THE DIFFUSE PHASE TRANSITION IN HTSC AND THE MAGNETIC FIELD INFLUENCE ON IT

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The results of electrical properties of bismuth (2212, 2223), yttrium (123), $YBa_2Cu_{2.87}Fe_{0.13}O_{7-y}$, and $La_{2-x}Sr_xCuO_4$ crystals in the superconducting phase transition (SCPT) region are interpreted within the framework of the theory of diffuse phase transition (SPT). The parameters of PT, characterizing the region and the degree of diffuse of SC transition are determined: T_0, a_B, $L(T)$, dL/dT, $2\Delta T^*$ and $2\Delta T^*/T_0$ at different values of a magnetic fields (B).

It was shown that in HTSC the supercoducting PT, without “premature” decreasing region of $\rho(T)$ and $\alpha(T)$ has the diffuse character. The SC transitions take placed under the $m_{SCP}/m_{NP}=exp[a_B(T-T_0)]$ law, and under magnetic field (B) strongly increased the diffuse degree. It was founded the most probably defects, which stipulate the diffuse of PT in HTSC and the reason leading to rise of degree of diffuse in magnetic field.

The study of processes take placed near by and in range of phase transformations (FT) is one of developing directions of solid-state physics. The interest to this, widely investigated, direction has increased after discovering high temperature superconductors (HTSC). One of actual questions of the given direction is the study of regularity of transition of one of coexisting phases in other, detection of classification FT, namely in what extent the transition is pointy or blurred. For this purpose the calculations of arguments FT is necessary, by which one are possible are to reveal the range and extent of diffusion FT. Such problems are reviewed in [1-4] for crystals Ag_2Te, Ag_2Se and $AgFeTe_2$, having structural FT. In particular, in [2,3] at study of electrical and thermal properties Ag_2Te and Ag_2Se near by and in range FT were observed a number of a feature. For interpretation of the obtained data the theory blurred FT was involved [5-7]. Proceeding from the theoretical reasons, the procedure of determination of masses coexisting in range FT of phases (m_α, m_β), by data, which were, calculated the parameters of FT, defining range and extent of diffusion FT. It was shown, that the electronic processes, which are flowing at FT, by virtue of them on many smaller inertness effect, than thermal processes, are most responsive to a subtle structure FT and can be applied for determination of parameters FT, irrespective of their origin. The given procedure was used for study FT in bismuth HTSC [8-9], where is shown, that SC FT in them have blurred nature. Under of an external magnetic field the diffusion hardly increases, the asymmetry FT and etc. feature occurs.

With the purpose of generalization and developments obtained in works [8-9] of result in whole for HTSC it is necessary to increase number considered HTSC, to expand a range of magnetic and electrical fields, to involve the data of crystalline samples etc. It to allow to reveal regularity of transitions SFT - NF, influencing on these transitions of external factors, to study variations take placed in range of "premature" decreasing of specific receptivity (ρ) in HTSC, to determine range and extent of diffusion FT in wide-spread HTSC, and also influencing on them of an anisotropy, related by layered crystalline structure of HTSC. Therefore in the given work is analyzed the electrical properties of specific receptivity $\rho(B,T)$ and thermal power $\alpha(B, T)$ in range FT most widely investigated HTSC: $YBa_2Cu_3O_{7-\delta}$ [10], $YBa_2Cu_{2.87}Fe_{0.13}O_{7-\delta}$ [11], in directions $B||$ to a plain (ab) and $B\perp(ab)$; $Bi_{1.72}Pb_{0.34}Sr_{1.83}Ca_{1.97}Cu_{3.13}O_{10+\delta}$ (2223) and $Bi_2Sr_2CaCu_2O_{10+\delta}$ (2212) and $La_{2-x}Sr_xCuO_4$ (214). The experimental data are interpreted within the framework of the theory DFT [5-7] on procedure offered in [2, 3].

