RESISTIVE TRANSITION OF SUPERCONDUCTING Nb-Ti

T. Hamada
Miyakonojo College of Technology, 473-1 Yoshio, Miyakonojo 885, Japan
E-mail: hamada@cc.miyakonojo-nct.ac.jp
and
M. Kiuchi, E. S. Otabe, T. Matsushita
Department of Computer Science and Electronics, Kyushu Institute of Technology, 680-4 Kawazu, Iizuka 820, Japan

ABSTRACT

The resistivity vs. temperature characteristics were measured under the magnetic field for a weakly pinned Nb-Ti specimen to discuss the behavior of fluxoids. A sharp variation in the resistivity was observed. The experimental results on the resistive transition, the critical current density and the irreversibility line are compared with the theoretical analysis based on the flux creep and flow. Agreement is satisfactory and the observed sharp variation in the resistivity comes from a sharp variation in the critical current density near the irreversibility line.

1. Introduction

A sharp variation in the resistivity in the low resistivity region observed for a single crystal YBCO under a magnetic field was interpreted as the first order transition associated with the melting of the fluxoid system.[1] On the other hand, a similar sharp variation can also be explained from the mechanism of flux flow.[2] According to the theory, the sharp variation in the resistivity comes from a rapid decrease in the critical current density with increasing temperature near the irreversibility line. It is necessary, therefore, to clarify which mechanism brings about the sharp variation. Since the melting of the fluxoids is expected to be quite in the vicinity of the upper critical field in metallic superconductors, if a sharp variation in the resistivity is observed at relatively low temperatures, it will be concluded that the melting is not responsible for the sharp variation in the resistivity. For this purpose we measured the resistive transition for a weakly pinned Nb-Ti specimen. The results are compared with the theoretical analysis using the flux creep-flow model.

2. Experimental

The measured specimen was Nb-65wt%Ti. The specimen was heat treated at 800°C to remove dislocations, and then heat treated again at 400°C for precipitation of the ω phase to introduce proper pinning centers. The precipitate size of the ω phase was in the range of $5 \sim 7$ nm. Then, the specimen was cut into a slab of the size of 20 mm $\times$ 1.7 mm $\times$ 0.15 mm. The resistive transition was measured by the common four terminals method under a magnetic field normal to the wide surface. The applied current density was 4.4×10^5 A/m^2 and distance between the voltage terminals was 5.6 mm. The critical current density J_c was estimated from the DC magnetization hysteresis and the irreversibility field was determined by the magnetic field at which J_c is reduced to 1.0×10^5 A/m^2.

The observed resistive transition are shown in Fig. 1. It is seen from the result at zero magnetic field that the specimen in not uniform. Nevertheless, relatively sharp

Fig. 1. Resistance vs temperature curves of Nb-Ti specimen under various magnetic fields.

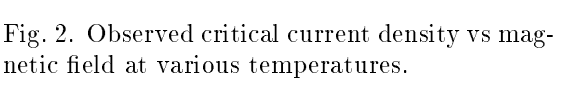

Fig. 2. Observed critical current density vs magnetic field at various temperatures.

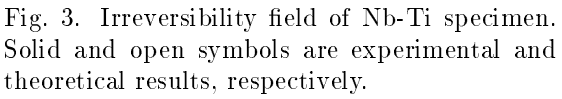

Fig. 3. Irreversibility field of Nb-Ti specimen. Solid and open symbols are experimental and theoretical results, respectively.

variations in the resistivity were observed under the magnetic field. Figures 2 and 3 show the critical current density and the irreversibility field, respectively.

3. Flux Creep-Flow Model

We assume a sinusoidal washboard potential for describing approximately the variation in the energy of flux bundle vs its position. This leads to an expression[3] of the activation energy, U, as a function of the pinning potential, U_0, and the normalized current density, $j = J/J_{c0}$, with J_{c0} denoting the virtual critical current density in the creep-free case. According to the flux creep theory[3] U_0 is expressed in terms of J_{c0}. The contribution from the flux creep to the induced electric field is given by

$$\begin{aligned} E_{\rm cr} &= B a_{\rm f} \nu_0 \exp\left[-\frac{U(j)}{k_{\rm B}T}\right]\left[1-\exp\left(-\frac{\pi U_0 j}{k_{\rm B}T}\right)\right]; \quad j \le 1, \\ &= B a_{\rm f} \nu_0 \left[1-\exp\left(-\frac{\pi U_0}{k_{\rm B}T}\right)\right]; \qquad\qquad\quad j > 1, \end{aligned} \tag{1}$$

Table 1. Parameters used in the numerical calculation.

