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Flicker noise in $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ bicrystal grain boundary junctions in weak magnetic fields

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Flicker noise in c -axis oriented long YBCO bicrystal grain boundary junctions was characterized as a function of temperature, biasing conditions, and magnetic field applied perpendicular to the a - b plane over a wide range of temperatures from 15 K to over 70 K. Aperiodic variations, as a function of magnetic field, were observed in both the junction voltages, V_J , and the flicker noise magnitude under constant current bias as the magnetic field was scanned from 0 to 8 G. The noise magnitudes were found to peak at the minima of V_J . Analyses of the field dependencies of the magnitudes and the functional form of the voltage noise power spectra show that the noise did not arise from thermally activated flux motion. Based on the dependencies of the noise power spectra on the bias current and the dynamic resistance of the junction, we conclude that the noise originates from the fluctuations of the critical current of the devices most likely due to trapping of carriers or defect motion within the grain boundary. © 1995 American Institute of Physics.

Flicker noise in YBCO thin films and bicrystal junctions¹⁻⁴ presents serious limitations in the low-frequency applications of high- T_C superconducting quantum interference devices (SQUIDs). In this article we report experimental results on $1/f$ noise in YBCO bicrystal grain boundary junctions as a function of temperature, biasing conditions, and applied magnetic field.

High quality c -axis oriented YBCO thin films were deposited on SrTiO_3 bicrystal substrates by laser ablation. The ab -plane misorientation across the junction was 36.8° . Microbridges, ranging from $10\ \mu\text{m}$ to $50\ \mu\text{m}$, were patterned using a standard photolithographic technique and EDTA etch. The critical temperature of the junctions at zero field was about 90.3 K with a transition region <0.6 K. Typical I - V characteristics can be well fitted to the resistively shunted junction (RSJ) model with J_C around $10^5\ \text{A cm}^{-2}$ at $T=25.4$ K under zero field condition.

Field dependencies of the device characteristics were investigated with the magnetic field, B_z , applied perpendicular to the a - b plane of the high- T_C film. Strong aperiodic dependencies of the junction voltage, V_J , on B_z were observed with the junction biased with a constant current and B_z slowly varying from 0 to 8 G as shown in Fig. 1. This pattern can be viewed as a magneto-“fingerprint” (MF) of the junction disorder unique to each sample.^{5,6} Curves A and B represent V_J measured for two different scans of the field separated by over an hour. A vertical shift is artificially introduced in the plots for comparison. In general, we found that the pattern remains unchanged as long as the devices were kept in low temperatures and small fields. Patterns and critical currents were strongly altered if fields ≥ 80 G were applied, most likely due to trapped flux.

Similar MF in the voltage noise power spectra across the junctions were also observed. The low-frequency noise was characterized with the device under constant current bias. Typical voltage noise power spectra, $S_V(f)$, varied as $1/f^\gamma$ where $\gamma \approx 1.15$. Most interestingly, the noise power spectra were found to peak at the minima of V_J as shown in Fig. 2. Here we show the detailed variations of V_J (curve A) and $S_V(100\ \text{Hz})$ (curve B) for B_z between 5 and 6 G.

Recent studies of MF and noise in high- T_C superconducting thin films suggested that the phenomenon originates from the simultaneous presence of flux flow and metastably pinned vortices⁵. Aperiodic variations of critical current with field are expected for Josephson junctions with disorder, which leads to spatial fluctuations in the critical current density along the grain boundary. In long junctions the disorder can be viewed as a pinning potential for fluxons that pen-

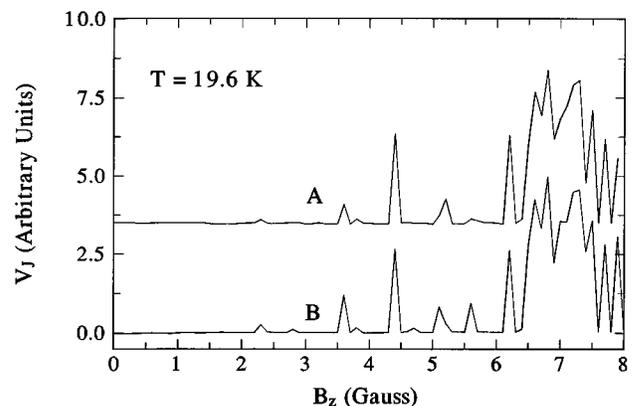


FIG. 1. Junction voltage vs B_z at $I=2\ \text{mA}$ and $T=19.6\ \text{K}$. Curves A and B represent two sets of data collected at times separated by at least 1 hr in between.

