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Publication Date

1988-08-01

LBL-26235

c.2

Center for Advanced Materials

CAM

Presented at the Applied Superconductivity Conference, San Francisco, CA, August 21–25, 1988, and to be published in the Proceedings

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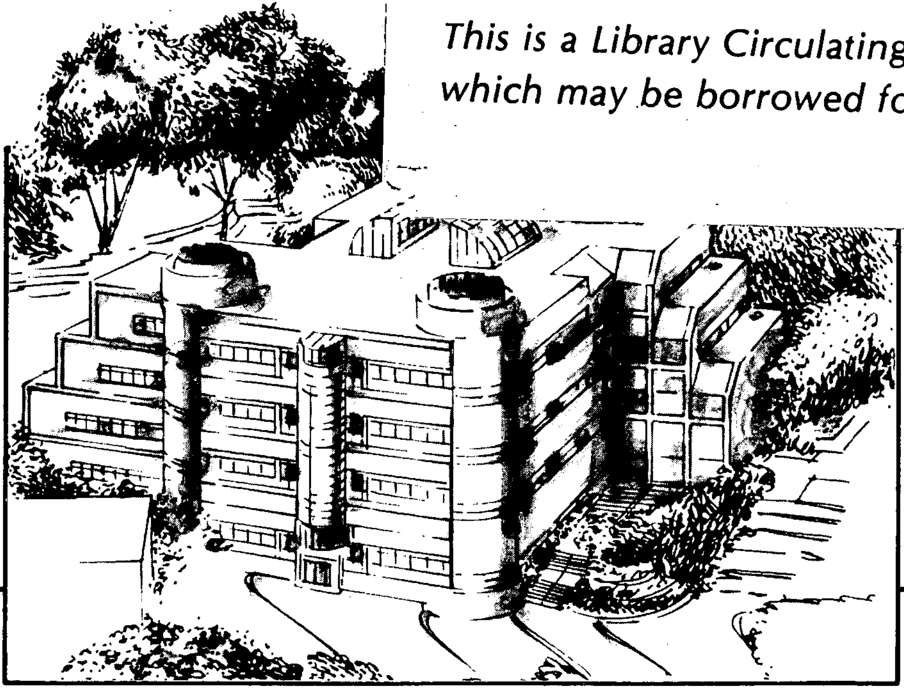
August 1988



LBL-26235 c.2

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Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

LOW FREQUENCY RESISTANCE FLUCTUATIONS IN FILMS OF HIGH TEMPERATURE SUPERCONDUCTORS

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Abstract

Low frequency voltage fluctuations in thin films of $YBa_2Cu_3O_{7-x}$ at and above the superconducting transition have a spectral density $S_v(f)$ proportional to $\bar{V}^2/f$, where $\bar{V}$ is the average voltage across the film and f is the frequency. The value of $S_v(f)/\bar{V}^2$ decreases markedly as the microstructure of the films is improved. In contrast to classic superconductors, the noise at the resistive transition does not arise from equilibrium temperature fluctuations.

Introduction

Since the discovery of superconductivity in ceramic oxides[1], great efforts have been devoted to the fabrication of oriented thin films with high transition temperature (T_c) and high critical current density J_c. This research is spurred not only by interest in the fundamental properties of these films, but also by their potential application to a wide variety of devices[2]. Dc SQUIDs (Superconducting QUantum Interference Devices) have already been fabricated from $YBa_2Cu_3O_{7-x}$ (YBCO). It has been found, however, that the spectral density of the magnetic flux noise exhibits a high level of 1/f noise (f is the frequency) that limits the resolution at low frequency [3]. Furthermore, measurements of the magnetic flux noise in thin-films rings of YBCO have shown that the magnitude of the 1/f noise depends strongly on the microstructure of the material, and is much lower for highly oriented samples with the c-axis perpendicular to the substrate[4]. It is therefore of some interest to investigate whether the low frequency noise at the resistive transition also depends on the microstructure of the films. Furthermore, since the temperature dependence of the resistance at the transition edge is potentially useful in bolometers[5] for the detection of submillimeter and far infrared radiation, one would like to know whether low frequency noise is likely to limit the resolution.

We have studied the low frequency voltage noise in four films of high T_c superconductors at and above the superconducting transition, in the presence of a bias current that generates a steady voltage $\bar{V}$ across the sample. We find that the spectral density of the noise, $S_v(f)$, scales as $\bar{V}^2/f$ at low frequencies, and that it is substantially higher in polycrystalline samples than in oriented samples. In this paper we summarize the results on two YBCO films.

