ANALYSIS OF THE RESULTS OF STUDYING THE PARTIAL REPLACEMENT OF YTTRIUM BY CADMIUM IN COMPOSITION X

V.M. ALIEV[1], G.I. ISAKOV[1], J.A. RAGIMOV[2], V.I. EMINOVA[3], G.A. ALIEVA[4]

[1]Institute of Physics Ministry of Science and Education of Azerbaijan, AZ 1073, Baku, G. Javid Ave., 131
[2]Azerbaijan Medical University, Baku, AZ 1022, st. Bakikhanova, 23
[3]Azerbaijani-French University under the Azerbaijan State Oil and İndustry University (UFAZ), AZ 1010, Baku, 183 Nizami str.
[4]Institute of National HP Ministry of Science and Education of Azerbaijan AZ 1025, Baku, Khojaly Ave., 30
E-mail: v_aliev@bk.ru

A study was carried out of the effect of substituting Y for Cd on the mechanism of formation of excess conductivity in $Y_{1-x}Cd_xBa_2Cu_3O_{7-\delta}$ (x=0÷1) polycrystals. It is shown that with increasing substitution, the resistivity ρ of the samples increases noticeably, and the critical temperature of transition to the superconducting state Tc decreases.

Increasing the cadmium concentration to x = 0.7, the formation of Cooper pairs (T*) and pseudogap (Δ*(T)) of the samples first increases up to x = 0.5 and then decreases noticeably. We believe that Cd doping creates internal pressure in YBCO, which leads to an observed increase (Δ* (T) due to structural defects.

Keywords: superconductivity, fluctuation conductivity, critical temperature.
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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 structure of $YBa_2Cu_3O_{7-\delta}$ 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, despite intensive research into HTSCs for more than 30 years, the mechanism of superconducting pairing in such compounds is still highly controversial. It is believed that understanding such an unusual phenomenon as a pseudogap (PG), observed in cuprate HTSCs at T*>>Tc, also allows us to answer the question about the mechanism of SC pairing. But the physics of the appearance of PSH is also not completely clear.

However, the closeness of the ionic radius of yttrium and cadmium gave us the basis to conduct a study on the substitution of yttrium by cadmium 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.

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

The presented work is devoted to the study of the above-mentioned substitutions for the normal and SP states of synthesized samples in the temperature range T*>T>Tc, on its influence on their physical characteristics, Δ*(T)). Note that all of the above are $YBa_2Cu_3O_{7-\delta}$ (Y1), $Y_{0,9}Cd_{0,1}Ba_2Cu_3O_{7-\delta}$ (Y2), $Y_{0,7}Cd_{0,3}Ba_2Cu_3O_{7-\delta}$ (Y3), $Y_{0,5}Cd_{0,5}Ba_2Cu_3O_{7-\delta}$ (Y4), $Y_{0,3}Cd_{0,7}Ba_2Cu_3O_{7-\delta}$ (Y5), $Y_{0,1}Cd_{0,9}Ba_2Cu_3O_{7-\delta}$ (Y6) and, $CdBa_2Cu_3O_6$ (Y7), SP composition are discussed in [9, 10, 11].

2. EXPERIMENT

Synthesis and preparation for measurements of polycrystalline compounds $Y_{1-x}Cd_xBa_2Cu_3O_{7-\delta}$ (x = 0.1÷1) is identical to [9,10]. The synthesis of all samples was carried out in two stages.At the first stage, the initial components were mixed in a stoichiometric ratio and annealed in air at a temperature of 1120 K for 25 hours. At the second stage, the resulting compositions were annealed in oxygen (P = 1.2–1.5 atm) at a temperature of 1190 K for 25 hours and slowly cooled to room temperature. The electrical resistance of the samples was measured using a standard four-probe circuit.

3. RESULTS AND DISCUSSIONS

Fluctuation conductivity (FC) for all studied samples was determined from the analysis of excess conductivity σ(T), which was calculated from the difference between the measured resistance ρ(T)

131, H.Javid ave, AZ-1073, Baku
Institute of Physics
E-mail: jophphysics@gmail.com

and the linear normal resistance of the sample $\rho_n(T) = aT + \rho_0$, extrapolated to the low temperature region.