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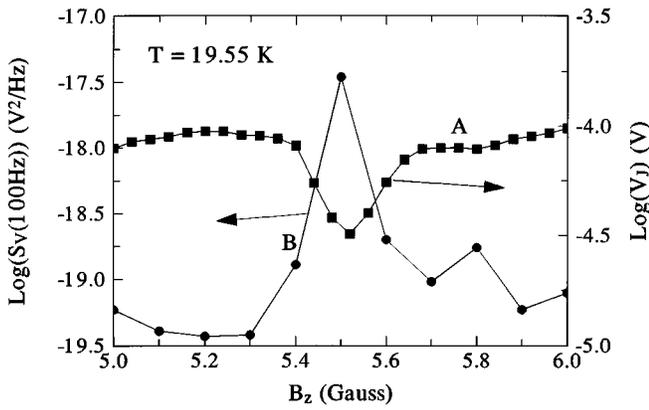


FIG. 2. Comparison between field dependencies of junction voltage (square) and S_V (100 Hz) (circle) at $I=2$ mA and $T=19.55$ K. Lines A and B are guides to the eye.

erate the junction due to the presence of both the external field and applied currents. The pinning of a single fluxon within the junction area is still expected to set the dominant field scale for modulation of the voltage. The junction area is the length ($40 \mu\text{m}$ in the present case) times the magnetic thickness which is approximately twice the ab penetration depth, i.e., $\sim 0.5 \mu\text{m}$, predicting a field scale of about 1.0 G, quite consistent with the observations.

Although MF were observed in the $1/f^\gamma$ noise, this doesn't imply that flux motion is ultimately responsible for the noise. Low-frequency noise arising from critical current fluctuations can occur due to carrier trapping, defect motion, or flux motion within or close to the junction. Our analysis show that the voltage noise power spectral density arising from critical current fluctuation noise can be expressed as

$$S_V(f) = \frac{r^2(I^2 R_n^2 - V_J^2)}{I^2 R_n^2} S_{Ic}(f) + \frac{r^2 V_J^2}{R_n^4 I^2} \left(\frac{\partial V_J}{\partial B_z} \right)^2 S_B(f), \quad (1)$$

where r is the dynamic resistance, and R_n is the junction resistance in the RSJ model. The second term in Eq. (1) arises from field fluctuations due to flux motion in the vicinity of the junction. In Fig. 3 we plotted S_I vs $[V_J/(dV_J/dB_z)]^2$, in which $S_I = S_V/r^2$. If the observed low-

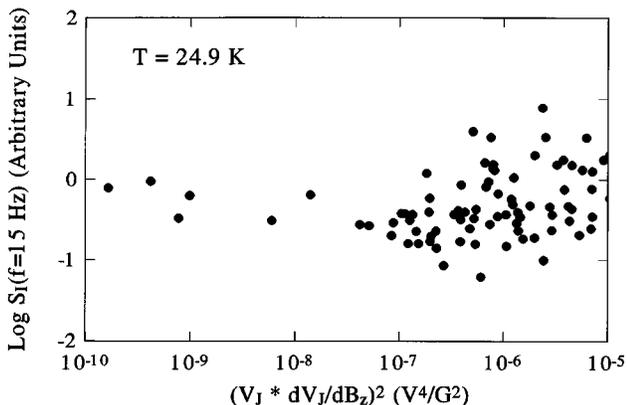


FIG. 3. $\text{Log}[S_I(15 \text{ Hz})]$ vs $(V_J dV_J/dB_z)^2$ at $T=24.9$ K and $I=2$ mA.

