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Excess conductivity of $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$ single crystals

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У роботі досліджено вплив допування празеодимом на провідність у базисній площині ВТНП-монокристалів $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$. Встановлено, що надлишкова провідність $D_s(T)$ монокристалів $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$ поблизу T_c задовільно описується в рамках теоретичної моделі Асламазова-Ларкіна. При цьому абсолютні значення величини поперечної довжини когерентності $x_c(0)$ зростають в міру збільшення вмісту празеодиму. У той же час для зразків з $z \geq 0.48$ спостерігається досить різке зниження величини $x_c(0)$, що може бути пов'язано із загальним пригніченням надпровідних характеристик при наближенні концентрації празеодиму до $z \approx 0.5$.

Ключові слова: надлишкова провідність, допування, монокристали YBaCuO, високотемпературна надпровідність, довжина когерентності.

В работе исследовано влияние допирования празеодимом на проводимость в базисной плоскости ВТСП-монокристаллов $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$. Установлено, что избыточная проводимость $D_s(T)$ монокристаллов $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$ вблизи T_c удовлетворительно описывается в рамках теоретической модели Асламазова-Ларкина. При этом абсолютные значения величины поперечной длины когерентности $x_c(0)$ возрастают по мере увеличения содержания празеодима. В то же время для образцов с $z \geq 0.48$ наблюдается достаточно резкое снижение величины $x_c(0)$, что может быть связано с общим подавлением сверхпроводящих характеристик в случае приближения концентрации празеодима к $z \approx 0.5$.

Ключевые слова: избыточная проводимость, допирование, монокристаллы YBaCuO, высокотемпературная сверхпроводимость, длина когерентности.

In present work effect of praseodymium doping on conductivity in a basic plane of HTSC $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$ single crystals are investigated. It is established, that exess conductivity $D_s(T)$ of $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$ single crystals nearby T_c satisfactory described by Aslamazov-Larkin theoretical model. Absolute values of cross-section coherent length $x_c(0)$ grow in process of an increase of a praseodymium content. At the same time for samples with $z \geq 0.48$ sharp enough decrease in size $x_c(0)$ that is maybe connected with the general suppression of superconducting characteristics at an come close of praseodymium concentration to $z \approx 0.5$.

Keywords: exess conductivity, doping, YBaCuO single crystals, high-temperature superconductivity, coherent length.

Despite the fact that since the discovery of high temperature superconductivity (HTSC) [1] has been more than twenty-five years, the microscopic theory of this phenomenon is not unclear until now. The dimensionality of critical fluctuations near the superconducting instability is important for understanding the mechanism responsible for the superconductivity [2]. The variation of the oxygen stoichiometry [3] and impurities [2,4,5] has a significant role in the behaviour of HTSC as this influence significantly the processes of forming fluctuation carriars. This in turn affects the realization of different regimes for the existence of fluctuation conductivity (FC) at temperatures above T_c [2]. The conductivity characteristics of the HTSC compounds can be tailored through total [6-8] or partial [2,4,5] substitution of their components. In this aspect, the $YBa_2Cu_3O_{7-\delta}$ compound has been studied more thoroughly and most rare-earth elements when substituted for yttrium yielded superconductors. This is a consequence of the relatively easy way in substituting yttrium with its iso-electron rare-earth analogues [8]. Of particular interest in this aspect is the partial substitution of Y by Pr[2,4,9,10], which, leads to the suppression of the superconductivity (unlike other rare-earth elements) and allows the lattice parameters [9,10] and oxygen stoichiometry of the compound to remain practically unaltered [2,5]. The investigation of the impact of Pr impurities on the conditions and regimes of existence of the fluctuation conductivity state of such compounds [2,11] plays an important role to elucidate the nature of HTSC but also for determining empirical ways of raising their critical parameters. In our previos works [2,11] we studied effect of small praseodimium doping ($0.05 \leq z$) on FC-regime in $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$ single crystals. In this paper we investigate the influence of admixtures of Pr in a wide interval of concentration ($0.0 \leq z \leq 0.5$) on the fluctuation conductivity in $Y_{1-z}Pr_zBa_2Cu_3O_7$-δ single crystals in the flow of transport current in the basal ab-plane.

$Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$ single crystals were grown from the flux in a gold crucible using a methodology which is analogous to that used to synthesize $YBa_2Cu_3O_{7-\delta}$ single crystals [2,5,11,12]. To obtain crystals with a partial substitution of Y by Pr, $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$, an amount of Pr_5O_{11} was added to the melting stock in an appropriate atomic ratio. The regimes of growth and oxygen saturation of the $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$ crystals were the same as for undoped single crystals [3,11.12]. As the initial components for growth of the crystals we used the compounds Y_2O_3, $BaCO_3$, CuO, and Pr_5O_{11}. For the resistive measurements we selected single crystals of rectangular form, of length 2.5 mm, width 1.5 mm, and thickness 0.4 mm. Electrical contacts were created in the standard 4-contact scheme. Temperature was measured by the platinum thermoresistor.

Figure 1 represents the temperature dependences $\rho_c(T)$ of eight samples with different Pr content. It is shown that the increase of the praseodymium content leads to an increase of the specific electrical resistance and a decrease of the critical temperature, in agreement with previous studies [4]. It follows from Fig. 1 that when the temperature is lowered below a certain characteristic value T* a deviation of $\rho_{ab}(T)$ from linear will occur, attesting to the appearance of some excess conductivity. The temperature dependence of the excess conductivity is usually defined as:

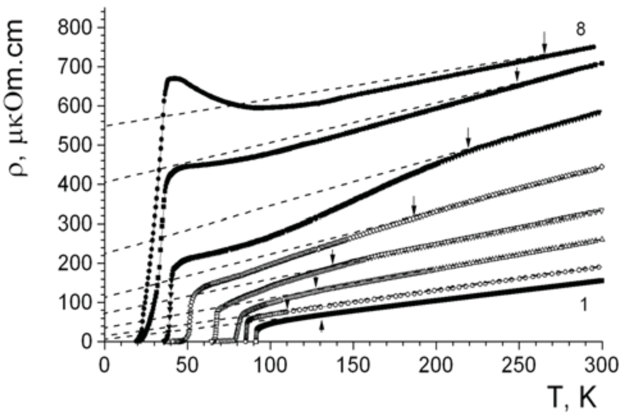

Fig. 1. Temperature dependences of excess conductivity ρ_{ab} for $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$ single crystals for different praseodymium concentrations *z*: *1* – 0.0, *2* – 0.05, *3* – 0.19, *4* – 0.23, 5 – 0.34, *6* – 0.43, *7* – 0.48, *8* – 0.5. Arrows show pseudogap-state transition temperatures T*. Dash lines – extrapolation of linear section to zero value of temperature

$$\Delta\sigma = \sigma - \sigma_0, \tag{1}$$

where $\sigma_0=\rho_0^{-1}=(A+BT)^{-1}$ is the conductivity determined by extrapolation of the linear part to zero temperature, and $\sigma = \rho^{-1}$ is the experimentally determined value of the conductivity in the normal state.

It is established from the theory [13] that near T_c the excess conductivity is due to fluctuation carrier-pairing processes, the contribution to the conductivity from which at $T > T_c$ for the two-dimensional (2D) and three-dimensional (3D) cases is determined by power laws of the form:

$$\Delta\sigma_{2D} = \frac{e^2}{16\hbar d}\varepsilon^{-1}, \tag{2}$$

$$\Delta\sigma_{3D} = \frac{e^2}{32\hbar\xi_c(0)}\varepsilon^{-1/2}, \tag{3}$$

where $\varepsilon = (T - T_c)/T_c$, *e* is the charge of the electron, $\xi_c(0)$ is the coherence length along the c axis for $T \to 0$, and *d* is the characteristic size of the two-dimensional layer. In our case T_c was determined as the point of the maximum on the $d\rho_{ab}(T)/dT$ curves in the superconducting transition region (Fig.2) in the interval corresponding to the high T_c phase, as in [2,9,11,14]. However, as seen in figure (2), the increase of praseodymium content leads to an increase in the width of the superconducting transition, and when the