Theory and procedure of determination of parameters FT

The theory DFT in solids is reviewed in [5-7]. With this purpose was used the theory DFT in condensate systems, founded on the introducing of a function of inclusion $L(T)$, describing a relative part of phases in range of their coexistence. It is supposed that, if thermodynamic potentials of α and β- phases to designate through Φ_α and $\Phi_\beta\Phi$, the thermodynamic potential $\Phi(T)$ in range FT can be introduced by

$$\Phi(T) = \Phi_\alpha(T) + \Delta\Phi \bullet L(T) \tag{1}$$

Where $\Delta\Phi(T)=\Phi_\beta(T)-\Phi_\alpha(T)$. In a case, when FT take placed in $\Delta T=T_2-T_1(T_2>T_1)$ interval, the function $L(T)$ should fit asymptotic conditions

$$L(T)=\left\{\begin{matrix} 0 & T<T_1 \\ 0<L<1 & T_1<T<T_2 \\ 1 & T>T_2 \end{matrix}\right\} \tag{2}$$

According to the theory DFT, for a function $L(T)$ is obtained

$$L(T) = \frac{1}{1+exp[-a(T-T_0)]} \tag{3}$$

Where T_0- temperature, at which mass of both phases are quantitatively equal, a – temperature dependent constant describing extent of diffusion FT, depending from a volume of possible fluctuations, and also energy and temperature FT. Informative the derivative $L(T)$ on temperature is also

$$\partial L/\partial T = \frac{a}{2}\frac{1}{1+ch[-a(T-T_0)]} \tag{4}$$

defining temperature speed of phase transformations in each transition point. Allowing, that $L(T)$ characterizes a relative part of phases in range FT, it can be determined and under the data of masses of each phase (m_α, m_β) by

$$L(T)=\left[1+\frac{m_\alpha(T)}{m_\beta(T)}\right]^{-1} \qquad (5)$$

From the joint solution (3) and (5) follows

$$a=\frac{1}{T_0-T}\ln\frac{m_\alpha}{m_\beta} \qquad (6)$$

According to (6) the dependence $\ln\left(\frac{m_\alpha}{m_\beta}=y\right)$ from T gives straight, the interception which with a temperature axis corresponds to T_0, and slope $\ln y/\Delta T$ - to a temperature constant - a.

In works [2-4] enabling, that in region of FT a temperature change of a differential - thermal analysis DTA and electrical properties of Ag_2Te and Ag_2Se in region of FT are related by, basically, quantitative change of α and β phases, the parameters of FT were determined: a, T_0, $L(T)$, dL/dT and change of some thermodynamic parameters in FT region. For this purpose it was necessary to achieve a linear temperature variation nearly and in FT region. Then from a beginning up to the end of transition the interval of ΔT may be to divide into equal intervals and corresponding values of investigated effects to refer to suspected phases, for example

$$\Delta T_y=T_{y,\alpha}(1-m_\beta/m_\alpha)+\Delta T_{y,\beta}(m_\beta/m_\alpha) \qquad (7)$$

If by analogy Ag_2Te and Ag_2Se to accept for one phase normal (NF), and for other superconducting (SCF), the offered procedure can be applied and for HTSC. Then the conforming masses will accept values m_{nf} and m_{scf}.

