Dc and microwave fluctuational conductivity of anisotropic superconductors

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Abstract

We present measurements of the dc and microwave excess conductivity above T_c in anisotropic superconducting cuprates and MgB_2. When temperature raises well above T_c, both the dc and microwave excess conductivities drop much faster than predicted by the well-established gaussian theory. We introduce a spectral cutoff in the calculation of the finite-frequency fluctuational conductivity in order to suppress the contribution of high-momentum modes at high temperatures. We find that our data are well described by the model for appropriate dimensionalities.

Key words: Fluctuations; paraconductivity; cuprates; MgB_2

1. Introduction and theory

The study of the fluctuation conductivity (paraconductivity) above T_c has been rejuvenated since the discovery of high-T_c cuprates: high temperatures, anisotropy, short coherence lengths contribute to enlarge the temperature range where fluctuation effects are observable. As a consequence, the critical region close to T_c and the small-fluctuations region far from T_c become experimentally accessible. In this paper we concentrate on the fluctuational paraconductivity at high reduced temperatures, $\epsilon = \ln(T/T_c)$.
The AC fluctuational conductivity has been calculated, e.g., within the time-dependent Ginzburg-Landau (GL) theory [1]. Introducing the uniaxial anisotropy in the original calculations, in the limit of frequencies $\omega \ll 1/\tau$ ($\tau = \tau_0/\epsilon$ is the GL relaxation time), one has for the complex paraconductivity:

$$\Delta\sigma_g(\epsilon,\omega) \simeq \sigma_{dc,3D}\left[1 - \frac{(\omega\tau)^2}{16} + \mathrm{i}\frac{\omega\tau}{6}\right] \quad (1)$$

where $\sigma_{dc,3D} = \frac{e^2}{32\hbar\xi_z(0)\epsilon^{1/2}}$ and $\xi_z(0)$ is the out-of-plane zero-temperature GL coherence length.
It was found early [2] that, with increasing temperature, the dc paraconductivity decreased faster than predicted by Eq.1. A similar result has been reported at microwave frequencies [3] in cuprates. This behaviour has been attributed [4,5] to the fact that Eq.1 is the result of a calculation near T_c, where the only relevant fluctuations are those with momentum $q \rightarrow 0$. At high T the full expression has to be considered. In 2D, this has been shown [6] to be equivalent to set a momentum cutoff $q_{max} \sim \Lambda\xi(0)^{-1}$. Extending the calculations to a generic dimensionality D=1,2,3, and taking into account the frequency dependence, one gets within the correlation-function formalism [7]:

$$\Delta\sigma_{c,D}(\epsilon,\omega) = \sigma_{dc,D}(\epsilon)F_D(\Lambda/\epsilon,\omega\tau) \quad (2)$$

The details of the calculations and the explicit expressions of the complex functions F_D can be found in Ref.[7]. We stress that Eq.2 contains the single additional parameter Λ with respect to Eq.1. We now compare our experimental results for the dc and microwave conductivity to Eq.1, and to Eq.2.

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Preprint submitted to LT23 Proceedings *15 June 2002*

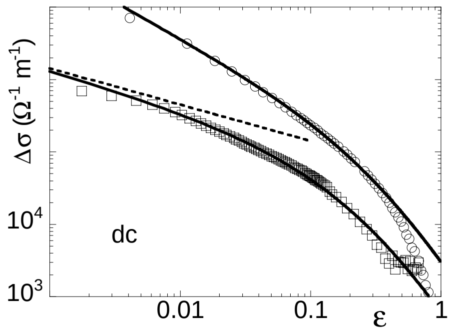

Fig. 1. dc excess conductivity in BSCCO (circles) and YBCO (squares). Continuous lines: fits to the cutoffed expression, Eq.2. 2D expression is used for BSCCO, and 3D for YBCO. Parameters: $\xi_z(0)$=1.7Å, Λ=0.6 (YBCO); Λ=0.63 (BSCCO). The gaussian expression would yield straight lines, as plotted as an example for the 3D case (dashed line).

