INFLUENCE OF THE SAMPLE GEOMETRY ON CRITICAL CURRENT DENSITY OF HIGH-Tc GRANULAR SUPERCONDUCTORS

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ABSTRACT

I-V characteristics of a polycrystalline Y-Ba-Cu-O sample of rectangular cross section were measured while varying the specimen thickness by succesive polishings.

The critical current density (Jc) was found to increase with the reduction of the sample thickness (e).

A model based on junctions decoupling due to the self magnetic field generated by the transport current is proposed to explain our results.

For this particular geometry and assuming a uniform current distribution along the sample, the magnetic field distribution inside the sample was calculated. From this, an expression for Jc as a function of e was derived which is in good agreement with the experimental results.

From the measured values, the value of the decoupling field obtained was of 4.47 Oe.

1- INTRODUCTION

A great dispersion in the measured values of critical current densities (Jc) is found in the literature. These values vary from 100 to 10,000 A/cm^2, making the evaluation and comparison between them difficult. This dispersion can be due either to intrinsic properties of the material or to sample size and geometry factors.

In general, it has been considered that to obtain the value of Jc, it is sufficient to normalize the measured critical current (Ic) to the area of the samples. However, several authors have observed an increase in Jc values with sample thickness reduction.[1,2,3,4,5]

There are several proposals to explain this phenomenon. One of them assumes that the role of microcracks becomes more important for thick samples[2]. Another considers the heat generated by Joule effect due to the measurement current[3]. In reference [1], the variation of Jc is attributed to the self magnetic field produced by the transport current. This field switches the weak links of the sample into a dissipative regime. In the same paper, an estimation of the dependence of Jc with the thickness of the sample (e) is made. Samples with rectangular cross-section are approximated to cylinders with an equivalent circular cross-section.

In this work, we have measured the dependence of critical current density with sample thickness in $Y_1Ba_2Cu_3O_{7-x}$ superconductors. We have performed the measurements on the same sample to be sure that the observed variations are only due to geometry effects.

2- EXPERIMENTAL PROCEDURE

The sample was prepared by a standard solid state reaction method. Stoichiometric quantities of Y_2O_3, CO_3Ba and CuO were reacted at 1243 K, ground, pressed into a disc of 6 mm height and 25 mm diameter and sintered at 1243 K during 8 hours in flowing oxygen.

To avoid inhomogeneous oxygenation, a rectangular bar of $17.04 \times 2.01 \times 3.07\ mm^3$ was cut from the center of the disc.

For sample characterization, four low resistance silver contacts were made as explained in reference [6]. Measurements were made by the four probe DC technique, with a distance of 10.0 mm between voltage contacts.

The sample with contacts and wires was included in polyester resin, in order to change its thickness by polishing it before each series of measurements. The thickness was controlled by measuring the height and weight of the ensemble after each polishing, with a precision of 0.01 mm and 0.0001 gr respectively.

The sample microstructure was characterized by measuring the transition parameter at 77 K, defined in references [7,8] as: $n = d\,[\log V\,] / d\,[\,\log I\,]$. Resistivity versus temperature measurements were made for the same purpose.

3- RESULTS AND DISCUSSION

The resistivity versus temperature measurements always showed a metallic behavior with an onset temperature of 93 K and zero resistance at 91.5 K.

The results obtained are summarized in table 1. They clearly show that Jc increases when the sample thickness is reduced.

Table 1					
#	Thickness [mm]	1/Area [cm^{-2}]	ρ (283 K) [μOhm cm]	Ic(77 K) [A]	Jc(77 K) [A/cm^{-2}]
0	3.07	16.29	1055	2.64	43.01
1	2.03	24.63	1073	2.33	57.39
2	0.87	57.47	1034	1.79	102.87
3	0.69	72.46	1102	1.69	122.46
4	0.29	172.41	1056	1.28	220.69

The measured I-V° characteristics in a log-log scale are displayed in figure 1. The Jc values versus e can be observed in figure 2 a.

We want to emphasize that the Joule effect is negligible for the currents used. Our contacts have very low resistance[6] (0.1 μOhm x cm^2). Under this condition, the power disipated was of a few microwatts.

Regarding the microstructure, the linkage between grains[9] does not vary appreciably after each polishing or thermal cycling between room and liquid nitrogen temperatures. This is evident in figure 1. Note that in the junction-decoupling dominant regime[7,9], the transition parameter n is practically the same for all the measured thicknesses.

