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Evolution of the pseudogap state in HTSC single crystals $ReBa_2Cu_3O_{7-\delta}$ (Re=Y, Ho) doped with Al and Pr

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Studied has been the effect of oxygen deficiency as well as of a low (up to 5 %) Al and Pr doping on conductivity in the basis plane of the $ReBa_2Cu_3O_{7-\delta}$ (Re=Y, Ho) HTSC single crystals. The excess conductivity $\Delta\sigma(T)$ of the studied samples has been found to show an exponential character in a wide temperature range $T_f<T<T^*$. The description of the excess conductivity as $\Delta\sigma\sim(1-T/T^*)\exp(\Delta^*_{ab}/T)$ can be interpreted within the frames of medium field theory where T^* is the mean field temperature of superconducting transition. The temperature dependence of the pseudogap can be satisfactorily described in terms of the BCS-BEC crossover theoretical model. The oxygen content reduction and a low Al doping results in widening of the temperature interval where the PG mode is realized, thus narrowing the area of linear $\rho(T)$ dependence in the *ab* plane. A low Pr doping concentrations ($z\approx0.05$) results in an unusual effect of a significant narrowing of temperature interval where the PG is realised, thus extending the linear $\rho(T)$ region.

Исследовано влияние кислородного дефицита, а также слабого (до 5 %) допирования алюминием и празеодимом на проводимость в базисной плоскости ВТСП-монокристаллов $ReBa_2Cu_3O_{7-\delta}$ (Re=Y, Ho). Установлено, что избыточная проводимость $\Delta\sigma(T)$ образцов в широком интервале температур $T_f<T<T^*$ подчиняется экспоненциальной температурной зависимости. При этом описание избыточной проводимости посредством соотношения $\Delta\sigma\sim(1-T/T^*)\exp(\Delta^*_{ab}/T)$ может быть интерпретировано в терминах теории среднего поля, где T^* представлена как среднеполевая температура сверхпроводящего перехода, а температурная зависимость псевдощели удовлетворительно описывается в рамках теории кроссовера БКШ-БЭК. Понижение содержания кислорода и слабое легирование алюминием приводит к эффекту расширения температурного интервала реализации ПЩ-режима, тем самым сужая область линейной зависимости $\rho(T)$ в *ab*-плоскости. Допирование монокристаллов YBaCuO малыми добавками празеодима $z\approx0.05$ приводит к необычному эффекту сужения температурного интервала реализации ПЩ-режима, тем самым удлиняя линейный участок зависимости $\rho_{ab}(T)$.

The investigation of the low temperature phase transitions to the fluctuation conductivity (FC) and the pseudogap (PG) mode in HTSC, being observed in the normal state around the critical temperature (T_c) and significantly higher temperatures is an important

issue [1–3]. This phenomenon is considered to be significant in understanding the HTSC nature [2, 3]. This motivated a number of experimental and theoretical studies of HTSC (for example [1] and references therein). Nevertheless, the nature of the PG anomaly and its formation mechanism in HTSC is still not completely understood. There are two main explanations for the origin of the PG anomaly in HTSC systems. The first explanation relates the PG anomaly to short-range ordering fluctuations of a "dielectric" type (e.g., anti-ferromagnetic fluctuations, spin and charge density waves) [1]. The second explanation assumes the formation of Cooper pairs at temperatures exceeding T_c significantly (i.e. $T^* >> T_c$, where T^* is the temperature that the PG commences) while their phase coherence is realized at $T<T_c$ [2, 3]. This is supported by the crossover theory from the Bardeen-Cooper-Schrieffer (BCS) mechanism to the Bose-Einstein condensation (BEC) [3] where the PG temperature dependences for weak and strong coupling were obtained. For temperatures lower than T^*, the PG value can be determined at a significant accuracy [2] within a wide temperature interval proceeding from the resistivity in the *ab* plane dependence $\rho_{ab}(T)$.

