January 1999

Noise measurement of $YBa_2Cu_3O_{7-\chi}$ and $Ti_2Ba_2Ca_2Cu_2O_{10-\chi}$ thin films

J.P. Zheng
Department of Electrical and Computer Engineering, State University of New York at Buffalo, Bonner Hall, Amherst, New York

Q.Y. Ying
Department of Electrical and Computer Engineering, State University of New York at Buffalo, Bonner Hall, Amherst, New York

S.Y. Dong
Department of Electrical and Computer Engineering, State University of New York at Buffalo, Bonner Hall, Amherst, New York

H.S. Kwok
Department of Electrical and Computer Engineering, State University of New York at Buffalo, Bonner Hall, Amherst, New York

Sy_Hwang Liou
University of Nebraska-Lincoln, sliou@unl.edu

Zheng, J.P.; Ying, Q.Y.; Dong, S.Y.; Kwok, H.S.; and Liou, Sy_Hwang, "Noise measurement of $YBa_2Cu_3O_{7-\chi}$ and $Ti_2Ba_2Ca_2Cu_2O_{10-\chi}$ thin films" (1999). *Si-Hwang Liou Publications*. 42.
https://digitalcommons.unl.edu/physicsliou/42

Noise measurement of $YBa_2Cu_3O_{7-x}$ and $Ti_2Ba_2Ca_2Cu_3O_{10-x}$ thin films

J. P. Zheng, Q. Y. Ying, S. Y. Dong, and H. S. Kwok
Department of Electrical and Computer Engineering, State University of New York at Buffalo,
Bonner Hall, Amherst, New York 14260

S. H. Liou
Behlen Laboratory of Physics and Center for Materials Research and Analysis, University of
Nebraska-Lincoln, Lincoln, Nebraska 68588

(Received 7 June 1990; accepted for publication 16 September 1990)

The noise of $YBa_2Cu_3O_{7-x}$ and $Tl_2Ba_2Cr_2Cu_3O_{10-x}$ thin films in the frequency range from 0.5 Hz to 100 kHz was studied. In the normal state, it was found that $1/f$ noise dominated, with a magnitude strongly dependent on temperature. In the superconducting state, the noise was only observable at frequencies below 5 Hz with our present setup. Equilibrium thermal fluctuation noise was not observed in these films.

Noise in conductors has attracted much attention for more than half a century.[1-5] It has been found that $1/f$ noise often dominates at low frequency when a current is applied to the conductor. Recently, $1/f$ noise was observed in high-temperature superconductors (HTS) by several groups.[6-10] The exact nature of the $1/f$ noise has not been well understood. Several mechanisms have been established in normal conductors, such as the scattering of carriers whose relaxation time has a wide distribution due to defect- motion-induced conductance fluctuation.[4] Several other origins of $1/f$ noise have also been considered.[5]

Besides fundamental interests, noise affects the performance of electronic devices. Recently, it has been found that superconducting films can be used as infrared detectors.[11,12] For infrared detectors, the most widely used figure of merit is the detectivity D^*, and the noise-equivalent power (NEP). These two parameters are related to each other and to the intrinsic noise voltage generated in the detector. In this communication, we present some recent measurements of the noise properties of several HTS films. Attempts will be made to correlate the noise properties to the superconducting characteristics of the samples.

In normal conductors, the noise spectrum can be expressed well by the following empirical formula[2]:

$$S_R(f)/R^2 = S_V(f)/V^2 = (\gamma/N)(1/f^\alpha), \tag{1}$$

where $S_R(f)$ and $S_V(f)$ are the power spectral density voltage and voltage fluctuations at frequency f, respectively. R and V are the resistance and the voltage across the sample, N is the total number of charge carriers, while γ and α are dimensionless constants. The value of α is close to 1 for most metals at low f. For metals, the value of γ is between $10^{-1}-10^{-5}$. For HTS materials, the range of values for γ has been reported[8-10] to be from 10^3 to 10^6. Obviously, small γ is desirable.

We performed a careful measurement of $S_R(f)$ in high-quality-laser deposited Y-Ba-Cu-O (YBCO) thin films. As a comparison, we also used a sputtered Tl-Ba-Ca-Cu-O (TBCCO) film in this study. Table I summarizes the electrical properties and the dimensions of the films. The sample preparation and patterning procedures of these films have been described previously.[13-15] The YBCO films were laser- deposited at 620 °C, while the TBCCO film was sputtered and then annealed in Tl vapor. Sample C was high-temperative treated (900 °C) to investigate its effect on γ.