T_{c0}[K]	$B^*_{c2}(0)$[T]	$\rho_n[\Omega m]$	A^*	m	γ	δ	g^2	σ^2
6.8	10.2	1.15×10^{-6}	1.0×10^9	6.0	0.3	2	1.0	0.13

where a_f is the fluxoid spacing and $\nu_0 = \rho_f J_{c0}/a_f B$ is the oscillation frequency of flux bundle and ρ_f is the flux flow resistivity, for which the Bardeen-Stephen model is assumed: $\rho_f = (B/B_{c2})\rho_n$. On the other hand, the contribution from the flux flow is

$$\begin{aligned} E_{ff} &= 0; & j \le 1, \\ &= \rho_f(J - J_{c0}); & j > 1. \end{aligned} \tag{2}$$

Here we approximate that the total electric field is simply given by $E = E_{cr} + E_{ff}$.

It is seen from Fig. 1 that the critical temperature T_c is locally fluctuated in the specimen. Hence, we assume the distribution function of T_c of the form:

$$f(T_c) = \frac{K}{\sqrt{2\pi\sigma^2}} \exp\left[-\frac{(T_c - T_{c0})^2}{2\sigma^2}\right], \tag{3}$$

where T_{c0} and σ are approximately the mean value and the standard deviation, respectively and K is a constant determined from the normalization condition. Here we approximately use $K = 1$. Because of the distribution of T_c, the upper critical field and the flux pinning strength are also distributed. Since the dependence of the flux pinning strength on T_c is not clear, we assume simply that J_{c0} varies as

$$J_{c0} = A\left[1 - \left(\frac{T}{T_{c0}}\right)^2\right]^m B^{\gamma-1}\left(1 - \frac{B}{B^*_{c2}}\right)^\delta. \tag{4}$$

In the above B^*_{c2} is the upper critical field for $T_c = T_{c0}$ and we assume that only A depends on T_c. It seems to be reasonable to simply assume that B_{c2} is proportional to T_c. Since the flux pinning strength is originally proportional to B^m_{c2} as shown in Eq. (4) and expected to be proportional to T^m_c. Thus, we have

$$B_{c2}(0) = B^*_{c2}(0)(T_c/T_{c0}), \qquad A = A^*(T_c/T_{c0})^m, \tag{5}$$

where A^* is a constant. The values of m and γ in Eq. (4) are obtained so that a good fit is obtained between this expression and the experimental results in Fig. 2 is obtained in the region of low temperature and low magnetic field. $\delta = 2$ is assumed because of weak pinning in the specimen.

As a result, the electric field is calculated by

$$E = \int_0^\infty (E_{cr} + E_{ff}) f(T_c) \mathrm{d}T_c. \tag{6}$$

The parameters used in the calculation are listed in Table 1. J_c is determined using the electric field criterion of 1.0×10^{-4} V/m and the irreversibility field is determined by the magnetic field at which J_c is reduced to 1.0×10^5 A/m^2.

4. Discussion

Fig. 4. Theoretically calculated critical current density.

Fig. 5. Theoretical results of resistivity vs temperature curves.

The theoretically calculated J_c is shown in Fig. 4. It is seen from Figs. 2 and 4 that the temperature and magnetic field dependences of J_c are approximately explained by the mechanism of flux creep and flow. The calculated irreversibility field is compared with the experiment in Fig. 3. This also suggests that this mechanism describes the phenomenon correctly. Figure 5 shows the calculated resistive transition. It is seen that the relatively sharp variation in the resistivity is realized in spite of inhomogeneity of the specimen. The present theoretical analysis predicts that the variation is much more sharp if the specimen is homogeneous. Therefore, the observed sharp resistive transition is brought about by a rapid variation in J_c near the irreversibility line. This is independent of the melting of the fluxoid lattice, since the melting is expected to occur only in the vicinity of B_{c2}. Hence, there is a possibility that a similar sharp variation in the resistivity in YBCO single crystals is also caused by the above mechanism. Therefore, much more detailed investigation is necessary to clarify the responsible mechanism in high T_c superconductors.

5. Summary

A sharp variation in the resistivity under the magnetic field is observed for a Nb-Ti specimen with a weak pinning force and the result is compared with the theoretical analysis based on the mechanism of flux creep and flow. Satisfactory agreement is obtained between the theory and the experiment on the critical current density, the irreversibility field and the resistive transition. The observed sharp resistive transition in Nb-Ti is ascribed to the occurrence of flux flow due to a rapid variation in the critical current density near the irreversibility line, since the melting is considered to occur only in the vicinity of the upper critical field.

6. References

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