The vortex motion and the magnetization study in $YBa_2Cu_3O_{7-\delta}$ single crystal

A. Ramzi[*, 1], A. Taoufik[1], A. Tirbiyine[1, 2], A. Abaragh[1], H. Darhmaoui[3], S. Senoussi[4], L. Bougarfa[1], F. Chibane[1], M. Boujida[5], A. Labrag[1], A. Bouaaddi[1] and M. Bghour[1]

[1] *Equip of Materials Superconductors at High Critical Temperature, Ibn Zohr University, Agadir, Morocco.*
[2] *Cadi Ayyad University, Poly-disciplinary Faculty, B. P. 4162, Route Sidi Bouzid 46000 Safi, Morocco.*
[3] *School of Science and Engineering, Al Akhawayn University, Ifrane, Morocco 53000*
[4] *Solids physics laboratory, Paris-Sud University, Orsay, France.*
[5] *Sidi Mohammed ben Abdellah University, sciences and technic Faculty, B. P. 2202, Route Route d'Imouzzarr Fes, Morocco.*

We have investigated the vortex motion and the magnetization of high critical temperature superconductors $YBa_2Cu_3O_{7-\delta}$. Measurements were made using a vibrating sample magnetometer technique. Several magnetization hysteresis cycles have been obtained for different angles, θ, between the applied magnetic field, H, and the crystallographic c-axis. For $T = 30$ K we observed a central peak and for $T = 80$ K we observed a second peak or ''fishtail''.

* Corresponding author : *ab_ramzi@yahoo.fr*

PACS 74.25.Fy, 74.40.+k

1. INTRODUCTION

Magnetic measurements on single crystals, In the Cu-O superconductors, are one of the tools used to clarify the phenomenology of the superconducting state. These measurements generally indicate a similarity to previously known low temperature anisotropic superconductors: however, several puzzling and novel features have appeared. At low temperatures, even in the highest quality crystals, flux pinning has a profound effect on attempts to estimate of the lower critical field, H_{c_1}, from magnetization data [1, 2]. Estimate of the upper critical fields, H_{c_2}, from ac susceptibility [3, 4] and resistance transitions [5, 6] have given lower results than measurements of magnetization.

Since the discovery of high critical temperature superconductors (HTSC's), a great deal of effort has been devoted to the investigation of their irreversible magnetization properties [7], M_{irr}, and the associated critical current density [8], J_c.

In type II superconductors as HTSC's, which present inhomogeneities, the applied magnetic field, H, is in general not uniform. In fact the presence of the pinning centers does not allow vortices to move freely: vortices whose core is constituted by the normal electron prefer to lodge in a well of potential, localized around defects, where the energy is minimum, this situation provokes an irreversible behavior: when the applied magnetic field increases, vortices penetrate in the sample and lodge in a potential well near the surface. If one increases favors the field, vortices continue to penetrate in the sample by occupying other pinning sites, when the applied magnetic field decreases, vortices are expelled out of the materials after depinning. Neighbor sites of the surface depopulate first. This process pinning and depinning of vortex is irreversible and gives place to a hysterisis phenomenon on the magnetization curve.

In this paper we measure, as a function of angle at two different temperatures, a series of registration of magnetization hysteresis cycles for $YBa_2Cu_3O_{7-\delta}$ single crystal, the curves $M(H)$ we permit to clear the behavior, with respect to the variation of the applied magnetic field and the angle, θ, certain largeness such as irreversible magnetization, M_{irr}, and irreversible magnetic field, $H_{irr.}$

2. EXPERIMENTAL

Magnetic measurements were performed by means of a vibrating sample magnetometer (V.S.M.). The applied magnetic field is up to 6 T and the angle, θ, between the direction of the applied magnetic field and the crystallographic c-axis, are ranging from 0 to about 90°. The sample used is a single crystal of $YBa_2Cu_3O_{7-\delta}$ which exhibits vanishing temperature at $T_c = 90$ K. Measurement was made after cooling the sample zero-field [9].

The sample was fixed inside a sample holder screwed on the measure cane. The temperature was ruled to T_{mes} at which the cycle has to be traced. The regulation of the temperature was made by an

enslavement system conceived for this function. Once the temperature is stable, we wait approximately 5 to 10 mn in for us be uniform in all the sample volume, then we started the statement sequence of the magnetization curve, *M(H)*, by making a cyclic sweeping of the applied magnetic field. The rotation of the sample to the desired direction was performed outside the cryostat at room temperature using a home-made rotatable sample holder.

3. RESULTS AND DISCUSSION

The shape and the amplitude of magnetization hysteresis cycles change according to the angle, θ, between the direction of the applied magnetic field and the crystallographic *c*-axis (see figures 1 and 2), the magnetization decreases in a monotonous way when the angle increases. This change is due to a strong anisotropy of the pinning forces.

