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Effect of transverse magnetic field on the excess conductivity of monodomain $YBa_2Cu_3O_{7-\delta}$ single crystals

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In present work the influence of a transverse on the temperature dependence of the excess conductivity in the temperature interval of the transition to the superconducting state in untwinned $YBa_2Cu_3O_{7-\delta}$ single crystals with optimal oxygen content are investigated. Causes of low-temperature "tails" (paracoherent transitions) in the resistive transitions in superconducting state are analyzed in the framework of the implementation of the various regimes of the phase state of vortex matter.

Keywords: excess conductivity, $YBa_2Cu_3O_{7-\delta}$ single crystals, oxygen deficiency, pinning, 2D-3D crossover, intrinsic pinning.

В роботі досліджено вплив поперечного магнітного поля на температурні залежності надлишкової провідності в області переходів у надпровідний стан роздвійникованих монокристалів $YBa_2Cu_3O_{7-\delta}$ з оптимальним вмістом кисню. Причини виникнення низькотемпературних «хвостів» (паракогерентних переходів) на резистивних переходах в надпровідний стан аналізуються в рамках моделі реалізації різних режимів фазового стану вихрової матерії.

Ключові слова: надлишкова провідність, монокристали $YBa_2Cu_3O_{7-\delta}$, дефіцит кисню, пінінг, 2D-3D кросовер, власний пінінг.

В работе исследовано влияние поперечного магнитного поля на температурные зависимости избыточной проводимости в области переходов в сверхпроводящее состояние раздвойникованных монокристаллов $YBa_2Cu_3O_{7-\delta}$ с оптимальным содержанием кислорода. Причины появления низкотемпературных «хвостов» (паракогерентных переходов) на резистивных переходах в сверхпроводящее состояние анализируются в рамках модели реализации различных режимов фазового состояния вихревой материи.

Ключевые слова: избыточная проводимость, монокристаллы $YBa_2Cu_3O_{7-\delta}$, дефицит кислорода, пиннинг, 2D-3D кроссовер, собственный пиннинг.

Creation of new functional materials with high current-carrying capacity continues to remain one of actual applied and fundamental problems of physics of high-temperature superconductivity (HTSC). The major role thus is played optimization of defective ensemble [1]. A small coherence length ξ [2] and a large penetration depth λ result in effective pinning in HTSC on small-scale defects, including oxygen vacancies [3] and the introduction of impurities [4]. The impact of such defects on the phase state of the vortex matter is often difficult to explain due to the presence in the HTSC intergranural boundaries, twin boundaries (TB), clusters of inclusions and other defects which are powerful pinning centers. The presence «intrinsic» pinning due to the layered structure of HTSC compounds is also significantly affected [3].

In the present study we investigate the magnetic conductivity in untwined $YBa_2Cu_3O_{7-\delta}$ single crystals under different values of magnetic field H in the ab-plane (H,ab). Using as samples untwined single crystals we eliminate the influence of intergranural boundaries and TB allowing the selected geometry of the experiment to control the changes of the contribution of intrinsic pinning. In this case, the measurement of the resistivity transitions to the superconducting state, allows the investigation of the impact of the point defects to the phase state and to the dynamics of vortex matter. This is achieved by analyzing the fluctuation to the conductivity that was observed in HTSC compounds at temperatures near to the critical temperature ($T \approx T_c$) [3-5].

The aim of this work is to study the effect of a constant magnetic field on the intrinsic pinning and the excess conductivity of single-domain single crystals of YBaCuO with optimal oxygen content.

Experimental methods

The $YBa_2Cu_3O_{7-\delta}$ single crystals were grown in a gold crucible with the solution-melting method, with the methodology described previously [3]. The $YBa_2Cu_3O_{7-\delta}$ oxygen saturating regime leads to the tetra-ortho structural transition that in its turn results to the crystal twinning in order to minimize its elastic energy. To obtain untwined samples, we used a special cell at 420° C and pressure 30-40 GPa, in accordance to the procedure [6]. To obtain homogeneous oxygen content, the crystal was annealed again in an oxygen flow at a temperature of 420°C for seven days.

To form electric contacts the standard four-contact scheme was used. In this, silver paste was applied onto the crystal surface and the connection of silver conductors (with diameter 0.05mm).Thereafter, they were annealed at a temperature of 200°C in an oxygen atmosphere for three hours. This methodology results in contacts with resistance than 1 Ohm and allows measurements with a current of 10 mA in the *ab*-plane. All the measurements were performed in a temperature drift mode using the method for two opposite directions of the transport current. This effectively eliminates the impact of the parasitic signal. A platinum thermoresistor was used to monitor the temperature, whereas the voltage was measured across the sample and the reference resistor with V2-38 nano-voltmeters. Data from the voltmeters interface is automatically transferred to computer. The critical temperature (Tc) was defined as the temperature corresponding to the main maximum in the $d\rho_{ab}(T)/dT$ dependence in the superconductive transition.