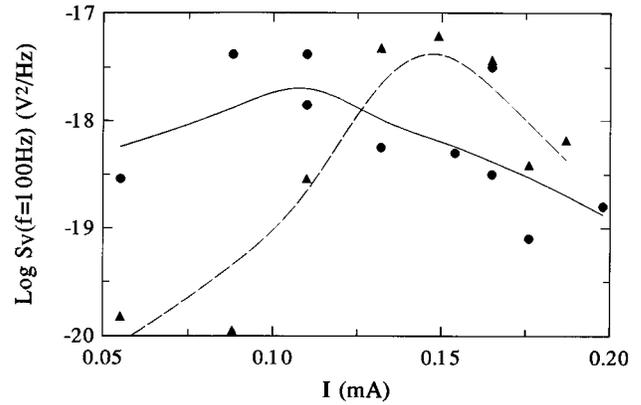


FIG. 4. Current dependencies of S_V (100 Hz) at 34.7 K (circle) and 54.7 K (triangle) at $B_z=200$ G.

frequency noise originated from thermally activated flux motion, one would expect to see a slope of one in Fig. 3. Instead, we do not observe any dependencies between the two parameters. In addition, thermally activated fluxons producing critical current fluctuation noise would cause the spectrum to deviate noticeably from a power law⁷ and should result in large variations in γ as the pinning energy distribution varied with the applied field.⁵ This is in contrast to the voltage noise power spectra which always exhibit a power law and, while the noise increased by nearly two orders of magnitudes when B_z varied from 5.2 to 5.5 G, no detectable changes in γ were observed. Thus our experimental data strongly indicate that thermally activated flux motion is not responsible for the observed flicker noise in bicrystal grain boundary junctions, at least not well below T_C .

Typical results on current dependencies of the $1/f$ noise measured at $B_z = 200$ G are shown in Fig. 4, where we have plotted the voltage noise power spectra for $T=34.7$ K and 54.7 K, in which the solid and dashed lines are guides to the eye. The magnitudes of the voltage noise power spectra were found to increase with I initially but decrease at large I , similar to Kawasaki's¹ observation for critical current fluctuations. In addition, the voltage noise power spectra exhibit, within experimental scatter, an r^2 dependence as shown in Fig. 5. From Eq. (1), R_n is of the order of 0.1Ω and is

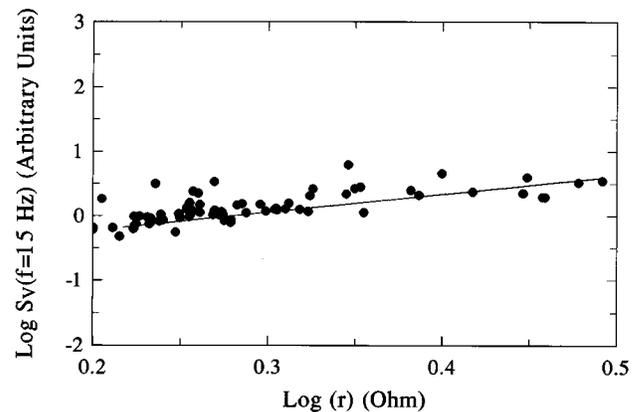


FIG. 5. $\text{Log}[S_V(15 \text{ Hz})]$ vs $\text{log}(r)$ at $T=24.9$ K and $I=2$ mA fitted to a line of slope =2.

relatively insensitive to the applied field, I is kept constant at 2 mA, and V_J typically varied between 10^{-5} and 10^{-6} V. Therefore $I^2 R_n^2 \gg V_J^2$ and $S_V(f) \propto r^2$ for flicker noise dominated critical current fluctuations. Thus our results are consistent with critical current fluctuations.

In conclusion, we have conducted detailed experimental studies of flicker noise in YBCO bicrystal grain boundary junctions in low magnetic fields. We observed magneto-fingerprints in both the junction voltage and the low-frequency noise due to the modulation with field of fluxon pinning within the junction. However, while flux motion affects the magnitude of the measured noise power spectra, it is not the underlying cause for flicker noise in the devices at low temperature. Our experimental results show that flicker noise in YBCO bicrystal junctions originates from critical current fluctuations most likely due to carrier trapping or motion of defects⁸ in the junction region.

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