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FLUX-FLOW AND FLUCTUATIONS IN THE MICROWAVE RESISTIVITY OF $\mathbf{YBa_2Cu_3O_{7-\delta}}$

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We present measurements of the microwave resistivity at 48 GHz in $YBa_2Cu_3O_{7-\delta}$ film, as a function of the temperature and the magnetic field. The magneto-dissipation from 60 K up to a few kelvins below T_c finds a quantitative description in terms of free flux flow. Approaching T_c, the data are not consistent with a dissipative mechanism based solely on flux dynamic. Fluxon viscosity is measured as a function of the temperature, and the in-plane coherence length is estimated. The analysis of the zero-field transition at 48 GHz in terms of anisotropic renormalized fluctuations yields identical estimate.

1. Introduction

Dissipative mechanisms in high-temperature superconductors (HTSCs) with and without an external magnetic field can be ascribed to flux dynamic and order parameter fluctuations. Flux dynamic is a difficult mechanism to be described quantitatively: depending on temperature, magnetic field, anisotropy and type and density of defects a variety of behaviors can be predicted.[1] For noninteracting vortices in a sinusoidal pinning potential, submitted to an alternating driving current $Je^{i\omega t}$ and to viscous, elastic, and thermal forces one can calculate[2,3,4] the complex resistivity $\tilde{\rho}(B, T, \omega)$ as a function of the magnetic field, the temperature and the frequency. Even in this simplified approach, the obtained vortex resistivity contains several phenomenological parameters such as the fluxon viscosity $\eta(T)$, the pinning

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constant $\kappa_p(B,T)$ and the vortex activation energy $u(B,T)$. However, the resulting expression takes a particularly simple expression when $\omega \gg \omega_p = \kappa_p/\eta$, and $T/T_c < 0.98$. In this case it reduces to the simple flux-flow expression:

$$\tilde{\rho}(B,T) = \Phi_0 B/\eta \tag{1}$$

where Φ_0=2.07 10^{-15} Tm^2, and the response becomes independent of ω and of flux creep effects. Moreover, adopting the Bardeen-Stephen model, one gets:[1,4]

$$\eta(T) = \frac{\Phi_0 B_{c2}(T)}{\rho_n} = \frac{\Phi_0 B_{c20}(1-(T/T_c)^2)}{\rho_n} \tag{2}$$

which links the phenomenological fluxon viscosity to the upper critical field $B_{c2}(T)$ (or to the coherence length $\xi(T) = (\Phi_0/2\pi B_{c2})^{1/2}$). In the last equality, we have taken the mean-field law: $B_{c2}(T) = B_{c20}(1-(T/T_c)^2)$.

A second quantity that depends only on fundamental parameters is the fluctuation conductivity above T_c. Since HTSC's are strong candidates for wide critical regime, it is necessary to go beyond a simple gaussian framework in the calculations. In a previous paper[5] we have calculated the frequency-dependent fluctuational conductivity above T_c in a uniaxial anisotropic superconductor, including the ψ^4 term in the Ginzburg-Landau functional through a Hartree approximation. The resulting expression[5] contains as parameters the critical temperature T_c, the zero-temperature in-plane coherence length ξ_{ab0} and penetration depth λ_{ab0}, and the anisotropy ratio γ.

In this paper we will present measurements of the field-dependence of the microwave resistivity below T_c and of the resistive transition at 48 GHz in zero applied field, in $YBa_2Cu_3O_{7-\delta}$ (YBCO). Below T_c the magneto-dissipation is fully consistent with a pure flux-flow behavior, and above T_c the excess conductivity is described by the anisotropic renormalized fluctuation model. The fundamental parameters extracted independently from the two kinds of measurements are found to coincide.

2. Experimental Results

Measurements of the microwave resistivity were performed in an YBCO film. The sample was a 300 nm-thick film, grown by rf sputtering[6] onto $LaAlO_3$ substrate. The film resulted to be highly c-axis oriented. Measurements of the real part of the microwave resistivity were obtained by the end-wall-replacement technique, with the film replacing one wall of a cylindrical resonant metal cavity. The experimental apparatus and the measurement method has been extensively described in Ref.[7].

The field dependence of the microwave resistivity at various temperatures is shown in Fig.1. The data are presented subtracting the temperature-dependent background as $\Delta\rho(B,T) = \rho(B,T) - \rho(0,T)$. It is readily seen that with increasing temperature, the magneto-dissipation increases up to ~86 K, and then decreases reflecting the transition to the normal state. It is to be noted that up to about ~82 K the field sweeps are linear (Fig.1a). This is fully consistent with Eq.(1), and the slope directly yields the fluxon viscosity η. Above ~82 K the data are linear only

for low fields (Fig.1b), and they assume a downward curvature at higher fields. The initial linear part still allows for a determination of η.
On the same film we have measured the zero-field transition at 48.2 GHz, as reported in Fig. 2a. These data are useful in the determination of the effects of the fluctuational conductivity above T_c, as explained in the following section.

