

MAGNETOELASTIC DOMAIN STRUCTURE AND PHYSICAL PROPERTIES OF THE UNDERDOPED HIGH-TEMPERATURE SUPERCONDUCTORS

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A theoretical model is proposed which describes the newly discovered physical properties: the shape-memory effect and anisotropy of magnetoresistance in under-doped copper oxides. The key issue of the model is a magnetoelastic mechanism which governs the formation of a domain structure in antiferromagnets and also is responsible for the shape-memory effect in the paramagnetic state. The long-range "stray" field resulting from the difference between the bulk and surface elastic properties ensures a reversible change of the domain structure from the polydomain to single-domain state in an external magnetic field. In a paramagnetic state, the strong magnetoelastic coupling is a cause of anisotropy of the g -factor at a copper site and thus mediates between the external magnetic field and the domain structure of the sample. The obtained theoretical relations are in quantitative agreement with the available experimental data.

the paramagnetic phase under the action of an external magnetic field.

1. Domain Structure of Underdoped HTSC

It is well established [3] that underdoped copper oxides show the structural phase transition from the tetragonal D_{4h}^{17} to orthorhombic D_{2h}^{18} phase induced by cooperative tilt of CuO_6 octahedra. The low-symmetry phase is represented by two types of equivalent domains with different rotation vectors $\Omega_{1,2} = (\Omega_0/\sqrt{2}, \mp\Omega_0/\sqrt{2}, 0)$ which are usually considered as a double degenerated structural (in fact, rotational) order parameter with the corresponding wave vectors $\mathbf{Q}_{1,2} = (1/2, \pm 1/2, 0)$ [4, 5]. This structural phase transition is usually classified as an improper ferroelastic one, that means that the corresponding spontaneous strain is proportional to the square of the order parameter as follows from the Landau theory [6]:

$$u_{XX} - u_{YY} = \lambda_{\text{st-rot}} \frac{\Omega_1^2 - \Omega_2^2}{2c'}, \quad (1)$$

where $\lambda_{\text{st-rot}}$ is the coupling constant between the strain and order parameter and c' is the in-plane shear modulus of the tetragonal phase. The axes X and Y make a 45° angle with the directions of Cu-O bonds.

Two possible configurations of the orthorhombic phase have different vectors $\Omega_{1,2}$ directed either along the X (X -domain) or Y (Y -domain) axis and different shear strains:

$$u_{XX} - u_{YY} = \begin{cases} u_0, & X\text{-domain} \\ -u_0, & Y\text{-domain,} \end{cases} \quad (2)$$

where $u_0 \equiv \lambda_{\text{st-rot}} \Omega_0^2 / (2c')$.

Application of an external magnetic field in the XY plane removes the degeneracy between the otherwise equivalent domains due to anisotropy of the

Introduction

Layered high-temperature superconductors (HTSC) based on copper oxide (LSCO, YBCO, etc.) have been widely and thoroughly studied during the last decade. Nevertheless, they still attract an interest of the researchers because of unusual magnetic properties observed in underdoped compounds. In particular, in the antiferromagnetic (AFM) state, these crystals show a domain structure which can be changed in a reversible manner in an external magnetic field. Recently, an unexpected shape-memory behaviour in an external magnetic field was experimentally observed in the paramagnetic state of an LSCO crystal [1, 2] which, beside being intriguing from the fundamental point of view, is also promising for technological applications.

The present paper is aimed at the theoretical description of the mechanisms that govern the processes of formation and restructurization of the domain structure of underdoped layered superconductors and interpretation of the observed shape-memory effect in

susceptibility tensor $\hat{\chi}$. Thus, the energy difference between X and Y domains may be expressed as

$$\Delta F = F^X - F^Y = \frac{1}{2}(\chi_{XX} - \chi_{YY})(H_Y^2 - H_X^2). \quad (3)$$

In the AFM state, the longitudinal χ_{XX} , and transverse, χ_{YY} , components are different due to the presence of the long-range spin alignment oriented in the X (Y) direction for the X (Y) domain.

