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Temperature dependence of some intragranular parameters in BSCCO polycrystalline superconductors obtained through the magnetic hysteresis of J_c

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Abstract

The hysteretic behavior of the $J_c(B_a)$ dependence for $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_3O_{10-x}$ polycrystalline samples at low magnetic fields ($B_a < 30$ mT) and different temperatures has been studied. A model which takes into account a two-dimensional series-parallel array of Josephson junctions and the magnetic flux trapped in the grains showed good agreement with the experiment. As a result, the temperature dependencies of the first critical field of the grains ($H_{c1g}(T)$) and the full penetration field of the grains ($H^*(T)$) were obtained and compared with the results expected from a BCS approximation near T_c. © 1997 Elsevier Science B.V.

1. Introduction

The transport critical current density, J_c, of the polycrystalline high temperature superconductors has been found to be strongly hysteretic in an applied magnetic field, H_a [1–8]. This behavior is commonly attributed to the presence of trapped flux in the grains [2]. Altshuler et al. have shown that the full penetration field of the Bean's model [9], H^*, and the first critical field of the grains H_{c1g}, can be determined using the so-called *flux trapping curve* [10].

The intragranular flux trapping model [11,12] was the first quantitative approach of this phenomenon. Muné et al. have proposed the introduction of negative values of the geometric factors to explain the differences between the hysteretic behavior of the $J_c(B_a)$ dependence in the Y–Ba–Cu–O and Bi–Pb–Sr–Ca–Cu–O systems [13,14]. More recently, a better agreement between theory and experimental data than in the case of a single-parallel Josephson junctions array for HTC ceramics has been achieved, employing a two-dimensional series-parallel array of Josephson junctions [15].

In this paper, a study of the hysteresis in the $J_c(B_a)$ dependence at different temperatures is presented. The $H^*(T)$ and $H_{c1g}(T)$ dependencies are obtained from the fit of the experimental data, taking into account the model described in Ref. [15]. The use of this method to determine these dependencies constitutes, as far as we know, the first report on the subject.

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Finally, the $H^*(T)$ and $H_{c1g}(T)$ dependencies are compared with those expected from the BCS approximation near T_c.

2. Experimental

Pb doped Bi–Sr–Ca–Cu–O oxide samples were prepared by a solid-state reaction of Bi_2O_3, PbO_2, $SrCO_3$, $CaCO_3$ and CuO powders [16]. The ratio of Bi : Pb : Sr : Ca : Cu in the starting material was 1.6 : 0.4 : 2 : 2 : 3. Appropriate amounts of the different components were weighed, manually mixed in an agate mortar using alcohol to homogenize the mixture, and heated at 750°C for 40 h. This powder was ground, pressed into 1 mm thickness pellets at 200–300 MPa, and heated at 800°C for 40 h. Finally, the pellets were again ground, pressed, and sintered at 850°C for 40 h. The latter process was repeated two times. Thin slabs of BSCCO ceramic were cut with typical dimensions of $d = 0.2$ mm (thickness), $w = 2$ mm (width) and $l = 10$ mm (length).

The standard four-probe technique was used to measure the $J_c(B_a)$ dependencies in ZFC conditions in increasing applied magnetic field (*virgin curves*) and decreasing applied magnetic field (*returning curves*) for different maximum values of the magnetic induction, B_{am}. The magnetic field was applied perpendicular to the current which was injected along the longest axis of the sample.

The measurements were done at different temperatures within the range 78–95 K using a silicon diode as a temperature sensor and a commercial PID controller. The system controlled the temperature within ±0.1 K.

The results of the X-ray diffraction analysis have shown that our sample contained about 85% of the high-T_c BSCCO phase and the rest basically composed of the low-T_c one. The optical microscopy revealed that the average grain size was approximately 5 μm.

3. The model

The experimental data have been compared with generated curves using the model described in Ref. [15], where the ceramic was regarded as a two-dimensional series-parallel Josephson junctions array and the intergranular magnetic field H_i in each junction, depends on applied magnetic field H_a, the geometric factor G, and the granular magnetization M, in the following way:

$$H_i = H_a - GM \tag{1}$$

Four parameters were considered in Ref. [15]: the first critical field of the junctions, H_0, the first critical field of the grains, H_{c1g}, the Bean's model full penetration field of the grains, H^*, and the statistical distribution of the geometric factors, $\eta(G)$ [11]. In our approximation, $\eta(G)$ is regarded as temperature independent. The expressions to obtain H_{c1g} and H^* as a function of the coherence length, ξ, and the penetration depth, λ, are based on those given in Ref. [17] as follows:

