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Angaben zur Veröffentlichung / Publication details:

Maglione, M., R. Böhmer, Peter Lunkenheimer, M. Lotze, Alois Loidl, and S. Kemmler-Sack. 1988. “High frequency resistivity in La2-xSrxCu1-yCoyO4 ceramics.” *Physica C: Superconductivity* 153-155 (Part 2): 649–50. https://doi.org/10.1016/S0921-4534(88)80019-4.

High Frequency Resistivity in $La_{2-x}Sr_xCu_{1-y}Co_yO_4$ Ceramics

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Resitivity measurements have been performed in La:Sr:Cu:Co:O ceramics in a frequency range from 5Hz - 10^9Hz. A strongly frequency dependent resistance has been observed in La_2CuO_4 which we interpret in terms of a smooth dielectric to metal transition due to localization effects.

1. INTRODUCTION

$La_{2-x}Sr_xCuO_4$ ceramics attract considerable attention not only because of the unusual high superconducting transition temperatures but also because of the structural and magnetic phase transitions which seem to be closely related to the occurence of superconductivity: the undoped material La_2CuO_4 is tetragonal at high temperatures and undergoes an orthorhombic distortion at 423K (1). Filamentary superconductivity has been reported below 40K (2,3). In La_2CuO_4 antiferromagnetic ordering appears near 200K (4,5). Furthermore a new magnetic state, a two dimensional quantum spin fluid has been detected (5) and an interpretation in terms of a "resonating valence bond" state has been suggested (6). Doping La_2CuO_4 with Sr gives bulk superconductivity with transition temperatures up to 40K (7). At present we undertake a systematic investigation of $La_{1-x}Sr_xCu_{1-y}Co_yO_4$ ceramics which are dominated by a competition between superconductivity, localization effects and electronically driven structural phase transitions. In this brief report we present results of high frequency resistivity measurements in La_2CuO_4, $La_{1.9}Sr_{0.1}CuO_4$ and $LaSrCu_{0.5}Co_{0.5}O_4$.

2. EXPERIMENTAL DETAILS

In the frequency range 1MHz-1GHz the resistance R(f) and the reactance X(f) were measured with a HP 4191A RF Impedance Analyzer. Temperatures between 10K and 450K were accessible using a closed cycle refrigerator or an oven. The sample and the measuring port of the analyzer were connected with an air line. This high frequency measurements utilize a two probe configuration and special attention has to be given to contact resistances. The lower frequency data (5Hz≤f≤10MHz) were measured with a HP 4192A LF Impedance Analyzer utilizing standard four probe techniques in a temperature range 2K≤T≤ 300K.