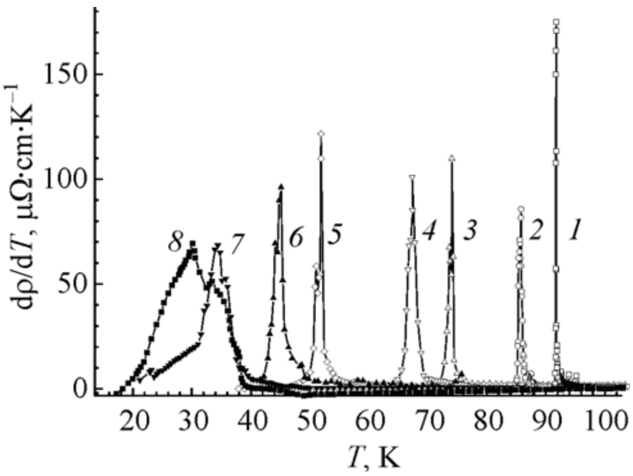

Fig. 2. The $d\rho_{ab}/dT$–*T* curves in the region of the superconductive transition regarding the K1–K8 samples. Enumeration of curves in the figure is the same as in Fig. 1.

concentration z ≥ 0.34 there appears a small additional peak on the $d\rho_{ab}(T)/dT$ curves. The latter is a reliable indication of phase bundle within the volume of the experimental sample [15,16]

In Fig. 3 shows the temperature dependence of $\Delta\sigma(T)$ in the coordinates ln Δσ– lnε. It is seen that in the temperature range between T_c and 1.05-1.1 T_c (at different concentrations of praseodymium) these curves are approximated satisfactorily by straight lines with slope $\tan\alpha_1$ ~ —0.5, corresponding to the exponent of —1/2 in the power law [Eq. (3)], which attests to a 3D characteristic of the fluctuation conductivity in this temperature interval. Upon further is in temperature the rate of decrease of

Δσ increases substantially (tan α_2 ~ — 1) which can be interpreted as an indication of a change of dimensionality of the fluctuation conductivity (FC). It follows from Eqs. (2) and (3) that at the point of the 2D-3D crossover:

$$\xi_c(0)\varepsilon_0^{-1/2} = d/2\,. \qquad (4)$$

In this case, having determined the value of ε_0 and using published data on the dependence of the interplane distance on δ [10] (d ~ 11.7 A), one can calculate the values of $\xi_c(0)$.

As can be seen from insert (b) to Figure 3, the value of $\xi_c(0)$, calculated according to (4), increased more than fourfold with increasing content of praseodymium in the sample from z = 0 and z ≤ 0.43, and respectively, lower T_c of 91.74 to 45.2 K, which agrees qualitatively with the values from the value of $\xi_c(0)$ obtained for the undoped YBaCuO samples with decreasing oxygen content [3]. At the same time for the samples with z ≥ 0.48, a fairly sharp decline in the value of $\xi_c(0)$, which may be due to a general suppression of the superconducting characteristics. These features (inset (a) in the Fig. 3), appearing in the form of a deep minimum, can be attributed to a general shift of the