Experimental techniques

The films were co-evaporated onto $SrTiO_3$ substrates using a method described elsewhere[6]. To characterize them, we measured resistance vs. temperature before patterning, estimated the critical current density (J_c) from magnetization experiments using a vibrating sample magnetometer, and determined the crystal structure from X-ray diffraction. Sample A was polycrystalline, while B was oriented predominantly with the a-axis perpendicular to the substrate. At 77K the critical current densities were 10^2 to $10^3 Acm^{-2}$ and 10^4 to $10^5 Acm^{-2}$, respectively. Using an acid etch we patterned the films into a standard 4-terminal configuration. The thickness of the films was about $0.3\mu m$, the width 400 μm and the separation between the voltage contacts 2 mm. Gold contacts were evaporated onto the film through a metal mask after the surface had been cleaned by ion milling. To minimize noise from fluctuations in the contact resistance we reannealed the samples using the recipe of Ekin et al. [7] before soldering wires to the pads with indium.

Each sample was mounted on a brass block suspended in a vacuum can immersed in liquid helium or nitrogen. The temperature, which could be raised above that of the bath with a resistive heater, was measured with a calibrated carbon-glass resistor. Typically, the system took 30 to 60 min to reach thermal equilibrium. Small temperature drifts (about 50mK) occurred during the measurement time, and the quoted temperatures represent an average. The current leads of the sample were connected in series with a battery and a large metal resistor at room temperature and the voltage leads were capacitively coupled to a low noise preamplifier. The output of the preamplifier was connected, via a bandpass filter at 0.1Hz and 40Hz, to a fast Fourier transform spectrum analyzer. Each spectrum was an average of at least 20 transforms. At each temperature, we measured the system noise with $I = 0$ and subtracted the power spectrum from that obtained at a particular value of I. We checked for spurious noise arising from fluctuations in the resistance of the current contacts by measuring the noise at the same value of I produced by several different values of the series resistance and battery voltage. We then ensured that the total circuit resistance was high enough to make such noise sources negligible.

Results and Discussion

Figure 1 shows resistivity vs. temperature for two of our YBCO samples for relatively low measuring currents. Film A was polycrystalline with a semiconducting behavior at temperatures above a broad transition, while film B was epitaxially grown and showed a metallic behavior when cooled from room temperature to the onset of superconductivity.

We found that, in the range of our measurements, the spectral density of the voltage noise, $S_v(f)$, scaled as $1/f$ at low

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frequencies. and as I^2. The fact that $S_v(f)$ is proportional to I^2 is strong evidence that the noise arises from resistance fluctuations in the film. and that the current serves only to probe these fluctuations. Figure 2 shows $S_v^{1/2}(10Hz)/\bar{V}$ vs. temperature for the two films. In each case. $S_v^{1/2}(10Hz)/\bar{V}$ decreases as T is increased through the resistive transition and becomes independent of T above a temperature which we define as T_o. In the case of sample A. which has a broad transition. T_o^A coincides with a pronounced knee in the resistive transition, as indicated in Fig. 1. On the other hand, for sample B. T_o^B is close to the onset of the normal state. The normalized spectral density of the noise. $S_v(10Hz)/\bar{V}^2$, in A above T_o^A is 250 times greater than in B above T_o^B. Similarly, at the midpoint of the transitions (where the resistivity has fallen to one-half the value just above the transition. $S_v(10Hz)/\bar{V}^2$ is about 600 times greater in A than in B. Thus. improvement in the microstructure of the films profoundly reduces the magnitude of the 1/f noise, as was the case for flux noise in thin film loops[4].

