ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ
ДУБНА

E17-90-84

S.A.Sergeenkov

ON EXCESS MAGNETOCONDUCTIVITY OF A SUPERCONDUCTIVE GLASS

Submitted to "Journal of Physics: Condensed Matter"

1990

As emphasized by many experimental groups (see e.g. [1-3] and references therein) fluctuation effects in high-T_c oxides in an applied magnetic field show a very unusual and complicated behaviour. On the other hand, one observes constant growth of evidences in favour of superconductive glass (SG) behaviour in HTS (see e.g.[4] and references therein). In the frame of the SG model, pioneered in [5], revived (due to HTS discovery) in [6,7], and then advanced in [8-11], rather a successful description of both equilibrium (magnetic phase boundary $T_c(H)$ [7,8,10]) and nonequilibrium (long-time relaxation of remanent magnetization [7,9], critical neutron scattering by diamagnetic correlations [11]) properties of HTS has been achieved.

In this Letter we consider via the SG model a fluctuation-induced magnetoconductivity of weak-links-containing systems.

As is well known [8,9] 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

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

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

The model (1) describes the interaction between superconductive clusters (with phases f_i) via Josephson junctions (with energy $J(T)$) on a 2-D disordered lattice (with cluster coordinates (x_i,y_j)) in a frustrated external magnetic field H = (0,0,H).So,as usual (see, however, [10]), we have neglected shielding current effects. The field is normal to the ab-plane where a glass-like picture of HTS is established.

Following [12], we calculate the enhancement of conductivity normal to the c-axis (on a square lattice with side d) within the SG model by the Kubo formula :

$$\sigma_{\perp}(\omega)=\int_0^{\infty} dt\cos(\omega t)\sum_{\mathbf{q}} \overline{\langle j^{\perp}_{\mathbf{q}}(t)\, j^{\perp}_{-\mathbf{q}}(0)\rangle}/k_B T \; . \qquad (3)$$

Here, $j^{\perp}_{\mathbf{q}}$ is the Fourier transform of the Josephson current density operator [11]:

$$j_{\mathbf{q}} = N^{-1}\sum_{ik} e^{i\mathbf{q}(\mathbf{r}_i-\mathbf{r}_k)} j_{ik} \; , \qquad (4)$$

$$j_{ij} = j_c \sin(f_i - f_j - A_{ij}) \; , \; j_c = 2eJ(T)/\hbar d \; . \qquad (5)$$

In our case $\mathbf{r}_i=(x_i, y_i, 0)$.

The bar denotes the configurational averaging with a Gauss-like distribution function over cluster coordinates (x_i, y_j) [8]. By using the mode-coupling approximation scheme (see e.g. [14]) from (3) to (5) one gets :

$$\sigma_{\perp}(\omega) = A \sum_{\mathbf{q}}(1-sq^2)\exp(-sq^2)\langle |D_{\mathbf{q}}(t)|^2\rangle_{\omega} \; , \qquad (6)$$

where

$$A = 4se^2J^2(T,H)/\hbar^2 k_B T d, \; J(T,H) = J(T)/(1+H^2/H_0^2)^{1/2} \; . \qquad (7)$$

Here s is the projected area of superconductive loops with a uniform phase, $H_0=\phi_0/2s$. $D_{\mathbf{q}}(t)$ denotes the Fourier transform of the correlator $D_{ij}(t)$:

$$D_{ij}(t) = \overline{\langle S^{*}_i(t) S_j\rangle} \; . \qquad (8)$$

The transition to the SG phase occurs at the temperature

$T<T_c(H)$, where $T_c(H)$ is defined by an equation $L_{q=o}(T_c,H)=0$ (it should be noted that $T_c(H)<T_s$, where T_s is a single grain superconductive temperature). A nonzero dynamic parameter $L_q(T,H)$ is connected with the correlator (8) in the following way [9] :

