FİZİKA 2002 CİLD VIII № 4

THE PHASE TRANSITION SPREADING IN BISMUTH HTSC

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Results of electric properties of bismuth crystals (2212) and (2223) are interpreted in a framework of the theory of spreaded phase transitions. Parameters, characterizing the spreading degree of *PT*, are determined. It is shown, that in bismuth *HTSC* phase transitions have strongly spreaded nature and the spreading degree grows to an order under the influence of the magnetic field.

INTRODUCTION

The research of phase transitions is one of the most studied directions in solid-state physics. This is caused by the close relation of *PT* theory with many branches of physics and has always both the scientific and practical interest.

Irrespective of the *PT* nature, they are followed by the jump-shaped changes of electric, segnetoelectric, heat, magnetic and other properties, which are successfully applied for the creation of converters of various types. The information on the rules of investigated effects changes in the *PT* region, on the influence of the external factors on these effects is necessary for the stable work of such converters. The interest to the *PT* research in solid states has grown after the discovery of high-temperature superconductors (*HTSC*).

One of the actual issues of the given directions is to find out the rules of the phase coexistence in the *PT* region. Theoretical aspects of this issue are observed in papers [1,2]. Experimental data can be found in papers [3,6]. In the paper [6] results of electric and heat properties of Ag_2Te in the *PT* region are interpreted in a framework of the theory of spreaded PT [1,2]. The parameters, determining the spreading degree of *PT*, are calculated. It is established, that structural phase transitions in Ag_2Te have the spreaded nature, electric and magnetic fields, impurities, and also the excess of Te or Ag do not essentially influence on the spreading degree. It is shown, that parameters, calculated from heat and electric properties, are in agreement with data, obtained from temperature dependences of roentgen reflections intensities and may be applied to determine the *PT* parameters.

The analysis of temperature dependences of *HTSC* electric properties in the *PT* region indicates on their analogous to the second type of superconductors, have peculiarities, which should be followed by the strong spreading of *PT*. Among such peculiarities the unusual mechanism of the interaction with magnetic, electric fields can be counted too in consequence of which the strong spreading of the transition region *BT (B,E)*, the asymmetry growth relatively to T_0, the fracture appearance on B_{c2} *(T)*. Therefore in the present paper the task is to observe the data of electric properties of bismuth superconductors (Bi (2212) and Bi (2223)) in the transition region in a framework of the *DPT* theory by methods, suggested in [1,2,6], to calculate *PT* parameters, determining the spreading degree and the influence of the magnetic field on it as well as to find superconductive one.

THE THEORY AND METHODS OF THE DETERMINATION OF PHASE TRANSITION PARAMETERS

Theoretical aspects of phases coexistence issues and the DPT parameters determination in solid states are considered in papers [1,2]. With this aim the theory of the spreaded phase transitions in condensed systems, based on the introduction of the switching function *L(T)* was used. It is assumed that if thermodynamic potentials of α and β-phase denote as Φ_α и Φ_β , then the thermodynamic potential *Φ(T)* in the phases coexistence region may be represented in the form:

$$\Phi(T) = \Phi_\alpha(T) - \Delta\Phi(T)\cdot L(T), \qquad (1)$$

where $\Delta\Phi(T) = \Phi_\alpha(T) - \Phi(T)$. In the case when the phase transition occurs in the temperature interval $\Delta T = T_2 - T_1 (T_2 \rangle T_1)$ the switching function should fulfill the conditions:

$$L(T) = \begin{cases} 0 \quad , & T \langle T_1, \\ 0 \langle L \langle 1 \ , & T_1 \langle T \langle T_2, \\ 1 \quad , & T_1 \rangle T_2. \end{cases} \qquad (2)$$