An appropriate system to investigate these issues is $YBa_2Cu_3O_{7-\delta}$ and its rare-earth analogues $ReBa_2Cu_3O_{7-\delta}$. This is due to the possibility to modify the conductivity characteristics and the crucial parameters by varying the oxygen content [4] or by substituting rare-earth elements for Y [5–7]. The admixture kind and concentration are also of importance here. Of particular interest in this aspect is the partial substitution Pr for Y, which, on the one hand, results in superconductivity suppression (unlike the case when other rare-earth elements are substituted for Y), and, on the other hand, allows the lattice parameters and oxygen index of the compound to remain practically unchanged [5, 6]. In particular, a study of Pr impurities influence on the existence conditions and modes of the pseudogap state region in such compounds [5] is of importance not only in elucidating the nature of high-temperature superconductivity (HTSC) but also for determining empirical ways to enhance its critical parameters. It is worth noting that until today, data regarding the Pr dopant influence on the transport properties of YBCO compounds remains considerably contradictory. This is because a large amount of experimental work was carried out on ceramics, films and textured samples [6, 7] of different technologic prehistories. In those works where the measurements that were carried out on single crystals (for example, [5]), the samples with Pr concentration exceeding 15 % were used.

Among other rare-earth elements, of a particular interest is replacement of yttrium with holmium. When yttrium (Y) is replaced with holmium (Ho), which has a magnetic moment of more than 10 μ_B, the resulting $HoBa_2Cu_3O_{7-\delta}$ compound is paramagnetic in the normal state. Nevertheless, the substitution paramagnetic Ho for Y does not affect substantially the superconducting properties [7]. This is because Ho is located away from the superconducting planes, which in turn interfere with the formation of distant magnetic order.

Alloying YBaCuO compounds with aluminium results in the substitution of copper atoms in the CuO planes [8, 9]. The impact of such changes on the transport properties (i.e. electro-conductivity) is still unclear. For example, an insignificant increase of the electro-resistance in the basic plane (ρ_{ab}) in $YBa_2Cu_{3-z}Al_zO_{7-\delta}$ single crystals with $z \leq 10$ % was reported [8], while a two-fold increase of ρ_{ab} was observed in a similar study at the same aluminium concentration [9]. Perhaps such a disagreement was due to inhomogeneous aluminium distribution in the body of the crystal, because under the crystal growth in alundum crucibles, an uncontrolled aluminium doping occurs. In particular, the inhomogeneous distribution of aluminium is evidenced by broad superconducting transitions $\Delta T_c \geq 2$ K and their stepwise shape [8, 9]. Moreover, there is a significant scatter in the superconducting state parameters. In addition, the YBCO single crystals contain always twin boundaries (TB) [4]. The contribution of these defects is difficult to determine in experiment.

The aim of this work was to study the effect of low aluminium and praseodymium doping (up to 5 %) and also influence of oxygen non-stoichiometry at replacement of yttrium with holmium on the PG mode in the single crystals of 1-2-3 system with the unidirectional TB system at different orientations of transporting current vector, providing regulated intensity of the carrier scattering processes.

The $ReBa_2Cu_3O_{7-\delta}$ (Re=Y, Ho) single crystals were grown using the technique described in [4]. As the initial components, Y_2O_3, $BaCO_3$, CuO powders were used (all of

Table. Sample data and experimental parameters

Sample	7–δ	T_a, K	T_c, K	ρ_{ab}(300), μΩ·cm	T^*, K	Δ^*_{ab}, meV
K1 ($\alpha_{I,TB}$ = 45°) $YBa_2Cu_3O_{7-\delta}$	6.92	670	91.74	155	143	89.05
	6.87	720	90.85	186	171	70
	6.83	760	88.71	192	192	51.64
	6.81	790	87.89	216	215	40.43
	6.77	810	78.52	243	232	25
K2 (I||TB) $HoBa_2Cu_3O_{7-\delta}$	6.9	710	91.3	120	188	68.02
	6.7	855	69.51	673	270	17.93
K3 $\alpha_{I,TB}$ = 45°) $HoBa_2Cu_3O_{7-\delta}$	6.9	710	91.33	125	185	69.91
	6.7	855	72.18	695	256	19.22
K4 (I||TB) $YBa_2Cu_3O_{7-\delta}$	6.9	710	91.8	150	143	88.4
K5 (I||TB) $YBa_2Cu_{3-y}Al_yO_{7-\delta}$	6.9	710	92.05	421	199	58.1
K6 (I||TB) $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$	6.9	710	85.8	255	110	98.1