$$L_q(T,H) = \lim_{t\to\infty} D_q(t) \quad . \tag{9}$$

In the critical region near the transition to the SG phase (when $\varepsilon<<1, \varepsilon = (T-T_c)/T_c$) we have [9,11] :

$$D_q(t) = D_q^c[\exp(-t/\tau_q)/(\pi t/\tau_q)^{1/2} - \mathrm{erfc}((t/\tau_q)^{1/2})], \tag{10}$$

where

$$D_q^c = D_o/(1+q^2\xi^2), \quad \tau_q = \tau_0/(1+q^2\xi^2)^2 ,$$
$$\tau_0 = \gamma/\varepsilon^2 \ , \ D_0 = 1/\varepsilon \ , \ \xi^2 = \xi_0^2/\varepsilon \ . \tag{11}$$

Here ξ_0 is the coherence length perpendicular to the c-axis, γ is the paraphase relaxation time.

After the time-frequency Fourier transform from (10) one obtains $<|D_q(t)|^2>_\omega = |D_q^c|^2\tau_q \ \mathrm{Re}\{(4/\pi)\tan^{-1}(Z)/Z - \mathrm{Ei}(-(t_0/\tau_q)(1+Z^2))\}$. (12)

Here $Z = (1-i\omega\tau_q)^{1/2}$, $\mathrm{Ei}(x)$ is an integral exponential function, t_0 is a lower cut-off time parameter.

Since it is the long-time behaviour of the correlator $D_q(t)$, which completely define glassy properties of the SG model and observable experimental peculiarities, in what follows we restrict ourselves to a low-frequency ($\omega \to 0$) behaviour of the paraconductivity (6). Moreover, for the sake of simplicity, we shall consider the case when $t_0 \gg \gamma$, it means that $\mathrm{Ei}(-t_0/\tau_q) \ll 1$. Integrating (6) over momentum **q**, in view of (10)-(12), for transverse paraconductivity one obtains :

$$\sigma_\perp(p,H) = \sigma(H)g(p) \quad , \tag{13}$$

where

$$\sigma(H) = \sigma(0)/(1+H^2/H_0^2), \quad \sigma(0) = e^2 p_0^4 J^2(T)\gamma/k_B T h^2 d \quad ,$$

$$g(p) = [2p-2p^2+3p^3+p^4+4p^4 e^p Ei(-p)+p^5 e^p Ei(-p)]/6p^4 \quad . \tag{14}$$

Here $p = p_0\varepsilon$, $p_0 = s/\xi_0^2$.

Let us consider two limiting cases of eq.(13). When $p \gg 1$ ($s \gg \xi^2$), i.e. well above T_c, eq.(13) reduces to the two-dimensional Aslamazov-Larkin-like law [3] :

$$\sigma_\perp/\sigma(0) \sim (2/3)s^4/p_0\varepsilon \quad . \tag{15}$$

In the opposite case, when $p \ll 1$ ($s \ll \xi^2$), i.e. in the region near T_c, $\sigma_\perp$ approaches the three-dimensional form of the XY-like model (cf.[14], where the law $\sigma_\perp \sim \varepsilon^{-2.8}$ for HTS ceramics was registered) :

$$\sigma_\perp/\sigma(0) \sim (1/3)s^4/p_0^3\varepsilon^3 + (2/3)s^4 \ln(p_0\varepsilon) \quad . \tag{16}$$

Thus, we have the following picture. The closer the temperature to T_c, the more important become effects due to the granularity of the system. It seems that observed anomalous fluctuations [15] occur owing to a crossover between 2-D and 3-D behaviours.

To compare the model predictions with the experimental data for HTS, it is interesting to consider a magnetic field dependence of the paraconductivity (13). Figure 1 shows the behaviour of reduced conductivity $-\Delta\sigma(H)/\sigma(0)$ (here $\Delta\sigma(H)=\sigma_\perp(p,H)-\sigma_\perp(p,0)$) versus reduced magnetic field $h = H/H_0$ for various temperatures above T_c (in reduced units $t = T/T_c(0)$). It is seen that paraconductivity decreases with increasing temperature t in qualitative agreement with the experimental data on excess magnetoconductivity (see e.g.[1-3,12]).