The magnetic field at 15 kOe was created by an electromagnet, which could vary the orientation of the field relative to the crystal. The accuracy of the field orientation relative to the sample was better than 0.2°. A sample was mounted in the measuring cell so that the vector field H was always perpendicular to the vector of the transport current ***j***.

For investigations of the resistive transitions in superconducting (SC) state we used the Kouvel- Fischer method [7]. This is based on the analysis of the quantity $\chi = \frac{-d(\ln\Delta\sigma)}{dT}$, where $\Delta\sigma = \sigma - \sigma_0$ is the excess conductivity, which arises in the conducting subsystem due to the fluctuation pairing of carriers at $T>T_c$ [8] and determined by the phase state of vortex matter at $T<T_c$ [4,5]. Here $\sigma=\rho{-1}$ is the experimentally measured value of conductivity, and $\sigma_0=\rho_0{-1}=(A+BT){-1}$ is a term, determined by extrapolating the high-temperature linear segment up to the area of the SC transition. Assuming that $\Delta\sigma$ diverges as $\Delta\sigma\sim(T-T_c){-}\beta$ at $T\approx T_c$, from the derivative $\chi = \frac{-d(\ln\Delta\sigma)}{dT}$ it follows that $\chi{-1}=\beta{-1}(T-T_c)$, where β is an indicator that depends on the dimension and the phase state of the fluctuation and vortex subsystems [4,5,8]. Thus, the identification of linear temperature dependence $\chi{-1}(T)$ at the same time allows the determination of important dimensional parameters and characteristic temperatures of dynamic phase transitions in the SC carrier's subsystem.

Results and discussion

Figure 1 shows the temperature dependences of resistivity in the basal ab-plane $\rho_{ab}(T)$, measured under H=0 (curve 1) and H = 3,2; 6,1; 9,3; 12,4; 15,05, respectively. As can be seen from the figure, the temperature is lowered from 300 K, $\rho_{ab}(T)$ decreases almost linearly up to a certain characteristic temperature T* ≈ 180 K. Below this temperature begins systematic deviation of experimental points down from the linear dependence, indicating that the appearance of excess conductivity $\Delta\sigma$, as discussed above. According to modern concepts such behavior depending $\rho_{ab}(T)$ at temperatures $T >> T_c$ conditioned by the manifestation of the so-called "pseudogap anomalies" (PG), which is discussed in more detail in [9].It should also be noted that the application of a magnetic field and change the magnetic field at temperatures $T> 1.15\ T_c$, within experimental error, have not effect on the behavior of the curves $\rho_{ab}(T)$, both leading to a significant broadening of the superconducting transition itself, in comparison with the sharp ($\Delta T_c \approx 0.3$ K) transition, observed at H = 0.

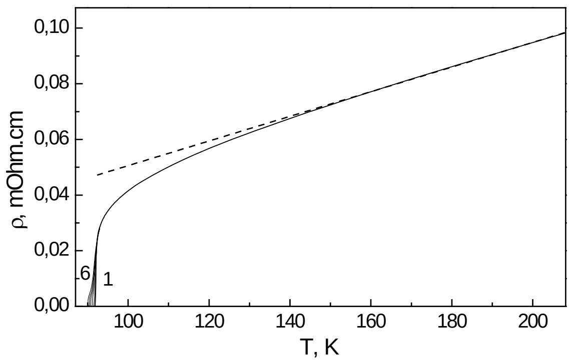

Fig. 1. Temperature dependences of resistivity in the basal ab-plane $\rho_{ab}(T)$ for the $YBa_2Cu_3O_{7-\delta}$ single crystal for H=0 (curve 1) and for H = 3,2; 6,1; 9,3; 12,4; 15,05 KOe (curves 2-6 respectively). The dotted lines in the figure shows a linear extrapolation of the plots in the low temperature region.

In this case, it is clear that on the tail of the superconducting transition is observed sharp "kink", which also appears in the form of sharp low-temperature peak in the temperature dependence of the derivative $d\rho_{ab}(T)/dT$ (Fig. 2).

