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Two dimensional behavior and critical current anisotropy in $(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10+x}$ tapes

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Abstract

The critical current anisotropy $I_c(B,\vartheta)$ of Ag-sheathed Bi-2223 tapes has been measured in detail at 77.3 K. We find that $I_c(B,\vartheta)$ is influenced only by the c-component of the magnetic field and can thus be rewritten as $I_c(B\cdot\sin\vartheta)$. This is considered as evidence for two dimensional behavior of this high-T_c superconductor. The data do not follow this relationship anymore, if the angle ϑ between the field and the a,b-plane is smaller than about 10°. Referring to published results on single crystalline films of Bi:2212, this is attributed to misalignments of the grains from the a,b-plane. After careful examination of the I_c-B relationship up to 1.4 Tesla (both for B∥c and for B∥tape) and by dividing $B_{\parallel c}$ by $B_{\parallel tape}$ at the same I_c level, we obtain an almost field independent constant, which corresponds to an angle of around 10°. A comparison of different tapes reveals that the pinning ability plays the most important role for J_c rather than the degree of texture, if the texture is good enough.

1. Introduction

According to Lawrence and Doniach[1], a dimensional crossover from 3D to 2D appears in layered superconductors under the condition that the coherence length ξ_c perpendicular to the superconducting layers is smaller than the distance between these layers. In the case of Bi:2212, Kes et al. [2] proposed (1) that in an external magnetic field only the field component perpendicular to the layers gives rise to dissipative behavior and (2) that for the external magnetic field B aligned along the CuO_2 planes, B should not influence superconductivity as long as the temperature is below the crossover temperature T_0 from 3D to 2D behavior. This has been confirmed by Raffy et al.[3] and Schmitt et al.[4] in their experiments on Bi:2212 thin films.

In this paper, we demonstrate that the model is applicable at 77.3 K to the anisotropy $I_c(\theta)$ of Ag-sheathed leaded Bi:2223 tapes.

2. Theoretical considerations

The 2D behavior of HTSC can be briefly described as: (1) I_c(B∥ab) is constant when B changes and (2) $I_c(B,\theta)= I_c(B\cdot\sin\theta)$, where θ is the angle between the a,b-plane and B. To describe the anisotropy of I_c in textured polycrystalline Bi:2223 tapes, the directions of both a,b and c must be defined. Considering the fabrication technique of the

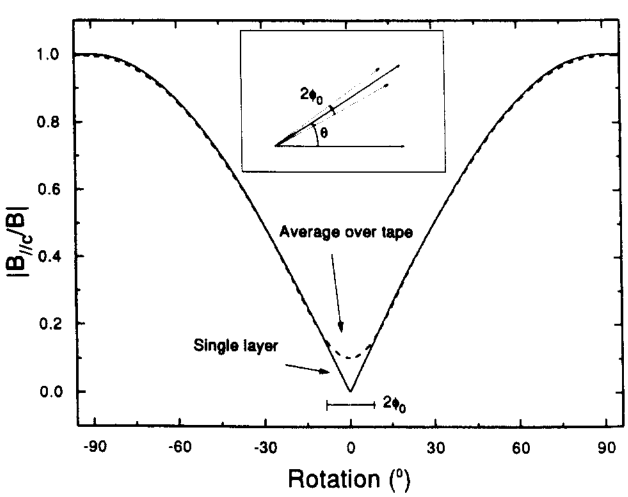

Fig. 1. Schematic illustration of the texture misalignment angle of the tape and the resulting averaging effect of B over the angular spread $2\varphi_0$.

tapes[5,6], it is reasonable to assume that the misalignment angles of the a,b planes of the grains are symmetrically distributed about the plane P which is parallel to the broad face of the tape, i.e. N(φ)=N(-φ), where N represents the number of the grains and φ is the angle between the a,b plane of each grain and P. We examine those two planes which enclose the largest angle, i.e. φ_0 and $-\varphi_0$ (Fig.1). We expect that the dissipation below T_0 is caused by the B component in the c-direction, i.e. $B_{\parallel c}$. Referring to