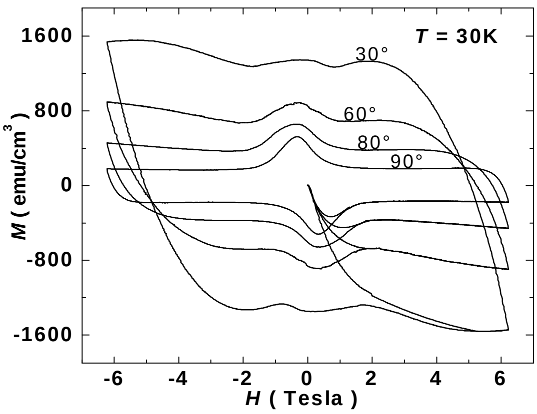

Figure 1. Magnetization hysteresis cycles, *M(H)* at temperature $T = 30$ K for several θ ranging from 30 to about 90°, it is indicate in the curves.

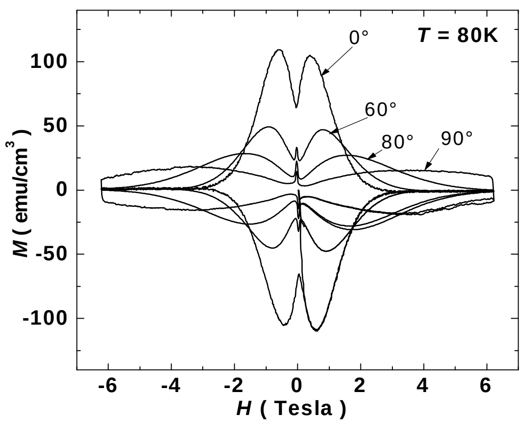

Figure 2. Magnetization hysteresis cycles, *M(H)* at temperature $T = 80$ K for several θ ranging from 0 to about 90°, it is indicate in the curves.

We present in figure 1 the magnetization hysteresis cycles for several angles between the applied magnetic field with the *c*-axis ($\theta = 30$, 60, 80 and 90°) at temperature $T = 30$ K. To the weak fields, the apparition of a central peak [10] that observed from elsewhere on the hysteresis cycles calculated by Chen et al. [11] while using the variation law,

$$J_c(H_i) = \frac{J(0)}{H_i / H_0 + 1},$$

$J_c(0)$ is the critical current density at $H_i = 0$, it depends on the temperature, H_i and H_0 are the local magnetic field and the applied magnetic field, respectively. This law is proposed by Kim et al. [12].

Figure 2 shows the *M* versus *H* hysteresis cycles of the single crystal of $YBa_2Cu_3O_{7-\delta}$ measured at several fixed angles, θ, ranging from 0 to about 90° at temperature $T = 80$ K. The magnetization curve exhibits a remarkable second peak "fishtail". The second peak decreases with increasing angle and almost disappears for the applied magnetic field perpendicular to the *c*-axis, the second peak appears in the case that the magnetic field crosses superconducting CuO_2 layers. This phenomenon is associated with an instability in the vortex lattice structure in the *c* direction [13] was detected a transition from an ordered to a disorder vortex solid [14]. The hysteresis cycle branches M^+ and M^-, where M^+ and M^- are magnetization at decreasing and increasing applied magnetic fields, respectively, meet for the irreversibility magnetic field, H_{irr}, $H_{irr} \approx 2.8$ T for $\theta = 0°$ and $H_{irr} \approx 5.4$ T for $\theta = 80°$, from which there are no more hysteresis cycles. The irreversible magnetization then becomes null and vortices are not pinned anymore: they can thus move freely in answer to an increase of the field, in the limit of fields explored, the magnetization not to annul, it means that the domain of the irreversible process is larger in applied magnetic field parallel with the *ab*-plane.

The irreversible magnetization M_{irr} disappears (Figures 1 and 2), $M_{irr}=(M^+ - M^-)/2$ where M^+ and M^- are magnetization at decreasing and increasing applied magnetic fields, respectively. The hysteresis loop branches M^+ and M^- meet for the irreversibility magnetic field H_{irr}, which depends on the temperature and the angle.

The irreversibility magnetic field H_{irr} versus the angle θ for $T = 80$ K (solid circles) and T = 85 K (open circles) is plotted in figure 3, beyond $\theta = 30°$, H_{irr} increases when θ increases. N. Kobayashi et al. [15] and K. Watanabe et al. [16] described H_{irr} measured by the effective-mass model. Since H_{irr} is usually defined by a certain voltage criterion, it seems that the H_{irr} is strongly

influenced by the flux pinning and the thermally assisted flux motion.

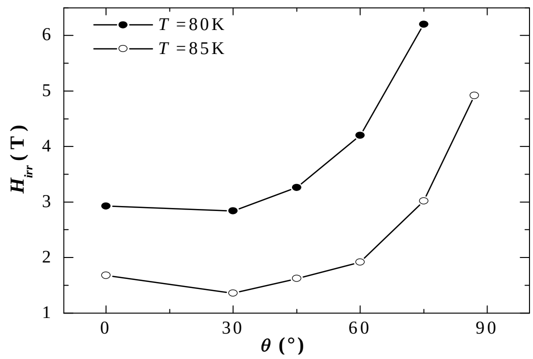

Figure 3. The irreversible magnetic field H_{irr} versus θ at T = 80 K (solid circles) and T = 85 K (open circles).

