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Hysteresis curves of the flux motion in $YBa_2Cu_3O_{7-\delta}$ thin films with nanoscale pinning centers

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Epitaxial $YBa_2Cu_3O_{7-\delta}$ thin films were prepared by DC magnetron sputtering technique. The Y_2O_3 nanoprecipitates were evidenced the complete thickness. Magnetic hysteresis measurements using a SQUID based DC magnetometer were performed. From the M(H) curve we deduced the critical current density J_c values function of magnetic field. The Kim and Bean critical state models were used for estimation of J_c.

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1. Introduction

Type II superconductors show three main regimes of behaviour in an external magnetic field. For a given temperature below T_c, there is no flux penetration provided that the applied field is below a lower critical value H_{c1}. As the external field is increased and exceeds an upper critical value H_{c2}, the sample reverts to its normal state. In the region between H_{c1} and H_{c2}, known as the vortex or mixed state, a lattice of quantized flux enclosing vortices is formed. The technological usefulness of type-II superconductors is directly linked to the pinning vortices in the material [1]. Increasing the current density J beyond the critical value J_c lead to the depinning of vortices and to dissipation in superconducting state.

In conventional superconductors NbTi and Nb_3Sn, the problem of controlling structural defects in order to enhance the flux pining was early solved, leading to industrial applications like wires, magnets, SQUIDS, etc.

In high temperature superconductors (HTS), thermal activation produce enough energy to unpin some vortices and restore dissipation in material, and the progress in enhancing the flux pinning is little. As the coherence length ξ(T) is rather small in HTS as compared to the conventional superconductors, the activation energy U(B,T) is determined by the coherence length, and the ratio U/k_BT is considerably reduced in HTS. In order to achieve high J_c, one has to effectively pin the flux and thereby to reduce the flux creep rate. Small defects with dimensions which not exceed 100 Angstrom were used as best pinning centers.

The importance of thermal activation in HTS leads to the existence of irreversibility line (IL) in the B-T diagram. Below this line pinning dominates thermal activation and the flux lines remains trapped in the pinning wells [2]. As the external field is swept up and down, a nonuniform spatial distribution of vortices appears, and a macroscopic supercurrent flow is observed. In this case the magnetic behaviour is of the material is hysteretic, and is designed as irreversible.

For the c-axis oriented $YBa_2Cu_3O_{7-\delta}$ (Y:123) thin films, the presence of Y_2O_3 precipitates as a defect is also observed [3-4].These precipitates grow semi coherently in a cubic form having a volume between 100 and 1000 nm^3, with a density estimated at 10^{16} particles/cm^3 [4]. These defects can be considered as good candidates for the effective pinning centers. Close to the surface of the film also some rectangular shaped Y_2O_3 precipitates have been identified [4].

2.Experimental

DC magnetron sputtering technique were used for the synthesis of high quality epitaxial thin films of the superconducting $YBa_2Cu_3O_{7-\delta}$ on MgO substrate. The FWHM (full width for high maximum) of rocking curve shows that the lineshape is equal to 0.247^0, and confirmed the excellent epitaxial quality of thin film, and the Y_2O_3 nanoprecipitates were evidenced throught the complete thickness [5].These normal defects with a numerical density estimated at 10^{16} particles/cm^3 and are fullfiling all the conditions for being effective pinning centers.

Electrical resistivity measurement function of temperature shows a critical transition temperature T_c = 88K and the transition width ΔT_c=1 K. The lower value of residual resistivity (defined by the linear extrapolation of the normal state resistivity), ρ(0K) = 2 μΩ cm, suggest the good quality of thin film.

The hysteresis curves M(H) were obtained by DC SQUID magnetometer technique, for different temperatures ranging from 5 to 60K.The film was mounted with its c-axis parallel to the magnetic field inside a quartz tube, was warmed up above the critical transition temperature and was then cooled down below T_c in zero applied field. So in this case the initial magnetization curve is close to zero.