Above the Néel point, T_N , anisotropy of the susceptibility tensor needs some special explanation. In the case of a short-range ordering reported in [7], local spin ordering still favours a transverse orientation of the magnetic field. If, contrary, short-range ordering is also suppressed, then anisotropy may originate from a variation of the local magnetocrystalline field for Cu^{2+} spins induced by rotation of CuO_6 octahedra. Due to a relatively large value of the spin-orbit coupling which phenomenologically may be described by a dimensionless constant $\lambda_{\text{sp-or}}$, the rearrangement of oxygen ions around a Cu^{2+} ion induces a noticeable splitting of the in-plane g -factor components compared with the tetragonal phase value $g_{XX}^{\text{tetra}} = g_{YY}^{\text{tetra}} \equiv g_{\perp}$. Thus, nontrivial components of the g -factor in the orthorhombic phase may be expressed as

$$g_{XX}^{\text{ortho}} = g_{\perp} + \lambda_{\text{sp-or}}(\Omega_1^2 - \Omega_2^2),$$

$$g_{YY}^{\text{ortho}} = g_{\perp} - \lambda_{\text{sp-or}}(\Omega_1^2 - \Omega_2^2). \quad (4)$$

The corresponding anisotropy of susceptibility calculated in the framework of the standard Langevin approach is

$$\Delta\chi \equiv \chi_{XX} - \chi_{YY} = 2N \frac{g_{\perp}^2 \mu_B^2 s^2}{k_B T} \frac{\lambda_{\text{sp-or}}}{g_{\perp}} \Omega_0^2, \quad (5)$$

where N is the number of spins per unit volume, s is a spin value, μ_B is the Bohr magneton, k_B is the Boltzmann constant.

Experiments [7] show that both types of domains are equally represented in an originally non-stressed sample, and a small (up to 30 MPa) external stress removes one type of domains. So, two main questions which we address in the following sections are “What is the reason of the formation of the inhomogeneous state?” and “Is the inhomogeneous polydomain state either thermodynamically equilibrium or it can be irreversibly changed by an external field?”

¹ We treat the surface as a very thin, two-dimensional layer which is inseparable from the bulk, inherits its properties, and defines the shape of the sample.

2. Origin of the Domain Structure

The traditional approach to the description of the equilibrium domain structure which has elastic origin is based on the idea of compatibility of average strains in different regions of a sample (see, e.g., [8]). Applicability of this method raises no doubts in the case of initially inhomogeneous media (e.g., multilayers with alteration of elastically active and passive layers) or in the vicinity of the 1st order phase transition where the sample is inhomogeneous due to coexistence of two different phases.

Another situation is observed in single crystals of HTSC where the ferroelastic phase transition is of the 2nd order and a sample contains only one phase (in neglect of small fluctuations in the close vicinity of the transition temperature). Origin of the domain structure in this case can be interpreted on the same basis as in antiferromagnets, as was proposed in our previous papers [9–11]. The corresponding phenomenological model of the domain structure in ferroelastics rests on i) the concept of quasiplastic stresses which produce spontaneous strains in the course of the ferroelastic phase transition [12]; ii) the concept of “elastic charges” (or quasidislocations) developed by Eshelby [13] and then applied by Kléman and Shlenker to the description of the domain walls in ferromagnets [14]; and iii) the assumption that the surface of a sample can be treated as a separate phase coherently conjugated with the bulk, with its own elastic, magnetic, and other properties. The last assumption is grounded on the well-known dimensional peculiarities [15] and experimentally observed difference in the characteristic temperatures of phase transitions [16–18] and magnetoelastic properties [19] of the ideal surface and the bulk¹.

