PREPARATION OF $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-d}$, $Y_{0,1}Cd_{0,9}Ba_2Cu_3O_{7-d}$, $CdBa_2Cu_3O_6$ MATERIALS AND ANALYSIS OF THEIR SUPERCONDUCTING TRANSITIONS

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A study was carried out of the possibility of the influence of substitution from 70% to 100% of yttrium by cadmium in $YBa_2Cu_3O_{7-\delta}$ polycrystals on the superconducting states of the synthesized materials. As a result, high-resistivity samples were obtained. In the normal phase they had semiconductor passages. Of the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_7$, $Y_{0,1}Cd_{0,9}Ba_2Cu_3O_7$ and $CdBa_2Cu_3O_7$ samples, only the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ sample made a superconducting transition at 84K. For the sample $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ HTSC material, the critical temperature in the mean field approximation (T_c^{mf}), the 3D-2D crossover temperature (T_0), the coherence length of the Cooper pair were determined, the temperature T_c of the SC transition and T_G-temperature were determined Ginsburg.

Keywords: superconductivity, coherence lengths, 3D-2D temperature Crossover.
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1. INTRODUCTION

The works [1-8] analyzed in detail the substitution of yttrium in the composition Y–Ba–Cu–O with rare earth elements (Nd, Tm, Sm, Gd, Er, Yb, La, Dy, Ho, etc.).

Note that Y–Ba–Cu–O, despite the maximum number of possible isomorphic substitutions [1–8], is not among the systems where isomorphic heterovalent substitution leads to an increase in the transition temperature Tc. Despite this, the study of substitution in the classical $YBa_2Cu_3O_{7-\delta}$ structure remains an urgent problem, since it allows us to draw certain conclusions about the mechanism of superconductivity and the contribution of Y, Ba, Cu layers to superconductivity.

However, the proximity of the ionic radius of yttrium and cadmium gave us the basis to conduct a study on the substitution of cadmium for yttrium in the Y–Ba–Cu–O composition. In this case, we believed that the difference in the ionic radii of Y and Cd leads to a distortion of the YBCO crystal structure. This leads to the formation of defects in the structure and the appearance of pinnings in the crystal structure. The formed pinnings reduce the probability of splitting of Cooper pairs and create the possibility of a HTSC material having a high resistance value in the normal phase transitioning to the superconducting state.

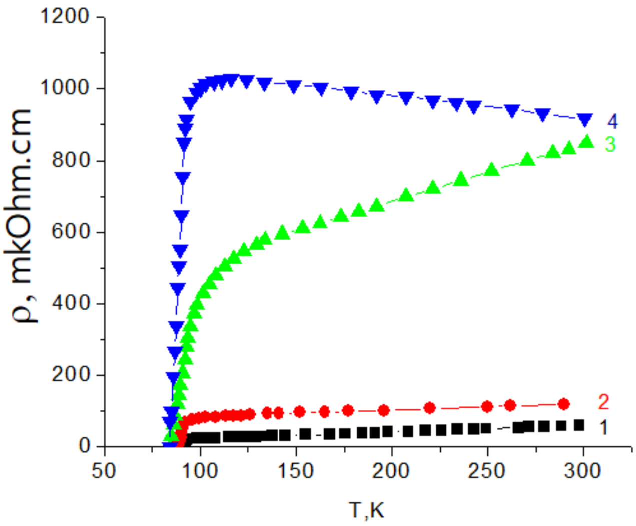

Fig. 1. Temperature dependences of resistivity ρ of samples: 1- $Y_{0,9}Cd_{0,1}Ba_2Cu_3O_{7-\delta}$ [9]; 2- $Y_{0,7}Cd_{0,3}Ba_2Cu_3O_{7-\delta}$ [9]; 3- $Y_{0,5}Cd_{0,5}Ba_2Cu_3O_{7-\delta}$ [10]; 4-$Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ [11]

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Note that so far the substitution of yttrium for cadmium from 0.1 to 0.7 parts in the $YBa_2Cu_3O_{7-\delta}$ HTSC material has been obtained and analyzed (Fig. 1) [9,10,11].

The result of the study from $Y_{0,1}Cd_{0,9}Ba_2Cu_3O_7$ and $CdBa_2Cu_3O_6$ is shown in Fig. 2.

