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Angaben zur Veröffentlichung / Publication details:

Lunkenheimer, Peter, Alois Loidl, C. Tomé-Rosa, P. Wagner, and H. Adrian. 1993. "AC conductivity in superconducting YBa2Cu3O7 and Bi2Sr2CaCu2O8 thin films." *Physica B: Condensed Matter* 186-188: 986–88. https://doi.org/10.1016/0921-4526(93)90763-v.

AC conductivity in superconducting $YBa_2Cu_3O_7$ and $Bi_2Sr_2CaCu_2O_8$ thin films

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Complex AC conductivity has been measured in thin films of $YBa_2Cu_3O_7$ and $Bi_2Sr_2CaCu_2O_8$ at frequencies $1\,kHz \leq \nu \leq 1\,GHz$ and temperatures $10\,K \leq T \leq 300\,K$. In both compounds, just at T_c, a peak shows up in the T dependence of the real part of the conductivity. The origin of this peak is interpreted in terms of fluctuation effects which are weak in $YBa_2Cu_3O_7$ but strong in $Bi_2Sr_2CaCu_2O_8$. No coherence-like phenomena were detected.

Measurements of the dynamic response in superconductors just below the superconducting phase transition have provided important information on the nature of the superconducting state. In the framework of BCS theory, the appearance of the so-called coherence peak [1] in the temperature dependence of the nuclear magnetic relaxation rate at $T \leq T_C$ [2] is a direct consequence of the correlations between scattering events due to electron pairing and of the strong increase in the density of states resulting from the formation of a gap. The coherence peak (Hebel–Slichter peak [2]) shows up as an increase in the relaxation rate at the transition into the superconducting state followed by an exponential decrease at lower temperatures, when the gap is fully established and the electrons must be excited across the gap.

The electromagnetic absorption belongs to the same class of coherence effects as does NMR relaxation. Electromagnetic absorption results from currents that are in phase with the electric field and hence is proportional to σ', the real part of the AC conductivity. Thus, a coherence peak is expected to occur in σ' for frequencies well below the gap and has been observed in superconducting lead at microwave frequencies [3].

The observation of a coherence peak in the AC conductivity of the high T_C cuprate superconductors has been reported recently: a peak below T_C has been found in superconducting $Bi_2Sr_2CaCu_2O_8$ single crystals [4] and in $YBa_2Cu_3O_7$ single crystals and thin films [5] in microwave experiments conducted at 60 GHz and 100 GHz and in superconducting $YBa_2Cu_3O_7$ thin films using coherent time-domain terahertz spectroscopy [6]. In contrast, no Hebel–Slichter peak could be detected in $YBa_2Cu_3O_7$ [7] and in $Bi_2Sr_2CaCu_2O_8$ [8] in NMR experiments.

The appearance of a peak due to Type II coherence factors in the electromagnetic absorption and the absence in the NMR relaxation rate has stimulated a number of theoretical and experimental investigations (see ref. 9 and references therein). Although the experimental situation and its interpretation [10] is confusing, it became quite clear that the microwave results are strongly sample dependent and it appears that the occurrence of a peak just below the superconducting transition temperature is driven by a distribution of T_Cs rather than by coherence effects. However, it has been pointed out by Horbach and Van Saarloos [11], following earlier work by Schmidt [12], that fluctuation effects can play an important role.

Here, we report measurements of the complex AC conductivity $\sigma = \sigma' + i\sigma''$ in thin films of superconducting cuprates for frequencies $1\,kHz \leq \nu \leq 1\,GHz$ and temperatures $10\,K \leq T \leq 300\,K$. We present data for $Bi_2Sr_2CaCu_2O_8$ as well as for $YBa_2Cu_3O_7$. It is well known that fluctuation effects are much more pronounced in the former compound.

Thin films of $YBa_2Cu_3O_7$ and $Bi_2Sr_2CaCu_2O_8$ were prepared by DC sputtering from single targets [13]. Silver contacts were evaporated onto the films and were subsequently annealed in an O_2 atmosphere [13]. $SrTiO_3$, MgO and ZnO_2 substrates were used.

The high frequency data ($1\,MHz \leq \nu \leq 1\,GHz$) were recorded using an HP 4191A impedance analyzer connected to a refrigerator system via an air line [14]. Using this technique, the sample was mounted between two pins connected to the inner and outer conductor of the air line. Pins and silver contacts of

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the films were connected with silver paint. Reflectometric methods require two-point contact configurations and hence, the contact resistances contribute to the observed conductivities. The audiofrequency measurements were performed using fully automated autobalance bridges. In this frequency regime, the measurements were performed in four-point contact geometry. However, for comparison with the high frequency data and to obtain an estimate of the influence of the contacts on the observed conductivities, these measurements were also performed with two-point contact configurations.

