Internal friction associated with magnetic flux pinning in high T_c superconductor $YBa_2Cu_3O_{7-x}$

1990 J. Phys.: Condens. Matter 2 661

(http://iopscience.iop.org/0953-8984/2/3/014)

J. Phys.: Condens. Matter **2** (1990) 661–663. Printed in the UK

Internal friction associated with magnetic flux pinning in high T_c superconductor $YBa_2Cu_3O_{7-x}$

Y T Wen†, L X Yuan†, C Y Xie†, T S Kê†, Y T Qian‡ and Z Y Chen‡
† Laboratory of Internal Friction and Defects in Solids, Institute of Solid State Physics, Academia Sinica, Hefei, People's Republic of China.
‡ University of Science and Technology of China, Hefei, People's Republic of China.

Received 27 March 1989, in final form 20 July 1989

Abstract. Internal friction Q^{-1} and resonant frequency f_r of the high T_c superconductor $YBa_2Cu_3O_{7-x}$ ($T_c = 90$ K) were measured as a function of the applied longitudinal magnetic field H_a at temperatures below and above T_c. At 110 K, Q^{-1} and f_r are independent of the applied magnetic field. At 77 K, f_r increases continuously when $H_a > 0$, while Q^{-1} increases abruptly when H_a reaches a certain value. The internal friction Q^{-1} can be represented by $Q^{-1} = Q_0^{-1} + dQ^{-1}$, where Q_0^{-1} is the background value and dQ^{-1} is due to the motion of the flux lines around the pinning centres while vibrating stress is being applied. When a cyclic magnetic field was applied, internal friction hysteresis curves were observed. And the area and the shape of the hysteresis loop are related to the condition of pinning of flux lines.

1. Introduction

It is well known that the pinning of magnetic flux lines is an important factor in increasing the critical current, J_c, in a non-ideal type II superconductors. The internal friction method has been successfully employed in the study of the magnetic flux pinning in low T_c superconductors with strong magnetic field up to H_{c_2} [1, 2]. In order to study the motion and pinning of the magnetic flux lines in high T_c oxide–ceramic superconductors, an apparatus comprising an electrostatically driven vibrating reed in a longitudinal magnetic field was designed and constructed so that the resonant frequency f_r and the internal friction, Q^{-1}, of $YBa_2Cu_3O_{7-x}$ specimens could be measured as a function of longitudinal magnetic field at temperatures below and above T_c.

2. Specimens and experimental methods

The specimens were prepared by the method of solid phase reaction. The mixed powder, with proportions Y:Ba:Cu = 1:2:3 was heated in a furnace at 930 °C for 12h, and cooled down to room temperature in the furnace. Then it was ground and pressed into a size of 60 × 4.5 × 1 mm and was heated again in the furnace at 950 °C for 12 h. The standard four-lines method was used for resistance measurement, and the critical temperature, T_c, was found to be about 90 K. The internal friction Q^{-1}, was measured using the free-decay method in the apparatus described above, with a resonant frequency $f_r = 430$ Hz.

0953-8984/90/030661 + 03 $03.50

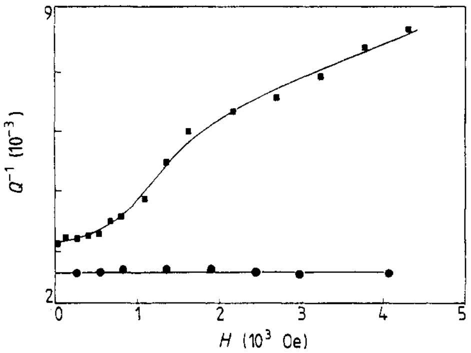

Figure 1. Variation of Q^{-1} with H_a below and above T_c (90 K) for ■, 77 K and ●, 110 K.

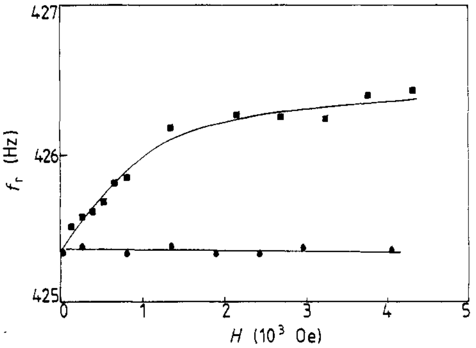

Figure 2. Variation of f_r with H_a below and above T_c (90 K) for ■, 77 K and ●, 110 K.

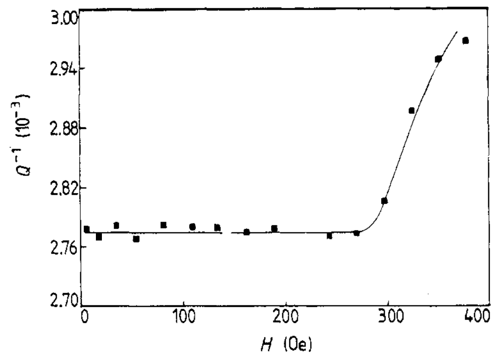

Figure 3. Variation of Q^{-1} with a lower magnetic field at 81 K.