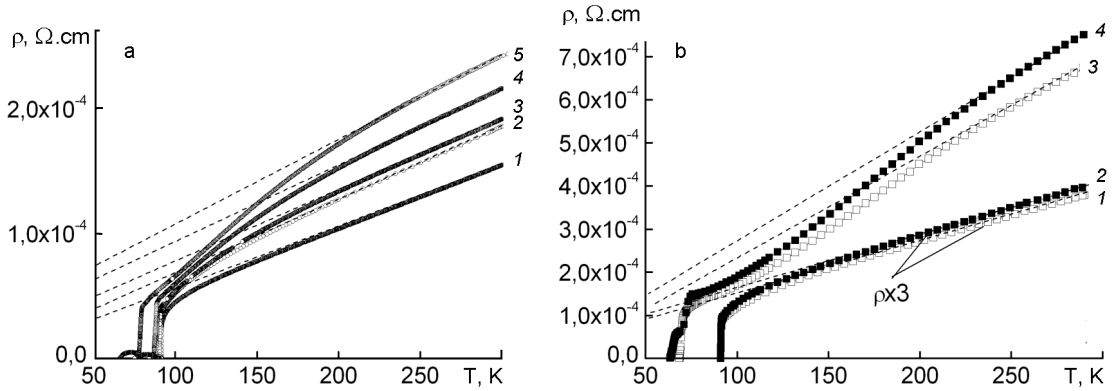

Fig. 1. Temperature dependences of the resistivity in the *ab*-plane, $\rho_{ab}(T)$ (a): K1 single crystal, $YBa_2Cu_3O_{7-\delta}$ (the curves *1–5* measured after annealing at 670; 720; 760; 790 and 810 K, respectively) and single crystals K2, $HoBa_2Cu_3O_{7-\delta}$ (hollow symbols) and K3, $HoBa_2Cu_3O_{7-\delta}$ (dark symbols) measured before (curves *1*, *2*) and after (curves *3*, *4*) decreasing the oxygen content. The dashed lines show the extrapolation of the experimental curves linear sections to zero temperature.

special purity grade). To obtain aluminium doped single crystals, 0.2 wt.% Al_2O_3 was added. To obtain $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$ single crystals, Pr_5O_{11} was added at atomic ratio Y:Pr=20:1. The growth and oxygen saturating regimes of $YBa_2Cu_{3-y}Al_yO_{7-\delta}$ and $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$ crystals were identical to those described for undoped single crystals [4]. To reduce the oxygen concentration, the crystals were annealed in air for one day at temperatures indicated in Table. The oxygen concentration δ was determined from the annealing duration and temperature in oxygen flow using the tables from [10] at an accuracy of 0.03.

For the resistivity measurements, the single crystals selected containing unidirectional TB of 0.5×0.5 mm^2 size. Thus we could cut out bridges with 0.2 mm wide unidirectional TB at distance between the potential contacts of 0.3 mm (see inset in Fig. 2). The electric resistance in the *ab* plane was measured using the standard four-contact method in a dc current up to 10 mA. The temperature was measured by a platinum thermoresistor.

Fig. 1 presents the temperature dependences of electric resistance $\rho(T)$ for $YBa_2Cu_3O_{7-\delta}$ (a) and $HoBa_2Cu_3O_{7-\delta}$ (b) single crystals in the *ab* plane prior to and

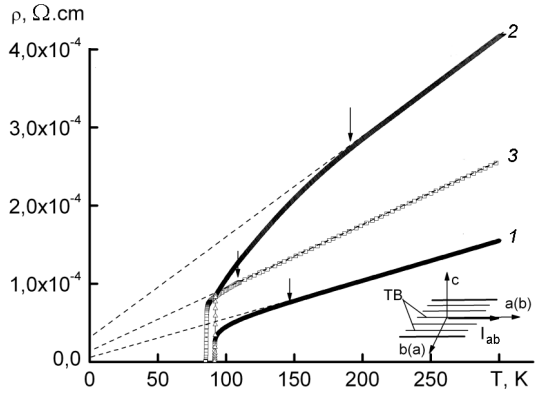

Fig. 2. Temperature dependences of resistance $\rho_{ab}(T)$ of K4, $YBa_2Cu_3O_{7-\delta}$ (curve 1), K5, $YBa_2Cu_{3-y}Al_yO_{7-\delta}$ (curve *2*) and K6, $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$ (curve 3*)* single crystals. Dashed lines show the extrapolation of linear sections to zero temperature. Arrows show transition temperatures T^* into the pseudogap mode. Inset shows schematically the experiment geometry.