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fig.2, these field components are given by

$$B_{\parallel c}=B\cdot\sin(\theta+\varphi_0) \quad (1)$$

and by

$$B_{\parallel c}=B\cdot\sin(\theta-\varphi_0) \quad (2)$$

Therefore, when $0°<\theta<90°$, $B_{\parallel c}(\theta+\varphi_0)>B_{\parallel c}(\theta-\varphi_0)$ and when $90°<\theta<0°$, $B_{\parallel c}(\theta+\varphi_0)<B_{\parallel c}(\theta-\varphi_0)$. Only when $\theta=0°$, both are equal and the critical current of the tape reaches its maximum. We define $\theta = 0°$ as the plane parallel to the tape surface and therefore $\theta=90°$ corresponds to the c-direction. Because we are not able to align B along the a,b planes of all the grains, we do not expect to observe a $B(\parallel ab)$-independence of I_c, which appears in the case of high quality thin films.

3. Experimental

The tapes were fabricated by the powder in tube technique (PIT), the details of which can be found elsewhere[5,6]. The critical current densities of the samples are listed in table 1. The critical current I_c has been measured as a function of (1) the angle between the tape surface and the magnetic field direction in different magnetic fields and (2) of $B\parallel c$ and $B\parallel$tape, keeping the magnetic field and the current perpendicular to each other. An electrical field criterion of 10^{-6}V/cm has been used for the I_c measurement. The angular resolution of the rotation is better than 1°.

4. Results and discussion

Fig.2 shows the results of the critical current of the tape as a function of the angle between the magnetic field and the plane of the tape surface. According to fig.2, $B\cdot\sin\theta$ is the B component in c-direction, which is written as $B_{\parallel c}(B,\theta)$

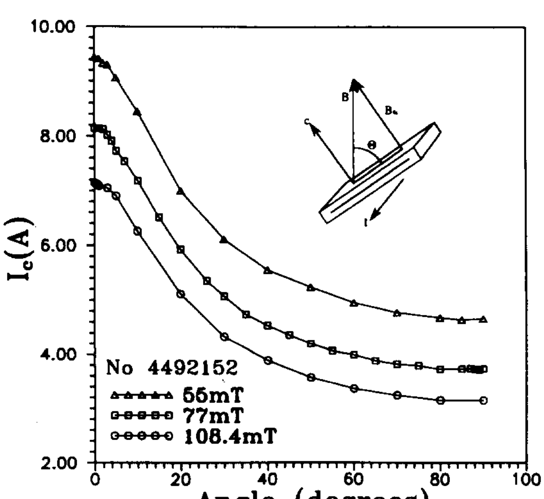

Fig. 2. Critical current as a function of the angle between the magnetic field and the tape surface.

in the following. In figure 3(a) and (b), the critical current of fig.2 is replotted as a function of $B_{\parallel c}(B,\theta)$ and for comparison, the magnetic field dependence of the critical current is also plotted in the same figure, where B is parallel to c-direction. From these figures, including 3(c) and (d) which present the results on other samples, we can see that, in the high field region, $I_c(B_{\parallel c}(B,\theta))$ coincides with $I_c(B\parallel c)$. This demonstrates that the dissipation behavior of this compound, at 77 K, results from $B_{\parallel c}$, i.e. the tape behavior is 2-dimensional. But in the low field regions, $I_c(B_{\parallel c}(B,\theta))$ deviates from $I_c(B\parallel c)$. This is not an indication of a failure of the 2D description, but caused by the texture misalignment of the tape. Because of the misalignment angle φ_0, $B_{\parallel c}(\theta)$ is not equal to $B\cdot\sin\theta$ anymore, instead

$$B_{\parallel c}(B,\theta)=B\cdot\sin\theta_{eff} \quad (3)$$

has to be used, where $\theta-\varphi_0<\theta_{eff}<\theta+\varphi_0$. According to fig.1, $B_{\parallel c}$ is averaged over the angular spread $2\varphi_0$. Let

$$dB_{\parallel c}(B,\theta)=B_{\parallel c}(B,\theta)-B_{\parallel c}(B,\theta_{eff}) \quad (4)$$