According to the *DPT* theory, the expression obtained for the function *L(T)* looks as:

$$L(T) = \{1+exp[-a(T-T_0)]\}^{-1}, \qquad (3)$$

where T_0 is the temperature, at which masses of both phases are quantitatively equal, *α* is the constant, characterizing the spreading degree of phase transitions and depends on the bulk of possible fluctuations and also the energy and *PT* temperatures. Taking into consideration the fact that the function *L(T)* characterizes the relative part of phase in the region of their coexistence, it may be represented in simple form:

$$L(T) = \frac{m_\beta(T)}{m_\alpha(T) + m_\beta(T)} = \left[1 + \frac{m_\alpha}{m_\beta}(T)\right]^{-1}, \qquad (4)$$

where m_o and m_β are masses of *α* and *β*-phases. Temperatures T_0 may be determined from the temperature dependences $ln\left(\frac{m_\alpha}{m_\beta}\right)$. We obtain from the joint solution of (3) and (4):

$$\alpha = \frac{1}{T_0 - T} ln \frac{m_\alpha}{m_\beta} \qquad (5)$$

If α is some constant, then the factor $ln\frac{m_\alpha}{m_\beta}$ should be the line function of the temperature.

No less informative is the derivative of *L(T)* with respect to the temperature:

$$dL\Big/dT = \frac{a}{2}\cdot\frac{1}{1+ch(a\cdot(T-T_0))} \quad , \qquad (6)$$

expressing the temperature velocity of phase transformations of each phase.

The possibility of *L(T)* determination on the base of the structural research of phase transitions of solid states was shown in the paper [5,6]. It was supposed by this, that in the indicated regions of the phases coexistence the temperature changes of roentgen reflections intensities were caused by the quantitative changes of phases. In paper 6 assuming, that in the PT region temperature changes of the differential thermal analysis (DTA) and electric properties are also caused by mainly quantitative changes of α-β phases of Ag_2Te and α, T_0, *L(T)*, *dL/dT* and other thermodynamic parameters are determined. It was necessary to achieve the line change of the temperature near and in the *PT* region. Then from the beginning of the transition to the end the interval $\Delta \boldsymbol{T}$ may be divided on equal periods and corresponding values of the investigated effect relate to the supposed phases, for example:

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

The results comparison of *a*, T_0, *L(T)*, *dL/dT* and other thermodynamic parameters, obtained for Ag_2Te on data of roentgen reflections intensities [3,4] with *DTA* results and electric properties gave almost coinciding values.

EXPERIMENTAL RESULTS AND THEIR DISCUSSION

If by the analogy to Ag_2Te, we take one phase as normal and another one as a superconductive *(SC)*, then the suggested method may be applied for *HTSC* too. Then corresponding messes will have values m_n and m_{cn}. Dependences $\rho(T,B)$ (*a*) and $\alpha(T,B)$ (*в*) for the crystal sample $Bi_2Sr_2CaCu_2O_x$ are represented on fig.1.

The characteristic dependences lny($y=\frac{m_{cn}}{m_n}$) on *T* at *B*=0(1) and *B*=2,2T(2) are represented on fig.2. The corresponding masses m_n and m_{cn} are determined from data $\rho(T,B)$ and $\alpha(T,B)$. Nominal temperatures T_0 are determined by the cross point of straight lines with the abcissa axis. The represented straight lines are described by the formula:

$$y=exp[-a(T-T_0)], \qquad (8)$$

where the values of α, determined from the straight lines slope $\left(\frac{ln\,y}{\Delta T}\right)$, are temperature constant of the transition. As it is seen, points of the «untime» reduction of $\rho(T)$ and $\alpha(T)$ part are declined from straight lines in the indicated coordinates. It indicates on the correctness of the applied method of m_{cn}/m_n determination for the main PT part. It is seen, T_0 and α reduce under the influence of the magnetic field. In spite of the strong stretching of the low-temperature part of curves $\rho(B,T)$ and $\alpha(B,T)$ in the magnetic field, they fully placed on the straight lines. Curves of the switching function *L(T)* (at *B*=0 and *B*=2,2T), calculated by formulae 4(a) and 3(b) with the data application α and T_0, are represented on fig.3.

