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The J_c versus T Dependence in YBaCuO Superconductors and the Ambegaokar-Baratoff Relationship

By

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Introduction Two main approaches have been proposed to explain the transport $J_c(T)$ characteristics of high T_c superconductors: one that regards the system as an assembly of type II superconducting grains linked by superconductor-normal-superconductor (S-I-S) or superconductor-conductor-superconductor (S-N-S) junctions /1 to 3/, and one which takes into account the thermally activated phenomena, mainly flux creep /3, 4/.

In this note we have used a granular model for Y-Ba-Cu-O ceramics (similar to that presented in /5/) in which a BCS-like behavior is assumed for J_c and the gap, while a statistical distribution function is assumed for the critical temperatures of the grains. This distribution not only affects the magnitude of the sample critical current (as a distribution of junctions I_c does) but affects, as we will see, the shape of the $J_c(T)$ dependence. Using the averaging formula obtained on such basis, we present some fits to experimental J_c versus T values reported by other authors. Finally, we discuss some features of our method from a physical point of view.

Theory Considering the granular character commonly exhibited by Y-Ba-Cu-O ceramics in experiments, we assume the dimensionless parameter $\varepsilon = E_j/E_c < 1$, where $E_j(T)$ is the Josephson coupling energy and E_c is the condensation energy /6, 7/, so that we can regard the material as a collection of superconductive grains interconnected by symmetrical S-I-S junctions governed by the Ambegaokar-Baratoff relationship /8, 9/

$$i_s = \frac{1}{2}\pi R_n^{-1}\Delta(T)\tanh\left[\frac{1}{2}\beta\,\Delta(T)\right], \qquad (1)$$

where i_s is the critical current of the junction, R_n is the junction resistance in the normal state, $\Delta(T)$ is the superconductor gap, and $\beta = 1/kT$.

The junctions are assumed to be symmetrical because it is reasonable to believe that adjacent grains have quite similar composition, and therefore reasonably identical superconducting properties. A BCS approximation, on the other hand, was assumed for the gap /10/.

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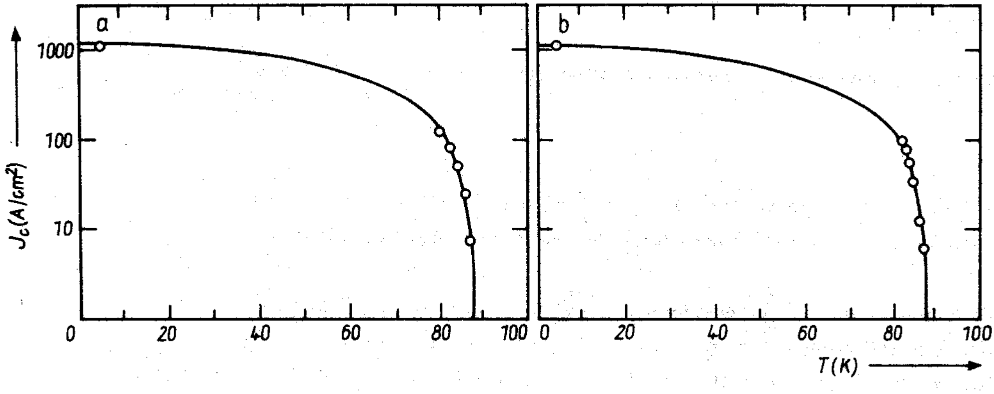

Fig. 1. Experimental J_c versus T values for two $YBa_2Cu_3O_{7-x}$ samples denominated 1133 (Fig. 1a) and 1132 (Fig. 1b) as reported in /11/. The continuous curves are the theoretical fits following (3)

Averaging the critical current density through a simple procedure analogous to the one used in /5/

$$J_c(T) = \frac{1}{2} \pi R_n^{-1} \int_T^{T_c(\max)} \delta(T_c)\Delta(T,T_c)\tanh\left[\frac{1}{2} \beta \Delta(T,T_c)\right]dT_c \quad , \tag{2}$$

where R_n will be used as a fitting parameter (supposed to be identical for all junctions) and $\delta(T_c)$ is the probability density function on T_c normalized to n, the number of grains per unit transverse area of the sample, which can be estimated from microscopic observations.