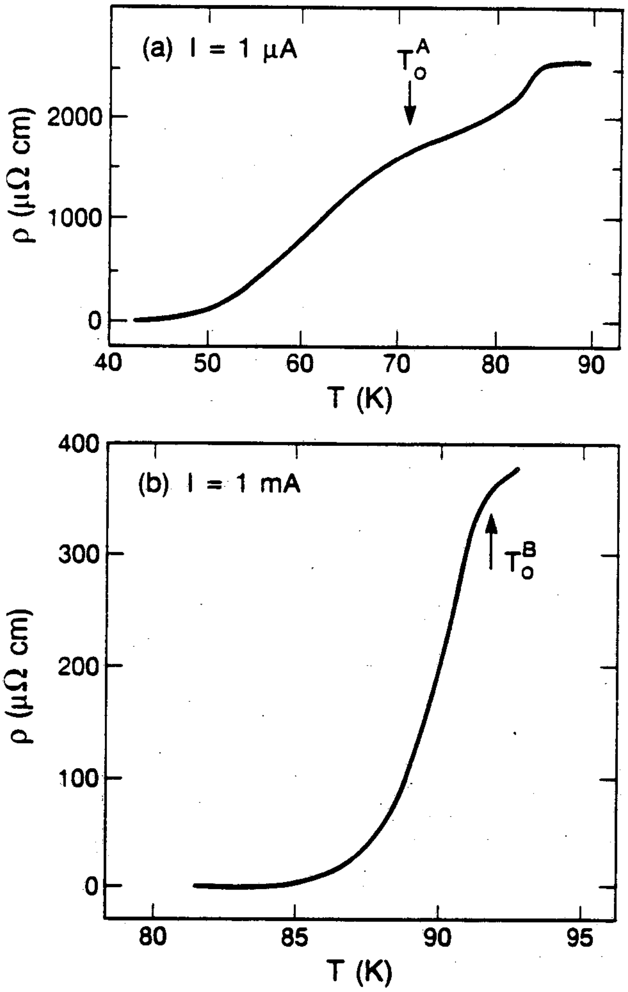

Figure 1. Resistivity as a function of temperature for (a) sample A. and (b) sample B. The measuring currents were 1 μA rms at 20 Hz and $1mA$ dc respectively.

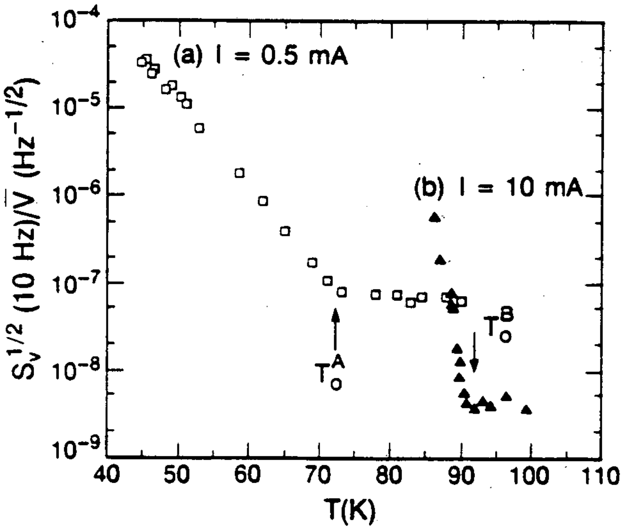

Figure 2. Normalized noise $S_v^{1/2}(10Hz)/\bar{V}$ as a function of temperature for (a) sample A. and (b) sample B measured with 0.5 mA and 10 mA currents respectively. Temperature T_o is defined at the knee of each curves.

In earlier work, it was shown that the low frequency noise at the transition edge of classical superconductors was due to equilibrium temperature fluctuations[3], with a spectral density proportional to $\bar{V}^2\beta^2$ where, $\beta \equiv dR/RdT$ and R is the sample resistance. We have made a polynomial fit to the shape of the resistive transition obtained at a bias currents 0.5 mA and 10 mA for sample A and B respectively, the values used for the noise measurements in Fig. 2. We then computed the values of β shown vs. T in Fig. 3. In each case. β varies smoothly across the transition. with a maximum of $0.25K^{-1}$ and $0.63K^{-1}$ for samples A and B, respectively. In Fig. 4, we plot $S_v^{1/2}(10Hz)/\bar{V}$ vs. β across the transition. The values of β correspond to a temperature range of $50K$ to $70K$ for sample A, and $87K$ to $91K$ for sample B. We find that $S_v(10Hz)/\bar{V}^2$ scales as β^α, where $\alpha = 4.4$ for sample A and $\alpha > 30$ for sample B. The fact that $S_v/\bar{V}^2$ is proportional to β^{30} rather than β^2 for sample B. with the steeper resistive transition. immediately rules out the thermal fluctuation model. For sample A not only is α about a factor of 2 higher than the value required by the thermal fluctuation model, but its noise is substantially higher than in B while its range of values of β is considerably smaller.

