Field- and temperature-dependent magnetic hysteresis in GBCO ceramics

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Abstract

Magnetic hysteresis measurements are performed in $GdBa_2Cu_3O_{7-\delta}$ (GBCO) ceramics, and effects of magnetic field, temperature and substitution are studied. The hysteresis ΔM is found to decay exponentially with temperature: $\Delta M \propto \exp[-T/T_0]$. The activation temperature T_0 varies mildly around 20 K, which seems to depend on the magnetic field as $H^{-1/n}$. Substitution tends to increase ΔM at lower fields. The results are examined in relation to ceramic nature of the sample.

Key words: Gd-based cuprate; flux pinning; hysteresis; activation temperature

1. Introduction

For various applications of high-T_c superconductors, the weak coupling between the crystal grains is the large obstacle and intensive investigations have been performed. The very promising way of solving the weak-link problem is the method based on the melt processing [1], which is particularly effective in the "bulk" applications. However, it may not be applied to other applications such as electric power cables.

Other possible direction for improving the nature of the grain boundary is methods with doping and substitution of foreign atoms. It was reported [2] that the doping of $YBa_2Cu_3O_{7-\delta}$ with Ca resulted in substantial enhancement of the grain boundary critical current J_c. Also in our previous study on GBCO, we observed some signs of T_c and J_c improvements [3] by partial replacement of Gd with Y.

In order to study enhancement of J_c with doping and substitution, it is important to first understand ceramic nature of the current path and flux pinning in the pristine material. In this report, we measure field- and temperature-dependent magnetic hystereses in GBCO ceramics and examine flux pinning characteristics in relation to the grain boundary coupling.

2. Experimental

The GBCO pellets were prepared by the conventional solid state reaction method [3]. The stick sample was cut from the pellet with typical dimensions of $1\times1\times3$ mm^3. Oxygen content $7-\delta$ was estimated with thermogravimetric analysis based on hydrogen reduction method.

Magnetic measurements were performed with the Quantum Design PPMS system at the Advanced Materials Institute. Magnetization was measured at respective constant temperatures, where the magnetic field (along the longer axis of the rectangular stick) was first set largely to minus value so as to cancel any virgin effects, waited for a few minutes, and then the DC magnetization data were taken by increasing and decreasing the field between 0 and +1 T with logarithmic interval.

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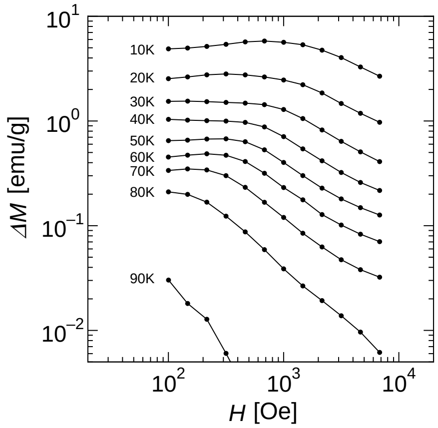

Fig. 1. Magnetic hysteresis ΔM as a function of external field H at various temperatures in the pure GBCO stick.

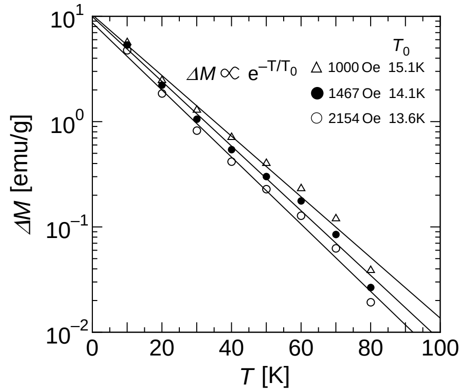

Fig. 2. Magnetic hysteresis ΔM exponentially decays with temperature T. Least square fittings (solid lines) yield activation temperature T_0.

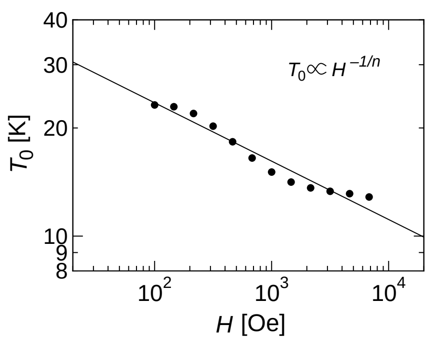

Fig. 3. Field dependence of the activation temperature T_0 is fairly mild: $T_0 \propto H^{-1/n}$ with $n \approx 6$.

3. Results and discussion

Figure 1 shows magnetic hysteresis ΔM which is the difference in magnetization between increasing and decreasing field H in the pure GBCO with $7-\delta = 6.94$. Flux penetration field H_p (as estimated from the maximum in each ΔM isotherm) varies up to 700 Oe. The maximum value of $\Delta M \approx 6$ emu/g at 10 K corresponds to $J_c \approx 6 \times 10^3$ A/cm^2, which is considered to largely reflect granular nature of the sample.

When we pay attention to variation of ΔM with temperature at the same field, we find that $\log(\Delta M)$ almost linearly decreases with rising temperature. Such dependence is represented in Fig. 2, where ΔM is plotted against temperature T for the fields of 1000, 1467 and 2154 Oe. The straight lines indicate least square fittings by the function:

$$\Delta M = A \exp[-\frac{T}{T_0}] . \tag{1}$$

These fittings have resulted in the similar values of the coefficient A around 10 emu/g, while values of the activation temperature T_0 vary from 15 to 14 K for the fields from 1000 to 2154 Oe.

Such exponential decay of ΔM of thermal activation type as an equation (1) is predicted when 2D pancake vortex surmounts the surface barrier [4], especially in the fields of $H \leq H_p$. However, since our ΔM can be fitted with the single value of T_0 over the wide temperature range in the respective fields even for $H \geq H_p$, we consider that not only the surface pinning but also the bulk pinning obeys the exponential decay characteristics in our sample. The field dependence of T_0 is given in Fig. 3. We note that the field dependence is rather weak and can be expressed as $T_0 \propto H^{-1/n}$ with n of about 6 (least square fitting, solid line).

As for the origins of the exponential decay of the bulk pinning ΔM, there are possibilities of weak intergrain coupling, weak intragrain pinning and weak pinning at grain boundaries. Considering that the field dependence of T_0 is weak, the major origin may be fragile current path due to the weak intergrain coupling.

As for the effect of substitution, preliminary analysis suggests larger ΔM at lower fields with smaller n in the Y-substituted GBCO ceramics.

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