Applied Magnetic field dependence of the critical current density J_c deduced from the magnetic hysteresis loops at $\theta = 0°$ for different temperature values, using the extended Bean model for H parallel to the c-axis [1, 17]:

$$J_c = \frac{40M_{irr}}{a\left(1-\dfrac{a}{3b}\right)},$$

where a and b ($b > a$) are the width and length of the sample, this derivation is valid for high fields well above the field H_p for full flux penetration [18], as it can be seen in figure 4. Far of the weak field region, we note that the critical current density always decreases when the applied magnetic field increases, this decrease is as much faster as the temperature increases. The J_c value in an increasing applied magnetic field shows an exponential decay as $J_c \alpha\ exp(-H/H_0)$ with a constant H_0 at high fields. In this case, J_c is due to the vortices pinning by the defects parallel with the c-axis.

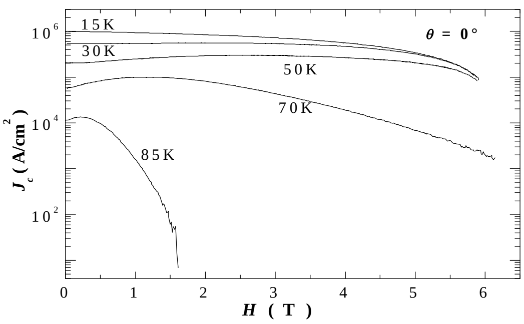

Figure 4. Variation of the apparent critical currant density with applied magnetic field H parallel to the c-axis in semi-logarithmic scales.

In conclusion, the temperature dependence of the irreversible magnetic field H_{irr} which exhibits a power law with power larger than unity. The angular dependence of H_{irr} is described by the effective-mass model. This result means that the anisotropy in H_{irr} is dominated by the anisotropic vortex structure intrinsic to the material and the second peak arises from the correlation between flux lines.

References

[1] T.R. Dinger, T.K. Worthington, W.J. Gallagher and R.L. Sandstrom, *Phys. Rev. Lett.* **58** (1987) 2687

[2] A. Umezawa, G.W. Crabtree, J.Z. Liu, T.J. Moran, S.K. Malik, L.H. Nunez, W.L Kwok., and C.H. Sowers, *Phys. Rev. B* **38**, (1988) 2843

[3] T.K. Worthington, W.J. Gallagher and T.R. Dinger, *Phys. Rev. Lett.* **59** (1987) 1160

[4] T.K. Worthington, W.J. Gallagher, D.L. Kaiser, F.H. Holtzberg and T.R Dinger., (Proc. Of Interlaken conf., Switzerland, Feb. 29-Mar. 4, 1988)

[5] Y. Iye, T. Tamegai, H. Takeya and H. Takei, *Physica B* **148** (1987) 224

[6] B. Oh, K. Char, A.D. Kent, M. Naito, M.R. Beasley, T.H. Geballe, R.H. Hammond , A. Kapitulnik and J.M. Graybeal, *Phys. Rev. B* **37** (1988) 7861

[7] A. Silhanek and L Civale., *Physica C* **341-348** (2000) 1227

[8] A. Taoufik, A. Ramzi, S.Senoussi and A.Labrag, *phys. stat. sol. (c)* **1**, No. 7, (2004) 1912

[9] A. Ramzi, A. Taoufik, S. Senoussi and A. Labrag, *J. Phys. IV France* **123** (2005) 409

[10] M.R. Koblischka, L.Pust, M. Jirsa and T.H. Johansen, *Physica C* **320** (1999) 101

[11] D.X. Chen and R.B. Goldfarb, *J. Appl. Phys.* **66** (1989) 2489

[12] Y.B.Kim, C.F. Hempstead and A.R. Strnad, *Phys. Rev. Lett.* **9** (1962) 306

[13] M.F. Goffman, J.A. Herbsommer, de la F. Cruz, T.W. Li and P.H. Kes, *Phys. Rev. B* **57** (1998) 3663

[14] E.E. Kaul, and G. Nieva, *Physica C* **341-348** (2000) 1343

[15] K. Kobayashi, K. Hirano, T. Nishizaki, H. Iwasaki, T. Sasaki, S. Awaji, K. Watanaba, H. Asaoka and H. Takei, *Physica C* **251** (1995) 255

[16] K. watanabe, S. Awaji, N. Kobayashi, H. Yamane, T. Hirai and Y. Muto, J. *Appl. Phys.* **69** (1991) 1543

[17] A. Umezawa, G.W. Crabtree, J.Z. Liu, W. Weber, W.K. Kwok, L.H. Nunez, T.J. Moran, C.H. Sowers and H. Claus, *Phys. Rev. B* **36** (1987) 7151

[18] M.D. Sumption, *Applied supercond* **2** (1994) 41