3. Results and discussion

Figure 1 shows the initial magnetization curve of thin film, at 10K, for H //c. This curve reveals the presence of two characteristic fields: H_{c1} when the first flux lines penetrate the sample (and M change the linear dependence on applied field) and H_p corresponds to maximum magnetization. The first critical field is quite low, H_{c1}= 275 G at 10K. The determination of H_p is important in order to be sure that the sample is fully penetrated by magnetic field, and we can apply any critical state model to experimental data. The critical fields H_{c1} and H_p decrease with increasing temperature. A further increase of magnetic field leads to the decrease of magnetization and it reaches zero at the irreversibility field.

Table 1.Kim model parameters for different temperatures.

Temperature [K]	J_c [10^6 A/cm^2]	H_k (G)	Square res. R^2
10	9.30	0.56	0.99532
20	6.92	0.98	0.99536
30	5.98	1.57	0.98139
40	4.37	2.50	0.97645

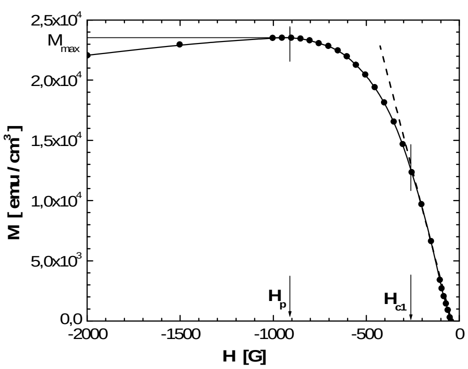

Fig.1. The critical fields H_{c1} and H_p of $YBa_2Cu_3O_{7-\delta}$ film from M(H) dependence at 10K for H//c.

In figure 2 we present the magnetization as a function of the field for different temperatures ranging from 10K to 40K. The arrow indicate in which direction the field was swept during the hysteresis loop. As the temperature is increased, magnetization decreases. The large hysteresis suggests that the pinning of flux lines inside the superconductor is strong.

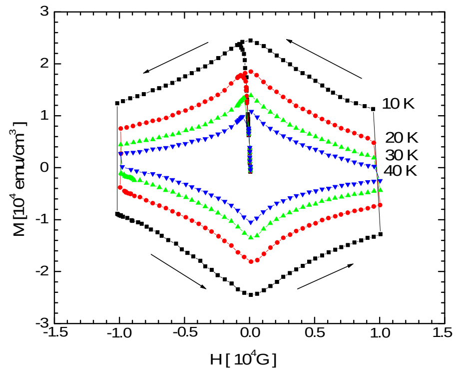

Fig.2 .M(H) for $YBa_2Cu_3O_{7-\delta}$ thin films measured at different temperatures from 10K to 40K.

The J_c (T) was obtained from the experimental curves of M(H) at different temperatures by using Bean critical model [6]. For a disc with a diameter d the critical current density is estimated from the magnetization curves using the following formula:

$$\mathbf{J_c} = \frac{30(\mathbf{M_p} - \mathbf{M_m})}{\mathbf{d}},$$

where M_p and M_m are the magnetizations measured for the increasing and decreasing applied field, respectively.

The shape of hysteresis for YBCO thin film is different from the one predicted by the Bean model, and it is questionable the validity of this model for our HTS sample where the critical current is dependent on magnetic field. For this, we compared the Bean model with the results given by the Kim model [7]. This model takes into account a field dependence of J_c:

$$\mathbf{J(H)} = \frac{\mathbf{J_c}}{1 + |\mathbf{H(x)}| / \mathbf{H_k}}$$

where the H_k is a characteristic field.

In figure 3 we compare the J_c values deduced from the Bean model with the field dependence of J_c given by Kim model, and table 1 shows the parameters of Kim model at different temperatures

This figure demonstrates that that these two models give the same J_c(H) dependence.