Discussion of obtained results

In a fig.1 are submitted the $\rho(T,B)$ and $\alpha(T,B)$ dependencies for a crystalline sample $Bi_2Sr_2CaCu_2O_{7+\delta}$ (2212) and $\rho(T,B)$ for a crystalline sample $Ag(Bi_{1.72}Pb_{0.34}Sr_{1.83}Ca_{1.97}Cu_{3.13}O_{10+\delta}$ (2223), investigated in [12] up to magnetic fields 12 T. For analysis are involved the data of [10], in which $\rho(T,B)$ of crystalline $YBa_2Cu_3O_{7-\delta}$ are investigated up to 5 T (fig. 2a), the data [11] in which $\rho(T,B)$ of $YBa_2Cu_{2.87}Fe_{0.13}O_{7-\delta}$ is investigated in a direction $B\|(ab)$ of plain and $B\perp(ab)$, accordingly up to 5 T and 4 T, and also $La_{2-x}Sr_xCuO_4$ (214) [13]. For each of introduced curves $\rho(T,B)$ and $\alpha(T,B)$ in FT region the masses m_{sf} and m_{nf} are found, the relations $\ln(m_{nf}/m_{sf})$ from T are constructed and are determined T_0 and a_B at different values of a magnetic field. In a fig. 3(a) are presented the characteristic dependencies of $\ln(y,T)$ only for $YBa_2Cu_{2.87}Fe_{0.13}O_{7-\delta}$ in a case $B\|(ab)$ plain. It is shown, that in all reviewed HTSC crystals with increasing of B the value T_0 and a_B hardly decreases. From the data of a fig. 3a are seen, that the temperature dependencies of distribution of coexisting phases (in FT region), by excepting of high temperature part of transition corresponding to "premature" region of $\rho(T)$, are well layed on straight ln (m_{scf}/m_{nf} =y, T). But the dependencies of $\ln(y,T)$ and in high temperature region also is linear, but with other slope independent of value B. The values of a on this segment (a_{sf}) on the order are less, than in a main segment SCFT (a_0) at B=0. In a fig. 3b are shown the a_B/a_0 dependencies from a magnetic field. As is seen the strong decreasing of a is occurred at weak fields. The data analysis are shown, that this segment of B corresponds to ranges of the lower critical field B_{c1}, at which one is always watched a fracture of communal dependencies of a critical field $B_c(T)$ from T. From the obtained here results it may be to conclude, that for reviewed HTSC the superconducting phase transformation, irrespective of value of a magnetic field, is realized under the law $m_{scf}/m_{nf} = \exp[a_B(T-T_0)]$, where a a_B - temperature-dependent constant for each crystals depending only on value B. It means, that the process of despairing of SC electronic pairs (or process of formation of vortex currents) in a magnetic field is realized by the indicated exponential law.

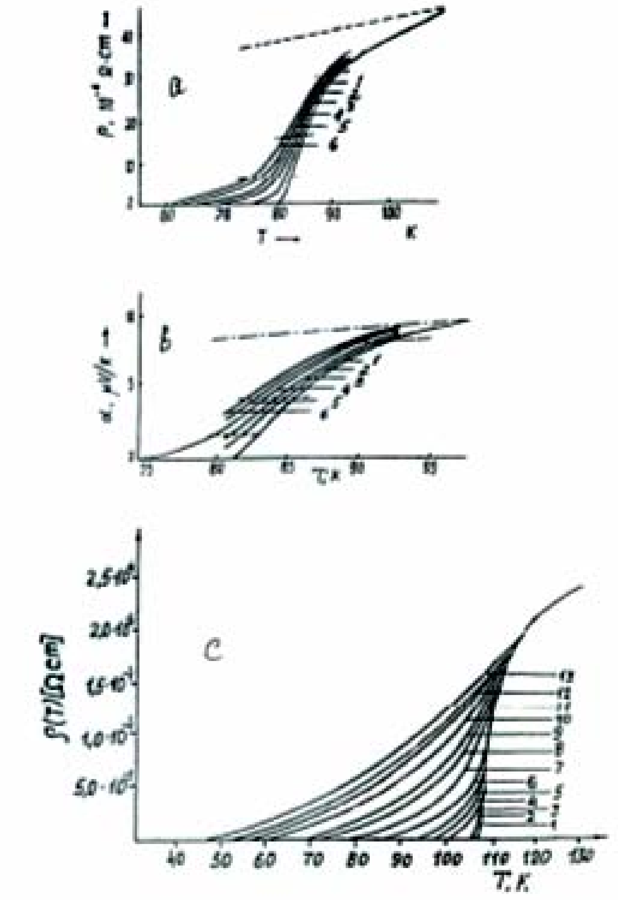

Fig. 1. Temperature dependencies of specific resistance (a), thermal power (в) of Bi-SC (2212) at B: 1 - 0; 2 - 0.1; 3 – 0.2; 4 - 0.5; 5 - 0.9; 6 - 2.2 T and Bi (2223) (c) at B: 1- 0; 2 - 0.01; 3 - 0.05; 4 - 0.1; 5 - 0.2; 6 - 0.5; 7 - 1; 8 – 2; 9 - 3; 10 - 5; 11 - 7; 12 - 9; 13 - 12T.

