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Study of the Behaviour of Critical Properties and Pinning Force in $YBa_2Cu_3O_{7-\delta}$

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Abstract In this work we have studied the critical properties of $YBa_2Cu_3O_{7-\delta}$ thin films. We have examined the variation of J_c as a function of temperature for different values of a fixed magnetic field. This investigation shows that, in the absence of thermal activation and for the weaker values of magnetic field, J_c exhibits a behaviour according to$[1-(T/T_c)^2]^{m'}$ with a critical exponent m' varying with a variation of magnetic field. On the other hand, we studied the variation of m' parameter with the pinning force variation for different value of magnetic field. More scaling formulas were used to adjust our results in a large range of temperature and field, different parameters depending on the pinning mechanism such as m, γ, n and δ were determined. m and γ represent respectively the temperature and magnetic field dependence. Moreover, the values of m are related to the pinning force variation. The calculated value of n is compared with other investigations results, n is a good parameter reflecting the anisotropy of superconductor's.

Keywords Superconductor YBaCuO, Critical properties, Critical current density, Pinning mechanism

1. Introduction

In order to explain the mixed state of a HTc superconductors, several researchers have studied the dynamic of the vortices. When a current is applied to a superconductor sample, the flux lines become in motion above a critical current density J_c threshold below which the flux lines are pinning.

The critical current density J_c is one of the most important parameters for application of superconductor materials. In the absence of thermal activation of flux pinning, the expression of J_c as function of temperature and magnetic field is[1]:

$$J_c(H,T) = A\, \mu_0^{m-1} H_{c2}^{m-\gamma}(T)\, H^{\gamma-1}[1-H/H_{c2}(T)]^{\delta}$$

m, γ and δ are parameters depending on the pinning mechanism, A is a constant. The upper critical field is expressed as function temperature with:

$$H_{c2}(T) = H_{c2}(0)[1-(T/Tc)^2]$$

For the weak values of magnetic fields, the expression of J_c is given as:

$$Jc = Jc(0)[1-(T/T_c)^2]^{m'}$$

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In this paper we will study the volume of pinning force of vortices in a superconductor type II. We will discuss the variation of pinning force with different applied magnetic field and we will determine the dependence of critical properties m and m' to the pinning force on the Kramer model for weak magnetic field.

n is depending on m and γ parameters, several investigations show that n is a parameter in expression of irreversibility field H_{irr} with H_{irr} is proportional to$[1-(T/Tc)]^n$. The value of n is a factor of film quality and strength flux pinning .

In this work, we will determine the value of m, γ, δ and n for our $YBa_2Cu_3O_{7-\delta}$ film.

2. Experiments

The studied sample is a monocristalline YBaCuO thin film deposited by the ablation laser method on the surface (001) of a $SrTiO_3$ substrate. In zero magnetic field, the resistance vanished a T_c= 90K. The C-axis of YBaCuO is perpendicular to surface on the film. Electrodes of measurement are in gold and deposited on the surface of the sample in situ by evaporation. The film has a thickness of 400 nm, and a width 7.53 µm. The distance between electrodes of power measurement is 135 µm. Contact resistances were less than 1 Ω[2]. A direct current, perpendicular to the magnetic field, is applied on edge of the sample.

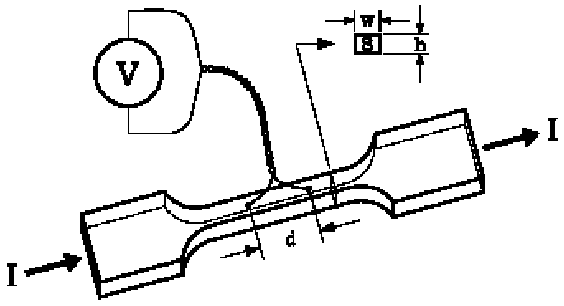

Figure 1. Schematic representation of the sample with the electrical contacts of transport measurements d = 135 µm, h = 400 nm, w = 7.53 µm

3. Experimental Results and Discussion

In figure 2, we shown the variation of critical current density J_c as function of $1-t^2$ with $t=T/T_c$, at different values of constant magnetic field. With the use of a linear fitting, we have determined the exponent *m*' for each value of the magnetic field.

$$J_c(t) = J_c(0)(1-t^2)^{m'} \quad (1)$$

Table 1 shows the obtained values of *m*', for the lower values of magnetic field. We observe that the value of *m*' increases when the magnetic field increases.

Table 1. Value of m' for the lower magnetic field

H (T)	0.2	0.6	1.2
m'	1.45	2.20	2.71

Referring to our previous research about pinning force A. Bouaaddi and al[3]. The variation in the volume density of pinning force as function of applied magnetic field is given on figure 3.