after the samples were annealed in oxygen flow at different temperatures. The resistance parameters of the samples are presented in Table. Fig. 1(a) shows that the conductivity nature in the *ab*-plane of $YBa_2Cu_3O_{7-\delta}$ is quasi-metallic in all cases. This is reflected in the presence of an extended linear section in the $\rho_{ab}(T)$ dependence and will be discussed below. At increasing the annealing temperature and decreasing the oxygen concentration, the resistance absolute value increases and the critical temperature (T_c) drops. The small superconducting transition width of the initial sample ($\Delta T_c \approx 0.3$ K) rises significantly with the increasing annealing temperature, which is in agreement with previous experimental studies [4]. A qualitatively similar behavior show $\rho_{ab}(T)$ dependences measured for $HoBa_2Cu_3O_{7-\delta}$ samples prior to and after annealing, Fig. 1(b).

The temperature dependences of the electric resistivity in the *ab*-plane, $\rho_{ab}(T)$, for the analyzed crystals YBCO (K1), $YBa_2Cu_{3-y}Al_yO_{7-\delta}$ (K2) and $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$ (K3) are shown in Fig. 2. The dependences are metallic in all cases, but the $\rho_{ab}(300\ \text{K})/\rho_{ab}(0\ \text{K})$ ratio varies and its value is 40, 12 and 22 for K1, K2 and K3 crystals, respectively. The $\rho_{ab}(0\ \text{K})$ value was determined by extrapolating the linear $\rho_{ab}(T)$ conductivity section to zero temperature, as shown in Fig. 2. The resistivity value in *ab*-plane for the K1, K2 and K3 crystals, in room temperature, is 155, 421 and 255 μΩ·cm and their critical temperatures are 91.7, 92.1, and 85.8 K, respectively. The main data obtained for the samples is given in Table. Using literature data on the dependence of T_c on aluminium [8, 9] and praseodymium [5, 6] concentrations, we can conclude that Al and Pr concentrations in the K5 and K6 crystals are lower than 5 %, while the oxygen concentration is $\delta \leq 0.1$ [4]. The superconducting transition is less than 0.5 K wide for the K4 and K5 crystals and for the crystal K6, it is about 2.5 K. The narrow superconducting transition width of the pure as well as for the aluminium doped single crystals shows a high quality of the sample (homogeneity), while a rather significant superconducting transition width of the crystal with Pr dopant evidences an inhomogeneous Pr distribution over the crystal volume.

As the transport current vector, **I**, was parallel to the TB for all three samples, the increase of electric resistivity in the Al doped crystal, having the smaller intertwin distance cannot be explained by the increased TB density. Thus, the observed twofold increase of ρ_{ab} value could be probably due either to the current carrier density reduction or to the appearance of efficient carrier scattering centers. Taking into consideration the increased Hall signal at comparable Al concentrations [8], we can conclude that the observed ρ_{ab} increase is defined mainly by the increased number of scattering centers. The change in $\rho_{ab}(300\ \text{K})/\rho_{ab}(0\ \text{K})$ ratio confirms also that conclusion. The role of such centers can be played by the three-valence Al dopant [9], as well as the increasing number of vacancies. The last preposition is supported by the increase of twin density in the crystal with Al impurity, which, in turn, could be due to the increased non-stoichiometry degree resulting from the increased vacancy concentration.

It is seen in Figs. 1 and 2 that when the temperature is dropped under a characteristic value T^*, a deviation of $\rho_{ab}(T)$ from the linear dependence occurs, which indicates the existence of excess conductivity that is due to the transition to a pseudo-gap mode [1–3]. As is seen in Table 1 and Fig. 2, aluminium and the praseodymium doping results in qualitatively different changes of the $\rho_{ab}(T)$ dependence character. As to the aluminium doped crystal, the linear section of the $\rho_{ab}(T)$ dependence is significantly narrower as compared with the undoped crystal, and the temperature T^* is shifted

