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# AC-SUSCEPTIBILITY OF YBaCuO AND YBaCuO:Ag CERAMICS IN TERMS OF THE PERCOLATION THEORY

V.F.GANTMAKHER, B.G.KAREPOV, A.M.NEMINSKY, D.V.SHOVKUN and N.S.SIDOROV

Institute of Solid State Physics, Academy of the USSR, 142432, Chernogolovka, Moscow dist., USSR.

At least three factors determine the magnitude of alternating magnetic flux which penetrates into inhomogeneous superconducting (*spcd*) material: 1. Geometrical parameters of *spcd* part of the material (fraction of the *spcd* volume *v*, correlation length, etc.) 2. Parameters of the Josephson network (coupling energy, normal resistance of the contacts, etc.) 3. Cooperative phenomena which control phase coherence of the *spcd* wave function; they depend on relations between different lengths: grain size *d*, *spcd* coherence length $\xi$, *spcd* penetration length $\lambda$, etc. To study comparative role of these factors, we measured ac-susceptibility of ceramic YBaCuO and YBaCuO:Ag with oxygen deficit. Grains in such samples have slightly different oxygen content and, as a result, different $T_c$ . This allows to alter the first factor, volume *v*, by changing *T*. By increasing the ac amplitude *h* the *spcd* contacts are destroyed. This allows to separate contributions from the grains themselves and from *spcd* clusters which embrace normal regions. Comparison of the samples with and without Ag clarifies the role of contacts parameters, as it is known that Ag in YBaCuO concentrates in the grain boundaries[1]. Finally, data analysis on the classical percolation basis brings light to cooperative phenomena.

## 1. EXPERIMENTAL

The samples in the initial state had a sharp *spcd* transition. After measuring the temperature dependences of ac-susceptibilities at different frequencies and amplitudes they were subjected to vacuum annealing, which resulted in a slight decrease in the oxygen content. Then a new series of the low-temperature measurements followed by further annealing was done and so on. In the main series which consisted of nine cycles, two samples – one without and another with Ag – were treated simultaneously. Their transition curves shifted along *T*-axis from 92K to approximately 30K.

The measurements were carried out in the frequency range of $10^2$-$10^5$ Hz. The amplitude of alternating field *h* varied from $2\cdot10^{-4}$ to 40 Oe. Details of the experiment are published in [2]. Fig.1a depicts, for example, the whole set of *Y(T)* curves, obtained after the third annealing of the sample. The value of *Y* in fig.1a is

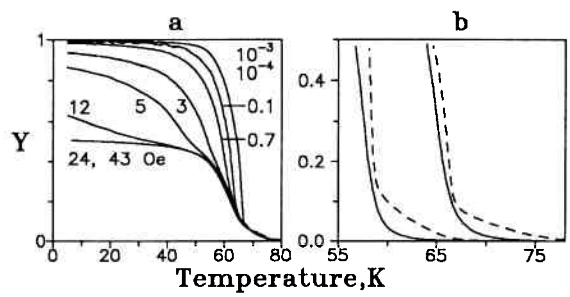


FIGURE 1
a. Set of curves *Y(T)* at different *h*. The curves are labelled by *h* values.

b. $Y^{(1)}(T)$ for the samples with (solid) and without (dashed) Ag after two different annealings.

proportional to magnetic moment of the sample. The value of *Y* = 1 means that the magnetic flux is fully extruded from the volume of the sample. The set displays specific features of the curves which were found in numerous works before: a kink, sensitivity to *h* at temperatures

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below the kink, etc. (see references in [2]). The most important trait is existence of two limiting curves: $Y^{(1)}(T)$ at low $h$ (upper curve) and $Y^{(2)}(T)$ at high $h$ (lower curve).

The main result in ac-susceptibility from inserting Ag (13%) can be seen in fig.1b: decrease of the signal on the right from the kink.

## 2. INTERPRETATION

Existing of the lower limiting curve can be interpreted in the only way: the field destroys all the *spcd* contacts between the grains but vortices do not penetrate inside them. Then, neglecting the meissner penetration, one gets that $Y^{(2)}(T) \approx v(T)$. Now, while handling experimental data, we can use $v$ as an argument instead of $T$ thus meeting the needs of percolation theory.

Let us introduce the distribution function of loops formed by grains with respect to the areas of these loops. Suppose the number of loops with area $s$ in the interval $ds$ per unit volume is $\varphi_{v,p}(s)ds$, and the volume, shielded by this loops is

$$f_{v,p}(s)ds = s^{3/2}\varphi_{v,p}(s)ds \ ;$$

$p$ is the fraction of *spcd* contacts between *spcd* grains. Dependence $p(T)$ includes implicitly cooperative phenomena. If $F_{v,p}(s)$ is a fraction of volume, shielded by all *spcd* grains and by all loops with the areas less than $s$, overlapping taken into account, then

$$[1 - F_{v,p}(s)] \ f_{v,p}(s) \ ds = dF_{v,p}(s) \ ,$$

wherefrom

$$F_{v,p}(s) = 1-(1-v)\exp(-I(s)), \quad I(s) = \int_0^s f_{v,p}(s)ds$$

and at the upper limiting curve one has

$$Y^{(1)}(T) = F_{v,p}(\infty) = 1 - (1-v) \exp(-I(\infty)) \ .$$

Note that $\exp(-I)$ is the mean value of the magnetic permeability $\bar{\mu} = (\overline{1 + 4\pi\chi})$ over the space between *spcd* grains.

Returning to experiment, fig.2 depicts $I^2(v)$ functions. It shows that dependence $I(v)$ can be described by the power law

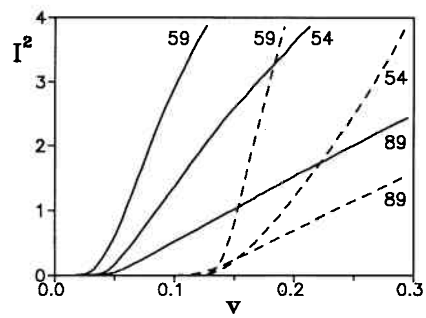


FIGURE 2
$I^2$ versus $v$ for samples with (solid) and without (dashed) Ag. Curves are labelled by the kink temperatures.

$$I = -\ln \bar{\mu} = K(p) \ (v - v_o)^{1/2} . \qquad (1)$$

But $I$ is not an universal function of $v$: coefficient $K$ takes different values. A sharper increase of $I$ with $v$ points to a greater $p$ value. It correlates with decrease of the width of grains $T_c$ distribution function [2].

## 3. SUMMARY

1. ac-susceptibility can reveal the distribution function of $T_c$ values over the grains.

2. Percolation theory can be applied to description of *spcd* transition in YBaCuO with parameter $p(T)$ phenomenologically incorporating cooperative phenomena. This is possible due to strong coupling between the grains.

3. Empirical law (1) for the mean permeability $\bar{\mu}$ over the space between *spcd* grains is established with coefficient $K$ depending on $p$.

4. Dispersion of $T_c$ values seems to be more important for cooperative phenomena than change of intergrain resistance by the help of Ag.

5. Ag in the intergrain space leads to pronounced proximity effect when *spcd* grains are isolated but does not affect significantly the junction network.

## REFERENCES


1. J.Lin and T.Chen, Z.Phys.B 81 (1990) 13.
2. V.Gantmakher et al.,Physica C177 (1991) 469.