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ANISOTROPY OF THE CRITICAL CURRENT DENSITY IN HIGH QUALITY $YBa_2Cu_3O_{7-\delta}$ THIN FILM

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Abstract: We have investigated the transport critical current density J_c as a function of the angle θ between the crystallographic *c*-axis and the applied magnetic field in high quality $YBa_2Cu_3O_{7-\delta}$ thin film. Measurements were performed for various temperature and magnetic field values. Our results show that the critical current density maximum occurs when the applied magnetic field is parallel to the *ab* planes (θ = 90°).The angular dependence of the critical current density shows the existence of the intrinsic pinning between the CuO_2 layers for *H* parallel to the *ab* planes and the extrinsic pinning in the configuration where the magnetic field is parallel to the *c*-axis. We have analyzed our results in the framework of the intrinsic pinning model proposed by Tachiki and Takahachi

Key words: The Critical Current Density; Intrinsic Pinning; Anisotropy

1. INTRODUCTION

The high critical temperature superconductors show a strong anisotropy in different properties: critical current density [1], resistivity [2, 3] and the upper critical field [2].

A large anisotropy in the superconducting critical current density J_c of high temperature superconducting thin film have been reported [4, 5]. A large enhancement when the applied magnetic field H (perpendicular to J) is precisely parallel to the copper-oxygen planes of the lattice structure. Also there are theoretical arguments that the enhancements arise from intrinsic flux pinning when the vortex cores are located in the weak superconducting regions between the Cu-O layers [6].

An intrinsic pinning model was proposed by Tachiki and Takahachi [7]. They derived the angular dependence of J_c. The intrinsic pinning model is based on the layer structure in the oxide superconductors which consist of strong superconducting layers such as CuO_2 and weak superconducting layers such as CuO chains and BaO planes in $YBa_2Cu_3O_{7-\delta}$. They supposed that weak superconducting layers work as natural pinning centers. The existence of extrinsic pinning centers, however was also assumed in this model.

They assumed that the flux lines may be pinned by weak superconducting layers (intrinsic pinning centers) or extrinsic pinning such as twin planes. They supposed that weak superconducting layers and twin planes work as pinning centers most effectively when $\theta = 90°$ and $\theta = 0$, respectively.

In this work, we have measured the critical current density of $YBa_2Cu_3O_{7-\delta}$ thin film in strong magnetic field H up to 10 T at various angle θ between H and the crystallographic c-axis. We have compared our results to the intrinsic pinning model proposed by Tachiki and Takahachi [7].

2. EXPERIMENTAL DETAILS

The epitaxial $YBa_2Cu_3O_{7-\delta}$ thin films were deposited by laser ablation method onto (100) surface of single crystal $SrTiO_3$. The sample showed a zero resistivity at 90 K in zero magnetic field. The film thickness and width were 400 nm and 7.53 μm, respectively. Electrodes of power measurement are in gold and deposited by in situ evaporation. The distance which separates this electrode was 135 µm. Contact resistance's were less than 1 Ω. Measurements were realized by using the DC four-probe method.

In order to rule out distortions of the *E-J* curve by extensive heating that could be induced by the very high extensive heating that could be induced by the very high dissipation levels employed here, a pulsed current power supply was used with a time duration $\tau = 10$ ms, a waveform repeat time of 2 s and an average over 64 pulses at the same fixed *J*, *T* and *H*.

The microstructure of several of these thin films was studied extensively, using Transmission Electron Microscopy (T.E.M.). These T.E.M. observations together with X-ray Energy Dispersion Spectroscopy (E.D.S.) as well as usual X-ray spectra show that the films are highly homogeneous and have essentially a single YBCO (123) phase.

Transmission electron microscopy (T.E.M.) observations performed on our samples revealed not only the presence of the usual twin boundaries as the major visible defect but also, a set of columnar-like defects. In addition, the sample certainly contains also point defects, in particular oxygen vacancies.

3. RESULTS AND DISCUSSION

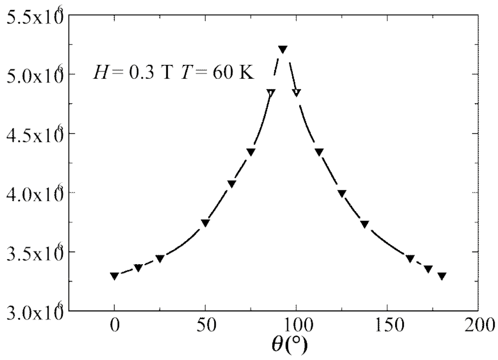

Figure III:5:1. The critical current density as a function of the angle θ at 0.3 T and 60 K.

In figure 1, we present an example of the critical current density J_c variations as a function of the angle θ between the crystallographic *c*-axis and the applied magnetic field.

The magnetic field and temperature values are 0.3 T and 60 K, respectively.

As can be seen in this figure, J_c increases as θ increases, it reaches its maximal value at $\theta = 90°$ corresponding to the configuration where the applied magnetic field is adjusted parallely to the *ab* planes of the sample. After the maximum value, $J_c(\theta)$ decreases and reaches its initial value.