Another evidence for the lack of microstructure variation is the small change of the resistivity at room temperature after each polishing (see table I).

The above considerations suggest that the increase in Jc with the reduction of e is not due to variations in the microstructure of the sample under study.

In order to explain our results, we propose the following hypothesis:

1) Granular superconductors have an arrange of junctions[7,9].
2) Transport properties are ruled by this arrange of junctions.
3) Junctions are uniformelly distributed in the sample and in all possible orientations.
4) The transport current produces a magnetic field that interacts with this arrange of junctions[1].
5) The superconductor turns to a disipative regime when this magnetic field reaches a value H_D that decouples the junctions thus reaching the critical current.

Taking into account all this considerations, we have calculated the magnetic field distribution produced by a transport current in a bar of rectangular cross section.

From the Biot - Savart law, considering that the current density, flowing in the z direction, is uniformelly distributed along the bar and defining the integration coordinates as shown in figure 2 b, we obtain the following equations for the magnetic field intensity inside the sample in the x and y directions:

$$b_x(e,x,y) = (y-a)\tan^{-1}\left[\frac{x-e}{y-a}\right] + \frac{(x-e)}{2}\ln\left[\frac{(x-e)^2+(y-a)^2}{(x-e)^2+y^2}\right] - y\tan^{-1}\left[\frac{x-e}{y}\right] - \frac{x}{2}\ln\left[\frac{x^2+(y-a)^2}{x^2+y^2}\right] - (y-a)\tan^{-1}\left[\frac{x}{y-a}\right] + y\tan^{-1}(x/y) \qquad (1.a)$$

$$b_y(e,x,y) = (x-e)\tan^{-1}\left[\frac{y-a}{x-e}\right] + \frac{(y-a)}{2}\ln\left[\frac{(x-e)^2+(y-a)^2}{(y-a)^2+x^2}\right] - x\tan^{-1}\left[\frac{y-a}{x}\right] - \frac{y}{2}\ln\left[\frac{y^2+(x-e)^2}{x^2+y^2}\right] - (x-e)\tan^{-1}\left[\frac{y}{x-e}\right] + x\tan^{-1}(y/x) \qquad (1.b)$$

$$H(e,x,y) = \frac{J_T}{2\pi} \left[b^2_x(e,x,y) + b^2_y(e,x,y) \right]^{1/2} \qquad (1.c)$$

Equation (1.c) gives the expression of the magnetic field generated by the transport current as function of the sample geometry. J_T is the transport current density, e the sample thickness and a the sample width. This field has a maximun at the edges of the bar and a minimum at its axis.

From equations (1), an expression can be derived for the critical current density as a function of the thickness. For that purpose, we take into account the following facts:

a) As the junctions located at the edges of the sample are the most affected by the magnetic field H, we evaluate the field H(e) (equation 1.c) at $x = 0$, $y = 0$.

b) When the sample turns into the disipative regime, H(e) will be equal to H_D and J_T will be equal to Jc.

We then obtain:

$$J_c(e) = 2\pi H_D \left[b_x^2\ (e,0,0) + b_y^2\ (e,0,0) \right]^{-1/2} \qquad (2)$$

By means of equation (2), we are able to obtain the values of $Jc(e)/H_D$ for the measured thicknesses and correlate them with the measured values of critical current densities. The value of H_D is taken from the slope of the straight line shown in fig. 3. We found an H_D of 355.9 A/m (4.47 Oe), which corresponds to a field of 4.47 Gauss in vacuum . The continuous line of figure 2 fits equation 2 with the parameters obtained from this adjustment.

4- CONCLUSION

From the above discussion and in agreement with reference [1], we conclude that the increase in Jc with the reduction in thickness is due to the fact that as the sample gets thinner, larger values of Jc are required for the self magnetic field to reach the value H_D needed to turn the superconducting junctions into a disipative regime.

We have calculated the dependence of the critical current density with the sample thickness for a superconducting polycrystalline sample of rectangular cross section, getting an excellent agreement with the experimental results. This can be observed in figures 2 a and 3.

We obtained a value of 4.5 Oersted for the decoupling magnetic field H_D. This value is of the order of the values observed in plots of Ic versus applied field Ha in ceramic superconductors of similar granularity. Figure 4 shows one of these curves for a similar sample[10]. In this case, the field needed for the junctions to get into disipative regime is $H_{onset} \cong 5$ Oersted.