$$H_{c1g} = \frac{\phi_0}{4\pi\mu_0\lambda^2}\ln\frac{\lambda}{\xi} \tag{2}$$

$$H^* \propto J_{cg} = \frac{\phi_0}{32\mu_0\lambda^2\xi} \tag{3}$$

where ϕ_0 is the magnetic flux quantum, μ_0 is the magnetic permeability of the free space and J_{cg} is the intragranular critical current density. The first critical field of the junctions can be written in the following way (see Ref. [15]):

$$H_0 = \frac{\phi_0}{2L\mu_0\lambda} \tag{4}$$

where L is the average of the projections perpendicular to the intergranular field of the junctions lengths. Near T_c, the BCS approximation gives $\xi(T) \propto \lambda(T) \propto 1/(1-T/T_c)^{0.5}$, where T_c is the critical temperature, then

$$H_0(T) \propto \frac{1}{\lambda(T)} \tag{5}$$

$$H^*(T) \propto J_{cg}(T) \propto \frac{1}{\xi(T)\lambda^2(T)} \tag{6}$$

$$H_{c1g}(T) \propto \frac{1}{\lambda^2(T)} \tag{7}$$

4. Results and discussion

The experimental virgin, returning and flux trapping curves at different temperatures were fit using a triangular statistical distribution of geometric factors, whose shape is shown in the inset of Fig. 1 [13,14]. Figs. 1–3 show the experimental and generated data for two different temperatures (for the sake of brevity, we will write the fields without the symbol μ_0 in our discussions, although it will be explicit in tables and figures). The values of H_0, H_{c1g} and H^* from the comparison with the experimental data for different temperatures are shown in the following table:

Temperature (K)	$\mu_0 H_0$ (mT)	$\mu_0 H_{c1g}$ (mT)	$\mu_0 H^*$ (mT)
77.8	2.5	5.0	12.5
85	1.3	4.0	7.3
87	1.2	3.5	7.0
89	1.1	3.0	6.8
91	1.0	2.5	6.0
93	0.75	2.3	4.5
95	0.72	1.7	4.2

The $H^*(T)$ and $H_{c1g}(T)$ dependencies are plotted in Figs. 4 and 5. Taking into account Eqs. (6) and (7) and the BCS approximation near T_c, we obtain the following theoretical expressions for $H^*(T)$ and $H_{c1g}(T)$:

$$H_{c1g}(T) = C_1\left(1 - \frac{T}{T_c}\right) \quad (8)$$

$$H^*(T) = C_2\left(1 - \frac{T}{T_c}\right)^{1.5} \quad (9)$$

where C_1 and C_2 are constants. By the least-squares method the dependencies $H_{c1g}(T)$ and $H^*(T)$ were fit to the expressions (8) and (9) respectively, which gave two values of the critical temperature which were near to the one obtained from the resistivity versus temperature curve (see Fig. 6). The difference between the T_c values obtained from the $H^*(T)$ and $H_{c1g}(T)$ dependencies ($T_c \approx 110$ K and $T_c \approx 105$ K, respectively) can be explained, within the limits of our approximation, by taking into account the systematic decrease of H_{c1g} because of the intergranular trapped flux which is not taken into account in our model. (Although, in principle, $H^*(T)$ also

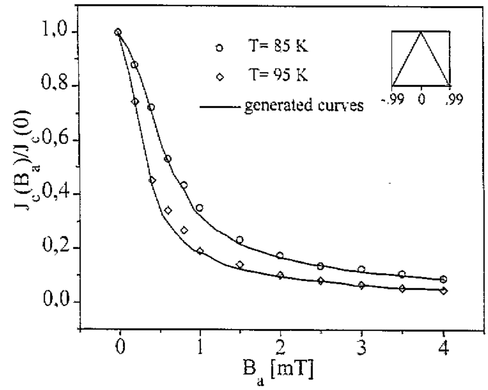

Fig. 1. Virgin curves. Experimental and generated data for two different temperatures. The inset displays the statistical distribution chosen for the geometric factors G.