Of the samples (Fig. 1 and 2) $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$, $Y_{0,1}Cd_{0,9}Ba_2Cu_3O_{7-\delta}$ and $CdBa_2Cu_3O_6$, only the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ sample made a superconducting transition at 84 K.

Analysis of Fig. 2 shows that both samples, $Y_{0,1}Cd_{0,9}Ba_2Cu_3O_{7-\delta}$ and $CdBa_2Cu_3O_6$ in the normal phase have a semiconductor behavior. Further lowering the temperature of the samples makes a metallic move and there is hope that, with a change in synthesis technology, it is possible to obtain the indicated samples.

In connection with the above, this work is devoted to the study of the normal state of $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ in the temperature range $T^*>T>T_c$ and the determination of its physical characteristics ((ρ, T_c, T_c^{mf}, T_0, T_G and $\xi_c(0)$).

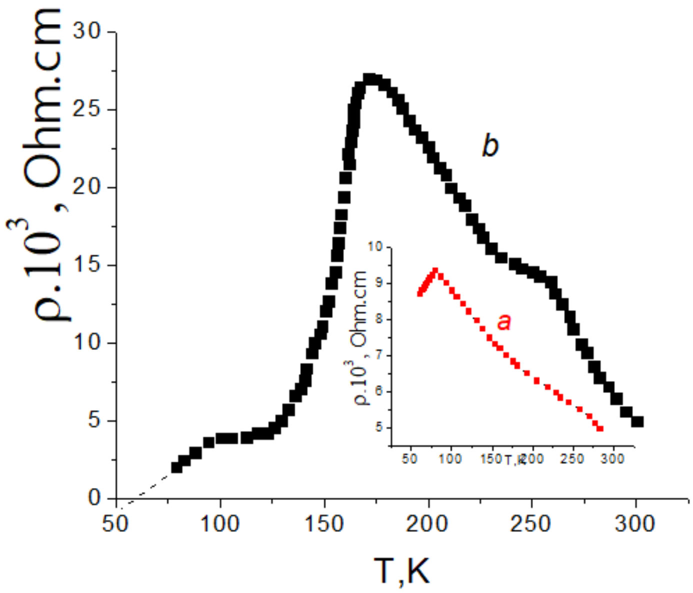

Fig.2. Temperature dependences of resistivity ρ of samples: *a*-$Y_{0,1}Cd_{0,9}Ba_2Cu_3O$ and $CdBa_2Cu_3O_6$.

Of the samples (Fig.1 and 2) $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$, $Y_{0,1}Cd_{0,9}Ba_2Cu_3O_{7-\delta}$ and $CdBa_2Cu_3O_6$, only the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ sample made a superconducting transition at 84 K.

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2. EXPERIMENT

The synthesis and sample preparation for measurements of the polycrystalline compound $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$, $Y_{0,1}Cd_{0,9}Ba_2Cu_3O_{7-\delta}$ and $CdBa_2Cu_3O_6$ is identical to [9,10]. The synthesis was carried out in two stages. At the first stage, the initial components in a stoichiometric ratio were mixed and annealed in an air environment at a temperature of 1120 K for 25 hours. At the second stage, the resulting compositions were annealed in an oxygen environment (P = 1.2–1.5 atm) at a temperature of 1190 K for 25 hours and slowly cooled to room temperature. It has been established that when up to 90% of yttrium is replaced by cadmium in the $YBa_2Cu_3O_{7-\delta}$ composition, the superconducting transition is not preserved (Fig. 2). The electrical resistance of the samples was measured using a standard four-probe scheme.

We believe that the superconducting transition of the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ sample occurs as a result of the difference in the ionic radius of Y and Cd leading to distortion of the YBCO crystal structure. This leads to the formation of defects in the structure and the appearance of pinnings in the crystal structure. The formed pinnings reduce the probability of splitting of Cooper pairs and create the possibility of a HTSC material having a high resistance value in the normal phase transitioning to the superconducting state.

In order to study the composition of the resulting $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ HTSC material, it was subjected to X-ray diffraction analysis. The result of the study is presented in Fig. 3.