The temperature dependence of the resistivity ρ(T) of the synthesized polycrystals $Y_{1-x}Cd_xBa_2Cu_3O_{7-\delta}$ (x = 0; 0.1; 0.3, 0.5, 0.7) is given in Fig. 1.

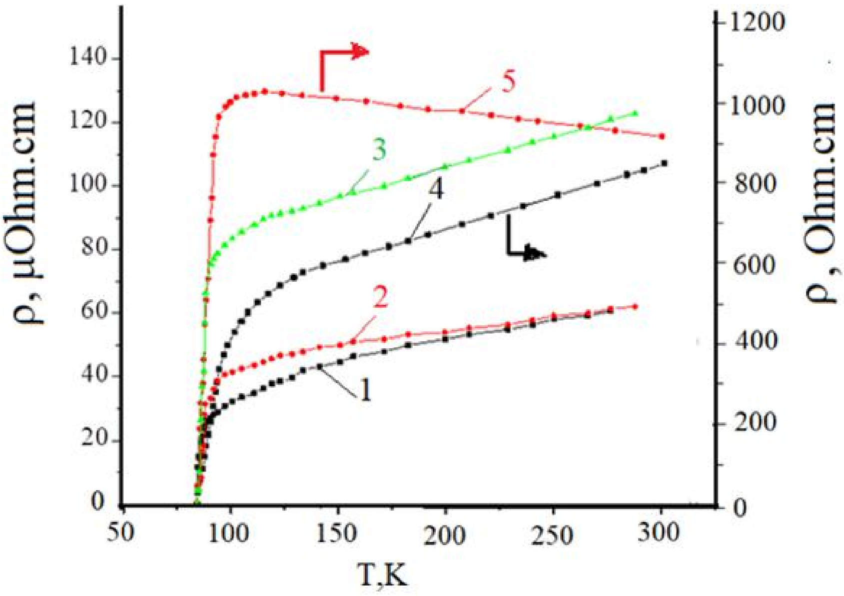

Fig. 1. Temperature dependences of resistivity ρ of polycrystals $Y_{1-x}Cd_xBa_2Cu_3O_{7-\delta}$ at different cadmium concentrations:1(Y1); 2(Y2); 3(Y3); 4(Y4); 5(Y5)

As can be seen in Fig. 1, the critical temperatures of samples of the Y–Ba–Cu–O system when doped with Cd in the case considered remain in the range 84 ~ 87 K. In this case, the resistivity ρ(T) of samples Y1–Y5 in the normal phase at 300 K from Y1 to Y5 increases almost 20 times. Despite the high resistivity, sample Y5 undergoes a SP transition.

We assume that the difference in the ionic radius 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 resulting pinning reduces the probability of splitting of Cooper pairs and creates the possibility of transition to the superconducting state of the studied composition, which has a high resistance value in the normal phase.

Note that further increase in substitution of samples, $Y_{0,1}Cd_{0,9}Ba_2Cu_3O_7$ and $CdBa_2Cu_3O_6$ in the normal phase has a semiconductor behavior (Fig. 2). As can be seen from Fig. 2, when the temperature of the samples decreases, it will attempt to make phase transitions of 81 (a) and 173 K (b), respectively. This means that with a change in the synthesis technology, it is possible to obtain SP materials.

