

VOLTAGE NOISE OF $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ FILMS IN THE VORTEX-LIQUID PHASE

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ABSTRACT

We have measured the voltage noise in the vortex-liquid phase of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ films at high magnetic fields. The voltage-noise spectral density S_V is found to be of the $1/f$ -type, and to vanish critically at the superconducting phase transition according to $S_V \propto (T - T_g)^x$, where T_g is the vortex-glass transition temperature and $x = 1.8 \pm 0.3$. A model is presented which explains the experimental observations. The model is based on a distribution of critically divergent lifetimes of vortex-glass domains.

The present paper reports on noise experiments in films of the high- T_c superconductor $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ in the resistive state at high magnetic fields. This resistive state is accepted to be a liquid of vortices carrying the magnetic flux lines. Whereas previous noise studies in $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ have focused on the regime near zero magnetic field, this work studies the regime at high magnetic fields. The principal new result is that in a high magnetic field the voltage noise vanishes at the superconducting phase transition according to a critical power law.

The magnetic field-temperature (H - T) phase diagram of high- T_c superconductors like $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ consists of several phases (Fig. 1): (i) the normal phase at high temperatures and fields ($H > H_{c2}$); (ii) the superconducting Meissner phase at low fields ($H < H_{c1}$); (iii) the superconducting vortex-glass phase¹ at higher fields, where the vortices are frozen into a glassy state; and (iv) the vortex-liquid phase in between the vortex-glass transition and the upper critical field H_{c2} . In the vortex liquid, the motion of the vortices causes the resistance to be finite. We have examined the voltage noise in this phase with the aim to study the dynamics of vortex lines. The sample was a c -axis-up 3000-Å $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ film, which was laser ablated onto a SrTiO_3 substrate. The film was photolithographically patterned to four-probe patterns with a central stripe of $150 \times 20 \mu\text{m}^2$. A gold layer was deposited onto the contact pads. Subsequent annealing yielded a contact resistance of much less than 1Ω . In zero magnetic field the film exhibited zero resistance below 91.2 K.

The voltage noise spectral density was obtained while biasing the superconductor with a constant dc current I . The noise signal was passed through a low-noise

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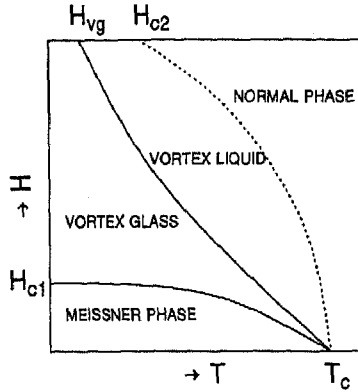


Figure 1: The H - T phase diagram of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$.

1:100 transformer and subsequently amplified by a low-noise preamplifier. The resulting signal was fed to a fast-Fourier transform spectrum analyzer. The noise spectrum was corrected for background noise and the system response,² to obtain the excess ($I > 0$) voltage-noise spectral density S_V . We measured S_V as a function of frequency f , current I , temperature T , and magnetic field H (up to 5 T along the c axis).

The low-frequency (< 2 kHz) noise is found to depend on the frequency essentially as $1/f^n$, with $n = 0.96 \pm 0.06$, independent of I , T , and H . A typical noise spectrum is shown in Fig. 2. At all temperatures and fields, we find that S_V depends on the current approximately as $S_V \propto I^2$. In the normal state this points to resistance fluctuations as the noise source. In the vortex-liquid phase, the I^2 dependence of S_V is not fully understood. Presumably it is related to the complicated crossover from ohmic to power-law behavior upon approaching the vortex-glass transition temperature T_g ($T_g = 76.3$ K at 5 T, $T_g = 84.3$ K at 2 T).

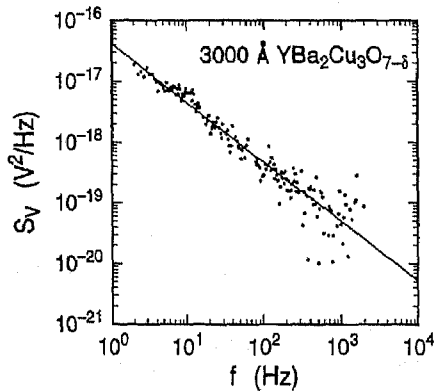


Figure 2: Typical excess noise spectrum, corrected for background noise and the system response; $H = 2$ T, $T = 90.11$ K, $I = 2$ mA. The solid line denotes a $1/f^{0.98}$ dependence.

In Fig. 3, we present S_V as a function of the reduced temperature $(T - T_g)/T_g$. With decreasing temperature, S_V vanishes at T_g . Quite remarkably, this temperature dependence can be described in terms of a critical power law

lated by⁵

$$S_V(\omega) \propto D(\tilde{l}) \int \frac{Cl^z}{1 + (\omega Cl^z)^2} dl \propto D(\tilde{l})/\omega^{1+1/z}. \quad (3)$$

Secondly, we make the reasonable assumption that the distribution $D(l)$ does not change much when scaling the length scale l to the vortex-glass correlation length ξ . We thus rewrite the distribution as

$$D(l) = D_0 \rho(l/\xi), \quad (4)$$

where ρ is a normalized form function, and $D_0 = 1/\xi$ is a normalization constant determined by $\int_0^\infty D(l)dl = 1$. Note that, upon approaching T_g , the form of $D(l)$ does not change much, whereas the length scale l for which $D(l)$ reaches a maximum critically shifts upwards, while the value of this maximum critically vanishes. Combining Eqs. (3) and (4) and substituting $\xi \propto 1/(T - T_g)^\nu$, we finally arrive at

$$S_V(\omega, T) \propto \frac{(T - T_g)^\nu}{\omega^{1+1/z}} \rho(\tilde{l}/\xi). \quad (5)$$

We thus expect that S_V vanishes upon approaching T_g from above according to $S_V \propto (T - T_g)^\nu$, with $\nu = 1.7$. This is in good agreement with the experimental result that S_V depends critically on the temperature with a critical exponent $x = 1.8 \pm 0.3$. From Eq. (5) a frequency dependence $S_V \propto 1/f^{1+1/z}$ would be expected, i.e., $S_V \propto 1/f^{1.2}$ for $z = 4.8$. The minor difference with the observed $1/f$ dependence can be accounted for by a slight length dependence of $D(l)$.⁵

In summary, we have observed that in the vortex-liquid phase (i) S_V has a $1/f$ character and (ii) S_V diverges critically upon approaching T_g . We have explained the $1/f$ character and the temperature dependence of the voltage fluctuations in the vortex fluid phase by the use of a model, based on a distribution of lifetimes of vortex glass domains with a critically diverging average lifetime.

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5. This is similar to the approach in P. Dutta and P. M. Horn, Rev. Mod. Phys. **53**, 497 (1981).