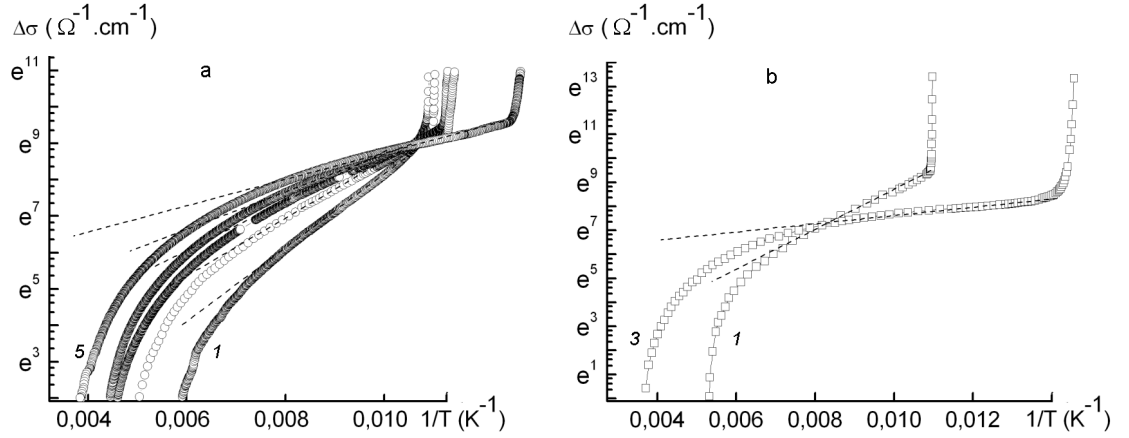

Fig. 3. Temperature dependences of the excess conductivity in the *ab*-plane for K1-$YBa_2Cu_3O_{7-\delta}$ (a) and K2-$HoBa_2Cu_3O_{7-\delta}$ (b) single crystals, in $\ln\Delta\sigma - 1/T$ coordinates. The numbering of the curves is consistent to the Fig. 1. Dashed lines show the approximation of experimental curves by equation (2).

towards higher temperatures by more than 55 K, thus evidencing the corresponding extension of the excess conductivity temperature range. On the other hand, in the praseodymium doped sample, the linear section of the $\rho_{ab}(T)$ dependence is significant wider as compared to the undoped crystal, and the temperature T^* is shifted towards lower temperatures by about 30 K. This, in turn, indicates the corresponding narrowing of the excess conductivity temperature range. It should be noted that such behavior of the $\rho_{ab}(T)$ curves is rather unusual, since up till now the opposite effect has been observed when doping of Y–Ba–Cu–O compounds with praseodymium at concentrations $z \geq 0.2$: a shift of T^* to higher temperatures [5]. Lowering of oxygen content in the case of $YBa_2Cu_3O_{7-\delta}$ and $HoBa_2Cu_3O_{7-\delta}$ single crystals, as well as in the case of aluminium doping, results in displacement upwards of temperature point corresponding to pseudogap opening in the case of both types of compounds, that it will be discussed below in more detail.

The temperature dependence of the excess conductivity is defined by equation:

$$\Delta\sigma = \sigma - \sigma_0, \qquad (1)$$

where $\sigma_0 = \rho_0^{-1} = (A + BT)^{-1}$ is the conductivity obtained by extrapolating the linear sections of the curves in Fig. 1 to zero temperature, and $\sigma = \rho^{-1}$ is the experimental value of the conductivity in the normal state.

The experimental dependences $\Delta\sigma(T)$ obtained for bridges K1 and K2, K3 are shown in $\ln\Delta\sigma$ vs. $1/T$ coordinates in Fig. 3 (a) and (b), respectively, and those for K4–K6, in Fig. 4. As is seen, these dependences are linear in a wide temperature range. It is possible to describe these features as

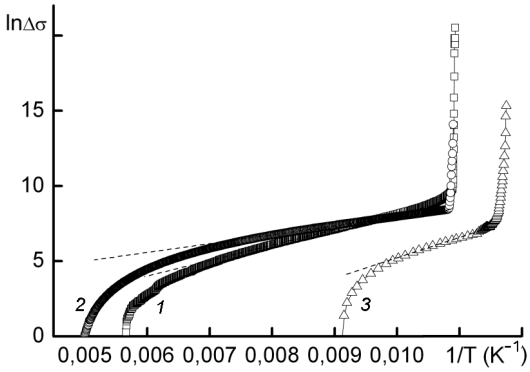

Fig. 4. Temperature dependences of the excess conductivity for K4, $YBa_2Cu_3O_{7-\delta}$, K5, $YBa_2Cu_{3-y}Al_yO_{7-\delta}$ and K6, $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$ in $\ln(\Delta\sigma)$ vs. $1/T$ coordinates. The curves are numbered as in Fig. 2. Dashed lines show the approximation of experimental curves by Eq.(2).