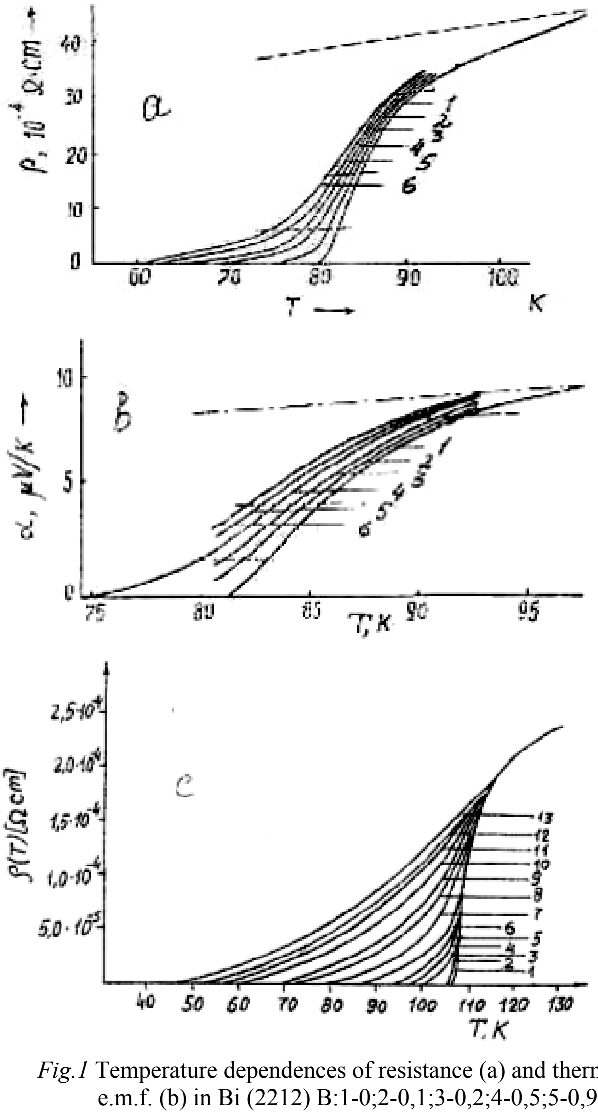

Fig.1 Temperature dependences of resistance (a) and thermo e.m.f. (b) in Bi (2212) B:1-0;2-0,1;3-0,2;4-0,5;5-0,9:6-2,2T и Bi (2223)(c) данные [7] B:1-0;2-0,01;3-0,05;4-0,1;5-0,2;6-0,5;7-1;8-2;9-3;10-5;11-7;12-9;13-12T

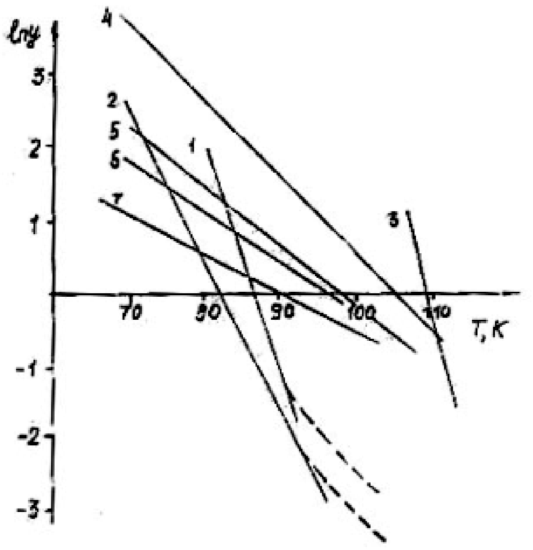

Fig.2 Temperature dependences of the masses distribution lny at various values of the magnetic field for Bi (2212) (1-at B=0;2-at B=2,2T) and Bi (2223) (3-B=0;4-2T;5-5T;6-7T;7-12T).