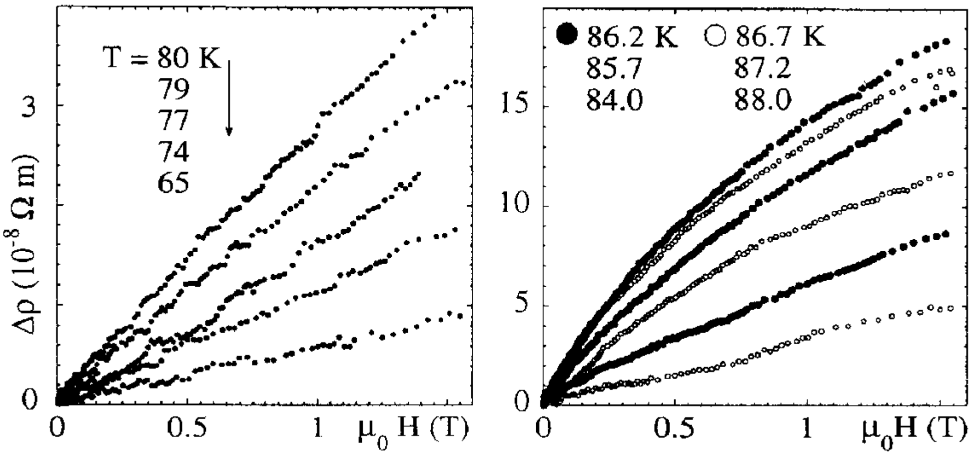

Fig. 1. Real part of the field-induced microwave resistivity at various temperatures. The field is applied along the c-axis of the film. Linear behavior at lower temperatures and downward curvature at higher temperature are evident.

3. Discussion and Conclusion

We discuss first the field sweeps, in order to demonstrate the consistency of the data with a flux flow behavior. The full expression for the vortex motion resistivity[2] can be analysed without entering into the details of the pinning. Based on the fact that both κ_p and u are, in general, decreasing functions of the field[1] and that ω_p is a decreasing function of the temperature,[4] one can see that with increasing field the resistivity should cross over from a linear behavior with a low slope (due to pinning of vortices) to the free-flux-flow linear behavior with higher slope, and it should have an overall "s" shape with upward curvature in the low field region. This is never observed in our high frequency data, where downward curvature is observed, instead. We are then led to exclude that vortex motion can be responsible for the entire dissipation approaching T_c. For the same reason, we conclude that the observed linear regime is due to flux-flow and Eq.(1) holds in that T and B region. We leave the high-temperature, high fields regime to a future investigation.
Let us discuss the temperature dependence of the viscosity. First of all, we note that our values for $\eta(T)$ are in agreemente with reported values.[4] We now compare the temperature dependence with Eq.(2), where the normal state resistivity ρ_n is obtained by extrapolating the measured linear behavior above 130 K. The fit of

the data is reported as a thick line in Fig. 2b, with T_c=86.7 K and B_{c20}= 160 T (or, equivalently, ξ_{ab0} = 14.3 Å) are the fit parameters. To further check the consistency, we have fitted the upper part of the resistive transition with the renormalized fluctuations theory.[5] Accurate agreement is found (Fig. 2a, thick line), and the fit yield λ_{ab0} = 1300 Å, γ = 6.4, ξ_{ab0}= 14.4 Åand T_c = 86.7, which coincide with the estimates obtained below T_c from magnetic measurements.

In summary, we have measured the real part of the microwave resistivity in an YBCO film as a function of the temperature and of the magnetic field. Sufficiently below T_c, the dissipation is fully described by a simple flux-flow law. Above T_c, the renormalized fluctuational conductivity fully takes into account the experimental results.

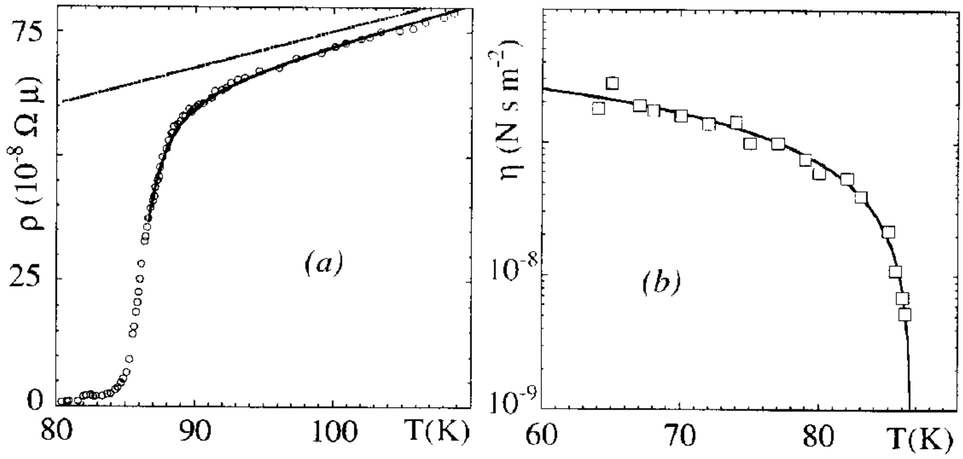

Fig. 2. (a): resistive transition at 48.2 GHz (circles) and fit with the renormalized fluctuations theory (line). Normal state ρ_n is depicted as a dotted line. (b): viscosity coefficient as obtained from the magneto-dissipation (squares) and fit with Eq.(2) (thick line).

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