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Temperature Dependence of the Microwave Conductivity near T_c in $YBa_2Cu_3O_{7-\delta}$ Thin Films

James C. Booth, Dong Ho Wu, and Steven M. Anlage

Center for Superconductivity Research, Department of Physics, University of Maryland, College Park, MD 20742

We present measurements of the temperature-dependent complex conductivity of $YBa_2Cu_3O_{7-\delta}$ (YBCO) thin films near T_c at several different fixed frequencies in the microwave range. Our measurements show a local maximum in $\sigma_1(T)$ in the vicinity of T_c, which becomes smaller and broader as the frequency increases.

1. INTRODUCTION

Thermal fluctuations can make important contributions to the conductivity of the high T_c superconductors at temperatures near the phase transition. In order to investigate the role of fluctuations in the electrodyamic response of superconductors near T_c, we have made a systematic study of the temperature dependent complex conductivity in YBCO thin films at a number of different frequencies in the microwave regime. By systematically varying the measurement frequency, we can observe the effects of the finite lifetime of conductivity fluctuations near T_c.

2. RESULTS

We measure the complex resistivity of thin YBCO films at any arbitrary frequency between 45 MHz and 50 GHz using a unique swept-frequency technique referred to as the Corbino reflection technique.[1] This technique allows for the simultaneous determination of both the real and imaginary parts of the complex conductivity as a function of temperature. The ability to evaluate the temperature dependent conductivity at more than one frequency provides valuable additional information about the time dependence of fluctuations in the system.

Figures 1 and 2 show our results for the temperature dependence of the real and imaginary parts, respectively, of the complex resistivity $\rho=\rho_1+i\rho_2$ of a YBCO sample as a function of temperature at a number of frequencies. The 1500Å thick YBCO samples are grown by pulsed laser deposition on $LaAlO_3$ substrates. The limited sensitivity of our non-resonant measurement limits us to temperatures very close to, and above, T_c.

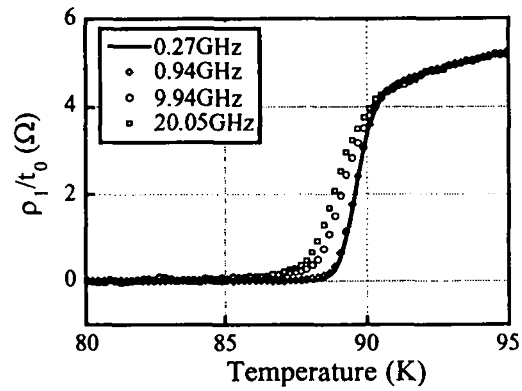

Fig. 1. ρ_1/t_0 vs. temperature for a YBCO thin film at several different measurement frequencies.

Notice from Fig. 1 that increasing the frequency from 0.27 to 20 GHz results in a substantially broader transition, and also shifts the apparent T_c to lower temperatures. In the normal state there is little frequency dependence, because the normal state scattering rate is much larger than the highest measurement frequency.

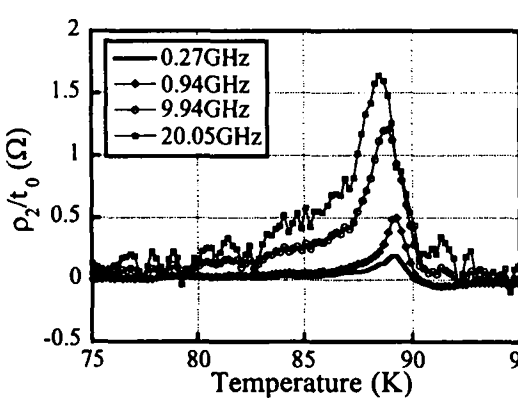

Fig. 2. ρ_2/t_0 vs. temperature for a YBCO thin film.

The temperature dependence of ρ_2 is shown in Fig. 2 for the same measurement frequencies as for the ρ_1 data. Note that the peak in ρ_2 near T_c becomes larger and moves down in temperature as the frequency is increased. Above T_c ρ_2 is approximately zero for all frequencies.