It should be noted, that on a segment of "premature" decreasing of ρ(T) of FT also is realized by the exponential law $m_{scf}/m_{nf} = \exp[a_{sf}(T-T_{0s})]$, but with the data a_{sf} and T_{0sf}, intrinsic to this region. It confirms opinion that the mechanism of pairing on a segment of "premature" decreasing of resistance differs from the mechanism of a main segment of SC transition.

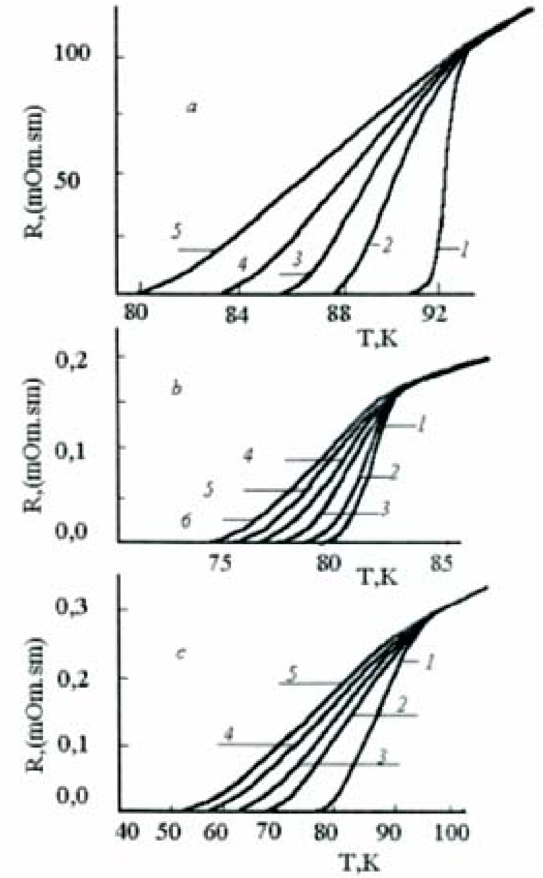

Fig. 2. Temperature dependencies of specific resistance of $YBa_2Cu_3O_{7-\delta}$ (a) at B: 1 - 0; 2 - 1; 3 - 2; 4 - 4; 5 - 5T [10], $YBa_2Cu_{2.87}Fe_{0.13}O_{7-\delta}$ at B||(ab) B: 1 - 0; 2 - 1; 3 – 2; 4 - 3; 5 - 4; 6 - 5T and B ⊥ (ab) B: 1 - 0; 2 - 1; 3 - 2; 4 - 3; 5 - 4T [11].

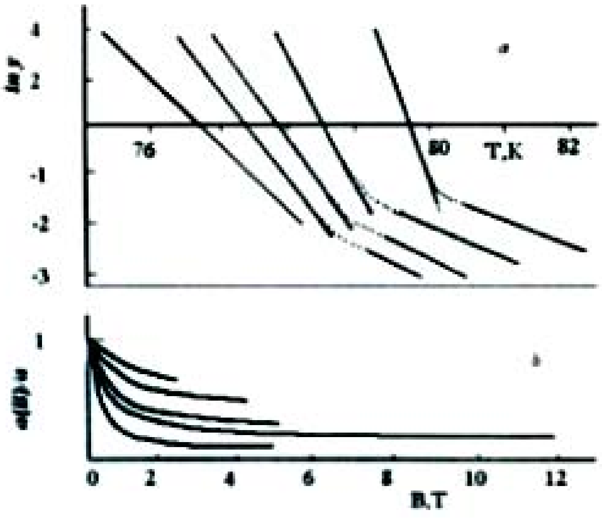

Fig. 3. Temperature dependence of mass distribution lnγ (a) in $YBa_2Cu_{2.87}Fe_{0.13}O_{7-\delta}$ In a case B || (ab) at B: 1 - 0; 2 –1; 3 - 2; 4 - 3; 5 - 4T and dependence of a temperature constant a_B (b) from a magnetic field: 1-Bi (2212); 2 - Bi (2223); 3 - Y (123); 4 - $YBa_2Cu_{2.87}Fe_{0.13}O_{7-\delta}$ B|| (ab) and 5 - $YBa_2Cu_{2.87}Fe_{0.13}O_{7-\delta}$ B⊥ (ab).