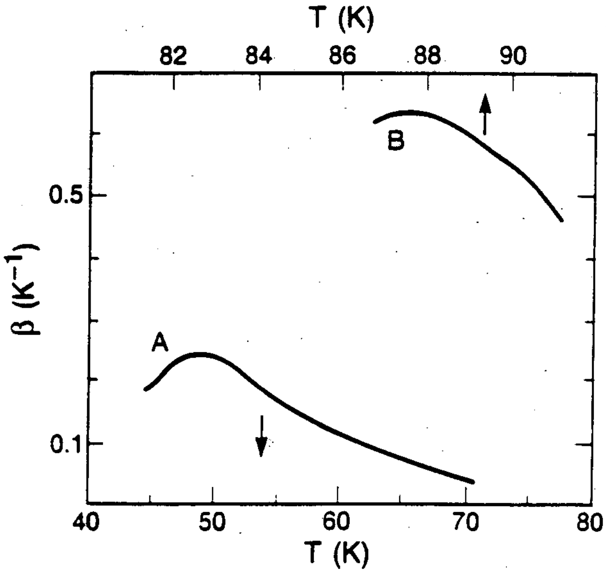

Figure 3. β vs. temperature for samples A and B. The ranges of temperature correspond to the transition regions.

Thus, we can also rule out the temperature fluctuation model for sample A. It appears that the value of β does not play an obvious role in the magnitude of the noise. We have no detailed explanation for the origin of the noise beyond speculating that it arises from regions of material that fluctuate in and out of the superconducting state with the broad distribution of time constants required to produce a 1/f power spectrum[9].

The fact that the 1/f resistance fluctuations persist above T_o may provide some insight into the normal transport behavior of these films. It seems likely that these resistance fluctuations are associated with grain boundaries. This notion seems quite plausible for the polycrystalline YBCO sample A, which shows an increasing resistivity with decreasing temperature. However, it appears also to apply to the more highly oriented a-axis sample B, which shows metallic conduction. Thus, noise measurements may provide a sensitive quantitative probe of the residual effects of grain boundaries on the normal state transport of the cuprate superconductors that are presently hard to quantify with other techniques.

Finally, we comment briefly on the temperature resolution of sample B were it to be used as a thermometer on a superconducting bolometer. One wishes to detect the smallest possible temperature rise, δT, which produces a corresponding voltage change $\delta V = \bar{V}\beta\delta T$. If we assume that the resolution is limited by 1/f noise, we can equate δV to $[S_v(f)\Delta f]^{1/2}$ in a noise bandwidth Δf to find $\delta T(f) = [S_v(f)\Delta f]^{1/2}/\bar{V}\beta$. This result, which is independent of $\bar{V}$, shows that the figure of merit for the 1/f noise in the thermometer is $S_v^{1/2}(f)/\bar{V}\beta$. From Fig. 4 for sample B, we find that the minimum value of this figure of merit at an arbitrarily chosen frequency of 10 Hz is about $1 \cdot 10^{-6}\ KHz^{-1/2}$.

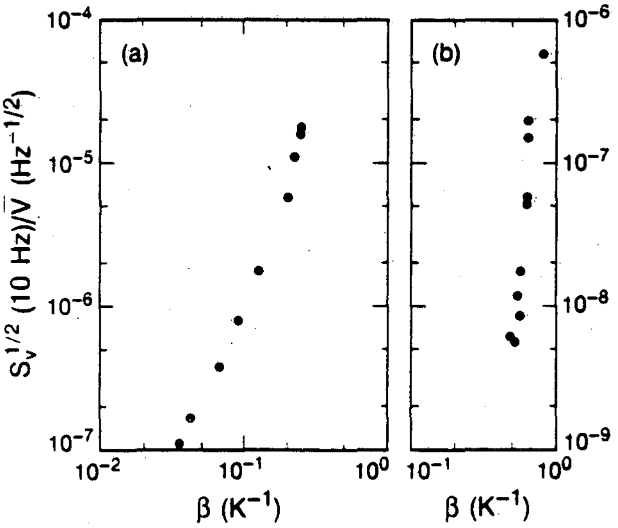

Figure 4. Normalized noise $S_V^{1/2}(10Hz)/\bar{V}$ vs. β. For sample B, shown in (b), the noise is lower and β is higher than for sample A, shown in (a).

In conclusion, we have shown that the 1/f noise at the resistive transition of YBCO films is reduced substantially as the microstructure of the films is improved. This result is qualitatively similar to observations of magnetic flux noise in thin films loops of YBCO, although it is far from clear that the mechanisms producing the noise are similar. In contrast to classical superconductors, the 1/f noise at the resistive transition does not arise from equilibrium temperature fluctuations. We are presently extending this study to highly oriented c-axis films.

R. L. and Ph. L. thank Progetto Finalizzato Materiali e Dispositivi per l'Elettronica a Stato Solido and the Swiss Science Fundation, respectively, for their financial support.

This work was supported by the Office of Naval Research under Contract No. ONR N00014-83-K-0391 and by the Director, Office of Energy Research, Office of Basic Sciences, Material Sciences Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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