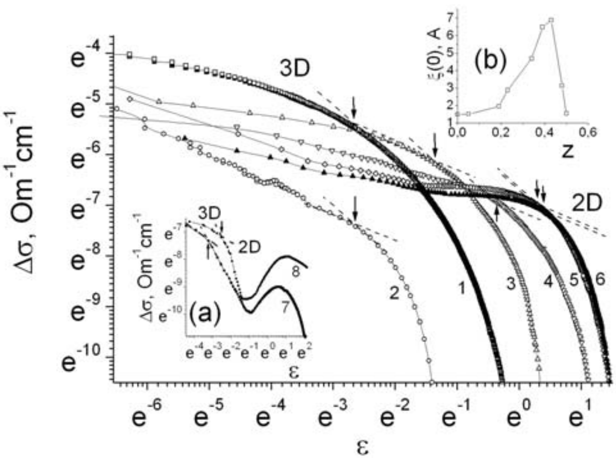

Fig. 3. Temperature dependences of excess conductivity in *ab*-plane for single crystals K1–K8 (the insert (a) – curves *7*, *8*) on the ln Δσ–lnε coordinates. Dash lines – approximation of experimental curves by equation (2) and (3). Enumeration of curves in the figure and insert is the same as in Fig. 1. The inset (b) shows the concentration dependence of the pseudogap and the transverse coherence length of $\xi_c(0, z)$.

conducting subsystem in the region of the phase diagram in which the normal state properties are determined by antiferromagnetic correlations and the demonstration of the so-called pseudo-gap anomaly (PG) [2,5,6,17].

The experimental technique we use is related with the measurement of the electrical resistivity and does not allow determining directly, the degree of the influence of the antiferromagnetic correlations in the fluctuation conductivity and the pseudo-gap. On the other hand, we can estimate the relative length of the existence of the PG-regime as $t^* = (T^* - T_f^{3D})/T_f^{3D}$, by defining the transition temperature in the three-dimensional fluctuation regime T_f^{3D} at the deviation point of the value Δσ upwards [2] and the temperature T* at the point that the ρ_{ab} diverges from linearity downwards, as the temperature is decreasing [2,5,17] . The calculations show that with increasing the concentration of praseodymium, there occurs a more than six-fold expansion of the temperature interval that the PG is realized: t^* = 0.5302-3.4895. This, qualitative agrees with the results obtained for the undoped samples YBaCuO [3,17] with decreasing the oxygen content.

Nevertheless, in the lowest praseodymium concentration z = 0.05, enhances a significant narrowing regarding the width of t^*, in comparison with the undoped YBaCuO with optimal oxygen content, to a value of t^* = 0.254. As noted above, at the same praseodymium concentration, we observed an anomalous (more than 30 K) expansion of the linear section of the $\rho_{ab}(T)$ dependence. Such behavior of the $\rho_{ab}(T)$ curves was also observed on ceramic [4] and film [18] YBaCuO samples, with low praseodymium content. This effect may be due to the peculiarities of the processes induced by the addition of praseodymium in the clustering processes in the $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ compounds, as well as possible to strengthen the role of some specific mechanisms of the quasiparticle interaction [19]. In distinction to the undoped $YBa_2Cu_3O_{7-\delta}$ samples, the clusters formation in the optimally oxygen doped $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ compounds occure at a certain threshold concentration of praseodymium [10]. For a relatively small ($z \le 0.1$) praseodymium content, the formation of such clusters is significantly reduced. In this case, the praseodymium content leads to an overall increase in the concentration of the point defects, which are efficient scattering centers of normal and fluctuating carriers. According to [2,5], the praseodymium in the $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ compound can have a powerful de-pairing influence that may hinder the formation of uncorrelated fluctuation bosons responsible for the appearance of excess conductivity at temperatures below T^*. This, in turn, should lead to a decrease in the absolute value of T^*, as observed in our work.

Summarizing the results we can conclude the following: Increasing the concentration of praseodymium in the superconductor $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$ can lead to phase bundle within the volume of the experimental sample. The excess conductivity Δσ(T) for the $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$ single crystals when approaching T_c, is well described by the Aslamazov–Larkin theoretical model. It is established that in the praseodymium concentration range $0.0 \le z \le 0.5$, there occurs a fourfold increase in the absolute values of the transverse coherence length $\xi_c(0)$ and a significant shift of the temperature intervals that the PG anomaly is realized. The doping of YBaCuO single crystals with a small amount of additives of praseodymium $z \approx 0.05$, leads to an unusual effect of narrowing the temperature interval of the implementation of the PG regime, thus extending the $\rho(T)$ linear dependence area in the *ab*-plane, which is probably due to the characteristics occurred by the induction of the clustering processes.

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