The high value of critical current density (up to 9 * 10^6 A/cm^2 at 10K) suggest that the nanoparticulate precipitates (evidenced the complete thickness [5]) are responsible for the strong pinning of flux lines in Y:123 film. Artificial pinning centers were introduced perpendicular to the Y:123 film surface using nanosized Y_2O_3 islands prepared on substrate [8]. These artificial defects enhanced J_c at 77K from 1.8 to 2.7 MAcm^{-2}. Trapped flux and critical current were enhanced by using nanoscale Y_2BaCuO_5 and $Y_2Ba_4CuMO_y$

(M=Nb,Ta,Mo,W,Ag,Sb,Sn,Bi) phases embedded in Y:123 films [9,10].

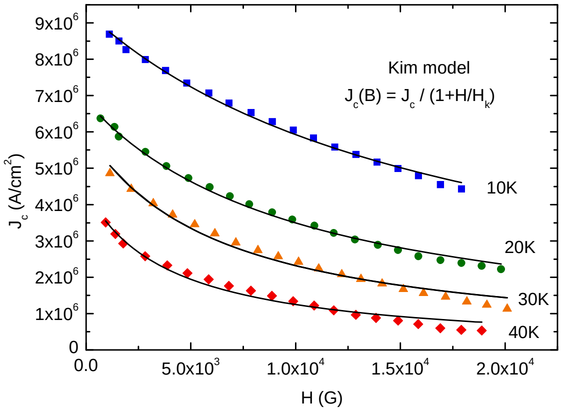

Fig. 3.Critical current density $J_c(H)$ estimated from Bean model (solid points) and Kim model).

Because the flux creep effect play an important role in the magnetization critical current density deduced from M(H) measurements is lower than the value obtained from direct transport studies [11]. The indirect measurements of J_c from M(H) has the advantage that the anisotropy of system and possible inhomogenities will be averaged over the complete sample (Jc from the direct measurement is averaged only on the narrow microbridge).

4. Conclusions

The Y:123 films synthesized by D.C. sputtering method are Y-rich and presents nanoparticulate precipitates (more probable Y_2O_3).

The large hysteresis obtained using a SQUID based DC magnetometer, suggest that the pinning of flux lines inside the superconductor is strong.

The critical fields H_{c1} and H_p (obtained from the initial magnetization curve) decrease with increasing temperature.

The critical current density $J_c(H)$ deduced from M(T) curves by using Bean model, shows high values and suggest that the nanoparticulate precipitates are strong pinning centers. The Bean and Kim models give the similar results for the estimation of $J_c(H)$.

Acknowledgments

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References

[1] M.Tinkham, Introduction to Superconductivity, 1996, McGraw-Hill Book-Singapore.
[2] E. H. Brandt, Supercond.sci.Technol.**5**, S52 (1992).
[3] T. I. Selinder,U. Helmerrson, Z. Han, J. E. Sundgren, H. Sjostrom, Physica C **202**, 69 (1992).
[4] J. Schroeder, PhD thesis, Universite Libre de Bruxelles (1994).
[5] A. V. Pop, G. Ilonca, D. Radulescu, M. Pop, J. Optoelectron. Adv. Mater. **9**(3), 554 (2007).
[6] C. P. Bean, Rev. Mod. Phys. **36**, 31 (1964).
[7] Y. B. Kim, C. F. Hempstead, A. R. Strand, Phys. Rev. Lett. **9**,306 (1962).
[8] P. Mele, K. Matsumoto, T. Horide, O. Miura, A. Ichinose, M. Mukaida, Y. Yoshida, S. Horii, Supercond.Sci.Technol. **19**, 44 (2006).
[9] N. Hari Babu, K. Iida, Y. Shi, T. D. Withnell, D. A. Cardwell, Supercond. Sci. Technol. **19**, S461 (2006).
[10] F. Li, C. Vipulanandan, X. Y. Zhou, K. Salama , Supercond. Sci. Technol.**19**, 589 (2006).
[11] S. Senoussi, J. de Phys **III**(2),1041 (1992).

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