According to note 7, we get:

$$\frac{dB_{\parallel c}(B,\theta)}{B_{\parallel c}(B,\theta)}=ctg\theta\cdot d\theta \quad (5)$$

Considering the averaging effect, $d\theta$ in (5) can be substituted by $2\varphi_0$, i.e.,

$$\frac{dB_{\parallel c}(B,\theta)}{B_{\parallel c}(B,\theta)}=ctg\theta\cdot 2\varphi_0 \quad (6)$$

From (6), we see that $dB_{\parallel c}/B_{\parallel c}$ is proportional to $ctg\theta$. Therefore, the smaller the angle θ, the larger is the ratio. This means that the averaging effect becomes remarkable, when the angle decreases. Furthermore, the low field region corresponds to low angles and the high field region to high angles. In the high angle region, even though the averaging effect exists, differences between $I_c(B\parallel c)$ and $I_c(B_{\parallel c}(B,\theta))$ cannot be detected, because they are small and within the resolution of our measurement (fig.1). However, when θ decreases, i.e. in the low field region, $dB_{\parallel c}/B_{\parallel c}$ becomes larger and finally leads to a deviation of $I_c(B_{\parallel c}(B,\theta))$ from $I_c(B\parallel c)$.

Because the dissipation of the samples results only from $B_{\parallel c}$, the same I_c in the curves $I_c(B\parallel c)$ and $I_c(B_{\parallel c}(B,\theta))$ corresponds to the same $B_{\parallel c}$. Since $I_c(B_{\parallel c}(B,\theta))$ is reduced compared to $I_c(B\parallel c)$ in the low field region, the real $B_{\parallel c}$ should be larger than the calculated one, i.e. $B_{\parallel c}(B,\theta_{eff})>B_{\parallel c}(B,\theta)$. The value of $B_{\parallel c}(B,\theta_{eff})$ in the curve $I_c(B_{\parallel c}(B,\theta))$ corresponds to the field of the curve $I_c(B\parallel c)$, at the same I_c level. At $\theta=0°$, $B_{\parallel c}(B,\theta_{eff})= B_{\parallel c}(B,\theta+\varphi_0)=B_{\parallel c}(B,\varphi_0)$, and φ_0 can be calculated from $\sin\varphi_0=B_{\parallel c}(B,\varphi_0)/B$. The calculated results are listed in Table 1. Hu et al. proposed[8] that for a rotation of the