Note the great importance of the parameter H_D. It depends only of the microstructure of the material and it is a sensitive indicator of its variations. On the other hand, the critical current density Jc, as is clear from this work, depends on the geometry of the sample under study.

5- ACKNOWLEDGMENTS

We thank Lic. María Teresa Malachevsky for her useful comments and critical review of the present article.

6- REFERENCES

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7- FIGURE CAPTIONS

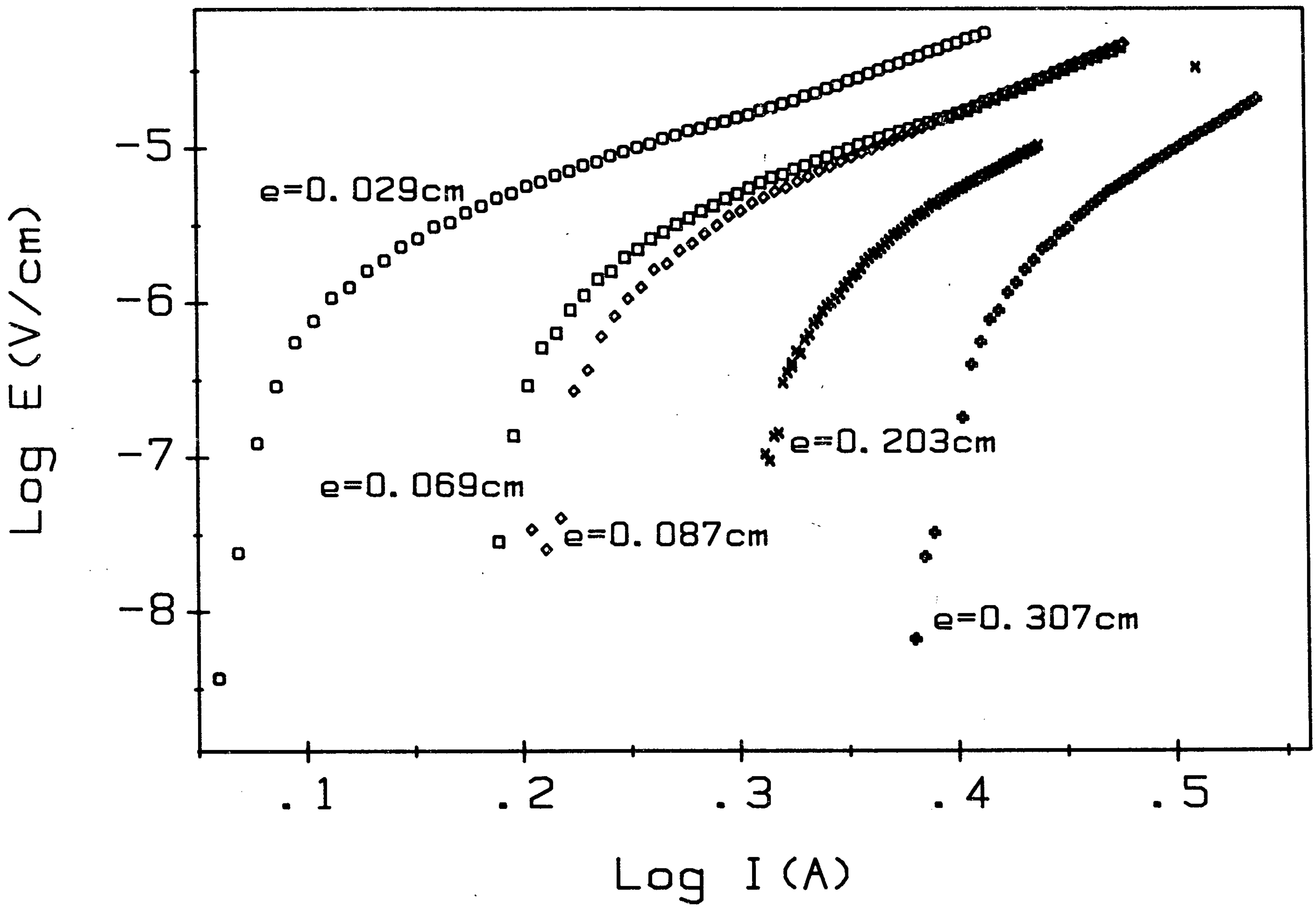
Figure 1 : Logarithmic plot of the electric field versus the applied current for different sample thicknesses (e).