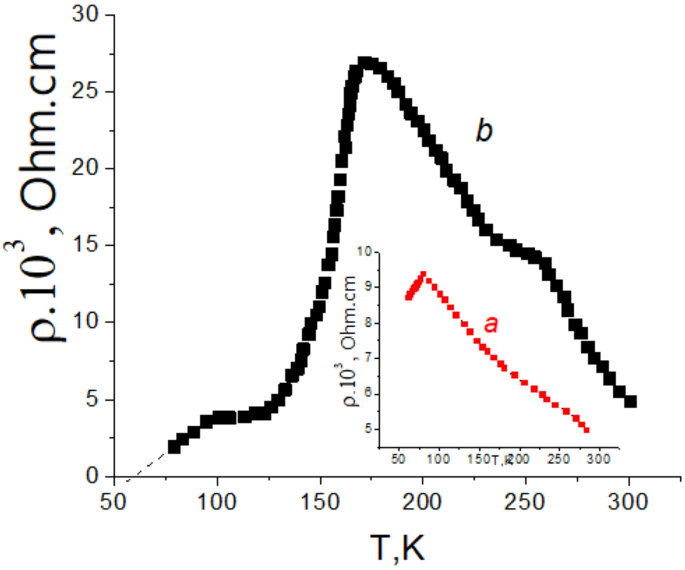

Fig.2. Temperature dependences of resistivity ρ of samples: a- $Y_{0,1}Cd_{0,9}Ba_2Cu_3O_{7-\delta}$ (Y6) and b- $CdBa_2Cu_3O_6$ (Y7)

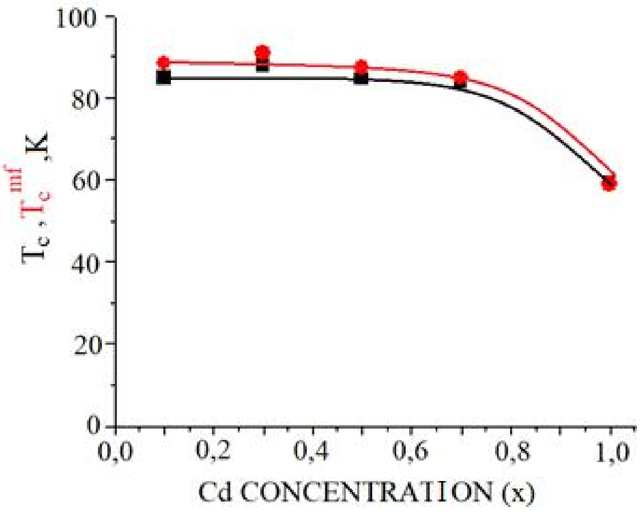

Fig.3. Dependence of T_c (1) andT_c^{mf} (2) of samples $Y_{1-x}Cd_xBa_2Cu_3O_{7-\delta}$ (x=0,1÷0,7)

To carry out fluctuation conductivity of the presented samples within the framework of the LP (local pair) model, it was first necessary to determine the critical temperature in the mean field approximation T_c^{mf}, which separates the FLP region from the region of critical fluctuations. T_c^{mf} - for the analysis of FLP and PS of samples, it is determined from the □σ^{-2}–T dependence [12,13].

The research results are presented in Fig. 3.

Analysis of Fig. 3 shows that T_c and T_c^{mf} first (up to 0.3 part substitution of yttrium for cadmium) increases respectively from 88K to 90.7 K and then decreases from 84K to 84.8K.

The temperature at which Cooper pairs begin to form (T*) is an important parameter of both the FLP and the PS, and is also included in all equations. The method for determining T* of samples uses the criterion $[\rho(T)-\rho_0]/aT = 1$, which is obtained by transforming the equation with a straight line [14], where ρ_0 is the residual resistance cut off by this line on the ordinate at T = 0 K. In this In this case, T* is defined as the temperature of the deviation of ρ(T) from 1 [15,16]. The research results for samples Y2–Y5 are shown in Fig. 4.

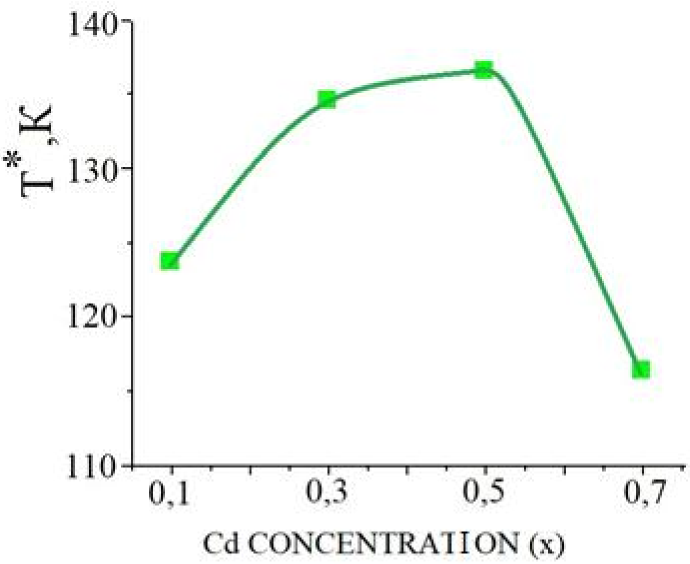

Fig.4. Dependences of pseudogap opening temperature T* for $Y_{1-x}Cd_xBa_2Cu_3O_{7-\delta}$ samples at different concentrations of cadmium (x=0.1÷0.7)