<u>Results and discussion</u> The continuous line shown in Fig. 1a is the fit made following (3) for a set of experimental values reported by Finlayson et al. /11/ for a $YBa_2Cu_3O_{7-x}$ flame-sprayed sample called 1133 by the authors. In this fit, a skewed triangular distribution was assumed for $\delta(T_c)$ with T_c(min) = 86 K, T_c(max) = 88 K, and T_c(peak) = 87.5 K; R_n was taken as 15 Ω and n was calculated as 1/a where a is the mean grain area of 3×15 μm² given in /11/.

The continuous line in Fig. 1b is the fit for the J_c versus T experimental values for sample 1132 given in /11/. Here, T_c(min) = 82.5 K, T_c(max) = 87 K, and T_c(peak) = 83 K; R_n was taken as 215 Ω and n corresponds to a mean grain size of 2×2 μm².

In both cases the value of Δ(0) was selected as 12 meV which is the lowest of some of the values reported for the gap from infrared and tunneling measurements /12, 13/.

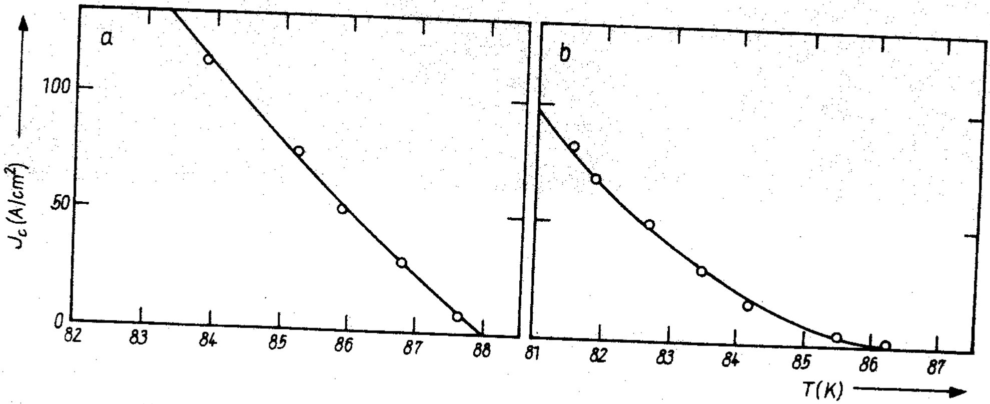

Fig. 2. Same fits as in Fig. 1 but here presented in more detail near T_c; Fig. 2a) sample 1133; b) sample 1132

The same measurements shown in Fig. 1 (a and b) are represented in Fig. 2 (a and b) in a scale suitable for a better appraisal of the quality of our fittings in the neighborhood of T_c.

By comparing Fig. 1a and b it can be seen that $J_c(T)$ is strongly dependent on the shape of $\delta(T_c)$ for T near T_c. This result quantitatively evaluates the importance of the influence of the T_c distribution on $J_c(T)$ near the transition temperature which was early pointed out by de Vries et al. /1/. The value of $J_c(0)$ is mainly determined by that of the product $R_n a$. On the other hand, for intermediate values of T, $J_c(T)$ is quite independent of the T_c distribution assumed.

Taking into account the work of Hampshire et al. /14/, in which it is stated that a narrow distribution of T_c corresponds to a flattened J_c versus B curve, as in the case of both samples studied in /11/, it is clear that our narrow $\delta(T_c)$ is a coherent result. A narrow $\delta(T_c)$ is also consistent with the work of Jorgensen et al. /15/ who have shown that, within the range $0 < x < 0.1$, the compound under study shows little variation in T_c.

As suggested in /16/, when the temperature is changed, the coupling energy between pairs of grains will change, so a temperature dependence exists of the effective number of superconductive grains per unit transversal area, which is not taken into account in (3).

Finally it is worth noting that although the S-I-S junction model does not seem to fit as well as the S-N-S model to the transport $J_c(T)$ data as reported by some authors /1, 3/ the account for a T_c distribution gives excellent fits to the S-I-S model. Junctions of this kind are naturally expected in a ceramic which tends to segregate an isolating phase ($Y_22BaCuO_5$) between the $YBa_2Cu_3O_{7-x}$ superconducting grains.

Conclusions We have obtained a fitting formula for the J_c versus T characteristics of Y-Ba-Cu-O superconductors, regarding the material as an array of superconductive grains separated by symmetrical junctions governed by the Ambegaokar-Baratoff relationship. The fits made using our formula are quite good.

Besides yielding an estimation of the normal states resistance R_n of the intergrain junctions, our method gives the shape of the statistical distribution of T_c within the sample, which is found to be quite sharp ($T < 5$ K) in agreement with some experimental evidence.

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