According the data of a_B and T_0 for each dependencies ρ(B,T) and α(B,T) were calculated a inclusion function L (T) and temperature speed FT dL/dT. In fig. 4 are shown the dependencies *L (T)* and *dL/dT* only for bismuthic (2223) HTSC at different values B. These characteristic and for remaining HTSC crystals data visually demonstrate a diffusing of SC phase transition in HTSC and influencing on them magnetic fields. It follows that according to the theory [5-7] at point FT tangent to inflection point L (T) there should be a vertical axis, and in a case DFT tangent will derivate a definite angle with a vertical axis, depending on value a. The calculations shows, that for the reviewed crystals the value of this angle reaches up to 45º. The rate of change of a function dL (T) /dT according to the theory DFT is figured by a curve with a final maximum at T_0 (as in a fig. 4), where as for point FT she can aspire in this point to infinity. For the quantitative characterize of diffusion FT it may be to use a half-width of a curve dL/dT i.e. interval ΔT^*, counted from T_0, in which dL/dT decreases twice as contrasted to with maximum rating dL/dT (ΔT^*) = 1/2, from which one, with allowance for (4) follows: $\Delta T^* = \frac{arcch3}{a_B} = \frac{1.76}{a_B}$

or, allowing the left and right party from T_0 we shall receive $2\Delta T^* = T_1 - T_2 = 3.52/a_B$. Then in the formulas (3) and (4) in a place *a* using 3.52 / (T_1-T_2) it is possible to calculate L (T) and *dL/dT* for region of diffusion IF. The calculations shows, that to an interval $2\Delta T^*$ there corresponds variation of a function L (T) from value 0.15 (at T_1) up to value 0.85 (at T_2). In a fig. 4 these regions are indicated with broken lines, the values which one coincides with counted on the data an a_B. It is expedient to enter into the table the value of the most relevant parameters for all reviewed HTSC at different values of a magnetic field. In particular: ΔT_{ST} - interval of temperature of SC phase transition (without region of "premature" decreasing ρ); T_K (B) - critical temperature; T_0 (B) temperature at which one $m_{SF}=m_{NF}$; a_B- temperature constant; *dL/dT* at T_0; $2\Delta T^*$ - interval of diffusion of SCFT and $2\Delta T^*/T_0$ - relative value of region of diffusion FT. Let's remark, what there is a tendency - than above temperature SCFT, the more FT interval ΔT_{ST}, therefore and region of diffusion FT, but ratio $2\Delta T^*/T_0$ excludes such relation and demonstrates an extent of diffusion FT temperature-independent of transition.

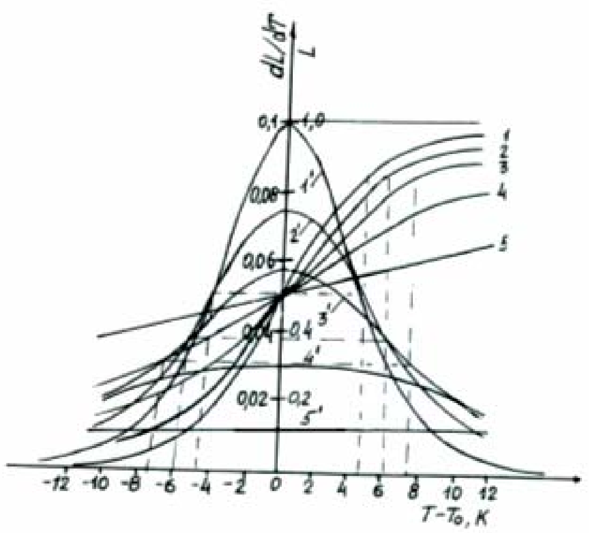

Fig. 4. Temperature dependencies of include function L (T) and its derivative dL/dT for Bi (2223) at B: 1 and 1 ' - 0; 2 and 2 ' - 0.1; 3 and 3 ' - 0.2; 4 and 4 ' - 2; 5 and 5 '- 12T.