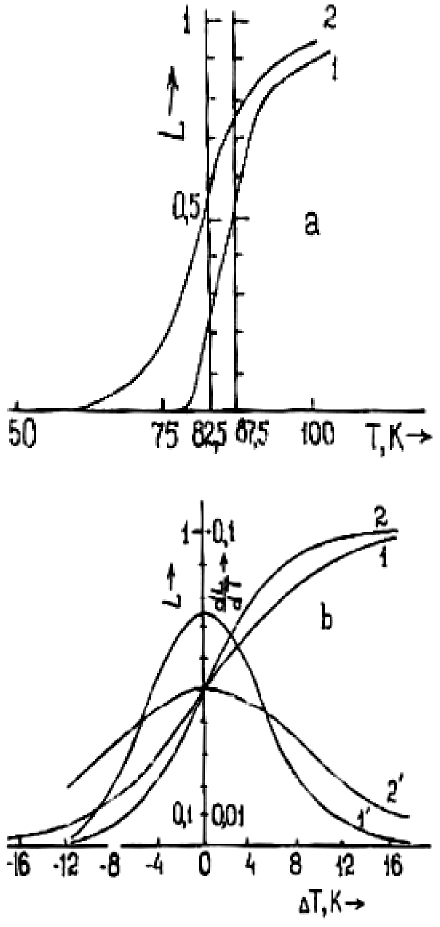

Fig.3 Temperature dependences of the switching function, calculated by formulae (4) (a) and (3) (b) and its derivative *dL/dT* for Bi (2212)

As it is seen, temperature dependences *L(T)* in separate parts differ quantitatively. It is connected with values change T_0 and *α* in the magnetic field, it leads to the *L(T)* bias on the temperature. Therefore the *L(T)* analysis is convenient to carry out on the formula (3) data. It is seen, that curves *l(T)* approach the zero value at $T \approx T_k$, they cross the axis at *L*=0,5 curves are spreaded by the growth of the magnetic field.

The derivatives L on the temperature *dL/dT* (1′,2′) are represented on fig. 3(b). As it is seen, curves *dL/dT (ΔT)* pass through the maximum at Δ*T*, and moreover the maximal value corresponds to $dL/dT=\frac{a}{4}$. As far as *B* grows, the curve *dL/dT* becomes more sloping and the values when $\Delta T= 0$ reduce proportionally to *a*.

Let us note, that weak magnetic fields, at which research for Bi (2212) was carried out, make it difficult to conclude about PT parameters dependence on the magnetic field with this aim, the data of authors of paper [7], in which the detailed research of *ρ(T,B)* in crystals $Bi_{1.72}Pb_{0.34}Sr_{1.83}Ca_{1.97}Cu_{3.13}O_{10+\delta}$ in magnetic fields to 12 T (fig (1c)) is carried out, are used, These data are useful not only because of high values of B, but as the another phase Bi (2223) of bismuth HTSC, having high values T_k. Straight lines *lny(T)* are represented on fig (2-7). In the case of Bi (2223) high-temperature parts points of curves fell out the straight lines. It is seen, that values α and T_0 reduce strongly by the *B* growth. Data of *α(B)* are represented on fig.4, from which it is seen, that the strong reduction of α occurs at relatively weak fields (0-1 T). Data of *L(ΔT)* (1-5) at various values B are presented on fig.5. It is seen clearly from data, that L approaches the zero value at $\approx T_k$ and curves *L(T)* are spreaded by the B growth analogous results are obtained from temperature dependences of derivatives on the temperature *dL/dT* (fig.5) (1′-5′). As it is seen, the curve *dL/dT* at *B=0* has more sharp peak and it losses the velocity as far as it removes from Δ*T=0*, the asymmetry is observed at high sloping form, cross the curve $(dL/dT)_{B=0}$ and decrease slower. By this the low-temperature part of curves falls behind from it more, than high temperature.

It follows from data a *(B)* and *L(T/B)*, the spreading degree is inversely proportional to the temperature constant *ρT-a*. The obtained value a for Bi (2212) and Bi (2223) tells about the strong spreading of PT in them, moreover the spreading degree in Bi (2212) is higher, than in Bi (2223). Estimations show, that the spreading degree is higher in phase Bi (2001), than in these two phases. The spreading degree of PT strongly increases in the magnetic field, especially at relatively weak values *B*. The temperature velocity of PT grows as far as the spreading degree reduces, what leads to more sharp realization of PT.

The points derivation of the premature reduction part *ρ(T)* and *α(T)* from the straight line *(T,B)* tells in favor of the fact, that, actually, the mechanism of SC couples formation and their uncoupling under the influence of the magnetic field in the main transition part and high-temperature part distinguish essentially.