$$\Delta\sigma \sim \exp\left(\frac{\Delta^*_{ab}}{T}\right), \qquad (2)$$

where Δ^*_{ab} is a quantity that defines thermal activated process through the energy gap — "pseudogap". Values of Δ^*_{ab} calculated from Eq.(2) for samples K1–K6 are presented in Table. It is seen that aluminium doping and oxygen decreasing in $ReBa_2Cu_3O_{7-\delta}$ (Re=Y, Ho) and $YBa_2Cu_{3-y}Al_yO_{7-\delta}$ samples result in a significant decrease of the absolute PG value. The praseodymium doping causes the inverse effect of the absolute PG value increase: $\Delta^*_{K4}/\Delta^*_{K6} \approx 0.9$.

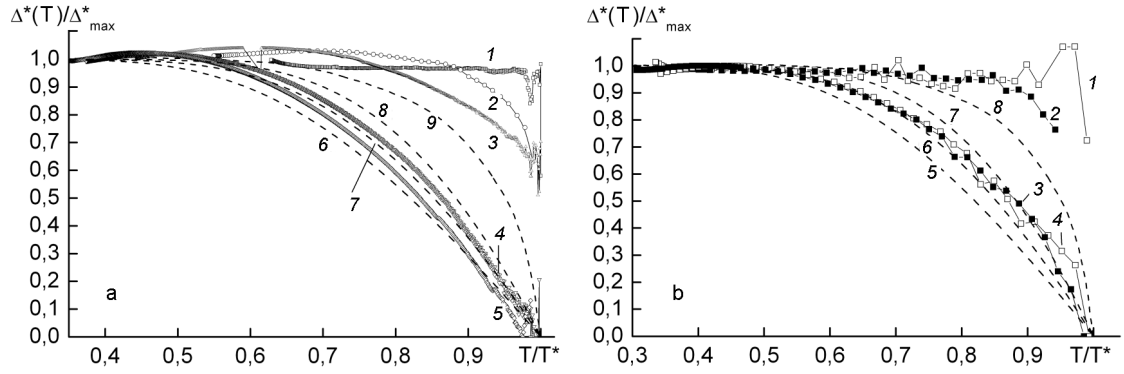

Fig. 5. Temperature dependence of the pseudogap for K1, $YBa_2Cu_3O_{7-\delta}$ (a) and K2, K3 — $HoBa_2Cu_3O_{7-\delta}$ (b) single crystals in $\Delta^*(T)/\Delta^*_{max}$ vs T/T^* coordinates (Δ^*_{max} is the Δ^* value in the plateau, far from T^*). The curves are numbered as in Fig. 1. The dashed lines show the $\Delta^*(T)/\Delta(0)$ vs T/T^* dependence calculated according to [3], for the crossover parameter $\mu/\Delta(0) = 10$ (BCS limit) and $\mu/\Delta(0) = -2, -5, -10$ (BEC limit) and are shown in (a) (b) as curves (*6–9*) and (*5–8*) respectively.

The exponential dependence of $\Delta\sigma(T)$ was observed before in YBaCuO film samples [2] where it was shown that the experimental data approximation can be improved by adding factor $(1-T/T^*)$. In this case, the excess conductivity becomes proportional to the superconducting carrier density $n_s \sim (1-T/T^*)$ and inversely proportional to the number of pairs $\sim\exp(-\Delta^*/kT)$ that are destroyed by thermal motion:

$$\Delta\sigma \sim \left(1 - \frac{T}{T^*}\right)\exp\left(\frac{\Delta^*}{T}\right), \qquad (3)$$

where T^* is considered as the mean field temperature of the superconducting transition. The temperature range $T_c<T<T^*$ where PG exists is defined by the phase of the order parameter that depends on either oxygen deficiency or doping element concentration. The approximation of the $\Delta\sigma(T)$ dependence by equation (2) is presented in Figs. 3 and 4 by dashed lines. Thus, using the method proposed in [2], one can obtain temperature dependence $\Delta^*(T)$ up to T^* can be obtained from the experimental curve $\ln\Delta\sigma$.