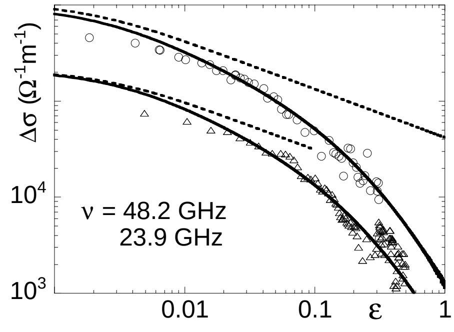

Fig. 2. Excess conductivity at 48.2 GHz in YBCO (squares) and 23.9 GHz in MgB_2 (triangles). Dashed lines: fits to gaussian expressions. Continuous lines: fits to the 3D cutoffed expression, Eq.2. The fit is not much sensitive to τ_0, since $\omega\tau \ll 1$ for $\epsilon > 10^{-2}$. The BCS value, $\tau_0 = \frac{\hbar\pi}{16 k_B T}$, has been used. Parameters: $\xi_z(0)$=1.8Å, Λ=0.74 (YBCO); Λ=0.74 (MgB_2).

2. Experimental results and discussion

We have measured the dc resistivity ρ in a BSCCO (2212) single crystal (T_c=86.2 K) and in a YBCO film (T_c=85.8 K), and the real part of the resistivity in YBCO (T_c=87.5 K) and MgB_2 (T_c=31.7 K) thin films at $\omega/2\pi = 48.2$ and 23.9 GHz, respectively. All cuprate samples were slightly overdoped. The dc resitivity was measured by an accurate eight-terminal technique [8] in BSCCO, and by four-probe configuration in YBCO. The microwave (real) resistivity was measured with an end-wall-replacement cavity technique [9], making use of the thin-film approximation (valid above T_c). The MgB_2 film was small with respect to the end wall of the cavity, resulting in an unknown scale factor, which prevents from the determination of the absolute value of ρ. However, the temperature dependence remains unaffected.

In all cases, the fluctuation conductivity was obtained by subtracting the normal state resistivity ρ_n, linearly extrapolated from high temperatures down to T_c:

$$\Delta\sigma_{\rm exp} = \frac{1}{\rho} - \frac{1}{\rho_{\rm n}} \tag{3}$$

In dc $\Delta\sigma_{\rm exp} = \Delta\sigma$, while in the microwave measurements there is an additional contribution from the imaginary part of the excess conductivity, relevant only very close to T_c (we have checked that above $\epsilon \simeq 10^{-3}$ Eq.3 approximates $Re\{\Delta\sigma\}$ to less than 5%). In Fig.1 we report the dc excess conductivity in BSCCO and YBCO as a function of the reduced temperature, and in Fig.2 we report the microwave excess conductivity in YBCO and MgB_2. Due to the unknown scale factor, data in MgB_2 are arbitrarily vertically shifted (as a consequence, it is not possible to evaluate $\xi_z(0)$). It is immediately seen that in all cases no simple power laws appear, as would be predicted by the gaussian calculations also at microwave frequencies since $\omega\tau \ll 1$ not too close to T_c. We then fitted our data with the cutoffed expressions, Eq.2. The results of the fits are reported in the figures as continuous lines. Gaussian predictions are reported as dashed lines. For ϵ not too small, it is found that for BSCCO the best fit is obtained with a 2D, cutoffed expression [6], while for YBCO and MgB_2 a 3D, cutoffed calculation yields the best fit for either the dc and the microwave data.

In conclusion, we have shown that the excess conductivity in several anisotropic superconductors decreases faster than the gaussian prediction at high reduced temperatures. The introduction of a momentum cutoff in the calculation of the excess conductivity gives a very good description of the data.

Acknowledgements

We thank G. Celentano at ENEA (Frascati, Italy) for providing the MgB_2 sample.

References

[1] H. Schmidt, Z. Phys.**216** (1968) 336.

[2] W. L. Johnson, C. C. Tsuei, Phys. Rev. B**13** (1976) 4827; W. L. Johnson et al., Phys. Rev. B**17** (1978) 2884.

[3] D. Neri et al., Int. J. of Mod. Phys. B**13** (1999) 1097; D. Neri et al., J. of Low Temp. Phys.**117** (1999) 1099.

[4] N. R. Werthamer, in *Superconductivity*, ed. by R. D. Parks (Marcel Dekker, New York, 1969), p.321-370.

[5] T. Mishonov, E. Penev, Int. J. Mod. Phys B**14** (2001) 3831.

[6] E. Silva et al., Phys. Rev. B**64** (2001) 144508.

[7] E. Silva, European Physical Journal B, in press (2002).

[8] M. Esposito et al., J. Appl. Phys.**88** (2000) 2724.

[9] R. Fastampa et al., Meas. Sci. Technol.**1** (1990) 1172; E. Silva et al., Meas. Sci. Technol.**9** (1998) 275.