Typically, the sample was mounted in a dewar with a temperature resolution of 0.05 K. Electrical noise-power spectrum was then measured by a standard 4-probe technique. 0.5- μm-thick silver pads were evaporated on the superconducting films for ohmic contacts. The contact resistance was $\sim 1\ \Omega$ which is about 1000 times smaller than that of the sample at room temperature. Therefore the noise generated at the contacts can be neglected.

Noise measurements between 0.5 Hz and 100 kHz were performed by measuring the voltage fluctuation under battery-generated dc current through the sample, with a large resistance (at least 100 times the sample resistance) in series to minimize contact noise. The voltage signal was sent through a low-noise preamplifier (SRS SR560) with a tunable bandpass filter from dc to 1 MHz. The amplified voltage signal was detected by a lock-in amplifier (SRS SR510) in the noise mode.

The noise spectrum was studied in order to understand its origin. Figure 1 shows $S_V(f)$ for sample A in the normal (300 K) and superconducting (6 K) states. The bias current was 0.67 mA. In the normal state, it can be seen that $S_V(f)$ follows $1/f$. In the superconducting state, the noise was too small to be seen at frequencies greater than 5 Hz with our present experimental setup. At $f < 5$ Hz, a small noise voltage can be seen above the background electronic noise. This low-frequency voltage fluctuation was possibly due to the telegraph noise or generation-recombination noise.[16] However, Ferrari *et al.*[16] recently showed that the magnetic flux noise in the superconducting state had a $1/f$ spectrum also.

Figure 2 shows $S_V^{1/2}(f)$ for the same sample as a function of temperature at a bias current of 0.67 mA. The dotted line shows the resistance of this sample. Figure 3 shows the temperature dependence of normalized excess noise spectra $\sqrt{S_V}/V$. Two interesting features can be observed: (1) The noise decreases abruptly at T_c. No sharp peak corresponding to equilibrium thermal fluctuation noise can be observed around T_c, contrary to reports by

0021-8979/91/010553-03$03.00

TABLE I. Sample data. All samples are 87 μm wide by 3 mm long.

Sample	Type	$T_c(R=0)$	ρ (300 K) (mΩ cm)	Thickness (nm)
A	YBCO/MgO	80 K	0.57	170
B	YBCO/MgO	86 K	0.52	220
C	YBCO/MgO	70 K	0.87	130
D	TBCCO/SrTiO$_3$	82 K	0.54	150

other groups.[8–11] (2) From Fig. 3, it can be seen that the value of γ/N is independent of temperature in the normal state. Using Hall resistance measurements, the carrier concentration n was found to be proportional to T for high-quality Y-Ba-Cu-O material.[17,18] Therefore, the values of γ should also be proportional to the temperature in the normal state. These features are common to all films studied.

Based on these experimental results, we can evaluate the value of γ in Eq. (1). In the normal state, the exponent α is ~ 1, and $1/f$ noise dominates. The carrier concentration n can be calculated from the resisitivity ρ using the following formula

$$1/\rho = ne^2\tau/m^* \tag{2}$$

where τ is the relaxation time of the carrier and m^* is the hole effective mass. The resistivity in the ab plane for single crystal YBCO was measured to be 0.5 mΩ cm at 300 K[19–21] which agrees with that of our *in-situ* films. Hall effect measurements give n in the range $1\text{–}10\times10^{21}$ cm^{-3},[22–24] while the value obtained by setting the hole concentration equal to the concentration of Cu^{3+} ions is 6×10^{21} cm^{-3}.[25]

Using the value of 5×10^{21} cm^{-3}, N can be evaluated and γ can therefore be calculated using Eq. (1). The results are summarized in Table II. It can be seen that the values of γ are at least $10^2\text{–}10^3$ times smaller than that observed by Testa *et al.*[8] and Maeda *et al.*[9] but agree with the results reported by Lee *et al.*,[10] taking into account the different values of n used. However, the values of γ are still 3–7 orders of magnitude larger than that in conventional metals.