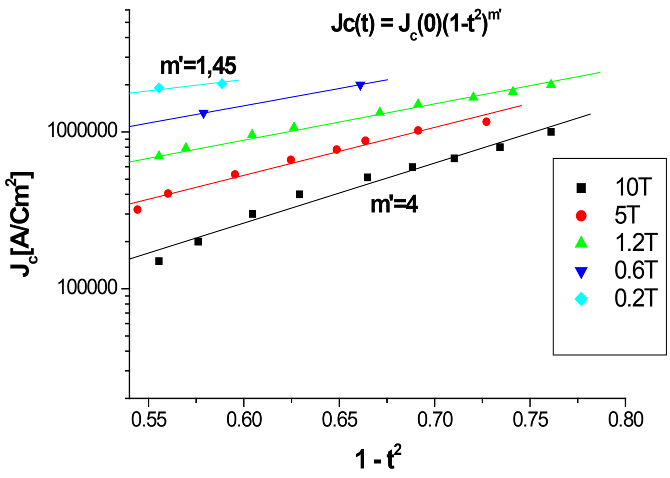

Figure 2. Variation of J_c as function as $1-t^2$, $t=T/T_c$

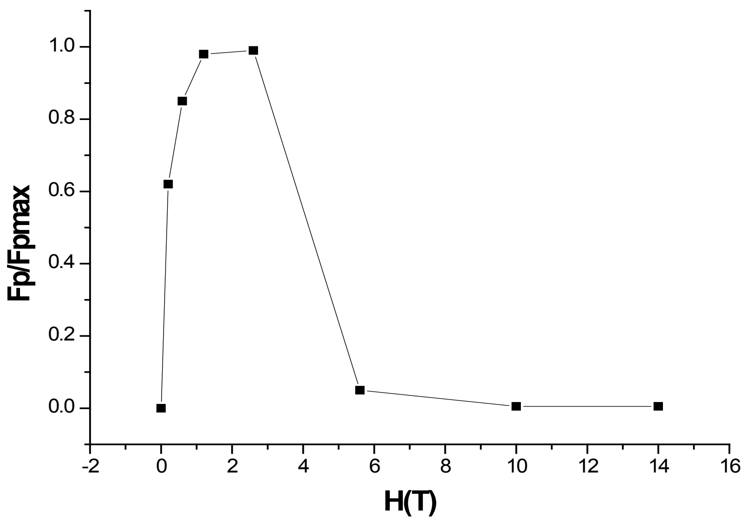

Figure 3. Variation of volume density of pinning force as function of applied magnetic field H // c

From figure 3, we observe that the volume density of pinning force presents two forms of behaviour with a high and weak magnetic field. For the lower values of magnetic field, Fp raises when the magnetic field increases. Referring to table 1, we can conclude that in Kramer model[4], the value of m' parameter increases with the increasing of pinning force.

In the absence of thermal activation of flux pinning, the expression of critical current density is given as:

$$J_c(H,T) = A\,\mu_0^{m-1}\,H_{c2}^{m-\gamma}(T)\,H^{\gamma-1}[1-H/H_{c2}(T)]^{\delta} \quad (2)$$

$H_{c2}(T)$ expression is:

$$H_{c2}(T) = H_{c2}(0)\,(1-t^2) \quad (3)$$

Then, the formula of equation (2) becomes:

$$J_c(b_0,t) = J_\gamma\, b_0^{\gamma-1}(1-t^2)^{m-\gamma}[1-b_0/(1-t^2)]^{\delta} \quad (4)$$

With $J_\gamma = A\,\mu_0^{m-1}\,H_{c2}^{m-1}(0)$, $b_0 = \mu_0 H/\mu_0 H_{c2}(0)$

When the applied magnetic field is weak, we can neglect$[1-b_0/(1-t^2)]^{\delta}$ term and equation (4) scale as equation (1) with $m' = m-\gamma$

When the applied magnetic field increases, the term$[1-H/H_{c2}(T)]^{\delta}$ becomes effective.

We have concluded that the expression of critical current density J_c for the lower values of magnetic field is:

$$J_c(b_0,t) = J_\gamma\, b_0^{\gamma-1}(1-t^2)^{m-\gamma}$$

From Equation (1) we can write $m' = m - \gamma$

The value of γ is depending on the temperature. However, the value of γ is constant for each value of temperature.

From $m = m' + \gamma$ and for a constant value of temperature. When the value of m' increases, the value of m increases too.

We can conclude that in Kramer model for the lower values of magnetic field, the value of m increases with the increasing of pinning force.

Subsequently, we will determine the value of n parameter in our sample. Referring to figure 1, we can determine the value of m' $(m-\gamma)$ with the weakest magnetic field, equals to 1,45.

Referring to literature, we can find that the value of δ equals 2[5].

Figure 4 shows the dependence of J_c as function magnetic field for each value of temperature.

From figure 4, we can determine the value of γ with a low value of temperature to avoid the flux creep. In figure 5, for a value of T = 50 and referring to Equation (4), we can observe that J_c depending of magnetic field as $J_c(H) \approx H^{-0.5}$.