It follows from the first concept that the spontaneous strain in the infinite sample which accompanies a structural phase transition can be calculated from the effective quasiplastic stresses $\hat{\sigma}_{\text{quasi}}$ that originate from the coupling between the primary order parameter and elastic subsystem. In a sample bounded with the surface S , one should distinguish between quasiplastic stresses, $\hat{\sigma}_{\text{quasi}}^S$, at the surface, and $\hat{\sigma}_{\text{quasi}}^V$, in the bulk, as follows from assumption iii). In this case, the equilibrium strain field which arises below the transition point may be found from the minimization of a free energy functional F represented as the sum of the surface, F_{surf} , and bulk,

F_{bulk} , contributions:

$$F = \int F_{\text{surf}} dS + \int F_{\text{bulk}} dV \quad (6)$$

with an additional condition of compatibility between the surface \hat{u}^S and bulk \hat{u}^V strains. In the approximation of linear elasticity, free energy (6) may be expressed through the tensor $\hat{c}^{S,V}$ of elastic moduli at the surface and in the bulk, correspondingly, and the surface tension tensor $\hat{\beta}^S$:

$$\begin{aligned} F_{\text{surf}} &= \hat{\beta}^S \hat{u}^S + \frac{1}{2} \hat{u}^S \hat{c}^S \hat{u}^S - \hat{\sigma}_{\text{quasi}}^S \hat{u}^S, \\ F_{\text{bulk}} &= \frac{1}{2} \hat{u}^V \hat{c}^V \hat{u}^V - \hat{\sigma}_{\text{quasi}}^V \hat{u}^V. \end{aligned} \quad (7)$$

A peculiar feature of expressions (7) different from the case of an externally stressed crystal is that internal stresses induced by a phase transition are inhomogeneous, i.e., $\hat{\sigma}_{\text{quasi}}^S \neq \hat{\sigma}_{\text{quasi}}^V$ and, as a result, produce an inhomogeneous deformation inside the sample².

If we suppose that the state with inhomogeneously distributed deformation is formed by the agglomerates of coherently conjugated domains of the same phase, the compatibility conditions which reflect a continuity of the crystal take a nontrivial form only at the surface of the sample:

$$e_{ip}^{(\text{inc})}(\mathbf{r}) \equiv -\varepsilon_{ikl} \varepsilon_{pmt} n_k^S [u_{it}^V - u_{it}^S] n_m^S \delta'[\mathbf{n}^S(\mathbf{r} - \mathbf{r}_S)] = 0, \quad (8)$$

where ε_{ikl} is the antisymmetric tensor Levi–Chivita, \mathbf{n}^S is the normal to the surface at a point \mathbf{r}_S , $\delta'(\mathbf{r})$ is a space derivative of the Dirac's delta-function.

The distribution of strains below the phase transition point can be defined by variation of the free energy potential (6) with account of compatibility conditions (8). This quite complicated problem may be essentially simplified using the idea of effective “elastic charges” (quasidislocations) analogous to demagnetization charges which arise at the surface of a ferromagnet and cause the formation of a domain structure. Instead of calculating the true compatible but inhomogeneous strain field all over the crystal, we start from some virtual configuration which minimizes the free energy F_{surf} at the surface and F_{bulk} in the bulk in neglect of compatibility conditions (8). Incompatibility charges $\hat{e}^{(\text{inc})}$ calculated for such a configuration are then treated as the source of a long-range stress field which can be relaxed by a proper choice of the domain fractions. The energy contribution

related with macroscopic stresses is analogous to the stray energy in FM. For a sample in the form of a thin plate with a surface normal \mathbf{n}^S , the general expression for a stray energy is analogous to that derived in [9–11]:

$$F_{\text{stray}} = \frac{1}{2} V \langle \hat{\mathbf{U}} \rangle \hat{c} \langle \hat{\mathbf{U}} \rangle, \quad (9)$$

$$\begin{aligned} \langle \hat{\mathbf{U}} \rangle &\equiv (\langle \hat{u}^V \rangle - \hat{u}^S) + \mathbf{n}^S \otimes \mathbf{n}^S \text{Tr}(\langle \hat{u}^V \rangle - \hat{u}^S) - \\ &- \mathbf{n}^S \otimes [(\langle \hat{u}^V \rangle - \hat{u}^S) \mathbf{n}^S] - [(\langle \hat{u}^V \rangle - \hat{u}^S) \mathbf{n}^S] \otimes \mathbf{n}^S, \end{aligned}$$

where brackets mean averaging over the sample volume V .