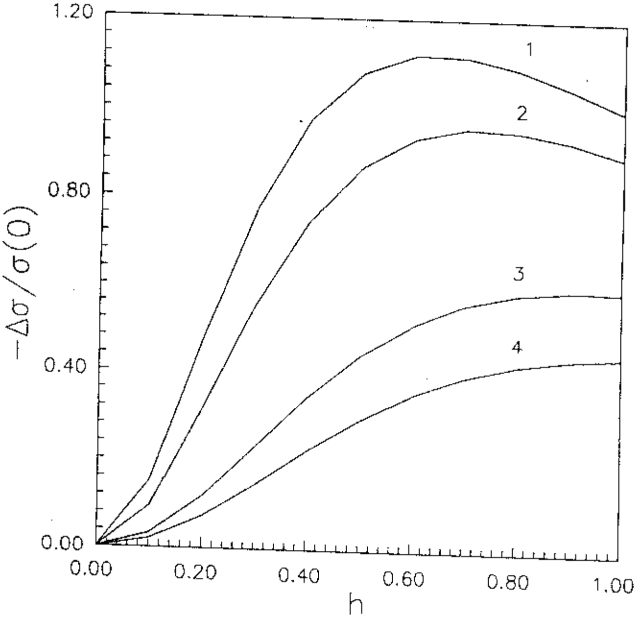

Fig.1: The behaviour of reduced paraconductivity $-\Delta\sigma/\sigma(0)$ versus reduced magnetic field $h=H/H_0$ at reduced temperature $t=T/T_c(0)$: 1) $t=1.005$, 2) $t=1.01$, 3) $t=1.03$, 4) $t=1.05$.

In conclusion, excess magnetoconductivity of a superconductive glass (SG) was considered. It was found that samples with weak links should show a crossover between two- and three-dimensional behaviours of excess conductivity, similar to that discussed for layered superconductors [16].

Discussions with Prof W Gótze and Dr I Morgenstern are gratefully acknowledged.

References

[1] Poddar A, Mandal P, Das A N and Ghosh B 1989 Physica C159 231

[2] Kamble S, Naito M, Kitazawa K, Tanaka I and Kojima H 1989 Physica C160 243

[3] Hikita M and Suzuki M 1989 Phys.Rev.B39 4756

[4] Morgenstern I 1989 IBM J.Res.Develop.33 307

[5] Ebner C and Stroud D 1985 Phys.Rev.B31 165

[6] Müller K A, Takashige M and Bednorz J G 1987 Phys.Rev. Lett.58 1143

[7] Morgenstern I, Müller K A and Bednorz J G 1987 Z.Phys. B69 33

[8] Aksenov V L and Sergeenkov S A 1988 Physica C156 18

[9] Aksenov V L and Sergeenkov S A 1988 Physica C156 235

[10] Schneider T, Würtz D and Hetzel R 1988 Z.Phys.B72 1

[11] Sergeenkov S A 1989 Physica C159 43

[12] Ikeda R, Ohmi T and Tsuneto T 1989 J.Phys.Soc.Jpn.58 1377

[13] Götze W and Sjögren L 1984 J.Phys.C:Solid St.Phys.17 5759

[14] Peyral P, Lebeau C, Rosenblatt J, Raboutou A, Perrin C, Pena O and Sergent M 1989 J.Less-Common Met.151 49

[15] Ausloos M, Laurent Ch, Patapis S K, Green S M, Luo H L and Politis C 1988 Mod.Phys.Lett.B2 1319

[16] Aronov A G, Hikami S and Larkin A I 1989 Phys.Rev.Lett. 62 965

Received by Publishing Department
on February 8, 1990.