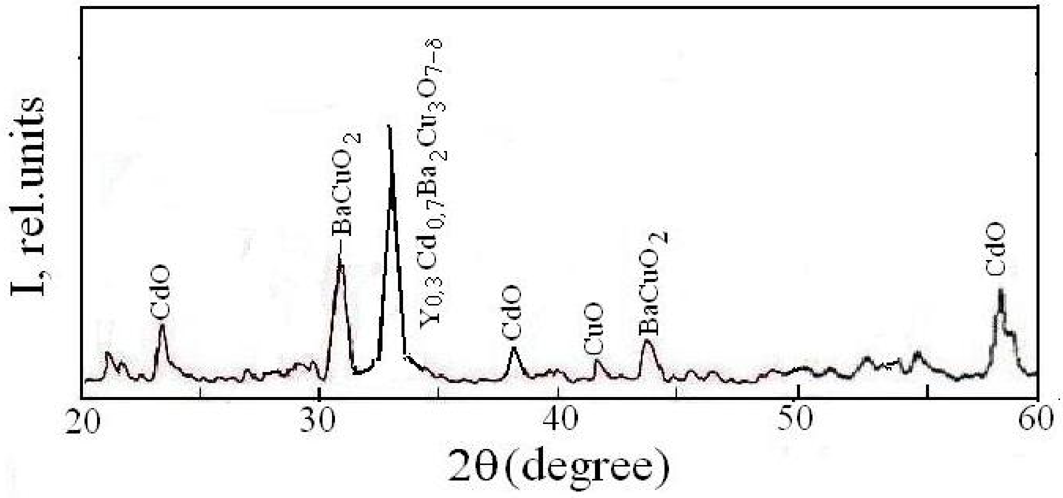

Fig.3. X-ray diffraction pattern of sample $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$

X-ray diffraction analysis showed that in addition to the main material $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$, there are also oxides $BaCuO_2$ and CdO in the X-ray. However, we note that in various compositions of SP polycrystals there are always, in addition to the main crystalline granules, various oxides.

3. RESULTS AND DISCUSSION

The temperature dependence of the resistivity ρ(T)=ρab (T) of the synthesized $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ polycrystal is given in Fig. 4.

Figure 4 shows the temperature dependences of the resistivity ρ(T)=ρab (T) of the studied $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ polycrystal.

The course of the temperature dependence of the resistivity of the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ sample in the normal phase is well extrapolated by the expression $\rho_n(T)= (\rho_0+ kT +BT^2$ (here B and k are some constants ρ0=1077 μOhm.cm, B=-0.0005 and k=-0.35). The straight lines represent the $\rho_n(T)$ dependences extrapolated to the low temperature region.

This linear dependence of the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ sample, extrapolated to the low temperature region, was used to determine the excess conductivity Δσ(T) according to [12]:

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

From Fig. 4 it can be seen that the value of the critical temperature of the sample when doped with Cd in the case considered remains close to ~ 85K, while the resistivity ρ(T) of the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ ample in the normal phase at 300K is ρ(300K)=918.3 μOhm• cm.

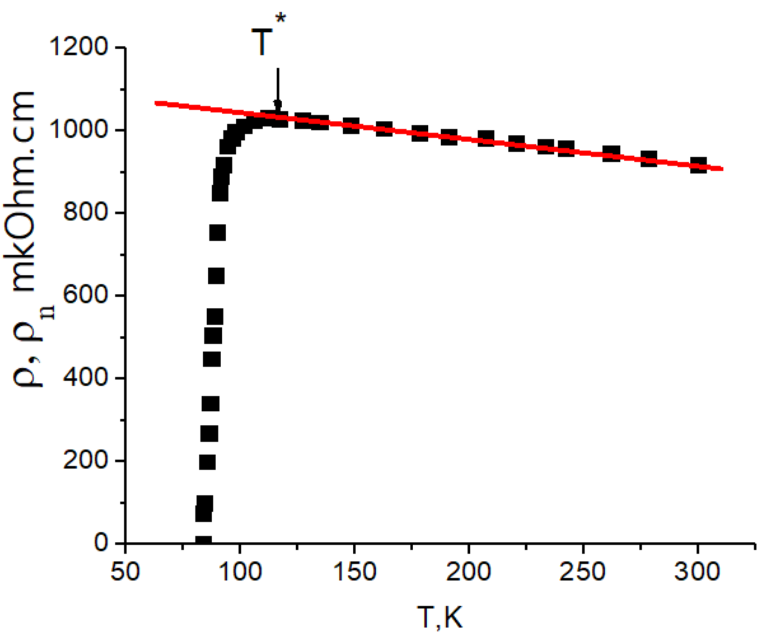

Fig.4. Temperature dependences of the resistivity ρ of the sample $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$