In the case of an LSCO crystal cut in the form of a thin Z -oriented plate, stray energy (9) is expressed through the volume fraction $\xi_X \equiv \xi$ of X and $\xi_Y \equiv (1 - \xi)$ of Y domains as:

$$F_{\text{stray}} = \frac{1}{2} c' [(2\xi - 1)u_0 - u^S]^2, \quad (10)$$

where the spontaneous strain u_0 is given by (2) and the surface strain u^S is represented by a shear component in [110] direction ($u^S = u_{XX}^S - u_{YY}^S$).

If the surface of the sample is quite inert in the vicinity of the Néel point, i.e., $u^S = 0$, then the stray energy (10) takes its minimum value for the equiprobable distribution of the domains, $\xi_X = \xi_Y = 1/2$.

3. Domain Structure in an External Magnetic Field

As was already mentioned, in the external magnetic field, X and Y domains have different free energy. This difference given by expression (3) can be treated as an additional pressure which forces domain walls to move in the direction of unfavorable domains. Equilibrium fractions ξ of X and $(1 - \xi)$ of Y domains are defined by the competition between the detwinning effect of the external field and tendency to diminish internal stresses produced by a surface/bulk incompatibility. Formally, ξ may be found from the minimum condition of the free energy potential

$$\begin{aligned} \Phi &= \xi \Delta F + F_{\text{stray}} = \frac{1}{2} [\xi \Delta \chi (H_X^2 - H_Y^2) + \\ &+ c' [(2\xi - 1)u_0 - u^S(\mathbf{H})]^2]. \end{aligned} \quad (11)$$

²In the mechanically loaded crystal, stress is applied at the surface of the sample.

In neglectation of relaxation processes (i.e., for a high field-swapping rate), this gives

$$\xi = \frac{1}{2} + \frac{u^S(\mathbf{H})}{2u_0} + \frac{\Delta\chi}{c'u_0^2}(H_X^2 - H_Y^2). \quad (12)$$

Critical field, H_{MD} , at which the parameter ξ attains its limiting value (i.e., 0 or 1), can be treated as a field of monodomianization, implicitly given by the equation

$$H_{\text{MD}}^2 = \frac{c'u_0}{2\Delta\chi}[u_0 - u^S(H_{\text{MD}})].$$

It can be clearly seen from (12) that: i) domain structure can be changed in a reversible manner by application of an external magnetic field; ii) equilibrium fraction of X domain and the field of monodomianization depend not only upon the anisotropy of magnetic susceptibility (the last term in (12)), but also from the response of the surface to \mathbf{H} (the second term in (12)). In the vicinity of the critical (Néel) point, where the surface is non-ordered and hence inert with respect to magnetic field, the main contribution into ξ obviously arises from the last term in (12). On the other hand, the role of the second term may become crucial well below the transition temperature or after a special thermal treatment (see below) when, due to the surface relaxation, the difference between spontaneous strains in the bulk and at the surface is rather small. In particular, this mechanism can explain the discrepancy between the monodomianization field $H_{\text{MD}}=14$ T measured for LSCO crystals [1] and the theoretical value $H_{\text{MD}} \approx 1000$ T calculated from (11) in neglectation of the surface strain u_S (with $u_0 = 1\%$ [3], $c'=100$ GPa, [6] and $\Delta\chi = 10^{-6}$ emu, [7]). If we assume that, under experimental conditions, the surface strain is rather close to the bulk value $|u_0 - u^S(H_{\text{MD}})| \approx 3 \cdot 10^{-4} \ll u_0$, then the corrected value of the monodomianization field attains the experimentally observed value.