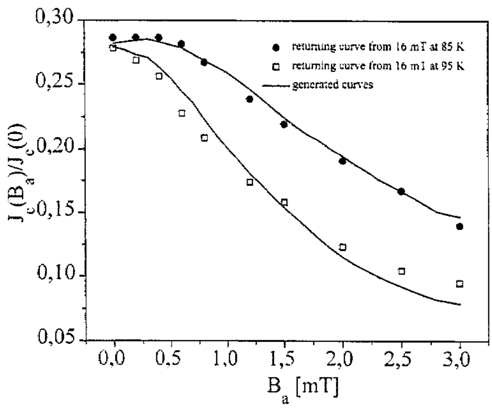

Fig. 2. Returning curves from 16 mT. Experimental and generated data for two different temperatures.

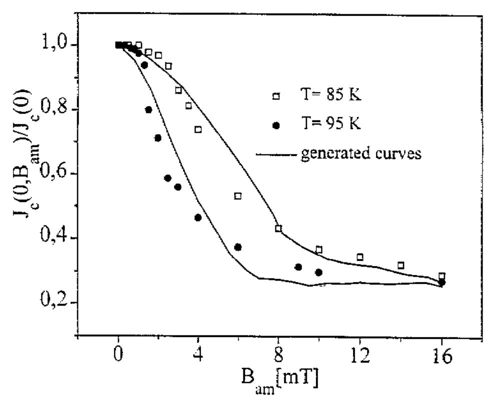

Fig. 3. Flux trapping curves ($J_c(0,B_{am})$ vs. B_{am}). Experimental and generated data for two different temperatures.

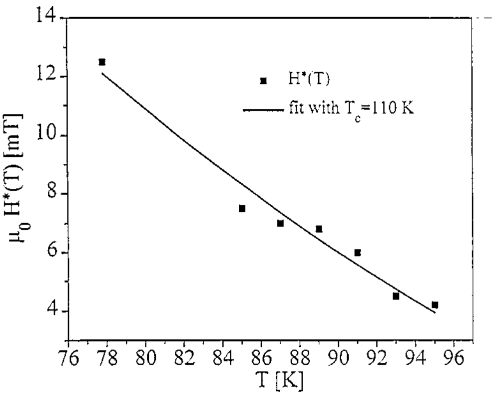

Fig. 4. $\mu_0 H^*(T)$ dependence and the corresponding fit by the least-squares method using Eq. (4) (see text).

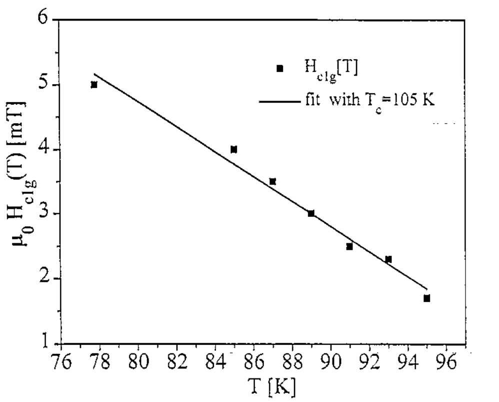

Fig. 5. $\mu_0 H_{c1g}(T)$ dependence and the corresponding fit by the minimum squares method using Eq. (5) (see text).

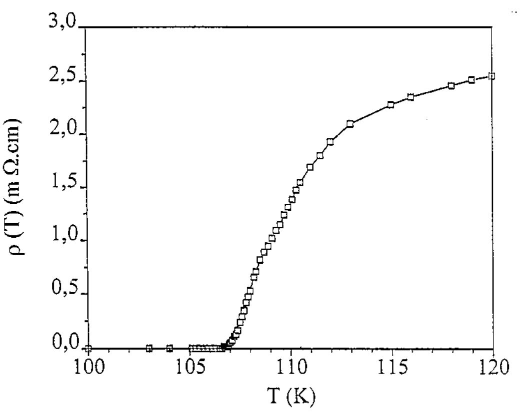

Fig. 6. Resistivity versus temperature experimental characteristic.

decreases with the trapped flux, the effect is relatively small at the applied field levels under study.)

The experimental dependence of $H_0(T)$ clearly disagrees with the approximation near T_c (see Fig. 7) that can be deduced from Eq. (5) and has the following form:

$$H_0(T) = C_3\left(1 - \frac{T}{T_c}\right)^{0.5} \tag{10}$$

where C_3 is a constant. A better approximation for $\lambda(T)$

$$\lambda(T) \propto \frac{1}{\sqrt{1-(T/T_c)^4}}$$

was also used, but the result was similar to the one shown in Fig. 7. It is very important to note that, from the fit by the least-squares method, we obtained a T_c value quite different from the experimental one. We also eliminated the (quite "distant") point corresponding to 78 K with the aim to study the fitting parameters in that case. This resulted in a good fit, but an even lower value of T_c had to be used.