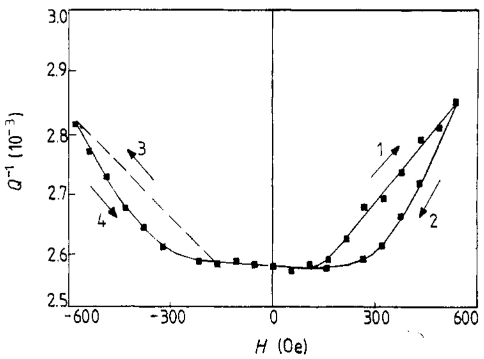

Figure 4. Hysteresis internal friction loop in cyclic magnetic field.

3. Experimental results

Figures 1 and 2 show the variation of Q^{-1} and f_r of the specimen with increasing applied longitudinal magnetic field, H_a. At 110 K, which is higher than T_c, f_r and Q^{-1} are independent of H_a. At 77 K, where the specimen is in the superconducting state, f_r and Q^{-1} increase with H_a.

Figure 3 shows the case for a lower applied magnetic field, and the Q^{-1} measurement was taken at 81 K, which is less than T_c (90 K). Here, Q^{-1} increases abruptly when H_a increases to a certain value, and it seems that this value is a reflection of the H_{c_1} of the specimen. On the other hand, as is shown by figure (2), f_r seems to increase continually once H_a is applied.

Figure 4 shows the internal friction hysteresis loop when a cyclic magnetic field is applied. In part 1 of the loop, internal friction increases with an increase of the applied field, and reaches a maximum value when H_a reaches $(H_a)_{max}$. When H_a is decreased, the internal friction decreases with the decrease in H_a, but its value is always lower than that of part 1, thus exhibiting a hysteresis behaviour (part 2). For the opposite direction of the field, the curves shown in parts 3 and 4 are similar to those of parts 1 and 2. This hysteresis phenomenon is obviously due to the pinning effect of flux lines.

4. Discussion

At temperatures above T_c, the magnetic flux lines pass completely through the specimen and distribute in an equilibrium state, so that the condition of the magnetic flux lines is not disturbed by the vibrating stress. Accordingly, the internal friction and resonant frequency of the specimen are independent of the applied magnetic field.

At temperatures below T_c, when a magnetic field is applied, there is a superconducting current in the surface layer of the specimen because of the diamagnetism of superconductors, and the interaction between this current and applied magnetic field will increase the resonant frequency of the specimen [1]. The increase of resonant frequency is very sensitive, even when the applied field is very small.

For the internal friction, the condition is more complex than that of f_r. When $H_a < H_{c_1}$, the internal friction Q^{-1} measured is a constant value Q_0^{-1}, because the magnetic flux lines are expelled from the specimen. But when $H_a > H_{c_1}$, the magnetic flux lines begin to penetrate the specimen. If the vibrating stress is not applied, the Lorentz force and the pinning force acting on the flux lines are equal, $F_L = F_P$, so that the flux lines in the specimen do not move. When vibrating stress is applied, the pinning centres on the magnetic flux lines are acted on by a periodic stress, so that the flux lines will move around the pinning centres, and therefore an extra internal friction dQ^{-1} is induced. Thus the measured internal friction Q^{-1} can be represented as $Q^{-1} = Q_0^{-1} + dQ^{-1}$. This dQ^{-1} increases with an increase of H_a, when more magnetic flux lines penetrate the specimen. When dQ^{-1} becomes larger than the sensitivity of internal friction measurement, the measured internal friction Q^{-1} begins to increase. As such, through a further improvement of the sensitivity of Q^{-1} measurement, the detection of the sudden appearance of dQ^{-1} can be considered a useful method for determining H_{c_1}.

It is pointed out that all the measurements shown in figures 1–3 were performed in an increasing magnetic field. The shape of the curves changes somewhat when measurements are taken with decreasing magnetic field. However, the general features of the curves remain the same.

As is shown in figure 4, an internal friction hysteresis loop appears with a cyclic magnetic field. The internal friction curve is seen to decrease with decreasing magnetic field. If the increase of internal friction over background value (dQ^{-1}) is associated with the motion and the pinning of magnetic flux lines (flux damping), then the change of shape of the internal friction curve signifies that the condition of pinning has changed after the application of a higher magnetic field. Preliminary experiments show that the area and the shape of the hysteresis loop are different for different $(H_a)_{max}$ of the applied cyclic magnetic field. It seems, thus, that the hysteresis internal friction loop is useful for studying the conditions of magnetic flux lines pinning in the specimen. Systematic work along these lines is in progress.

Acknowledgment

This work has been subsidised by the Office of Superconductivity of Academia Sinica and National Natural Science Foundation of China.

References

[1] Brandt E H, Esquinazi P and Neckel H 1986 *J. Low Temp. Phys.* **63** 187
[2] Esquinazi P, Neckel H, Weiss G and Brandt E H 1986 *J. Low Temp. Phys.* **64** 1