At a long observation time or a low field swapping rate, the domain structure which arises during the phase transition or after the application of the external field may be then fixed by dopants (e.g., Sr or Ba in LSCO) which diffuse to the more preferable sites. In the underdoped LSCO crystal, Sr^{2+} ions reduce a compressive stress produced by La atoms in CuO_2 layers [3] and thus must have preferable position along the direction of the shorter of two Cu—O bonds (i.e., along the a -axis). This tendency may be described phenomenologically in the frame of the Krivoglaz—Smirnov theory [20]. Let $\Delta c \equiv c_X - c_Y$ be a relative excess of Sr^{2+} ions along the X direction compared to the Y direction averaged over a small but macroscopic

region. Effective tension in the X direction produced by Sr^{2+} is then can be modeled as $\sigma_{XX} - \sigma_{YY} = \eta\Delta c$, where β is a phenomenological constant (details of the phenomenologic theory of ordering magnetic alloys can be found in [21]). The corresponding contribution to the Gibbs potential,

$$\Delta\Phi = \int \left[\frac{1}{2}p\Delta c_V^2 - \eta_V\Delta c_V(u_{XX} - u_{YY}) \right] dV, \quad (13)$$

creates an additional energy difference between X and Y domains and is also the source of a generalized thermodynamic force which induces a relaxation of the domain structure. The constant p in (13) models the self-energy of a given dopant configuration.

Structural order parameter, Δc , should be a rather “slow” variable, that is, its variation is due to thermally activated atomic jumps and takes place on the time scale characteristic of diffusion. Interface motion and the related variation of the domain fraction ξ are, in the present context, “rapid” processes — they are caused by the cooperative small shifts of atoms and thus their time scale is evidently defined by sound velocity. So, a relatively rapid variation of the strain-induced domain pattern (under the action of an external field or in the course of the tetra-to-ortho phase transition) should be followed by a slow thermoactivated migration of Sr^{2+} ions towards the direction of “shorter bond” in each domain. Thus, the state of a crystal in an external magnetic field should depend upon the crystal pre-history and field-swapping rate and may show irreversible features. This is, in our opinion, the essence of the shape-memory effect observed in LSCO crystals [1].

4. Shape-Memory Effect

Experimentally observed behavior of the domain structure in LSCO crystals in an external magnetic field has three peculiar features: i) when the magnetic field was rotated in the XY plane, the value ξ which is proportional to the anisotropy $\Delta\rho/\rho$ of magnetoresistance (AMR) [22] is periodically changed; ii) field dependence of AMR (and ξ) shows a certain irreversibility which appears as small (10 – 15°) hysteresis; iii) once treated for a long time in a strong magnetic field, the sample may keep its shape after the field is removed. All three effects may be described from minimization of the free energy potential (11) and (13), supplemented with the kinetic equation

for Sr^{2+} ions taken according to general principles of thermodynamics (see, e.g., [23]) as

$$\Delta c = -\Gamma \frac{\partial \Delta G}{\partial \Delta c} = -p\Gamma \Delta c + \Gamma\beta(2\xi - 1)u_0, \quad (14)$$

where Γ is the relaxation constant.

If the external field is rotated in the XY plane with a frequency ω , then the calculated domain fraction is

$$\xi = \frac{1}{2}[1 + \cos(2\omega t - \phi) - e^{-t/\tau} \cos \phi], \quad (15)$$

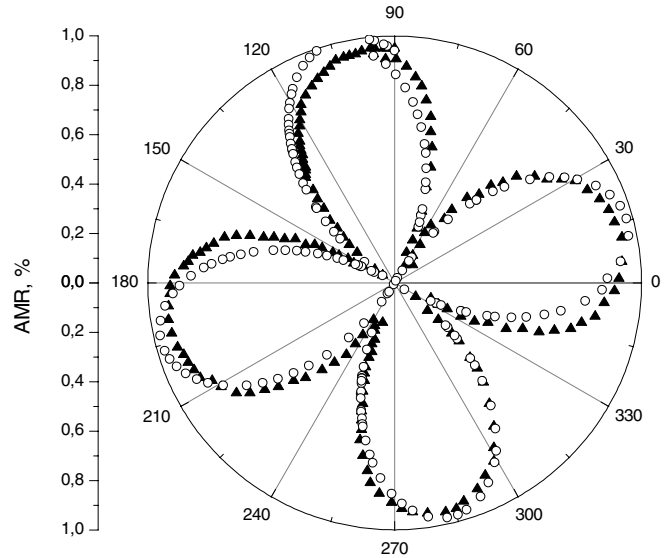
where $\phi = \arctg 2\tau\omega$ is a phase shift between the field and ξ , $\tau \approx 1/\Gamma p$ is the characteristic relaxation time. Figure represents the angular dependence of the AMR *vs* orientation of the external magnetic field calculated according to (15) (solid curve) and reproduced from the experimental data given in [1] (points). The absolute value of the magnetic field is equal to $H_{\text{MD}}=14$ T, field frequency $\omega=8.73 \cdot 10^{-4}$ s $^{-1}$, and relaxation time $\tau=300$ s.

