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Microwave absorption in the presence of dc transport current in polycrystalline YBCO

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Low-field microwave absorption in polycrystalline $YBa_2Cu_3O_{7-x}$ was measured as a function of dc current applied through the sample at various temperatures below T_c. The peak-to-peak value of the magnetically modulated microwave absorption (MMMA) signal increases with dc current at a fixed temperature. Above a threshold value of the current, the absorption signal level rapidly drops to zero, indicating quenching of superconductivity. If this critical current is plotted as a function of temperature, the results can be explained on the basis of the flux creep model. The MMMA signal obeys a scaling rule as predicted by the flux creep model. We conclude that flux creep limits the critical current density in these materials; also, this presents a new way of measuring critical current densities while using only a two-contact method. It gives some insight into the relationship between microwave properties and dc transport phenomena in these superconductors.

INTRODUCTION

Low-field microwave absorption experiments are considered to be useful in providing information concerning the dissipation mechanism of a type-II superconductor in a perturbing microwave field. In previous work it was suggested that the magnetically modulated microwave absorption (MMMA) losses were due to the circulation of supercurrents through a network of Josephson junctions[1-3] We report in this paper some preliminary analysis of the loss mechanism in a bulk ceramic superconducting $YBa_2Cu_3O_{7-\delta}$ sample as a function of temperature. A more detailed report will appear elsewhere. EPR absorption techniques and dc transport currents were applied simultaneously to the sample during the measurements. We find that the experimental results can be best described by the flux creep model which has not been reported previously in EPR-type measurements.

EXPERIMENT

Low-field differential microwave absorption signals were measured utilizing modified EPR equipment operating at 9.33 GHz and 0.2 mW level in a TE_{102} cavity. The modifications have been reported elsewhere.[4] Polycrystalline YBCO samples, with a T_c $(R=0)$ of approximately 85 K, were used in the experiment with typical size of $0.1\times0.1\times0.5$ mm^3. A four-point measurement was done, on a larger sample, simultaneously with the microwave absorption measurement,[5] both showing the same onset of T_c. The sample was mounted on a gold-plated alumina substrate patterned with a cross for the four contacts. Silver paint was used to make contact between the sample and the gold-plated alumina substrate. In addition, the sample along with the substrate was covered with heat shrink tubing to establish a slight pressure and mechanical stability. Contact resistance of the bond was about 1 Ω at room temperature. The wires connected to the holder were passed through a quartz tube. The whole assembly was immersed into the cavity with liquid helium flowing at a rate of about 2 ℓ/h. Temperature was controlled through an electronic controller (Oxford ESR 900 cryostat). Temperature was measured using a gold/ferric aluminum thermocouple. Typically a modulating field of amplitude 2 Oe and frequency 100 kHz was employed parallel to the applied dc field.

RESULTS AND DISCUSSION

The temperature dependencies of the sample's dc resistivity and the observed MMMA signal with the dc biasing magnetic field fixed at 10 Oe have been reported previously.[5] The onset temperature of superconductivity measured by both methods correlate fairly well (85 K). We have measured, for each fixed temperature, the MMMA signals for various applied dc currents sweeping a dc magnetic field from -100 to $+100$ Oe. Figure 1 shows the observed derivative absorption curves for temperature held at 40 K. For each dc current value the MMMA signal first rises from the origin to a peak value at a field strength equal to H_{ci} (Ref. 4); it then declines slightly and reaches a constant value at very large fields [ideally up to the field $H^*_{c2}(I)$ discussed later]. In Fig. 2 the peak-to-peak values of the MMMA sig-

