EFFECT OF ANNEALING ON A PSEUDOGAP STATE IN UNTWINNED YBa$_2$Cu$_3$O$_{7-\delta}$ SINGLE CRYSTALS

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The effect of annealing both in the oxygen atmosphere and at room temperatures on the excess conductivity $\sigma'(T)$ and pseudogap (PG), $\Delta^*(T)$, of untwined YBa$_2$Cu$_3$O$_{7-\delta}$ (YBCO) single crystal with a small deviation from oxygen stoichiometry is studied. It was revealed that as the charge carrier density, nf, increases, T$_c$ also slightly increases, whereas T* decreases noticeably, which is consistent with the phase diagram (PD) of cuprates. The excess conductivity in the vicinity of T$_c$ is well described by the Aslamazov-Larkin and Hikami-Larkin fluctuation theories, demonstrating the 3D-2D crossover with an increase in temperature. The crossover temperature T0 determines the coherence length along the c axis, $\xi_c(0) = 0.86$ Å, which is 2.6 times larger than for optimally doped YBCO single crystals with defects. Taking into account the short coherence length in high-temperature superconductors, in the model of free charge carriers the phase relaxation time of fluctuation Cooper pairs is determined, τ_φ (100 K) = 4.42 ± 0.4 s, which is slightly (1.3 times) large than in well-structured YBCO films, and, as in films, in fact does not depend on nf. It is shown that $\Delta^*(T)$ at different annealing stages practically does not change its shape. As in the well-structured YBCO films, $\Delta^*(T)$ demonstrates maximum at T$_{pair}$ ~ 124 K which depends weakly on n$_f$. However, the maximum value of Δ^*(Tpair) increases with increasing n$_f$, as it follows from the PD of cuprates. Comparing the experimental data with the Peters-Bauer theory we estimated the density of local pairs $\langle n_\uparrow n_\downarrow \rangle \approx 0.3$ near T$_c$, which can be a universal value for high-temperature superconductors.

We take advantage of single crystals to study fluctuation conductivity (FLC) and PG in untwined YBCO single crystal with n$_f$ close to optimal doping (T$_c$ = 91.6 K), when n$_f$ changes upon annealing in an oxygen atmosphere. We have studied three samples with different n$_f$. For a short notation, we name these samples A1, A2 and A3. The fluctuation contributions to $\sigma'(T)$ were derived from the dc resistivity $\rho(T)$ measurements, and temperature dependences of PG [1,2] $\Delta^*(T)$, as a function of n$_f$ were calculated.
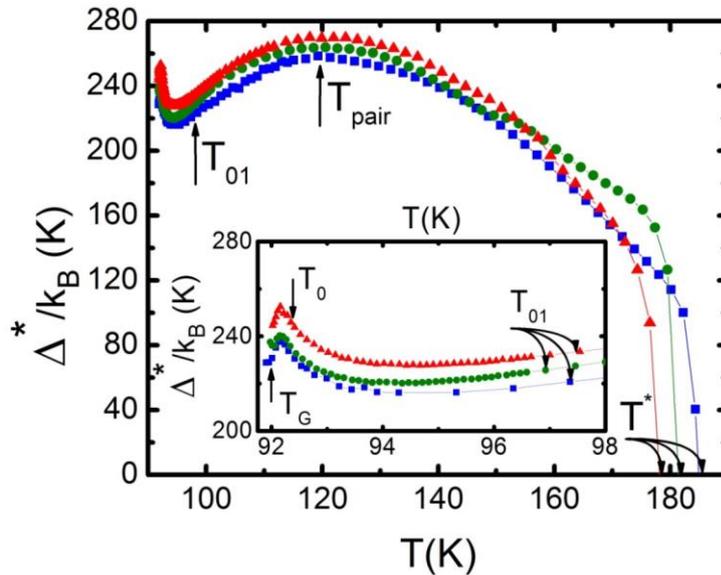

Fig. 1. Temperature dependences of the pseudogap $\Delta^*(T)$ of the untwined YBa$_2$Cu$_3$O$_{7-\delta}$, single crystal for all annealing stages: A1 - blue squares, A2 - green points, A3 - red triangles. Insert: The same dependence for the temperature interval T$_G$ < T < T$_{01}$. The arrows show all characteristic temperatures. Solid lines are to guide the eye.

[1] A. L. Solovjov, in *Superconductors - Materials, Properties and Applications*, edited by A. Gabovich (InTech, Rijeka, 2012), Chap. 7, p. 137.
[2] A. L. Solovjov and V. M. Dmitriev, Low Temp. Phys. **32**, 99 (2006).