Figure 2 : a) Experimental points showing the variation of Jc with sample thickness, fitted by Equation 2.

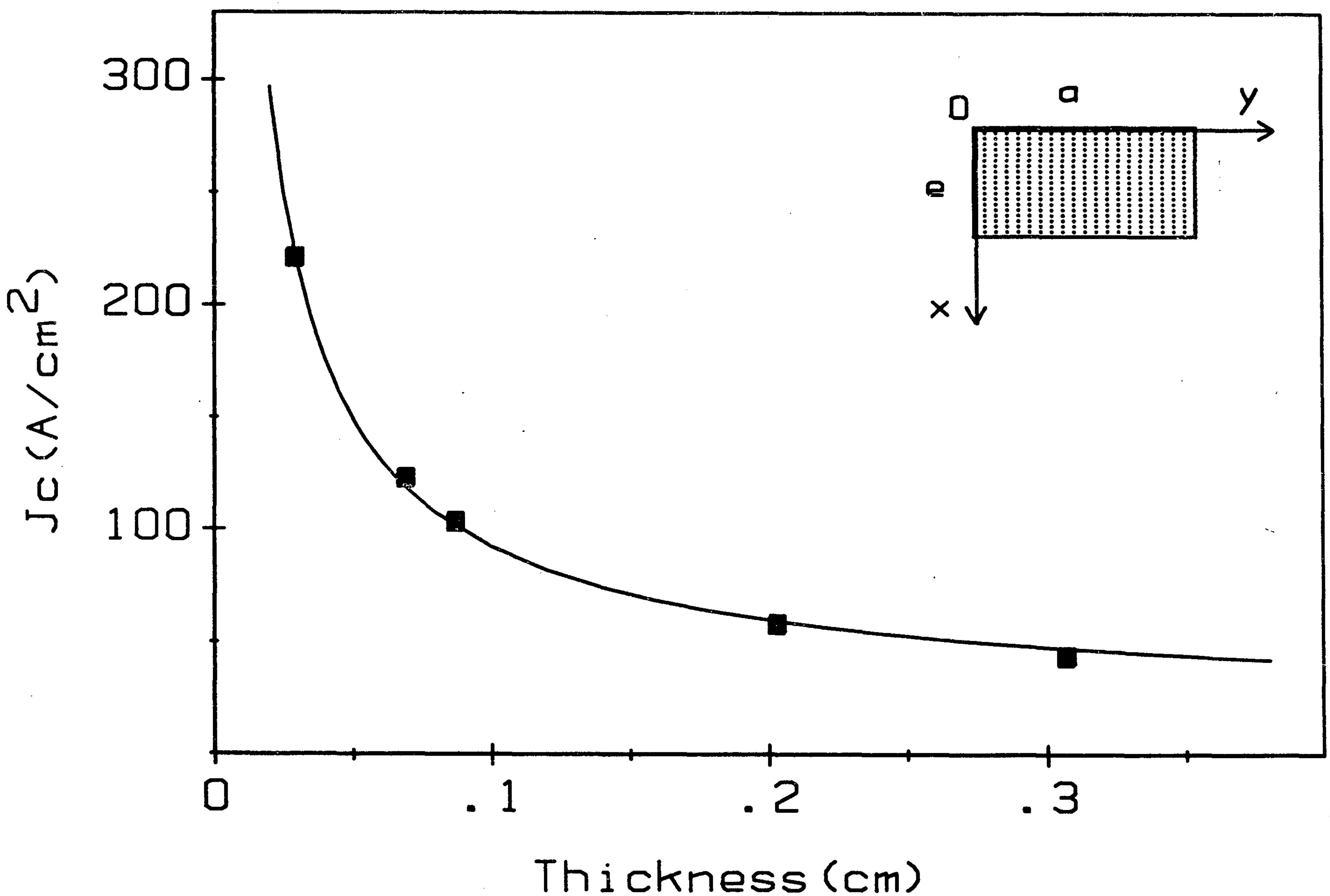
b) In the inset , sample cross section with integration coordinates.