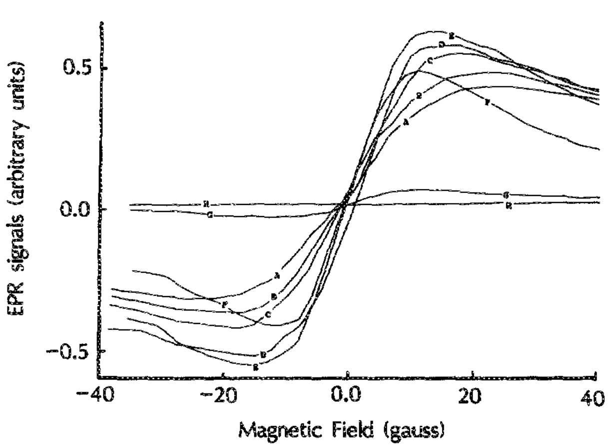

FIG. 1. Differential EPR signals for various imposed currents at $T=40$ K.

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nal are plotted as functions of the transport dc currents with the temperature treated as a parameter. One observes that for each temperature the amplitude of the differential microwave absorption signals increases with the dc current before a rapid falling down to zero near a critical value of the current $I_c(T)$. In addition, $I_c(T)$ decreases with increasing T. We shall see later that the rising parts of the curves in Fig. 2 satisfy the scaling rule and the dependence of I_c on T can be explained by a flux creep model. Therefore, we shall view the curves in Fig. 2 "ideally" as monotonically increasing curves up to $I_c(T)$ where the curves drop "precipitously" to zero.

The raw data are represented in Fig. 2. We shall now explain the data in terms of the flux creep model. If the flux creep model is applicable to the high T_c sample, the absorbed microwave power shall be proportional[6] to the volume fraction of the normal region V_n, or

$$V_n/V \cong B/H^*_{c2}(I), \tag{1}$$

where V is the total volume and $H^*_{c2}(I)$ denotes the field predicted by the Landau–Ginsberg theory and is larger than the conventionally observed upper critical field $H_{c2}(I)$ due to the so-called "paramagnetic effect."[7] For $H_{cl} \ll H, H \approx B$. The linear relation between V_n and B in Eq. (1) holds for all values of I. According to the flux creep model the application of a dc current will lower the barrier height of a pinning center and so it is equivalent to the addition of thermal energy. The MMMA or the derivative microwave absorption signal would increase with current drive below I_c. The increase of the derivative signal with I is related to the increase in slope of the V_n/V vs B. When I equals I_c, all of the volume becomes normal and superconductivity is quenched out. The slopes of the line segments in (V_n/V vs B), which are inversely proportional to $H^*_{c2}(I)$, are proportional to the actual observed differential signals for $H \gg H_{cl}$, which, when compared in Fig. 1, can be roughly viewed as half the peak-to-peak values of the differential microwave absorption signals. Therefore, we conclude that the peak-to-peak values of the microwave absorption signals are "inversely" proportional to $H^*_{c2}(I)$. In Fig. 3 we plot, as a function of temperature, the inverse of the peak-to-peak EPR signal values up to the maximum values in Fig. 2, denoted as "1/pp." We notice in Fig. 3 that 1/pp scales linearly with temperature and all the curves have the same slope. Therefore, we conclude that the scaling rule, and hence the flux creep model which predicts Eq. (1), can adequately describe the observed microwave absorption data on a bulk ceramic YBCO sample. Note that in Fig. 3 $H^*_{c2}(I)$ scales quite well with $[T^*_c(I) - T]$ with the extrapolated $T^*_c(I)$ being larger than the true observed critical temperature $T_c(I)$ due to the paramagnetic effect.[7]

As has been recently proposed by Yeshurun and Malozemoff,[8] the flux creep mechanism is responsible for the magnetization relaxation processes in a single crystal YBCO. We propose here that the flux creep mechanism also applies to polycrystalline YBCO samples. We plot in Fig. 4