Expression (15) clearly shows that all three types of the domain structure behaviour are possible depending on the ratio between the frequency of field swapping ω and the relaxation time τ :

- If $\omega\tau \gg 1$, that is, the field variation is rather fast compared with the migration of dopants, the domain structure (described with the parameter ξ) follows immediately and in a reversible manner after the field changes.
- If $\omega\tau \approx 1$, the dopants have time to follow the field. In this case, the behaviour of the domain structure is partially reversible, there is a pronounced hysteresis and a noticeable difference between the initial magnetization curve and the rest of the data (see Figure).
- If $\omega\tau \ll 1$, the shape memory behaviour should be observed. These conditions mean, in fact, the ageing of a sample in a stable field until relaxation toward the full thermodynamic equilibrium. Relaxation of the surface strain u^S induced by the segregation of Sr^{2+} reduces incompatibility (8) between the bulk and the surface and diminishes the restoring force conditioned with incompatibility. Thus, behaviour of the domain structure is almost irreversible.

Conclusions

In summary, we have developed a phenomenological model which adequately describes the peculiarities of



Field dependence of magnetoresistance anisotropy for LSCO crystals calculated from (15) (hollow circles). Full triangles reproduce the experimental data taken from [1]. Absolute field value corresponds to a monodomianization field of 14 T, the field direction is rotated counterclockwise in the XY plane

the domain structure behaviour in underdoped copper oxides under the action of the external magnetic field. The domain structure originates from the divergence of the elastic properties at the surface of the sample and in the bulk. Incompatibility between the bulk spontaneous strains produced in the course of the structural phase transition and those at the more inert surface is a source of the long-range stress field which can be reduced by the formation of the domain structure.

Due to the strong magnetoelastic coupling, the external magnetic field may remove the degeneracy between the domains with different strains and thus diminish the fraction of less preferable domains. The domain structure is governed in this case by the competition between the detwinning effect of the surface and the effective pressure produced by the magnetic field. For the high field swapping rate, a variation of the domain structure in the external field is almost reversible.

The Sr^{2+} dopants tend to occupy the sites in the direction of shorter Cu—O bonds and thus map the distribution of the domains on a long time scale. This effect may be the main reason of the observed shape-memory effect. Characteristic relaxation time calculated for LSCO is of the order of 5 minutes at room temperature. Migration of dopants in the course of the domain redistribution reveals itself in the hysteresis phenomenon observed experimentally.

