameter Δ*(T) (Fig.4) were calculated based on equation (6) with the parameters given above. As

Noted in [3,4,14], the value of the coefficient A is selected from the condition of the coincidence of the temperature dependence Δσ (eq.(5), assuming $\Delta* = \Delta^*(T)$) with experimental data in the region of 3D fluctuations near T_c. According to [14,16], the optimal approximation for an HTSC material is achieved at the values $2\Delta*(T_c)/K_BT_c = 5$. As a result, from the LP analysis for Y2 $\Delta^*(T_c^{mf})$= 89.23•2.5 = 223.075K, which is consistent with the experimental data (Fig.4).

From the presented data in Fig.4, it is also seen that as T decreases, the pseudogap value first increases, then, after passing through a maximum, decreases.

This decrease is due to the transformation of the SCB in the PCF as a result of the BEC-BCS transition, which accompanied by an increase in excess conductivity at $T \rightarrow T_c$. Such a behavior of Δ * with decreasing temperature was first found on YBCO films [3.14] with different oxygen contents, which seems to be typical of cuprate HTSC [14].

The pseudogap parameters of the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ sample obtained from fluctuation conductivity analysis are given in Table 2.

Table 2.

Parameter of pseudogap analysis of HTSC material $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$

YBCO	T*, K	A*	T_m, K	D*, K	$\Delta^*(T_m)$, K	$\Delta^*(T_G)$, K
Y2(x=0,5)	142,6	16,6	122,6	2,5	660	385

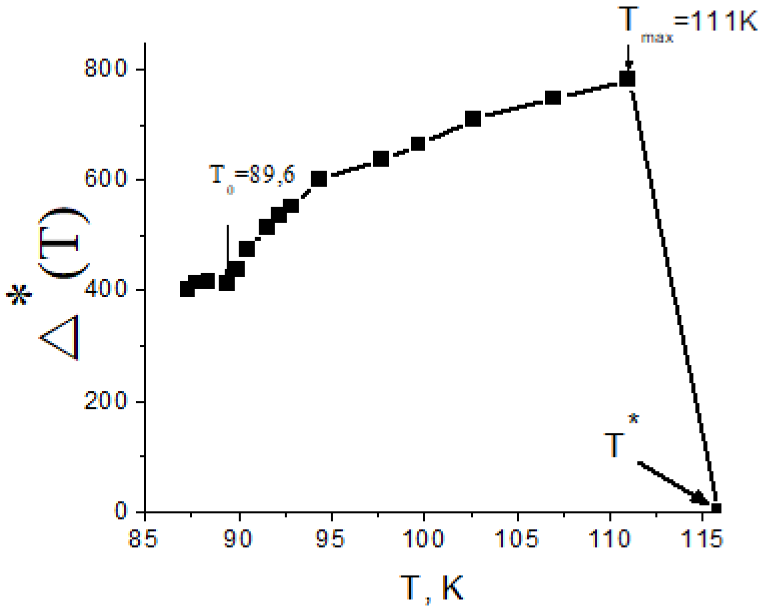

Fig.4. Temperature dependences of the calculated value of the sample pseudogap Y2 with parameters given in the text. The arrows show the maximum values of the pseudogap.

CONCLUSION

Thus,we can conclude that, in the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ studied by us, the formation of local pairs of charge carriers at $T>>T_c$ is possible, which creates conditions for the formation of a pseudogap [10-12] with the subsequent establishment of the phase coherence of fluctuation Cooper steam at $T>T_c$ [14,17].

The study showed that near T_c the fluctuation conductivity is well described in terms of the Aslamazov-Larkin fluctuation theory: 3D-AL. Above the 3D-2D crossover temperature, the 2D-AL theory is applicable.

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