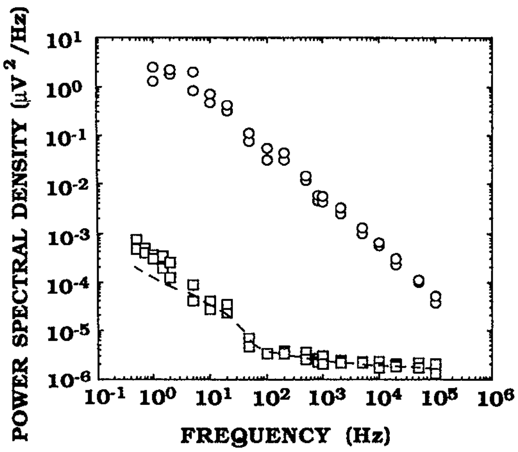

FIG. 1. Frequency dependence of the noise power spectral density for sample A, at a bias current of 0.67 mA. ○ 300 K, □ 6 K. The dashed curve represents the background electronic noise level.

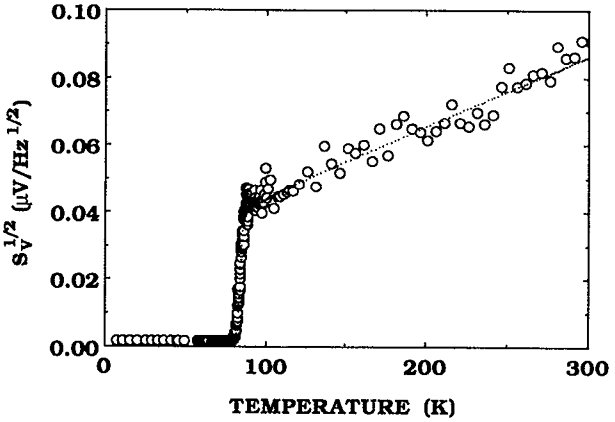

FIG. 2. Temperature dependence of the square root of the noise power spectral density at a chopping frequency of 830 Hz. (sample A). The dashed line is the temperature dependence of the resisitivity plotted with arbitrary units. Both results were measured at a bias current of 0.67 mA.

Some general trends can be observed from the results in Table II. Sample B is a high-quality *in situ* film and yet it has the largest γ among the YBCO films. Sample C is a laser-deposited film which we deliberately anneal at high temperature (900 °C). The γ value is slightly smaller even though T_c is lower. Among the YBCO films, it seems that thinner ones tend to have smaller γ. Finally, the TBCCO film has the largest γ. The TBCCO films in general are noisier than the YBCO films, even though the T_c is higher.[26] This fact may be important in considering practical electronic applications.

The above observations are in general agreement with the view that high-quality epitaxial films have less noise.[16] This conclusion was also reached by comparing the noise voltage between granular and epitaxial films.[27] Moreover, it was confirmed that higher-quality films do not exhibit the so-called"equilibrium thermal fluctuation noise," which peaks at T_c.[28]

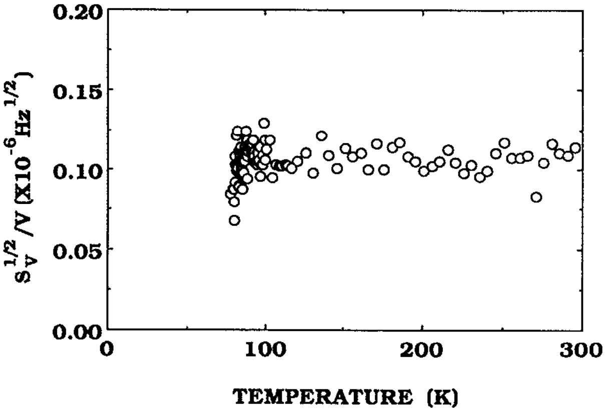

FIG. 3. S_V (830 Hz)/V^2 vs temperature for sample A.

TABLE II. Summary of results at 300 K. All samples biased at 0.67 mA.

Sample	Frequency (Hz)	S_V ($\mu V^2/Hz$)	γ
A	10	0.6	2 200
	830	0.008	2 400
B	10	0.4	4 600
	830	0.0045	3 900
C	10	2.4	1 250
	830	0.03	1 250
D	10	1.7	14 700

In conclusion, noise properties were investigated in HTS films. It was found that $1/f$ noise dominated in the normal state, and telegraphlike generation-recombination noise was observed in the superconducting state. At $T > T_c$, the noise power is 3–7 orders of magnitude larger than that in normal metals. However, there is some weak evidence that thinner films are less noisy.