Figure 1 shows the real (left) and imaginary part (right) of the complex admittance $G^* = G' + iG''$ in $Bi_2Sr_2CaCu_2O_8$ measured at 1, 27.5 and 83.2 MHz. With decreasing temperatures, the real part of the conductivity reveals a continuous increase with a sharp peak close to T_C and a rapid drop at $T \leq T_C$. The height of the peak decreases as ν^{-1}. The temperature of the maximum conductivity is almost independent of frequency. For frequencies $\nu \geq 100$ MHz, the peak becomes suppressed and $G'(T)$ reveals a steplike drop at T_C only. These results reveal the characteristic features of two-dimensional fluctuation effects [11]. G'' is small in the normal conducting state and increases rapidly below T_C. Within the framework of BCS theory, from the temperature dependence of the imaginary part of the conductivity, the T dependence of the energy gap $\Delta(T)$ can be calculated. We found that $\Delta(T)$ remains constant below T_C and drops almost discontinuously to zero at T_C in accordance with experimental observations [15] and theoretical predictions [16].

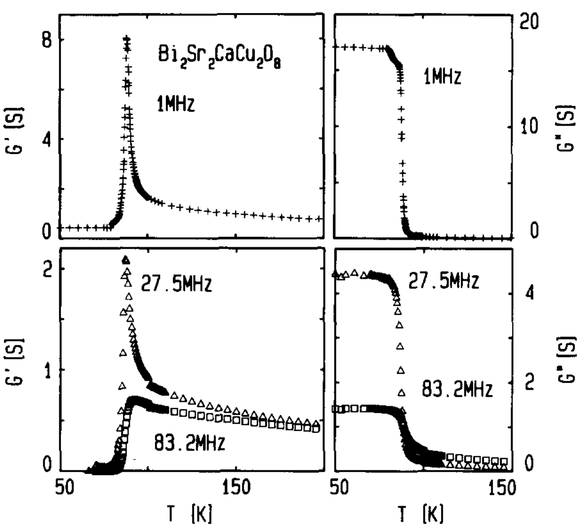

Fig. 1. Real G' (left) and imaginary part G'' (right) of the complex admittance in $Bi_2Sr_2CaCu_2O_8$ versus temperature at different measuring frequencies as indicated.

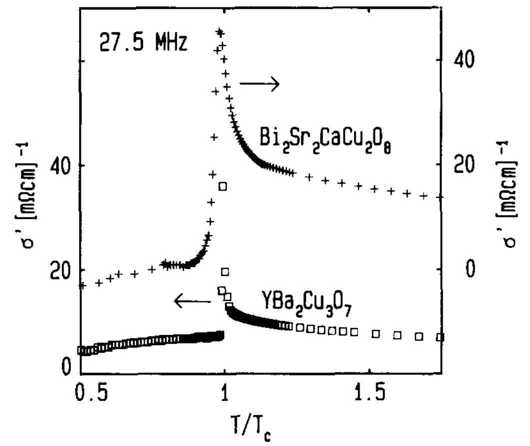

Fig. 2. Real part of the conductivity σ' versus the reduced temperature in $Bi_2Sr_2CaCu_2O_8$ and in $YBa_2Cu_3O_7$, as measured at 27.5 MHz.

In fig. 2, the real part of the conductivity $\sigma'(T)$ in $Bi_2Sr_2CaCu_2O_8$ is compared with the results obtained in superconducting $YBa_2Cu_3O_7$ thin films. Here σ' was calculated from G' using the sample dimensions. In both compounds, the conductivities behave rather similarly. However, in $YBa_2Cu_3O_7$ the high temperature wing of the peak is much less pronounced indicating that the two-dimensional fluctuation effects are significantly weaker in this compound. Figure 2 reveals that in both compounds, the fluctuation effects below T_C are strongly suppressed. We interpret this effect as being due to the discontinuous increase of the superconducting energy gap at T_C.

In conclusion, the peaks in the temperature dependence of the real part of the conductivity in $Bi_2Sr_2CaCu_2O_8$ and $YBa_2Cu_3O_7$ reveal the signature of two-dimensional fluctuation effects and no coherence effects show up in $\sigma'(T)$ in both compounds in accordance with the NMR results [7,8].

Acknowledgements

This work was supported by the Sonderforschungsbereich 252 (Darmstadt, Frankfurt, Mainz, Stuttgart) and by the Bundesministerium für Forschung und Technologie under the contract number 13N5705. C.T.-R. was financially supported by the Conselho Nacional de Desenvolvimento Cientifico e Technologico do Brasil–CNPq.

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