Then $\gamma - 1 = -0{,}5 \Leftrightarrow \gamma = 0{,}5$ and $m = m' + \gamma = 1{,}95$.

The expression of the n parameter mentioned above is given as[5]:

$$n = 2(m-\gamma)/(3-2\gamma).$$

With $m = 1.45$ and $\gamma = 0{,}5$, we can determine that the value of n equals to 1,45 ($n \approx 1{,}5$).

It's known that the value of n increases with the degree of anisotropy of superconductors[6,7], according to other previous researchs, we find that the value of n in YBCO films is nearly equals 1,5[8,6].

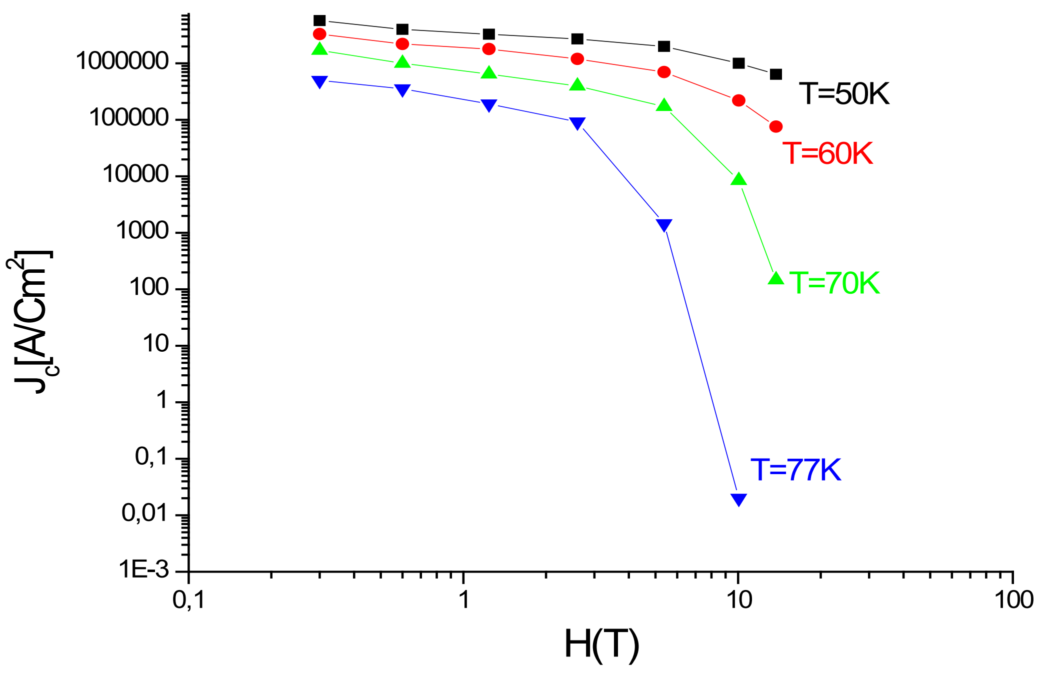

Figure 4. Variation of J_c as function as magnetic field for different values of temperature

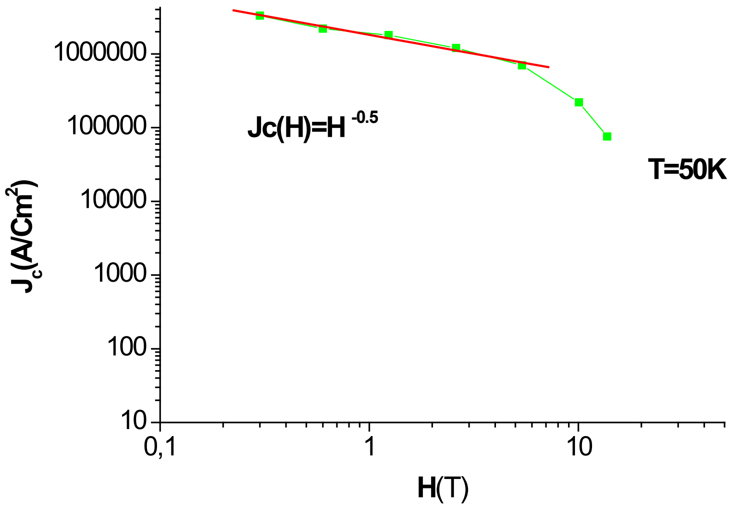

Figure 5. Variation of J_c with magnetic field H for T= 50K

4. Conclusions

In this work, we have presented a research of some parameters of the YBCO high T_c superconductor such as *m*, γ and δ depending on pinning mechanism. The main results in this research are the dependence of the parameters m and m' to the volume density of pinning force. In the Kramer model, for the weaker values of the magnetic field, m and m' increase with the increasing of the pinning force. On the other hand, the result of the n parameter (n ≈1,5) in our sample with 400 nm of thickness is estimated to be in consistence with other author's finding.

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