3. DISCUSSION

In order to analyze our data more effectively, we convert the complex resistivity to a complex conductivity by the simple relation $\sigma=1/\rho$. The resulting plots of the real and imaginary parts of the complex conductivity are shown in Figs. 3 and 4, respectively.

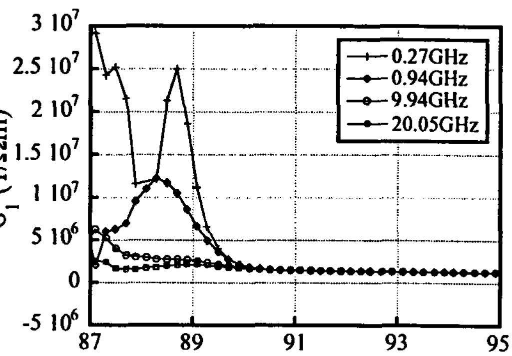

Fig. 3. Temperature dependence of the real part of the conductivity of YBCO at various frequencies.

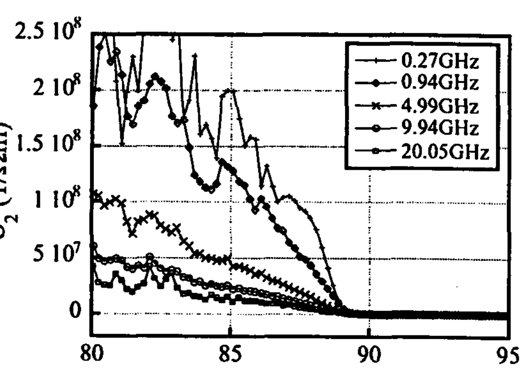

Fig. 4. Temperature dependence of the imaginary part of the conductivity of YBCO at various frequencies.

The temperature dependence of σ_1 at lower frequencies shows a definite peak near the transition temperature. As the measurement frequency increases, this peak becomes smaller and broader, eventually becoming almost unnoticeable at the highest frequency of 20 GHz. Such a peak in $\sigma_1(T)$ has been observed previously in YBCO single crystals,[2] and also other materials.[3] This peak represents a very rapid increase in σ_1 very close to T_c, and may be due to fluctuation effects. It should be pointed out that the local maximum in the conductivity observed here at 10 GHz is much smaller than the corresponding peak observed in single crystals at the same frequency.[2]

The temperature dependence of σ_2 shows approximately linear behavior within 10 K of T_c, which is consistent with a temperature dependence of $1/\lambda^2$ of $1-(T/T_c)$ for $T < T_c$. Fitting the σ_2 data to a straight line in this temperature range gives a zero-temperature penetration depth λ_0 of approximately 2100Å at 5 GHz (assuming $\lambda(T) = \lambda_0/[1-(T/T_c)^2]^{1/2}$. Interestingly, λ_0 decreases slightly with increasing frequency above 5 GHz, while below 5 GHz λ_0 increases more rapidly with decreasing frequency.

The diminishing size of the $\sigma_1(T)$ peak with increasing frequency means that the mechanism that gives rise to the enhanced conductivity is less effective at higher frequencies. This has been observed previously in frequency-dependent measurements of σ_1 near the transition temperature in YBCO thin films.[4] If we interpret the enhanced conductivity near T_c as resulting from fluctuation effects, then our measurements at different frequencies suggest that the fluctuation contribution to the conductivity decreases with increasing frequency. This implys that near T_c the fluctuation relaxation rate is passing through the microwave frequency range, which explains the diminishing peak in $\sigma_1(T)$ at higher frequencies.

4. CONCLUSIONS

We find experimentally a sharp peak in $\sigma_1(T)$ in the vicinity of T_c that decreases in magnitude and width with increasing measurement frequency. If our observations are interpreted as arising from thermal fluctuations, our results imply that the fluctuation relaxation rate is within the microwave frequency range for temperatures near T_c.

REFERENCES

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