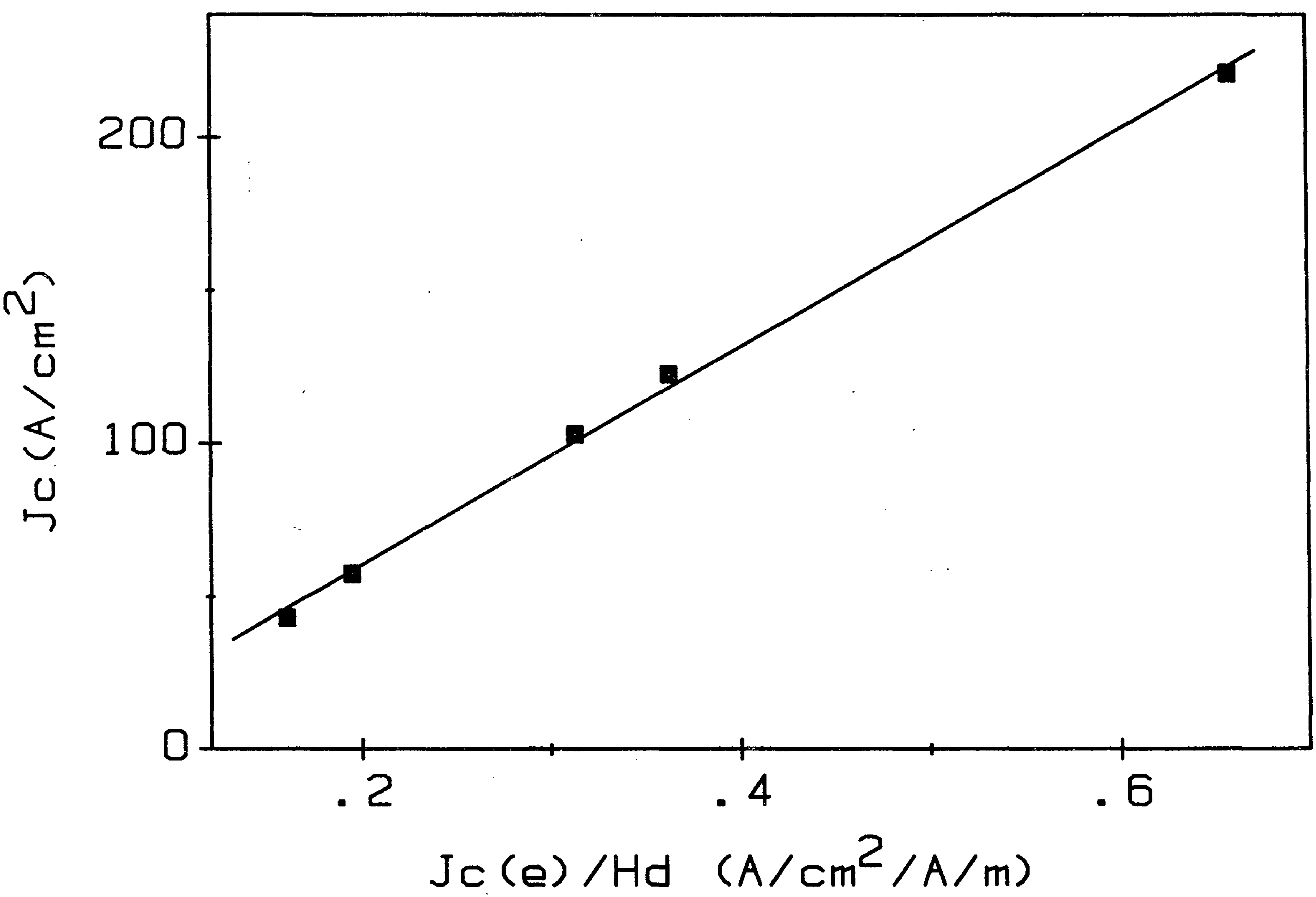
Figure 3 : Measured Jc as function of calculated $2\pi\ (b_x^2 + b_y^2) = Jc(e)/H_D$. The value of H_D is taken from the slope of the curve.

Figure 4 : Logarithmic plot of Ic versus applied magnetic field H_a for a similar Y-Ba-Cu-O sample (from reference 10).