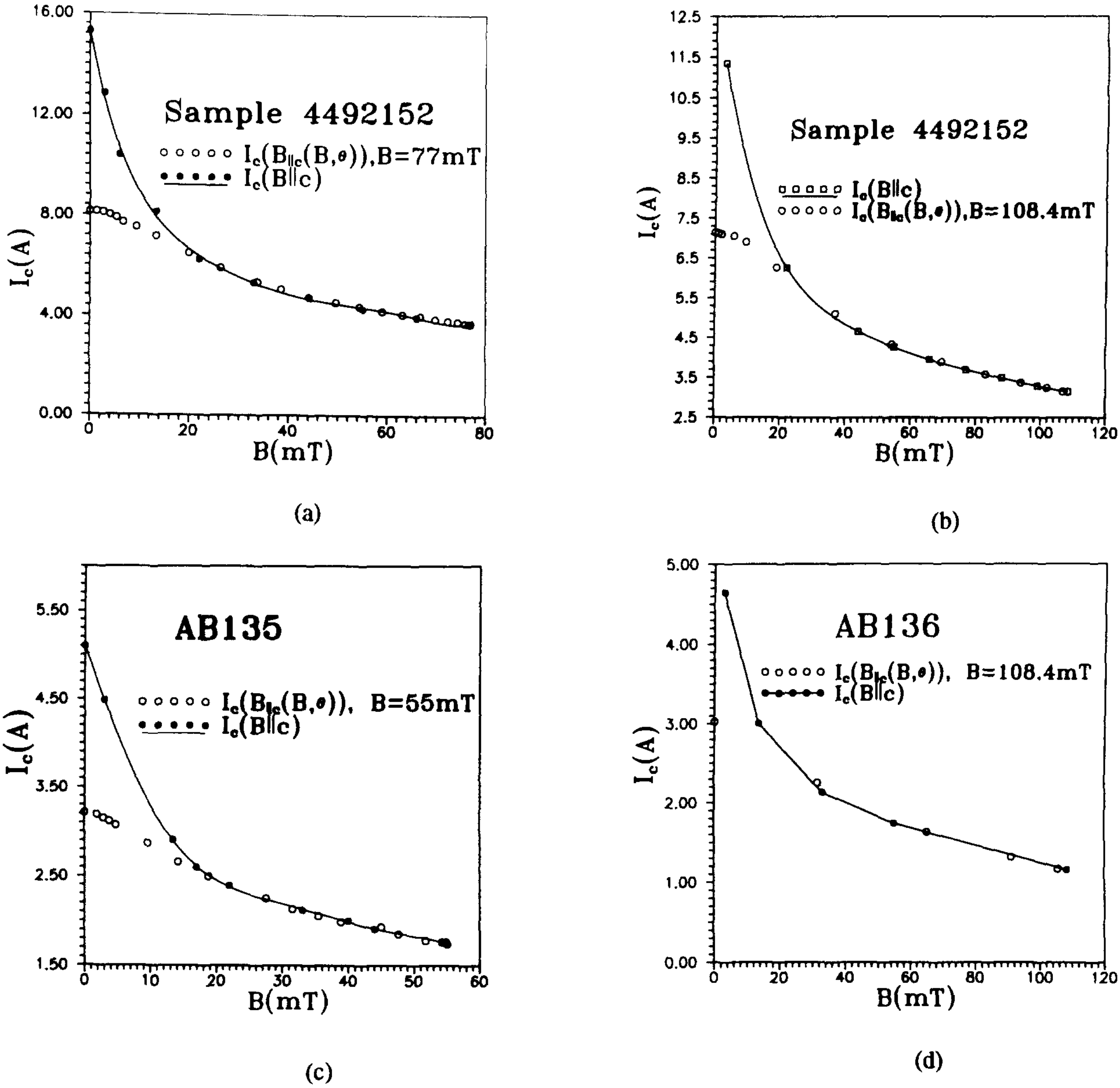

Fig. 3. Critical current as the function of $B_{\parallel c}(B,\theta)$ and B∥c: (a) sample 4492152, 77 mT (b) sample 4492152, 108.4 mT (c) sample AB135, 55mT and (d) sample AB136, 108.4 mT.

tape in a field B from its c-direction (θ=90°) to its a,b-direction (θ=0°), $I_c(B,\theta)$ will go along I_c(B∥c) from point c to point b and be cut off by I_c(B∥ab) (point a). From fig.4, we can see that in a field B, point c corresponds to $I_c(B_{\parallel c}(B,\theta=0°))$. Using the results of fig.4, we calculate φ_0 of the tape over the whole field range investigated. We note that although I_c changes with B∥c and B∥tape, φ_0 varies very little, i.e. by less than 2°, as shown in fig.5. This is not surprising because the texture misalignment of the tape is an intrinsic property and should not change with field. Wilhelm et al.[9] have reported on a misalignment angle of 10° of the platelets based on SEM observations along the longitudinal section of a Bi:2223 tape. This is quite similar to our results. However, the misalignment angle that we define, is in the plane of the cross section of the tapes.