3. EXPERIMENTAL RESULTS AND DISCUSSION

La_2CuO_4: starting with the undoped material Fig. 1 shows the temperature dependence of the resistance in La_2CuO_4 for different frequencies. This set of data has been measured with a standard four probe technique. The measurements at GHz frequencies fit well into the observed behaviour if one takes contact resistances into account. At high temperatures (300K≤T≤100K) the resistance is only weakly T-dependent and exhibits a slight increase with decreasing temperatures, followed by a sharp increase for T≤80K. At 32K a peak in R(T) indicates the onset of filamentary superconductivity. The decrease in the resistivity is followed by a strong increase for T≤15K. Fig. 1 demonstrates that below 80K, where the resistance exhibits a strong temperature dependence, dispersion effects become apparent and for the highest frequencies investigated the increase in R(T) is fully suppressed. For a quantitative analysis we plotted the resistance versus the reactance (Fig. 2). This Cole-Cole-like plot in the complex resistivity plane gives ideal semicircles. In an electronic equivalent circuit this behaviour can be described by an ohmic resistor (R_1) in series with an R-C network. An interpretation of this equivalent circuit is straightforward: R_1 is the contact resistance between different grains, R_2 and C describe the bulk resistivity properties of the ceramic. In terms of the equivalent circuit R_2*C determines the relaxation time of the system. From these semicircles R_1, R_2 and C can be calculated. R_1 is small and nearly temperature independent. Focusing on temperatures above the superconducting transition, R_2 is steadily increasing with decreasing temperatures. In a first approximation R_2 is determined by the low frequency resistance as shown in Fig. 1. Above 150K the capacitance is almost zero and the conductivity is purely ohmic. C increases with decreasing temperatures and passes through a maximum at $T \approx 80K$. This behaviour of $R_2(T)$ and $C(T)$ characterizes a transition from a high temperature metallic to a low temperature insulating state. Together with the appearance of hopping conductivity $\ln R \propto (T_0/T)^{1/4}$ (8) which is observed for temperatures $70K \leq T \leq 35K$, the complex resistance can be described by the localization of the charge carriers through a random potential (8). The data imply a continuous transition, where at high temperatures the electrons are excited to the mobility edge, while at low temperatures the conduction occurs through phonon assisted hopping. This behaviour is characteristic for a "Fermi glass" (8) where the Fermi energy lies below the mobility edge. We also performed a series of experiments applying dc-bias. For temperatures above 100K the conductivity is purely ohmic, while for temperatures $100K \leq T \leq 35K$ the resistivity decreases for increasing fields. Also this behaviour can be described by a theory of localized states within the conduction band. Ofcourse we are aware, that the equivalent circuit as shown in Fig. 2 is also the fingerprint of a Charge-Density-Wave state. We feel that the latter can be ruled out for the following reasons: there exists no experimental evidence for a structural transition in the temperature range where the onset of frequency dependent conductivity was detected and R(T) exhibits a thermally activated behaviour for $T \geq 100K$. Below 32K the insulating dielectric properties of La_2CuO_4 are masked by the onset of filamentary superconductivity.

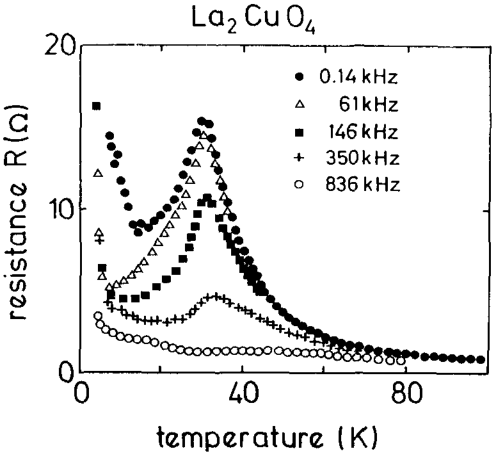

Fig. 1: Resistance versus temperature in La_2CuO_4 for different frequencies.

$La_{1.9}Sr_{0.1}CuO_4$: In the Sr-doped sample, which exhibits bulk superconductivity below 30K, the resistance passes through a minimum near 120K. Again, like in the undoped sample dispersion effects develop below the minimum, but the dispersion step is much smaller and appears at much higher frequencies ($f \geq 500MHz$).

$LaSrCu_{0.5}Co_{0.5}O_4$: Doping the La:Sr:Cu:O ceramics with Co results in a semiconducting behaviour of the samples. The $LaSrCu_{0.5}Co_{0.5}O_4$ ceramic, which is monoclinic down to the lowest temperatures exhibits thermally activated semiconducting behaviour with a large gap.

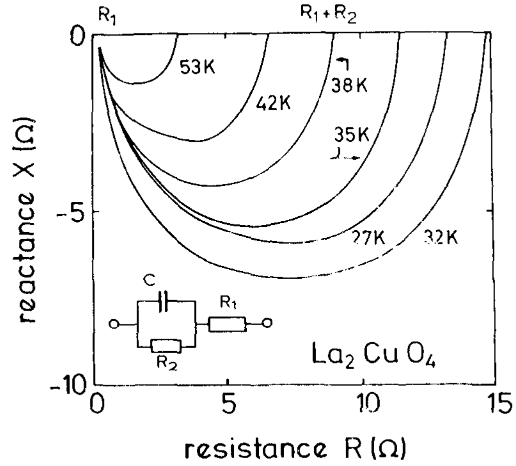

Fig. 2: A Cole-Cole-like plot in the complex resistivity plane. An electronic equivalent circuit is shown as inset.

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