We plot in figure 2 the angular dependence of the critical current density J_c/J_{c1}, J_{c1} is the critical current density when a magnetic field is applied parallel to the film surface. We note that J_{c1} is independent of the angle θ. The solid circles are the experimental data obtained for $YBa_2Cu_3O_{7-\delta}$ thin film at 10 T and 60 K. For comparison, the solid curve presents the theoretical values given by [8]

$$J_c = \frac{J_{c2}}{|\cos\theta|^{1/2}}$$

where J_{c2} is the critical current density in the configuration where the magnetic field is parallel to the *c*-axis. The values of J_{c1} and J_{c2} are 1.35×10^6 A/cm^2 and 3.7×10^5 A/cm^2, respectively.

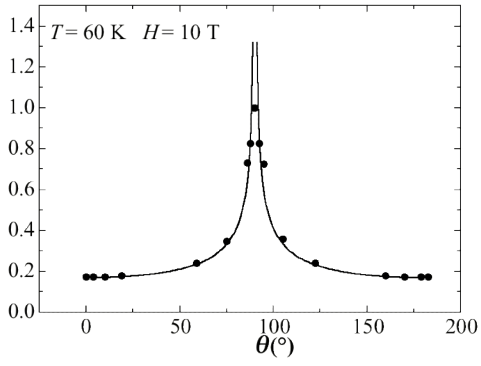

Figure III:5:2. Angular dependence of J_c/J_{c1} at 60 K and 10 T as a function of the angle θ. $J_{c1} = 1.35 \times 10^6$ A/cm^2 and $J_{c2} = 3.7 \times 10^5$ A/cm^2.

As can be seen, in this experimental condition, the theoretical curve proposed by the intrinsic pinning model of Tachiki and Takahachi are in good agreement with our experimental data.

The experimental values obtained at 60 K, in an applied magnetic field of 0.6 T are plotted in figure 3. For comparison, with the theoretical values the solid line presents the intrinsic pinning model values using $J_{c1} = 6.07\text{x}10^6$ A/cm^2 and $J_{c2} = 2.3\text{x}10^6$ A/cm^2.

The concordance between the two curves is less good than in the case where the applied magnetic field is 10 T especially for angles close of 90°.

A single crystal film of $YBa_2Cu_3O_{7-\delta}$ is considered with the CuO_2 layers parallel to the film surface. These layers and their vicinities are strongly superconductive and the other layers like CuO chains are weakly superconductive. Accordingly, these crystals are considered to be constructed by an alternate stacking of strongly and weakly superconducting layers.

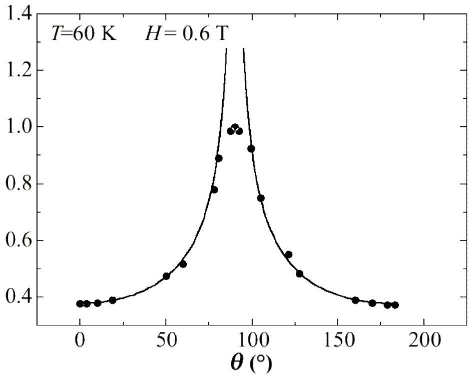

Figure III:5:3. Angular dependence of J_c/J_{c1} at 60 K and 0.6 T as a function of the angle θ. $J_{c1} = 6.07\text{x}10^6$ A/cm^2 and $J_{c2} = 2.3\text{x}10^6$ A/cm^2.

At low temperature, flux lines preferentially penetrate into the weakly superconducting layers cause they are stabilized the most when they are at the weakly superconducting layers, since the loss of the superconducting energy due to the inclusion of the flux lines is least in this case.

The peak in $J_c(\theta)$ at $\theta = 90°$ corresponding to the configuration where the magnetic field is parallel to the *ab* planes can be explained by the following pinning mechanism which is characteristic for the layered oxide. The weakly superconducting layers work as natural pinning centers. The pinning strength is considerably high, and thus the critical current density becomes very high. The critical current density is strongly dependent on the direction of the applied magnetic field.

In the weak magnetic field region (0.6 T), the experimental results are not in agreement with the intrinsic pinning model. In this case, the flux pinning at the film surface becomes more dominant than the intrinsic pinning by the *ab* planes.

We have reported a large anisotropy in the critical current density J_c of high quality $YBa_2Cu_3O_{7-\delta}$ thin films. A large enhancement of J_c when the applied magnetic field H is precisely parallel to the Cooper-Oxygen planes of the lattice was observed.

REFERENCES

1. Y. Enomoto, T. Murakami, M. Suzki, K. Moriwaki, Jpn. J. Appl. Phys., 1987; 26: L1248.
2. Y. Iye, T. Tamegar, T. Sakakibara, T. Goto, N. Miura, H. Takeya, H. Takei, Physica C, 1988; 153-155: 26.
3. A. Taoufik, S. Senoussi, A. Tirbiyine, Ann. Chim. Sci. Mat, 1999; 24: 227-232.
4. D. K . Christen, et al., Physica C, 1989; 162: 653.
5. B. Roas, L. Schultz, G. Saemann-Ischenko, Phys. Rev. Lett., 1990; 64: 479.
6. M. Tachiki, S. Takahachi, Physica C, 1989; 162-164: 241.
7. M. Tachiki, S. Takahachi, Solid State Commun., 1989; 70: 291.
8. M. Tachiki, S. Takahachi, Solid State Commun., 1989; 72: 1083-1086.