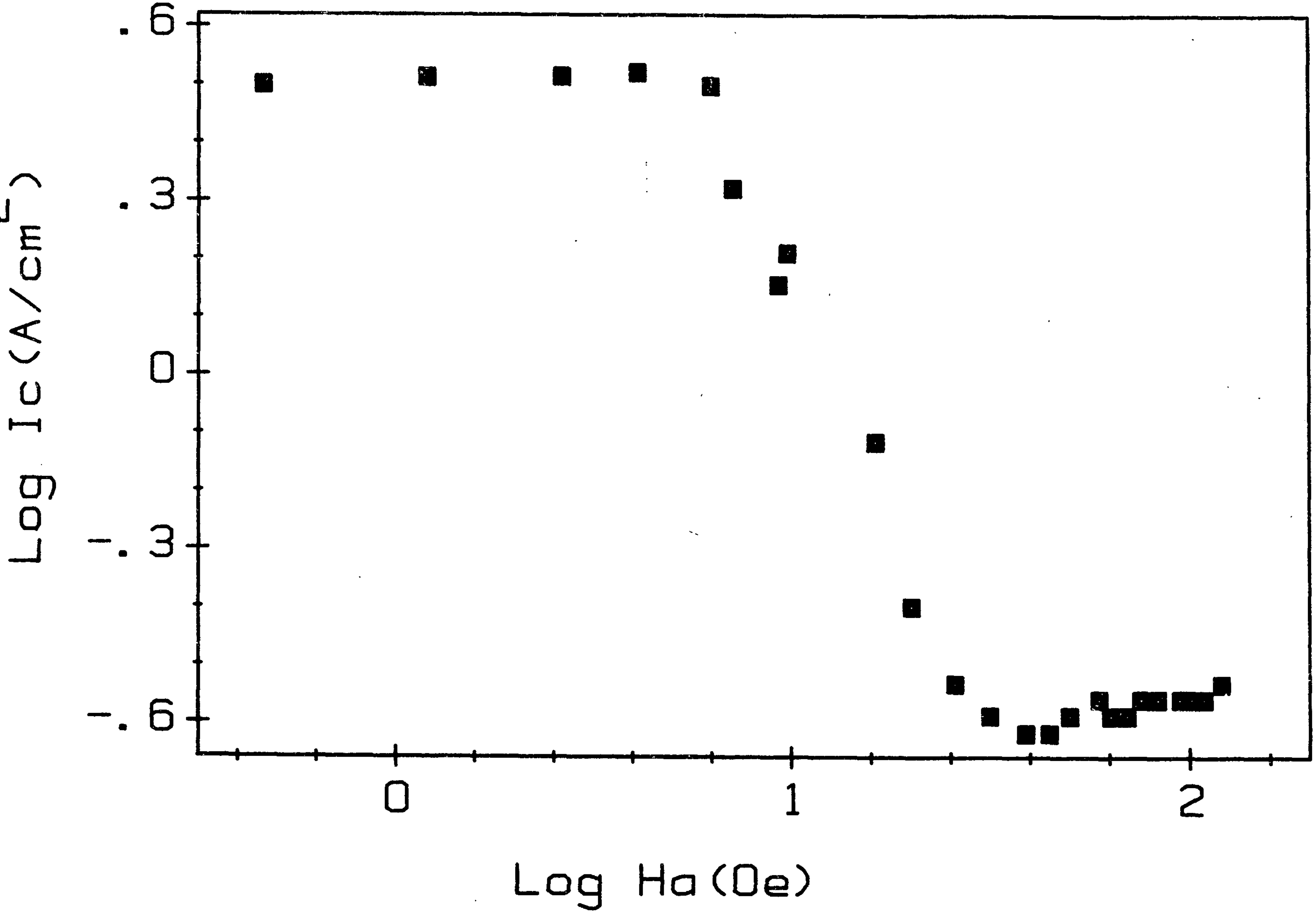


Log E (V/cm)
-5
-6
-7
-8
e=0.029cm
e=0.069cm
e=0.087cm
e=0.203cm
e=0.307cm
.1
.2
.3
.4
.5
Log I (A)


300
200
100
Jc (A/cm2)
0
.1
.2
.3
Thickness (cm)
0
a
y
e
x



200
100
0
Jc (A/cm2)
.2
.4
.6
Jc(e)/Hd (A/cm2/A/m)


.6
.3
0
-.3
-.6
Log Ic(A/cm2)
0
1
2
Log Ha(Oe)