To calculate the temperature dependence of the pseudogap, we used data obtained from the fluctuation conductivity of the $Y_{0.3}Cd_{0.7}Ba_2Cu_3O_{7-\delta}$ HTSC material. An analysis of the magnitude and behavior of the temperature dependence of the pseudogap was presented in the local pair model [17] and further refined in [18] based on the possibility of transition from Bose-Einstein condensation (BEC) to the BCS regime with decreasing temperature in the interval $T^*<T<T_c$ [19].

Note that with decreasing temperature, the value of the pseudogap of the samples first increases, then, after passing through a maximum, it decreases. This decrease is due to the transformation of FCPs into FCPs (fluctuation Cooper pairs) as a result of the BEC-BCS transition, accompanied by an increase in excess conductivity at $T \to T_c$[19].

The study of the pseudogap continues to be one of the most relevant areas in the physics of high-temperature superconductors (HTSC) [18]. 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.

The pseudogap phase in HTSCs 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.

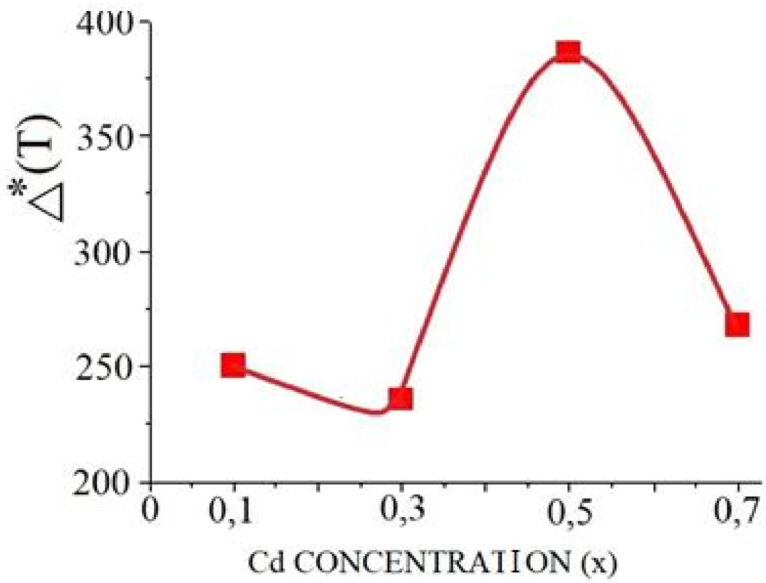

Fig.5. Dependences of the pseudogap (Δ*) of samples $Y_{1-x}Cd_xBa_2Cu_3O_{7-\delta}$ (x=0,1÷0,7)

With an increase in the concentration of cadmium in the sample $Y_{1-x}Cd_xBa_2Cu_3O_{7-\delta}$, the value of the curves (T*) and (Δ*(T) first increases to x=0.5, then decreases noticeably (Fig. 4 and 5). It can be assumed that Cd doping creates an internal pressure in YBCO, which leads to the observed increase due to structural defects. We also assume that a sharp increase in the distance between the conducting planes of CuO_2.

CONCLUSION

A study was carried out of the effect of partial substitution of Y for Cd on the mechanism of formation of excess conductivity and pseudogap in $Y_{1-x}Cd_xBa_2Cu_3O_{7-\delta}$, polycrystals.

Fluctuation conductivity was determined from the analysis of excess conductivity Δσ(T) in Y1–Y5 in the temperature range $T^*>T>T_c$. It was shown that near Tc FLC is well described within the framework of the Aslamazov–Larkin fluctuation theory.

Thus, it can be noted that various defects resulting from Cd intercalation significantly affect the properties of the studied $Y_{1-x}Cd_xBa_2Cu_3O_{7-\delta}$, polycrystals.

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