Table 1 lists the values of φ_0 of different samples. It shows that sample AB136 has a smaller φ_0 than sample 4492152 and therefore a better degree of texture. On the contrary, AB136 has a lower J_c than the latter. Another sample, AB135 possesses almost the same J_c as AB136, but its φ_0 is 12°, which is nearly twice as large as that of AB136. These facts, namely that a smaller φ_0 does not guarantee a higher J_c and that samples with the same J_c may have different φ_0, suggest that the pinning capability for $B_{\parallel c}$ is the most important factor for the enhancement of J_c, when φ_0 is small enough. We suggest, that the

Table 1. Critical current density and misalignment angle

Sample	J_c (77.3 K, 0T)	φ_0
#4492152	$2.77\cdot10^4$ A/cm^2	10°
#AB135	$1.73\cdot10^4$ A/cm^2	12°
#AB136	$1.67\cdot10^4$ A/cm^2	7°

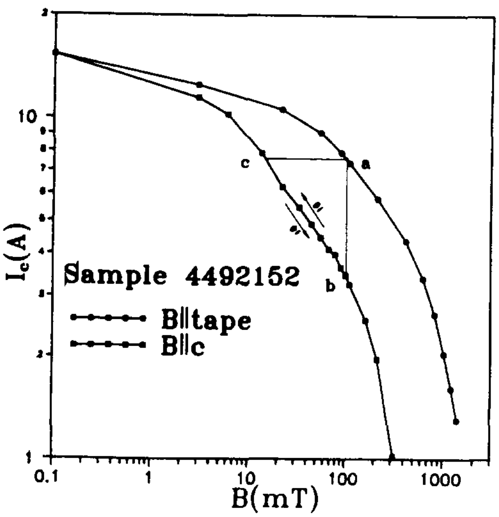

Fig. 4. Critical current of tape 4492852 as a function of B for B||tape and B||c.

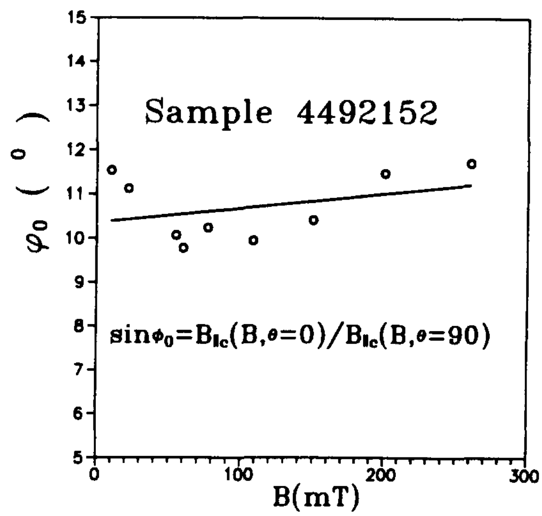

Fig. 5. Texture misalignment angle calculated from fig.4.

efforts toward improving J_c of Bi:2223 tapes should concentrate on the introduction of extrinsic pinning defects such as dislocations, twin boundaries and surface pinning effects, which would play an important role for $J_c(B_{lc})$, rather than on attempts to obtain tapes with higher degrees of texture.

5. Conclusions

Two dimensional behavior of superconductivity has been observed in polycrystalline Ag-sheathed leaded Bi: 2223 tapes. The texture misalignment angle of the tapes is calculated from the data of $I_c(B,\theta)$ measurements and found to be around 10°. We suggest that, for tapes with small misalignment angles, the pinning capability for B_{lc} is the determining factor of J_c .

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References and notes

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7. Note:
In an external magnetic field, the c-component of the field is given by

$$B_{lc} = B\cdot\sin\theta \qquad (1).$$

Differentiation of (1) leads to

$$dB_{lc} = B\cdot\cos\theta\cdot d\theta \qquad (2).$$

Substituting B from (1) into (2) results in

$$dB_{lc} = B_{lc}\cdot\mathrm{ctg}\theta\cdot d\theta \qquad (3)$$

or

$$dB_{lc}/B_{lc} = \mathrm{ctg}\theta\cdot d\theta \qquad (4).$$

(4) represents, therefore, the relative change of B_{lc} with θ.
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