Figs. 5 and 6 show the temperature dependences of PG in $\Delta^*(T)/\Delta_{max}$ vs T/T^* coordinates, where Δ_{max} is the Δ^* value in the plateau, far from T^*. In [3], the temperature PG dependences were obtained in the context of the BCS-BEC crossover theory using the expression

$$\Delta(T) = \Delta(0) - \Delta(0)\sqrt{\pi/2}\ \sqrt{T/\Delta(0)}\ \times$$
$$\exp\left(-\frac{\Delta(0)}{T}\right)\left[1 + erf\left(\frac{\sqrt{x_0^2+1}-1}{T/\Delta(0)}\right)^{1/2}\right], \qquad (4)$$

where $x_0 = \mu/\Delta(0)$, μ is the chemical potential of the carrier system and $\Delta(0)$ is the energy gap value at zero temperature. In the limiting case $x_0\to\infty$ (weak coupling), Eq.(4) takes the form

$$\Delta(T) = \Delta(0) - \Delta(0)\sqrt{2\pi\Delta(0)T}\exp\left(-\frac{\Delta(0)}{T}\right), \qquad (5)$$

well known in the BCS theory. For the strong interaction limit in the three-dimensional case ($x_0<-1$), Eq.(4) takes the form:

$$\Delta(T) = \qquad (6)$$
$$= \Delta(0) - \frac{8}{\sqrt{\pi}}\sqrt{-x_0}\left(\frac{\Delta(0)}{T}\right)^{3/2}\exp\left(-\frac{\sqrt{\mu^2+\Delta^2(0)}}{T}\right).$$

The $\Delta^*(T)/\Delta(0)$ vs T/T^* dependences calculated according to Eqs.(5) and (6) in the mean field approximation within the frame of the BCS-BEK crossover theory [3], for the value of crossover parameter $\mu/\Delta(0) = 10$ (BCS limit) and $\mu/\Delta(0) = -2, -5, -10$ (BEC limit) are shown in Figs. 5 and 6 by dotted lines. It is seen that for $ReBa_2Cu_3O_{7-\delta}$ (Re=Y, Ho) samples stoichiometric in oxygen and low-doped with praseodymium, the temperature dependence of the pseudogap shows a significant disagreement with the theory [3]. The same behavior was determined for $YBa_2Cu_3O_{7-\delta}$ film samples [2]. In contrast, for the samples non-stoichiometric in oxygen and doped with aluminium, the agreement with the theory is quite satisfactory.

As is seen from Figs. 3 and 4, $\Delta\sigma$ increases sharply near T_c. It is known from the theory [11] that, in the vicinity of T_c,

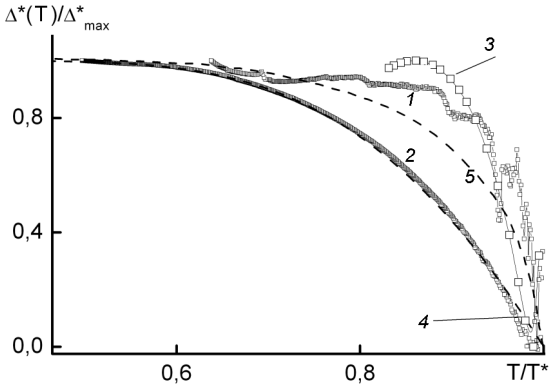

Fig. 6. Temperature dependences of the pseudogap for K4, $YBa_2Cu_3O_{7-\delta}$, K5, $YBa_2Cu_{3-y}Al_yO_{7-\delta}$ and K6, $Y_{1-z}Pr_zBa_2Cu_3O_{7-\delta}$ single crystals in $\Delta^*(T)/\Delta^*_{max}$ vs T/T^* coordinates (Δ^*_{max} is the Δ^* value on plateau far from T. The curves are numbered as in Fig. 2. Dashed lines (curves *4* and *5*) show the dependence $\Delta^*(T)/\Delta(0)$ vs. T/T^* calculated according to [3], for the crossover parameter $\mu/\Delta(0) = 10$ and -10.