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1. Lavrov A.N., Komiya S., Ando Y.//Nature **418** (2002) 385.
2. Lavrov A.N., Komiya S., Ando Y.//cond-mat/0208013 3 p. (2002).
3. Kastner M.A., Birgeneau R.J., Shirane G., Endoh Y.//Rev. Mod. Phys. **70** (1998) 897–928.
4. Bar'yakhtar V.G., Loktev V.M., Yablonskii D.A.//Physica C. **156** (1988) 667.
5. Böni P., Axe D., Shirane G., et al.//Phys. Rev. B. **38** (1988) 185.
6. Nohara M., Suzuki T., Maeno Y. et al.//Ibid. **52** (1995) 570.
7. Lavrov A.N., Ando Y., Komiya S., Tsukada I.//Phys. Rev. Lett. **87** (2001) 017007.
8. Roytburd A.L., Slutsker J.//Mat. Sci. and Eng. A. **238** (1997) 23.
9. Gomonay E., Loktev V.M.//J. Physics: Cond. Matter. **14** (2002) 3959.
10. Gomonay E., Loktev V.M.//JMMM. **242—245** (2002) 1418.
11. Gomonay E., Loktev V.M.//Low Tem. Phys. **28** (2002) 860.
12. Olson G.B., Cohen M. Dislocation Theory of Martensitic Transformations. — NH Amsterdam, ADDRESS, 1986. — Vol. 7. — P.297—403.
13. Eshelby J.D.//Proc. Roy. Soc. A. **241** (1957) 376.
14. Kléman M., Schlenker M.//J. Appl. Phys. **43** (1972) 3184.
15. Dyson F.J., Montroll E.W., Kac M., Fisher M. Theory of Singularity in a Critical Point. — Moscow: Mir, 1973.
16. Watson G.M., Gibbs D., Lander G.H. et al.//Phys. Rev. Lett. **77** (1996) 751.
17. Watson G.M., Gibbs D., Lander G.H. et al.//Phys. Rev. B. **61** (2000) 8966.
18. Wolfram T., de Wames R.E., Hall W.F., Palmberg P.W.//Surf. Sci. **28** (1971) 45.
19. Gutjahr-Löser T., Sander D., Kirschner J.//JMMM. **220** (2000) L1.
20. Krivoglaz M.A., Smirnov A. The Theory of Order-disorder in Alloys. — London: Macdonald, 1964.
21. Gomonay E.V., Klugmann E.//J. Appl. Phys. **77** (1995) 2160.
22. Gomonay E., Loktev V.M.//Phys. Rev. B. **64** (2001) 064406(6).
23. Dyrmati. Nonequilibrium thermodynamics. — Moscow: Mir, 1974.

ДОМЕННА СТРУКТУРА МАГНІТОПРУЖНОЇ ПРИРОДИ ТА ФІЗИЧНІ ВЛАСТИВОСТІ ВИСОКОТЕМПЕРАТУРНИХ НАДПРОВІДНИКІВ З НЕВЕЛИКОЮ КІЛЬКІСТЮ ДОМШКИ

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Резюме

Запропоновано теоретичну модель, що адекватно описує ефекти пам'яті форми та анізотропію магнетоопору в слаблегованих купратах, які нещодавно спостерігалися. В основі моделі лежить припущення про магнітопружний механізм утворення доменної структури в антиферомагнетиках. Ми припускаємо, що той самий механізм визначає і ефект пам'яті форми в парамагнітній фазі. Оборотно зміна доменної структури з поліу однодомений стан під впливом зовнішнього магнітного поля зумовлена наявністю далекодіючого поля “роздвійникування”, що виникає завдяки відмінностям фізичних властивостей зразка та його межі (поверхні). У парамагнітному стані сильна магнітопружна взаємодія зумовлює анізотропію g -фактора на іонах міді і у такий спосіб забезпечує зв'язок між зовнішнім магнітним полем та доменною структурою зразка, яка наведена структурним перетворенням. Отримані теоретичні залежності кількісно узгоджуються із наявними експериментальними даними.

ДОМЕННАЯ СТРУКТУРА МАГНИТОУПРУГОЙ ПРИРОДЫ И ФИЗИЧЕСКИЕ СВОЙСТВА ВИСОКОТЕМПЕРАТУРНЫХ СВЕРХПРОВІДНИКОВ С МАЛЫМ КОЛИЧЕСТВОМ ПРИМЕСИ

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Резюме

Предложена теоретическая модель, адекватно описывающая недавно обнаруженные в слаблегованных купратах эффект памяти формы и анизотропию магнетосопротивления. В основе модели лежит допущение о магнитоупругом механизме образования доменной структуры в антиферромагнетиках. Предполагается, что тот же механизм определяет эффект памяти формы и в парамагнитной фазе. Обратимое изменение доменной структуры из полидоменного в однодоменное состояние под действием внешнего магнитного поля обусловлено наличием дальнедействующего поля “раздвойниковогования”, которое возникает из-за имеющихся различий физических свойств образца и его границы (поверхности). В парамагнитном состоянии сильное магнитоупругое взаимодействие обуславливает анизотропию g -фактора на ионах меди и таким образом обеспечивает связь между внешним магнитным полем и доменной структурой образца, сформированной структурным превращением. Полученные теоретические зависимости находятся в количественном соответствии с имеющимися экспериментальными данными.