In order to determine the FLP within the framework of the local pair (LP) model [6], it is first necessary to determine the critical temperature in the mean field approximation, which separates the FLP region from the region of critical fluctuations [6, 13]. Fluctuation of the SP order parameter Δ_0 directly near T_c (where $\Delta_0 < K_BT$), where it is not taken into account in the Ginzburg–Landau theory [1314]. Determination of Tcmf is necessary for the analysis of the FLP and PSH, which is used in equation (2) to calculate the reduced temperature:

$$\varepsilon=(T/T_c^{mf} - 1) \qquad (2)$$

The method for determining Tcmf for the $Y_{0.3}Cd_{0.7}Ba_2Cu_3O_{7-\delta}$ sample based on analysis of the temperature dependence is presented in Fig. 5.

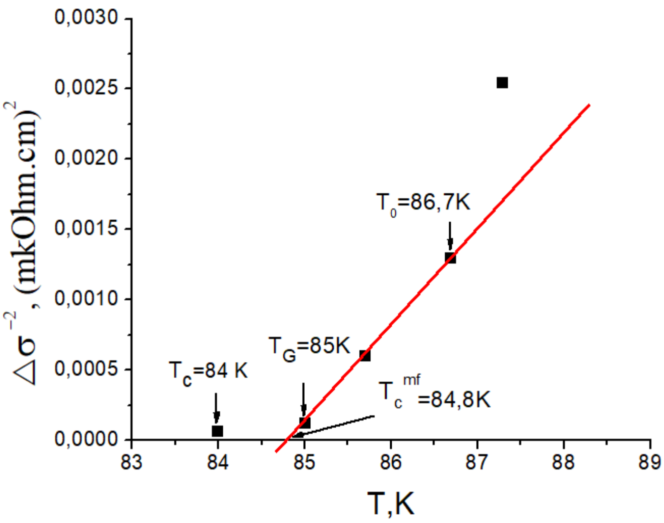

Fig. 5. Temperature dependence of the inverse square of the excess conductivity σ^{-2} (T) of the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ polycrystal, which determines the Tcmf of the sample. Arrows the characteristic temperatures T_c, T_G and T_0 are indicated.

From Fig. 5, the temperature T_c of the SC transition is determined, T_G is the Ginzburg temperature, up to which the mean field theory is valid as temperatures decrease [15, 16], and T0 is the 3D–2D crossover temperature, limiting the region of 3D–AL fluctuations from above [17, 18].

Having determined Tcmf (Fig. 5), it is possible to plot the dependence of ln σ on ln ε for the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ sample (Fig. 6).

From Fig. 6 it is clear that, near T_c, the FLP is well approximated by the fluctuation contribution of AL for 3D systems (3) (straight 3D–AL lines with slope $\lambda = -1/2$). This means that classical 3D FLP is always realized in cuprate HTSCs when T tends to Tc and ξc(T) > d [6, 19, 20, 21]. Above T_0, the dependence of ln ε sharply changes its slope. This dependence with a slope of $\lambda = -1$ is characteristic of 2D–AL fluctuations [22]. Having determined the values of ε (Fig. 6), the values of the coherence length along the c axis (ξc) were calculated using the equation ξc(0) = d√(ε)0. Note that in HTSC near T_c the coherence length along the c axis is greater than the corresponding size of the YBCO unit cell d = c = 11.7 Å [9] and fluctuation Cooper pairs (FCPs) interact throughout the entire volume of the superconductor. The calculated value of the coherence length of $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ HTSC material is 1.74 Å.

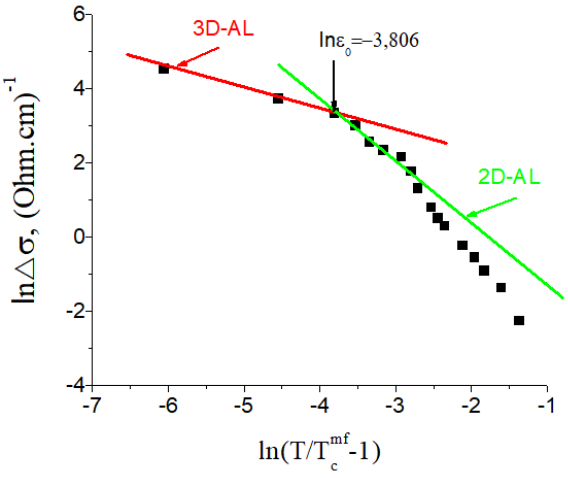

Fig.6. Dependence of the logarithm of excess conductivity on ln(T/Tc-1) of the sample $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$. Solid lines - calculation within the framework of theory Aslamazov -Larkin.