The physical nature of defects, leading to the PT spreading in the absence of magnetic field, may serve heterogeneity, connected with the presence of other bismuth *SC* phase (2201, 2212 and 2223) in each *SC* phase, the derivation from the stechiometry of multicomponent ingredients, the slightest oxygen lack and other imperfections [8,9]

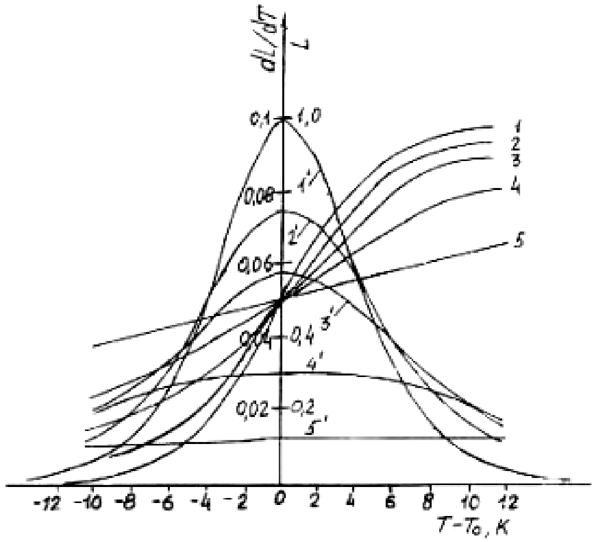

Fig.4. Temperature dependences L(1-5) and dL/dT (1′-5′) for Bi (2223) B: 1,1′-0; 2,2′-0,1; 3,3′-0,2; 4,4′-2; 5,5′-12T.

Defects, leading to the spreading in the magnetic field are caused by the vortical state of super conductors of the second type, in which the vortical currents occurs spontaneously beginning from very weak fields $B_{C_1}\,(B_{C_1}\langle\langle B_{C_2})$.

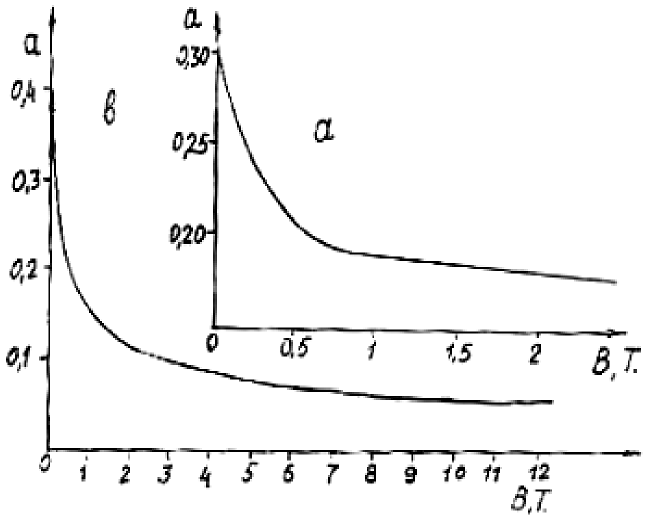

Fig.5 The dependence of the temperature constant of PT *a* on the magnetic field: *a* -Bi (2212), b-Bi (2232)

At the further *B* growth the vortex size and the value of the magnetic field flow, which they conduct, remain stable, the vortex number grows, forming alike crystals atoms the right lattice *L* in the cross-section of the trigonal shape, which causes the growth of the spreading degree in them.

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YTİK BİSMUTDA FAZA KEÇİDİNİN YAYILMASI

Bismut (2212) və (2223) kristallarının elektrik xassələri yayılmış faza keçidləri nəzəriyyəsi çərçivəsində izah edilmişdir. Faza keçidlərinin yayılma dərəcəsini xarakterizə edən parametrlər müəyyən edilmişdir. Göstərilmişdir ki, yüksək temperaturlu ifratkeçirici (YTİK) vismutda faza keçidləri güclü yayılma xarakterinə malikdir və maqnit sahəsinin tə'siri ilə yayılma dərəcəsi bir tərtib artır.

С.А. Алиев

РАЗМЫТИЕ ФАЗОВОГО ПЕРЕХОДА В ВИСМУТОВЫХ ВТСП

Результаты исследования электрических свойств висмутовых кристаллов (2212) и (2223) интерпретированы в рамках теории размытых ФП. Определены параметры, характеризующие степень размытия ФП. Показано, что в висмутовых ВТСП фазовые переходы носят сильно размытый характер и под действием магнитного поля степень размытости возрастает до одного порядка.

Received: 25.07.02