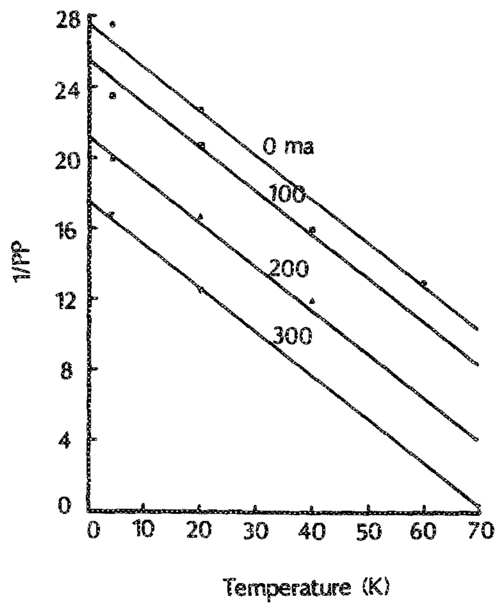

FIG. 3. Plots of 1/pp vs temperature: a linear scaling relation.

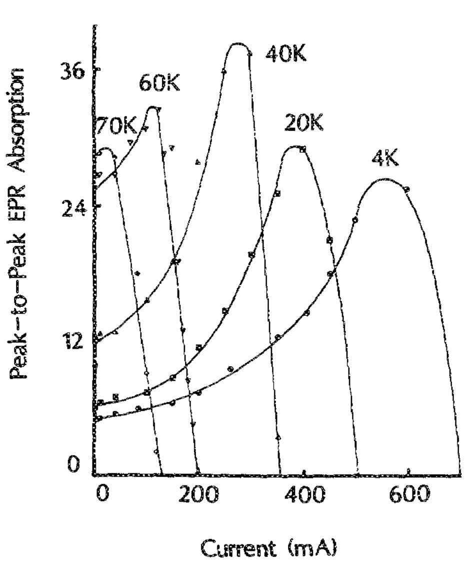

FIG. 2. Peak-to-peak values of the differential microwave absorption signals measured as function of current at various temperatures.

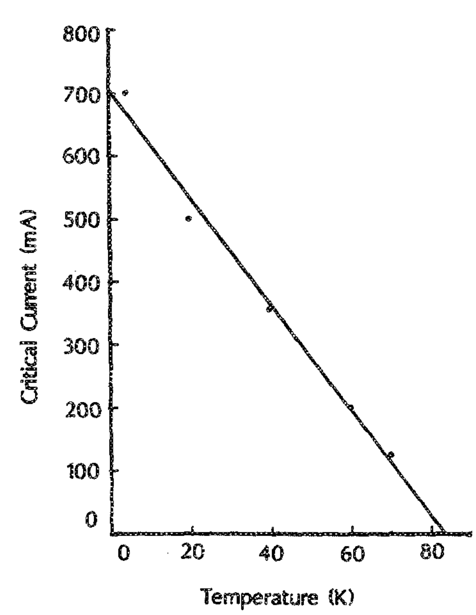

FIG. 4. Plot of critical current vs temperature.

the critical current $I_c(T)$ observed in Fig. 2 versus temperature and the result yields a linear relationship. Recalling in a flux creep model that[6,9]

$$I_c(T) = I_c(0)\left[1 - \frac{k_B T}{U}\ln\left(\frac{B\nu L d}{cE_c}\right)\right], \tag{2}$$

we can immediately interpret the experimental data in terms of the flux creep theory. In Eq. (2) B is the field induction, ν is the vibrational frequency of the fluxoid within a pinning position, d is the separation distance between two pinning positions, L is the length of the sample, E_c is a minimum voltage assigned in measurements, and U is the potential depth of a pinning center. In the experiment we have monitored the rate of change of fluxoid volume which is related to the creep motion of the fluxoid in and out of the superconductor with a rate faster than the applied modulation frequency (100 kHz).

We summarize this paper by concluding that the flux creep model describes very well the loss mechanism under both microwave absorption and dc resistivity measurements for a bulk ceramic superconducting YBCO sample. Since the MMMA signal amplitude rises before falling sharply to zero at the critical current, this presents a very accurate two contact method for measuring critical current densities in very small samples such as single crystals and thin films.

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