an excess conductivity is caused by the fluctuation carrier coupling (FC) processes. If the transition temperature from PG to FC mode, T_f, is determined as the point where $\ln\Delta\sigma$ vs. $1/T$ curve deviates from linear dependence [2], the relative range of PG existence can be estimated as $t^* = (T^*-T_f)/T_f$. The calculation results show that, at increasing the oxygen non-stoichiometry in $ReBa_2Cu_3O_{7-\delta}$ (Re=Y, Ho) single crystals and low Al-doping, the pseudogap temperature range increases by more than three times, from $t^* = 0.459$ (for $YBa_2Cu_3O_{7-\delta}$ sample) to $t^* = 1.877$ with a simultaneous relative narrowing of the FC region. On the other hand, the Pr doping at the same concentration results in an inverse effect, i.e. narrowing of the pseudogap temperature range to 0.210.

It is to note also that all the characteristic shape changes of the PG temperature dependences and absolute values of the resistivity parameters observed in the course of the sample annealing at room temperatures, were more pronounced for $HoBa_2Cu_3O_{7-\delta}$ as compared to $YBa_2Cu_3O_{7-\delta}$. In the case of the $HoBa_2Cu_3O_{7-\delta}$, the substitution of Y with Ho having larger ionic radius seems to play a part in the structural range in the system, which, in its turn, results in change of the oxygen ions interactions in the Cu–O planes. In fact, the substitution of Y with other Re elements with larger ionic radius results in significant changes in the $T_c(\delta)$ dependence [12]. It is observed that the characteristic $T_c(\delta)$ dependency for the $YBa_2Cu_3O_{7-\delta}$ with the two plateaus at 60 K and 90 K is degenerated to a much more sharp monotonous dependence and the ortho-II structure is not realized at all [12]. Thus, the non-stoichiometric $HoBa_2Cu_3O_{7-\delta}$ is characterized by a more disordered superstructure as compared to $YBa_2Cu_3O_{7-\delta}$.

In conclusion, Al and Pr dopants are both effective scattering centers for current carriers. The homogeneous dopant distribution in the sample bulk as well as the character of the initial components substitution in the compound is of significant importance. The excess conductivity $\Delta\sigma(T)$ for single crystals of all the compounds shows exponential dependence in a wide temperature range $T_f<T<T^*$. The temperature dependence of the pseudo-gap can be described satisfactorily in terms of the BCS-BEC crossover theory. The lowering oxygen doping in $ReBa_2Cu_3O_{7-\delta}$ (Re=Y, Ho) crystals and low Al doping of YBaCuO single crystals result in a considerable narrowing of the linear section in $\rho_{ab}(T)$ dependence and an extension of the PG mode region. In Pr-doped crystal ($z\approx0.05$), an unusual decreasing of the pseudogap temperature range and thereby linear section extension in the $\rho_{ab}(T)$ dependence is observed.

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Еволюція псевдощілинного стану у ВТНП-монокристалах $ReBa_2Cu_3O_{7-\delta}$ (Re=Y, Ho), допованих Al та Pr

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Досліджено вплив кисневого дефіциту, а також слабкого (до 5 %) допування алюмінієм і празеодимом на провідність у базисній площині ВТНП-монокристалів $ReBa_2Cu_3O_{7-\delta}$ (Re=Y, Ho). Встановлено, що надлишкова провідність $\Delta\sigma(T)$ зразків у широкому інтервалі температур $T_f<T<T^*$ підпорядковується експоненціальній температурній залежності. При цьому опис надлишкової провідності за допомогою співвідношення $\Delta\sigma \sim (1-T/T^*)\exp(\Delta^*_{ab}/T)$ може бути інтерпретований у термінах теорії середнього поля, де T^* представлена, як середньопольова температура надпровідного переходу, а температурна залежність псевдощілини задовільно описується у рамках теорії кросовера БКШ-БЕК. Зниження вмісту кисню і слабке легування алюмінієм приводить до ефекту розширення температурного інтервалу реалізації ПЩ-режиму, тим самим звужуючи область лінійної залежності $\rho(T)$ в ab-площині. Допування монокристалів YBaCuO малими домішками празеодиму $z\leq 0.05$ приводить до незвичайного ефекту звуження температурного інтервалу реалізації ПЩ-режиму, подовжуючи лінійну ділянку залежності $\rho_{ab}(T)$.