From the reduced data follows, that among reviewed HTSC yttrium have the least diffusion SCFT, the replacement of $Cu_{0.13}$ atoms by $Fe_{0.13}$ atoms does not result in noticeable variation of diffusion FT. In a direction B⊥ (ab), J|| (ab) region of diffusion hardly extends, as enhances influence a magnetic field on an extent of diffusion in it. The data on $La_{2-X}Sr_XCuO_4$ (X=0,15; 0,16; 0,18) demonstrate, that, despite of rather low extreme temperature, in them the diffusions SCFT are higher, than in yttrium HTSC. For comparison in the table are brought the data for classic SC 1 kind of stannum (Sn) at different values of a current density (j), flowing through it [14]. As is seen, in Sn the value of a_i, though and on three orders it is more than in HTSC, but SC transition is not pointy, and the diffusion increases with increase of a current density, which one acts to an identically external magnetic field. From these data also follows, that the degree of diffusion of FT in SC- I of a kind, approximately one order is less, than in HTSC (in relative units $2\Delta T^*/T_0$).

Concerning the nature of defects resulting in to diffusion in SCFT in HTSC in absence of a magnetic field is possible to indicate on a non-uniformity, related by deviation from a stoichiometry of multicomponent structures, defect or excess of oxygen etc. imperfection. In case of bismuthic HTSC the presence of other phases (2201, 2212, 2223) is possible. Probably in bismuthic HTSC these factors cause a high scale of diffusion of FT. The defects resulting in to strong diffusion SCFT in a magnetic field, undoubtedly, are conditioned by a vortex state of SC- II kind, in which one, since very weak fields, are spontaneously arisen vortex currents. At further increasing of B the dimensions of vortexes and value of a flow of a magnetic field, which one they carry out, remains invariable, but quantity of vortexes is increased, forming similarly to atoms of a crystal an exact lattice, which leads to increase of diffusion degree of SCFT.

The table

The title of HTSC	B,T	$\Delta T_{\text{СП}}$ K	$T_K(B)$, K	$T_0(B)$, K	a_B,K^1	*dL/dT* At $\Delta T=0$	$2\Delta T^*(B)$ K	$\frac{2\Delta T^*}{T_0}$
$YBa_2Cu_3O_{7-\delta}$ (123) [10]	0	1.1	91.4	91.8	6	1.5	0.6	0.0065
	1	3.5	88	89.3	1.25	0.31	2.8	0.03
	2	6	85.8	87.75	1.1	0.28	3.2	0.036
	5	11	80	83.75	0.75	0.19	4.7	0.05
$YBa_2Cu_{2.87}Fe_{0.13}O_{7-\delta}$ B|| (ab),B⊥J J⊥ (ab) [11]	0	1.5	79	79.85	5	1.25	0.7	0.0088
	1	2.7	77.3	78.6	2.9	0.72	1.2	0.0153
	3	4	75.5	77.5	1.94	0.49	1.8	0.023
	5	4.5	74.5	76.75	1.36	0.34	2.6	0.034
$YBa_2Cu_{2.87}Fe_{0.13}O_{7-\delta}$ B⊥ (ab), B⊥J , J ||(ab) [11]	0	7	78	79.5	1.2	0.30	2.9	0.0365
	1	17	68	73.4	0.64	0.16	5.5	0.075
	2	20	62	69.6	0.43	0.11	8.2	0.118
	4	27.3	52.7	63.9	0.25	0.08	14	0.22
$Ag(Bi_{1.72}Pb_{0.34}Sr_{1.83}$ $Ca_{1.97}Cu_{3.13}O_{10+\delta})$ (2223) [12]	0	10	107	109.5	0.4	0.1	8.8	0.08
	0.5	28	85	107	0.18	0.045	19.6	0.23
	2	38	72	106	0.12	0.03	29	0.27
	12	62	45	90	0.05	0.012	70	0.78
$Bi_2Sr_2CaCu_2O_{10+\delta}$ (2212)	0	12.5	80	86.5	0.3	0.075	11.7	0.13
	0.5	27	65	83.5	0.24	0.06	14.7	0.18
	2	32	60	82.5	0.2	0.05	16	0.19
$La_{1.85}Sr_{0.15}CuO_4$	-	10	40	41.75	0.65	0.16	5.6	0.13
$La_{1.84}Sr_{0.16}CuO_4$	-	5.4	40	41.25	0.8	0.2	4.8	0.12
$La_{1.82}Sr_{0.18}CuO_4$	-	4.6	36.75	37.30	0.43	0.11	7.6	0.2
Sn [14]	10μA	0.0038	3.721 2	3.722	2.088	522	0.00266	0.0007
	20μA	0.0045	3.72	3.721	1.75	436	0.00315	0.00085
	40μA	0.006	3.718	3.719	1.382	345	0.0042	0.001