As can be seen from Fig. 2, the peak is present for all values of H, while its height increases with increasing values of H. According to [3,4], the appearance of such features in the temperature dependences $\rho_{ab}(T)$ and $d\rho_{ab}(T)/dT$ shows the implementation in the first order phase transition corresponding to melting of the vortex lattice. Figure 3 shows the resistivity transitions to the SC state in coordinates $\left[\frac{-d(\ln\Delta\sigma)}{dT}\right]^{-1} - T$ In all curves in the

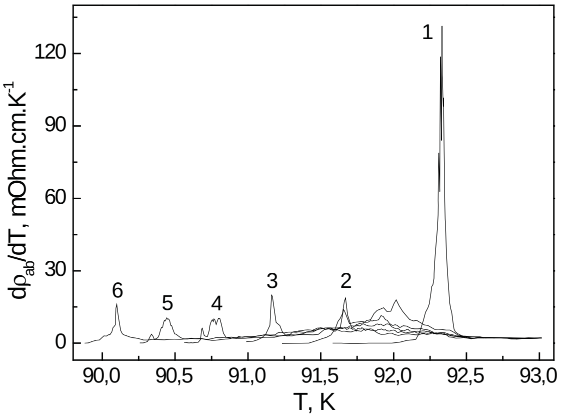

Fig. 2. Resistivity transitions to the superconducting state for the $YBa_2Cu_3O_{7-\delta}$ single crystal in $d\rho_{ab}/dT - T$ coordinates . The numbering of the curves is consistent to Fig. 1.

high-temperature area of the SC transition we observe a linear area with slope ≈ 0.5, which according [8] indicates the realization of a three-dimensional (3D) regime of fluctuation carriers' existence in the system. In this, the section corresponding to 3D regime is essentially unstable in the magnetic field, which is consistent with the results obtained by [3-5]. When increasing the temperature from Tc upwards, an increase of the absolute value of β occurs, this suggests the realization of a 3D-2D crossover in the system [3,4,8].

The application of magnetic field and the increase of the H, leads to a significant transformation of the form of the SC-transition occurs, which is expressed in the appearance of an additional low-temperature peak, so-called «para-coherent transition». At the same time, the shift of the transition to lower temperatures accompanied by a significant increase in simultaneous amplitude and width of the peak with increasing H. Similar behavior may be due to a decrease with an increase in the proportion H own intrinsic pinning, and thus increasing the role of bulk pinning. This, in turn, can contribute to the transition from the ordered phase in the phase grating of the vortex so-called "vortex" or "Bragg" glass due to the accommodation of a chaotic vortex pinning potential. This chaotic pinning potential violates the long-range order of vortex lattice, thereby suppressing the first –order phase transition and results to formation of glassy state of vortices. In the resistive transitions appear "tails", whose amplitude is less than the resistance of viscous flow ρff. These are probably due to a partial pinning of the vortex liquid. In our case, the role of this potential can play oxygen vacancies [9].

Conclusions

In summary, the application of a constant magnetic field to $YBa_2Cu_3O_{7-\delta}$ single crystals leads to additional

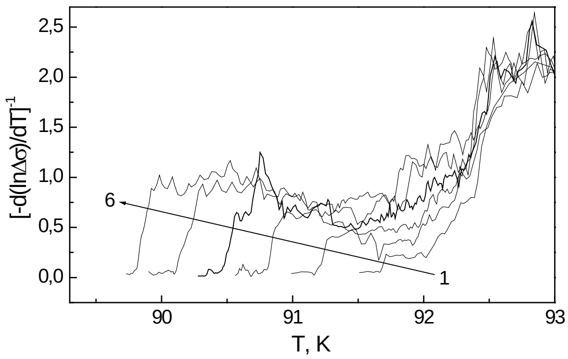

Fig. 3. Resistivity transitions to the superconducting state for the $YBa_2Cu_3O_{7-\delta}$ single crystal in $\left[\frac{-d(\ln\Delta\sigma)}{dT}\right]^{-1} - T$ coordinates. The numbering of the curves is consistent to Fig. 1. The dash lines correspond to the extrapolation of the areas corresponding to various 3D FC regimes.

of the additional para-coherent transition in the excess conductivity temperature dependences in the basic *ab*-plane in the area of the resistive transition to the superconducting state.

The increase in the magnetic field leads to a simultaneous increase in the amplitude and width of the peak, which corresponds to this transition, and its displacement to lower temperatures. This may be due to a decrease with increasing H contribution of its own vortex pinning subsystem and the role of bulk pinning due to the presence in the structure of the experimental sample of oxygen vacancies. As a result, at temperatures below the critical $T < T_c$, the phase transition manifests dynamic vortex liquid form - vortex "Bragg" glass.

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