4. CONCLUSION

Thus, we can come to the conclusion that in the $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ we studied, the formation of local pairs of charge carriers at $T>>T_c$ is possible [21, 22].

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

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[1] *T. Suzuki, T. Yamazaki, and R. Sekine.* J. Mat. Sci. Lett. 8, 381 1989.

[2] *V.N. Narozhnyi and V.N. Kochetkov.* Phys. Rev. B53, 5856, 1996.

[3] *M. Murakami, N. Sakai, and T. Higuchi.* Supercond. Sci.Technol. 12, 1015, 1996.

[4] *A.L. Soloviev, V.M. Dmitriev.* FNT 33, 32 2007. [LowTemp. Phys. 33, 23, 2007].

[5] *R.V. Vovk, M.A. Obolensky, A.A. Zavgorodniy, A.V. Bondarenko, M.G. Revyakin.* FNT, 33, 546, 2007.

[6] *L.P. Kozeev, M.Yu. Kamenev, A.I. Romanenko, O.B. Anikeeva, V.E. Fedorov*. Materials 6th International Conference “Crystals: growth, properties, real structure, application": Alexandrov, September 8–12, 2003, VNIISIMS Publishing House.

[7] *E.V. Yakubovich, N.N. Oleynikov, V.A. Ketsko, I.V. Arkhangelsky.* Dokl. RAS 386, 502, 2002.

[8] *S. Kambe, G. Samukama, K. Yamaguchi, O. Ishu, I. Shime, T. Nomura, S.Ohshima, K.Okuyama, T. Itoh, H. Suematsu, and H. Yamauchi.* Solid State Phys. 108, 283 (1998)

[9] *V.M. Aliev, R.I. Selim-zade, J.A. Ragimov, L.V. Omelchenko, E.V. Petrenko.* FNT, vol. 46, №9, p. 1068–1077, 2020.

[10] *V. M. Aliev, G.I. Isakov, J.A. Ragimov, R.I.Selim-zade, G.A.Alieva.* Solid State Physics bodies, 65, no. 3, p. 404-410, 2023.

[11] *V.M. Aliyev, G.I. Isakov, J.A. Rahimov, V.I. Eminova, S.Z. Damirova, G.A. Aliyeva.* AJP FIZIKA, vol. X1X, №1, 44-41, 2023.

[12] *A.L. Soloviev, V.M. Dmitriev.* FNT, vol. 35, №3, pp. 227-264, 2009.

[13] *P.G. De Gennes.* Superconductivity of Metals and Alloys, W. A. Benjamin, INC., NewYork–Amsterdam, p. 280. 1966.

[14] *L.G. Aslamazov and A. I. Larkin.* Phys. Lett. A 26, 238 (1968).

[15] *A. Kapitulnik, M. R. Beasley, C. Castellani, and C. Di Castro.* Phys. Rev. B 37, 537 (1988).

[16] *S. Hikami and A. I. Larkin.* Mod. Phys. Lett. B 2, 693 (1988)

[17] *Y.B. Xie*. Phys. Rev. B 46, 13997 (1992).

[18] *A.L. Solovyov, L.V.Omelchenko, R.V.Vovk, S.N. Kamchatnaya.* FNT 43, 1050, 2017.

[19] *A.L. Solovjov, L.V. Omelchenko,*

[20] *V.B. Stepanov, R.V. Vovk, H.-U. Habermeier, H. Lochmajer, P. Przyslupski, and K. Rogacki.* Phys. Rev. B 94, 224505 (2016).

[21] *W. Lang, G. Heine, W. Kula, and Roman Sobolewski. Phys. Rev. B* 51, 9180 (1995).

[22] *В.В. Флорентьев, А.В. Инющкин, А.И.Талденков и др.*, СФХТ, 3, 10, 2 (1990)

[23] *Ya. Ponomarev, M. Mikheev, M. Sudakova, S. Tchesnokov, and S. Kuzmichev,* Phys. Status Solidi C, 6, 2072 (2009).

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