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YTİK-DƏ FAZA KEÇİDLƏRİNİN YAYILMASI VƏ ONLARA MAQNİT SAHƏSİNİN TƏSİRİ

Bismut (2212, 2223), ittrium (123), $YBa_2Cu_{2.87}Fe_{0.13}O_{7-\delta}$, və $La_{2-x}Sr_xCuO_4$ kristallarının ifratkeçirici faza keçidi oblastında (İKFK) elektrik xassələrinin nəticələri yayılmış faza keçidi (YFK) nəzəriyyəsi əsasında izah edilmişdir. Maqnit sahəsinin (B) müxtəlif qiymətlərində İK keçidlərin yayılma dərəcələri və oblastlarını xarakterizə edən T_0, a_B, L(T), dL/dT, $2\Delta T^*$ и $2\Delta T^*/T_0$ kimi FK parametrləri təyin edilmişdir. Göstərilmişdir ki, YTİK-də ifratkeçirici FK vaxtından əvvəl azalma oblastını nəzərə almadıqda yayınıq xarakterli olur, sahənin (B) təsiri altında yayınıqlıq dərəcəsi artır və $m_{\text{СПФ}}/m_{\text{НФ}} = \exp[a_B(T-T_0)]$ qanunu ilə baş verir. YTİK-də FK-nin yayınıqlığını təmin edən defektlər və maqnit sahəsində yayınıqlıq dərəcəsini artıran səbəblər göstərilmişdir.

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РАЗМЫТИЕ ФАЗОВЫХ ПЕРЕХОДОВ В ВТСП И ВЛИЯНИЕ НА НИХ МАГНИТНОГО ПОЛЯ

Результаты электрических свойств висмутовых (2212, 2223), иттриевых (123), $YBa_2Cu_{2.87}Fe_{0.13}O_{7-\delta}$, и $La_{2-x}Sr_xCuO_4$ кристаллов в области сверхпроводящего фазового перехода (СПФП) интерпретированы в рамках теории размытых фазовых переходов (РФП). Определены параметры ФП, характеризующие область и степень размытия СП переходов: T_0, a_B, L(T), dL/dT, $2\Delta T^*$ и $2\Delta T^*/T_0$ при различных значениях магнитного поля (B). Показано, что в ВТСП сверхпроводящие ФП, без учета области “преждевременного” уменьшения $\rho(T)$ и $\alpha(T)$, носят размытый характер, СП переходы, происходят по закону $m_{\text{СПФ}}/m_{\text{НФ}} = \exp[a_B(T-T_0)]$ и под действием B сильно возрастает степень размытия. Обоснованы наиболее вероятные дефекты, обуславливающие размытие ФП в ВТСП и причина, приводящая к возрастанию степени размытия в магнитном поле.

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