The magnitude and temperature dependence of pseudogap in YBCO obtained from resistance measurements

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Abstract

We report the analysis of the temperature dependence of excess conductivity $\Delta\sigma$ of the underdoped YBCO epitaxial thin films at temperatures much higher than the superconducting critical temperature T_c. The excess conductivity was determined as the difference of the extrapolated normal resistivity and the measured resistivity. It was found that the temperature dependence of the excess conductivity can de described by the following relation $\Delta\sigma = (1 - T/T^*)exp(\Delta^*/T)$. It is proposed that this relation reflects the pseudogap appearance and the magnitude and temperature dependence of the pseudogap were calculated and compared with published experimental and theoretical results.

Key words: resistivity; pseudogap; $YBa_2Cu_3O_7$; thin films

The measurements of the electric, magnetic and optical properties of the normal state of the HTSC single crystals with the concentration of carriers, which corresponds to maximal T_c (optimally doped) or lower one (underdoped), revealed some peculiarities. These peculiarities were observed at temperatures $T_c < T < T^*$, where T^* decreases linearly with increasing charge carrier density. The unusual properties of the normal state at $T < T^*$ are attributed to the pseudogap effect - formation of an energy gap in excitation spectrum of HTSC, considered to be crucial for understanding the superconducting state [1]. Up to now, there is no consensus about the origin of the pseudogap effect. There are a few models, which suggest pairs formation at $T=T^*$ and creation of the phase coherency of preformed pairs at $T=T_c$ [2]. The existence of electron pairs at $T_c < T < T^*$ should reflect itself in the temperature dependence of resistance in this temperature range.

For the measurements of the temperature dependence of resistance we used c-axes oriented epitaxial thin films $YBa_2Cu_3O_{7-\delta}$ (YBCO), obtained by laser deposition on $SrTiO_3$ substrates. A few bridges have been formed with the dimensions 3mkm*40mkm*260nm, equipped with silver sputtered contact pads. The films had resistivity $\rho_{300} \simeq 160$ mkOhm * cm, resistance ratio $\rho_{300}/\rho_{100} \simeq 2.1$, and critical temperature $T_c(0.5R_{100}) = 89.5$. The amount of oxygen was estimated using the T_c and ρ values, and was 7-$\delta \simeq 6.85$, so the films were slightly underdoped. The temperature dependence of resistance was measured by 4-probe method with dc current density 10 A/cm^2 and with step-like temperature changes. The temperature stability during resistance measurements was better than 0.02 K.

The insert on the figure shows temperature dependence of resistivity for one of the measured thin-film bridges. At high temperature (from 300 K up to appr. 200 K) the $\rho_n(T)$ dependence can be described by the relation $\rho_n = AT^2+BT+C$, where A, B, C - constants and $|A| \ll |B|$. The small deviation from usual linear temperature dependence of resistivity is a common trend of underdoped HTSC materials [1]. Dot line on the insert is the extrapolation of this dependence toward low temperatures. At lower temperatures (T < 200K), starting from a temperature T^*, the resistivity

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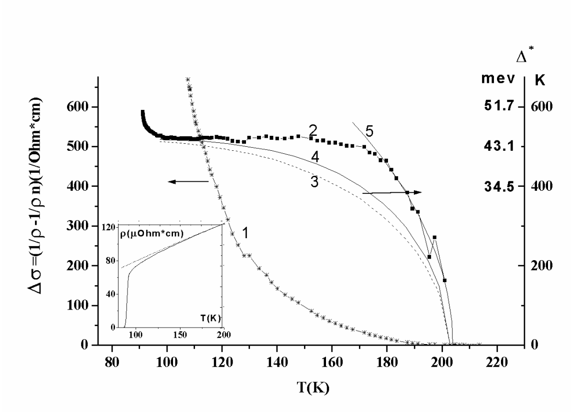

Fig. 1.

falls with temperature more rapidly. The temperature dependence of resistivity of this type is a common feature of optimally doped and underdoped HTSC single crystals and epitaxial thin films.

In our work we analyze this rapid decrease of resistance below T* in terms of additional or excess conductivity $\Delta\sigma$, calculated using the values of measured and extrapolated normal resistivities $\Delta\sigma = 1/\rho(T)$ - $1/\rho_n(T)$, i.e. in the same way, as is used for the analysis of fluctuation conductivity at superconducting transition.

On the figure the curve 1 shows the temperature dependence of this excess conductivity. In a wide temperature region this dependence can be very well approximated by the relation

$\Delta\sigma = (1 - T/T^*) exp(\Delta^*(T)/T)$ (1),

where A = 11.3 (1/Ohm*cm), T*=203 K. This dependence was chosen due to simple physical reasons: in the region from Tc up to T* the number of superconducting pairs decreases as $\exp(\Delta^*/kT)$ and the term $(1 - T/T^*)$ is introduced to satisfy $\Delta\sigma = 0$ at T=T*. The fitting of relation (1) and $\Delta\sigma(T)$ leads to the Δ^*(T) dependence shown as curve 2 on the figure. In a wide temperature region Δ^* is almost temperature independent and near T* the temperature dependence of Δ^* can be approximated by the square root relation (curve 5):

$\Delta^*(T) = 95.5\sqrt{203.2 - T}$ (2)

The value of Δ^* in the region of low temperature plateau Δ^*_{max} = 520 K (45 meV) is close to the value of pseudogap ($\simeq$ 500 K), obtained in [3] from optical measurements for YBCO thin films with the same oxygen content. We suppose that Δ^*(T), obtained using excess conductivity $\Delta\sigma$ and relation (1) presents the value and temperature dependence of pseudogap observed in electrical, magnetic and optical properties of underdoped HTSC crystals.

The temperature dependence of Δ^* can be compared with the results of theory [4], where the crossover from BCS superconductivity to Bose - Einstein condensation was investigated and in the mean-field approximation the dependencies Δ^*(T)/Δ^*(0) were calculated. These dependencies for the values of crossover parameter x_0 = -2 and -5 are shown on the figure (curves 3 and 4 respectively, for the value Δ^*(0) the "plateau" value $\Delta^*{}_{max}$ =520 K was used).

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