This result indicates that our hypothesis based on the uniformity of the $J_c(0,T)$ dependencies in the whole ceramic Josephson junctions array from which Eq. (5) was deduced is not a good approximation. Indeed, when the temperature increases, some junctions switch from the superconducting to the normal state according to their Josephson critical temperatures, T_{cj} [18,19]. In this way a new superconducting array of Josephson junctions appears whose average

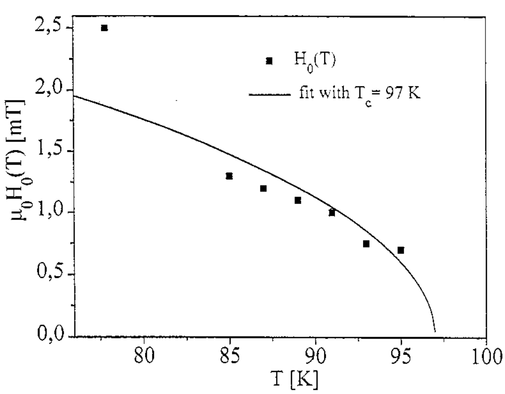

Fig. 7. $\mu_0 H_0(T)$ dependence and the corresponding fit by the least-squares method using Eq. (6) (see text).

H_0 at this new temperature could be different from the one existing before the temperature was increased. In other words, we do not regard the variations in $H_0(T)$ dependence because of the existence of a statistical distribution of T_{cj}.

5. Conclusions

We reported a new method to determine the temperature dependencies of the intragranular parameters in polycrystalline superconductors based on the combination of the experimental study of the hysteretic behavior in $J_c(B_a)$ dependence at different temperatures with a model which takes into account a two-dimensional series-parallel array of Josephson junctions under the effect of the magnetic flux trapped by the superconducting grains.

The temperature dependencies of the first critical field of the grains and the Bean's model full penetration field obtained by this method are in good agreement with a standard BCS approximation near T_c.

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References

[1] T. Aomine, K. Tsuru, Jpn. J. Appl. Phys. 26 (1987) 2013.
[2] J.E. Evetts, B.A. Glowacki, Cryogenics 28 (1988) 641.
[3] Ch.V. Narashimha Rao, S.K. Agarwal, B. Jayaram, S. Takacs, A.V. Narlikar, Z. Metallkd. 79 (1988) 271.
[4] K. Chen, Y.J. Quian, Physica C 159 (1989) 131.
[5] K. Vad, S. Mészaros, G. Halasz, Sz. Balauyi, Cryogenics 30 (1990) 660.
[6] P. Mocaër, L. Tessler, M. Laguës, Physica C (1991) 185.
[7] T.R. Askew, R.B. Flippen, K.J. Leary, M.N. Kunchur, J. Mater. Res. 6 (1991) 1.
[8] E. Blinov, E.B. Somin, A.K. Tagantsev, K.B. Traito, Supercond. Sci. Technol. 4 (1991) 340.
[9] Ch.P. Bean, Rev. Mod. Phys. (1964) 31.
[10] E. Altshuler, S. García, J. Barroso, Physica C 177 (1991) 61.
[11] E. Altshuler, J. Musa, J. Barroso, A.R.R. Papa, V. Venegas, Cryogenics 33 (1993) 308.
[12] K.H. Müller, D.N. Matthews, Physica C 206 (1993) 275.
[13] P. Muné, E. Altshuler, J. Musa, S. García, R. Riera, Physica C 226 (1994) 12.
[14] P. Muné, E. Altshuler, J. Musa, Physica C 246 (1995) 55.
[15] P. Muné, J. López, Physica C 257 (1996) 360.
[16] K. Jain, D.K. Suri, K.C. Nagpal, S.U.M. Rao, B.K. Das, Jpn. J. Appl. Phys. 29 (1990) 576.
[17] T.P. Orlando, K.A. Deli, Foundation of Applied Superconductivity, Addison-Wesley, New York, 1991.
[18] M.A. Dubson, S.T. Herbert, J.J. Calabrese, D.C. Harris, B.R. Patton, J.C. Garland, Phys. Rev. Lett. 58 (1988) 1061.
[19] L.E. Flores, E. Altshuler, S. García, J. Musa, Physica C 234 (1994) 368.