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ON LOGARITHMIC CVC OF HIGH-T_c SUPERCONDUCTIVE GLASS MODEL

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Up to date there is a number of experimental papers dealing with the investigation of the current-voltage characteristics(CVC) of the high-T_c oxides. The most interesting of them have a power-law /1/ and a logarithmic one /2/ behaviour. On the other hand ,in the frame of the superconductive glass (SG) model (see e.g./3-7/) a rather successful description of the nonequilibrium (nonergodic) properties of high-T_c superconductors was achieved.Besides, a power-like CVC has been already considered by the SG model in /8/.

In the present note we consider via the SG model a logarithmic-law CVC as well as temperature-field dependencies of a critical supercurrent.

As is well known /4,5/ the Hamiltonian of the SG model in the pseudospin representation has a form

$$\hat{H} = -\mathrm{Re} \sum_{ij} J_{ij} S_i^* S_j , \qquad (1)$$

where

$$J_{ij} = J(T)\exp(iA_{ij}), \quad S_i = \exp(if_i),$$

$$A_{ij} = \pi H(x_i+x_j)(y_i-y_j)/\phi_o, \quad \phi_o = hc/2e. \qquad (2)$$

The model (1) describes the interaction between superconductive clusters (with phases f_i) via Josephson junctions (with an energy J(T)) on a 2-D disordered lattice in a frustrated external magnetic field $H = (0,0,H)$. Following /8/ for the supercurrent density operator (on the square lattice with a side d) we have

$$j_s = 2ie\sum_{i,j} J_{ij}S_i^*S_j r_{ij}/\hbar d^2 \quad , \qquad (3)$$

where $r_{ij} = r_i - r_j$ is the distance between clusters. In our case $r_i = (x_i, y_i, 0)$.

When an electric field E is applied to the system (1) , the coupling energy $J_{ij}(T,H)$ is renormalized in a way : $J_{ij} \to J_{ij}\exp(i\omega_{ij}t)$, where $\omega_{ij} = 2eEr_{ij}/\hbar$.

According to the linear response theory the thermal averaging of the Fourier transform of the supercurrent density $j_s(\omega)$ has a form

$$\langle j_s(\omega)\rangle = 4e^2\int_0^\infty dt\cos(\omega t)\sum_{i,j} J_{ij}e^{i\omega_{ij}t}\langle S_i^*(t)S_j(0)\rangle(r_{ij}E)r_{ij}/\hbar^2 d^2. \qquad (4)$$

In order to obtain from (4) the mean value of the supercurrent density in the SG model (1), one needs to perform averaging over random cluster coordinates (x_i, y_j) (by the Gaussian $P(x_i,y_j) = \exp(-x_i^2/2\sigma - y_j^2/2\sigma)/2\pi\sigma$, where σ is the projected area of superconductive loops with a uniform phase) /4/. Choosing, for simplicity, $E = (E,0,0)$, after the configurational averaging one gets for the supercurrent density

$$j_s \equiv \overline{\langle j_s^x(\omega)\rangle} = A\int_0^\infty dt\cos(\omega t)\exp(-4e^2E^2\sigma t^2/\hbar^2)D(t)E \ , \qquad (5)$$

where

$$J(T,H) = J(T)/(1+H^2/H_0^2)^{1/2}, \quad A = 8e^2\sigma J(T,H)N/\hbar^2 d, \quad H_0 = \phi_0/2\sigma,$$

$$D(t) = \sum_{i,j}\overline{\langle S_i^*(t)S_j(0)\rangle}/N \ .$$

So, the form of CVC (5) is determined by the behaviour of the

correlator $D(t)$. As is shown in /5/ the long-time (low-frequency) singularities of the correlator $D(t)$ define glassy properties of the SG model and observable experimental peculiarities. In the present paper we restrict ourselves to the simplest Ansatz of this kind . Namely, we take a logarithmic-like relaxation law /5/

$$D(t) = L - s\ln(t/\tau) \ , \qquad \tau = \hbar^2 N/4e^2RT . \qquad (6)$$

Here, $L(T,H)$ is the order parameter in the SG model (1) (see /4,5/), s is the relaxation rate /5/, N is the number of superconducting clusters, and R is the normal state resistance between two grains. According to (6) from (5) one gets a logarithmic-law CVC

$$j = j_c + j_1\ln(E/E_0) \quad , \qquad (7)$$

where

$$j_1 = j_0 s/2, \quad j_c = j_0(L + s(\ln 2 + C/2)), \qquad (8)$$

$$j_0 = (\hbar/2e)(\pi/\sigma)^{1/2}A(T,H), \quad E_0 = \hbar/2e\tau\sigma^{1/2}.$$

Here, C is the Euler constant. So, in view of (7) and (8) the temperature and field dependencies of the nonlinear current j_1 and the critical current j_c are governed by the order parameter $L(T,H)$ and via the Josephson energy $J(T,H)$ (5). In the range of validity of the glass-like picture /8/ we have $s = \beta L$, $L \sim 1-T/T_c$, $\beta \sim 1$, and it follows from (8) that $j_c \geq 5j_1$ in good agreement with the experimental estimate /2/ $j_c \leq 10j_1$. The temperature behaviour of the j_c near T_c has an asymptotic form $j_c \sim (1-T/T_c)$ (cf./8/). The magnetic field dependence of the critical current is influenced mainly by the coupling energy $J(T,H)$ (via j_0 (5)). In the case of weak fields ($H \ll H_0$) from (5) and (8) it follows that :

$$j_c(H) = j_c(0)(1-H^2/H_0^2). \qquad (9)$$

In the opposite case of strong fields ($H \gg H_0$) one gets :

$$j_c(H) = j_c(0)H_0/H \ . \qquad (10)$$

Let us make some estimates for typical values of the current $I_0 = j_0 d$ and the voltage $V_0 = E_0 d$. In view of $\beta \sim 1$, and $d \sim N\sigma^{1/2}$ for $J \sim 50K$ and $R \sim 5\Omega$, from (6) and (8) one gets :

$$I_0 \sim 4eJ/\hbar \sim 10^{-5}A \quad , \quad V_0 \sim 2eRT_c/\hbar \sim 10^{-3}V. \qquad (11)$$

Following /2/ , this is the range of parameters where the obtained above peculiarities in a logarithmic-law CVC behaviour were registered .

In summary, logarithmic current-voltage characteristic (CVC) is calculated via the superconductive glass (SG) model. Temperature and magnetic field dependencies of the critical current are discussed. The obtained results are in qualitative agreement with experimental data for high-T_c oxides.

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