Scenario of superconducting transition for quasi-2D HTS

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Abstract

For quasi-two-dimension HTS with spin-fluctuation pairing mechanism the scenario of superconducting transition is discussed. The interaction of fluctuational spin waves with holes in CuO$_2$ planes in the mean field theory leads to the pairing of holes and to the fluctuation generation of superconducting regions at $T_{c0}$ (where $T_{c0}$ is the temperature of two dimension superconducting transition) and also to essential temperature dependence of the strength of interlayer coupling $t_c(T)$. At sufficiently small values of $t_c(T)$, the transition of the sample to the coherent superconducting state occurs at $T_c < T_{c0}$.

1. Layer compounds with weak interaction between the copper-oxygen planes and with anisotropic resistivity (for example, $\rho_{c}/\rho_{ab} \sim 10^5$ for Bi2212 and $\rho_{c}/\rho_{ab} \sim 10^3$ for $YBa_2Cu_3O_{6.7}$ and $La_{2-x}Sr_xCuO_4$) belong to quasi-2D superconductors. The dependence of the resistivity $\rho_c(T)$ for such HTS’s near the transition temperature $T > T_{c0}$ has the semiconducting character that is evidenced about noncoherent charge transfer along axis $\hat{c}$. It’s need to note that three dimension anisotropic superconductors with coherent dynamics of charge in normal state becomes quasi-2D ones under magnetic field $B > B_{cr}$ which is parallel to axis $\hat{c}$ (here $B_{cr}$ is the dimensional crossover field) or in the case if the HTS is underdoped sample. In this paper following scenario of superconducting transition is discussed for quasi-2D HTS with spin-fluctuation pairing mechanism described by the generalized BCS theory [1-3]:

1) in normal state the fluctuational spin excitations exist in CuO$_2$ planes in the regions with measures which are confines by the correlation length of the antiferromagnetic (AFM) fluctuations;

2) the interaction of holes with fluctuational spin excitations leads to the fluctuational generation in CuO$_2$ planes of superconducting regions at the temperature $T < T_{c0}$ where $T_{c0}$ is 2D superconducting transition in the mean field theory $T_{c0}$;

3) the difference of the temperature dependencies of coherent lengths $\xi_{ab}(T)$ in the CuO$_2$ planes and out-of-plane $\xi_c(T)$ leads to anomal increase of $\rho_c(T)$ at the decreasing the temperature $T < T_{c0}$ and to essential temperature dependence of the strength of interlayer coupling $t_c(T)$ [4-6];

4) the transition to superconducting state with coherent dynamics of charge transfer occurs at enough small values of $t_c$, and the transition temperature $T_c < T_{c0}$ is defined by the inequalities which at first were received for layer systems in papers E.I.Kats [7] and L.N.Bulayevsky [8].

2. Strong AFM fluctuations in quasi-two dimensions HTS are prevented to 2D Heisenberg ordering in copper-oxygen planes, in spite of on essential anisotropy of exchange constants of in-plane and out-of-plane interactions. In CuO$_2$ planes long AFM order absences but spin waves with linear dispersion are existing in the dielectric regions with sizes
which are confines by the correlation length of the AFM fluctuations. We can suppose
that at $T \sim T_{c0}$ the exchange of the holes by such spin excitations leads to quasi-particles
pairing with mechanism which is discussed nearly 10 years [1-3], and to the generation in
$CuO_2$ planes of superconducting regions with measures which are confined by the corre-
lation length of the AFM fluctuations. The temperature $T_{c0}$ defines by the mean value of
exchange interactions in $CuO_2$ plane with taking to the account disrupted couplings of
copper spins in the dielectric regions.

3. In temperature region, where $\rho_c(T)$ are sensible over the Mott limit, the transfer
of charge along axis $\hat{c}$ can consider as a tunneling process of electron over nonconductor
barrier $\rho_c \sim (N_0 t_c)^{-1}$, where $N_0$ is the density of states in $CuO_2$ planes. The interest to
the studying of the temperature dependence $t_c$ is due by the inefficiency of the attempts
to account semiconductive character of dependence $\rho_c(T)$ near $T_c$ by the decrease of
state density $N_0$ [9-10]. With decreasing of the temperature to $T < T_{c0}$ the dependence
$t_c(T) \approx (\xi_{ab}(T))^{2}$ is caused by 2D-superconductive fluctuational effects, namely by the
expression of temperature dependencies of coherent lengths $\xi_{ab}(T) = \xi_{ab0}(1-T/T_{c0})^{-1/2}$in
$CuO_2$ plane and out-of-plane $\xi_c(T) = \xi_{c0}(T)$ [6].

At $T = T_c$ in quasi-2D HTS the coherent three dimension superconducting state the
dependencies $\xi_{ab}(T)$ and $\xi_c(T)$ settles and the value $t_c$ doesn’t depend on the temperature,
that is accorded with the London penetration depth measurements [11].

4. For quasi-2D HTS the temperature transition to superconducting state $T_c$ with
coherent dynamic of charge transport along axis $\hat{c}$ can be defined by inequalities for layer
systems (see [7,8], and the equation (12) in review [12]):

$$\ln t_c(T_c)^{-1/3} > T_{c0}/\varepsilon_F; \quad t_c \ll T_{c0}/\varepsilon_F,$$

where $\varepsilon_F$ the Fermi energy. As we can see from (1), the value $T_c$ dependence from
the values of three parameters: $t_c, T_{c0}, \varepsilon_F$. The values of $t_c$ and $T_{c0}$ can be found out at
resistivity measurements $\rho_c(T)$ and permit to define the relation between $T_c$ and $\varepsilon_F$. The
comparison the results of the resistivity measurements and the solution of the inequalities
(1) let us to qualify the pairing mechanism: or it is a mechanism described by generalized
BCS theory (such as discussed in Refs.[1-3]), or it is a pairing mechanism that cannot be
explained by the BCS theory (such as spin analog of the superconducting proximity effect
[13]).

Thus, in proposed variant superconductivity in quasi-2D HTS assumes spin-fluctuational
pairing mechanism described by the generalized BCS theory and occurs in two stages. At
first at $T \sim T_{c0}$ strong superconducting fluctuations are settled in copper-oxygen planes,
which leads to essential temperature dependence of the strength of interlayer coupling
$t_c(T)$. The transition of the sample to the coherent superconducting state occurs at
$T_c < T_{c0}$ at sufficiently small values of $t_c(T)$, which fulfil to the inequalities (1).

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