This research was supported by the National Science Foundation.

[1] A. Van der Ziel, Physica **16**, 359 (1950).

[2] F. N. Hooge, T. G. Kleinpenning, and L. K. Vandamme, Rep. Prog. Phys. **44**, 31 (1981).

[3] P. Dutta and P. M. Horn, Rev. Mod. Phys. **53**, 497 (1981).

[4] M. B. Weissman, Rev. Mod. Phys. **60**, 537 (1988).

[5] H. Furukawa, Phys. Rev. A **34**, 2315 (1986).

[6] J. A. Testa, Y. Song, X. D. Chen, J. Golben, S-I Lee, B. R. Patton, and J. R. Gaines, Phys. Rev. B **38**, 2922 (1988).

[7] A. Maeda, Y. Nakayama, S. Takebayashi, and K. Uchinokura, Phys. C **160**, 443 (1989).

[8] P. Rosenthal, R. H. Hammond, M. R. Beasley, R. Leoni, Ph. Lerch, and J. Clarke, IEEE Tran. Magne. **25**, 973 (1989).

[9] R. D. Black, L. G. Turner, A. Mogro-Campero, T. C. McGee, and A. L. Robinson, Appl. Phys. Lett. **55**, 2233 (1989).

[10] J. H. Lee, S. C. Lee, and Z. G. Khim, Phys. Rev. B **40**, 6806 (1989).

[11] H. S. Kwok, J. P. Zheng, Q. Y. Ying, and R. Rao, Appl. Phys. Lett. **54**, 2473 (1989).

[12] Q. Hu and P. L. Richards, Appl. Phys. Lett. **55**, 2444 (1989).

[13] S. Witanachchi, S. Patel, H. S. Kwok, and D. T. Shaw, Appl. Phys. Lett. **54**, 578 (1989).

[14] M. Hong, S. H. Liou, D. D. Bacon, G. S. Grader, J. Kwo, A. R. Kortan, and B. A. Davidson, Appl. Phys. Lett. **53**, 2102 (1988).

[15] J. P. Zheng, Q. Y. Ying, H. S. Kim, P. Bush, R. Barone, D. T. Shaw, and H. S. Kwok, Appl. Phys. Lett. **55**, 1044 (1989).

[16] M. J. Ferrari, M. Johnson, F. C. Wellstood, J. Clarke, R. A. Rosenthal, R. H. Hammond, and M. R. Beasley, Appl. Phys. Lett. **53**, 695 (1988).

[17] H. L. Stormer, A. F. J. Levi, K. W. Baldwin, M. Anzlowar, and G. S. Boebinger, Phys. Rev. B **38**, 2472 (1988).

[18] I. O. Parker and R. H. Friend, J. Phys. C **21**, L345 (1988).

[19] M. Matsuda and S. Kuriki, Appl. Phys. Lett. **15**, 621 (1988).

[20] S. W. Tozer, A. W. Kleinsasser, T. Penney, D. Kaiser, and F. Holtzberg, Phys. Rev. Lett. **59**, 1768 (1987).

[21] I. D. Parker and R. H. Friend, J. Phys. C **21**, 345 (1988).

[22] B. W. Ricketts, R. B. Roberts, R. Driver, and H. K. Welsh, Solid-State Commun. **64**, 1287 (1987).

[23] S. W. Cheong, S. E. Brown, Z. Fisk, R. S. Kwok, J. D. Thompson, E. Zirngiebl, G. Gruner, D. E. Peterson, G. L. Wells, R. B. Schwarz, and J. R. Cooper, Phys. Rev. B **36**, 3913 (1987).

[24] G. S. Grader, P. K. Gallagher, and A. T. Fiory, Phys. Rev. B **38**, 844 (1988).

[25] M. Gurvitch and A. T. Fiory, Phys. Rev. Lett. **59**, 1337 (1987).

[26] V. Foglietti, R. H. Koch, W. J. Gallagher, B. Oh, B. Bumble, and W. Y. Lee, Appl. Phys. Lett. **54**, 2239 (1989).

[27] R. D. Black, A. Mogro-Campero, and L. G. Turner, paper presented at SPIE Meeting, Orlando, FL, April 1990.

[28] P. L. Richards, S. Verghese, T. H. Geballe, and S. R. Spielman, IEEE Trans. Magn. **MAG-25**, 1335 (1989).