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Fluctuation-induced excess conductivity in the compounds $CaREBaCu_3O_{7-y}$ (RE = La and Sm)

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Abstract. The compounds $CaREBaCu_3O_{7-y}$ (RE = La and Sm) are tetragonal at room temperature with T_c between 60 and 70 K. The single-phase compounds were prepared by solid-state reaction. The resistivity was measured by a four-probe technique in a continuous flow cryostat with the temperature being controlled to an accuracy of 10 mK. The resistivity vs temperature showed a break in slope around 180 K in $CaLaBaCu_3O_{7-y}$ and around 220 K in $CaSmBaCu_3O_{7-y}$. The results were analysed for fluctuation conductivity from 180 K downwards. A plot of $d\rho/dT$ vs T showed a sharp peak at $T_m = 69{\cdot}69$ K for La compound and 66·00 K for the Sm compound. Detailed analysis of the resistivity in the region T_{on} to 180 K was carried out using the procedure due to Veira and Vidal. The results are discussed in this paper.

Keywords. High T_c superconductors; $CaREBaCu_3O_{7-y}$; fluctuation; excess conductivity.

1. Introduction

The short coherence length of high T_c materials compared to the conventional superconductors gives rise to a larger excess conductivity in these materials. The high resistivity of these materials in principle makes it easier to detect the fluctuation conductivity. However, there are the following two major problems in analysing fluctuation conductivity: (a) The determination of the mean field transition temperature (T_m) and (b) the estimation of background resistivity. These problems are discussed by Srinivasan (1990). The mean-field transition temperature is taken as close to the temperature at which the peak in $d\rho/dT$ occurs in the low temperature region. The background contribution is usually estimated by extrapolating the resistivity vs temperature plot from room temperature to $2T_c$. High T_c compounds have a shorter coherence length along the c-axis compared to the ab-plane. So it is believed that the excess conductivity varies as for a layered compound (Lawrence and Doniach 1971),

$$\Delta\sigma_{flu} = (e^2/16\hbar d)\,[\varepsilon(\varepsilon + \Delta)]^{-1/2}, \tag{1}$$

where

$$\varepsilon = \ln(T/T_m), \tag{2}$$

and

$$\Delta = (2\xi_c(0)/d)^2. \tag{3}$$

Here d is the distance between adjacent superconducting layers. Some workers have taken d as the value of c-lattice parameter (Veira and Vidal 1989) and others as half of the c value (Hagen *et al* 1988). The contribution to resistivity from fluctuation conductivity at high temperature will vary as ε^{-1} and cannot be separated from the background conductivity. While the single crystal and oriented thin films are the best samples for study of fluctuation effects, Veira and Vidal (1989) have shown that meaningful results can also be obtained from a proper analysis of data from polycrystalline single phase pellets in which the samples show a single peak in $d\rho/dT$ vs temperature plot.

Many studies have been carried out in $YBa_2Cu_3O_{7-y}$ and $Tl_2CaBa_2Cu_2O_8$ compounds (see references in Srinivasan 1990). We have studied the fluctuation conductivity in a sample each of $CaLaBaCu_3O_{7-y}$ and $CaSmBaCu_3O_{7-y}$. These samples were tetragonal at room temperature. The results of these studies are presented in this paper.

2. Experimental results

The $CaREBaCu_3O_{7-y}$ compounds were prepared by high temperature solid-state reaction using high purity RE_2O_3 (RE = La and Sm), $CaCO_3$, $BaCO_3$ and CuO (Varadaraju *et al* 1990). The characterization by XRD shows that the compounds were single-phase. The lattice parameters obtained by least squares method were $a = 3{\cdot}86$ Å and $c = 11{\cdot}57$ Å for $CaLaBaCu_3O_{7-y}$ and $a = 3{\cdot}85$ Å and $c = 11{\cdot}48$ Å for $CaSmBaCu_3O_{7-y}$. These values agree with the reported values in the literature (de Leeuw 1988). The oxygen content of the samples was found to be in the range 6·82 and 6·86.

The resistivity was measured by the four-probe technique due to Montgomery (1971). A continuous flow cryostat was used to get the temperature variation. The temperature was controlled to better than 10 mK using an electrodynamic valve and Leybold Variotemp temperature controller. A Keithley constant current source and a Keithley nanovoltmeter were used to measure resistivity. At each temperature the current was reversed to eliminate thermo emf effects.

Figure 1 shows the plot of ρ vs T for both the samples. In the case of $CaLaBaCu_3O_{7-y}$ a break in the slope of the resistivity curve is seen clearly around 180 K and in the case of $CaSmBaCu_3O_{7-y}$ the break in the slope is around 220 K. A

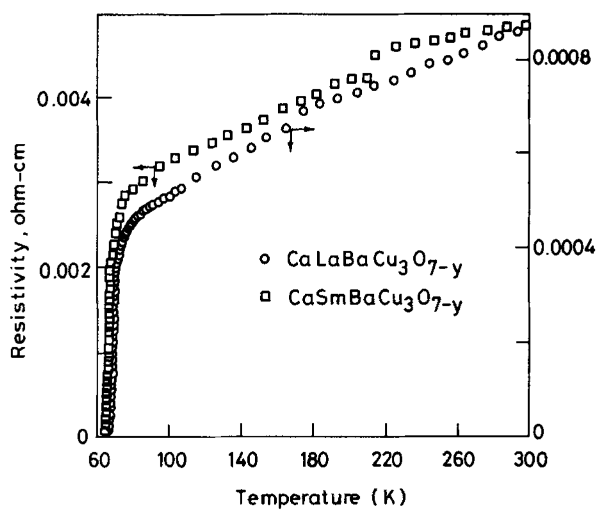

Figure 1. Variation of electrical resistivity with temperature for $CaLaBaCu_3O_{7-y}$ and $CaSmBaCu_3O_{7-y}$.

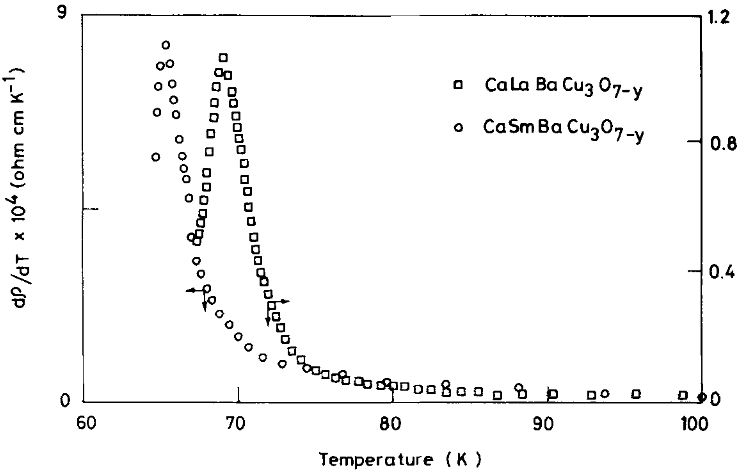

Figure 2. Variation of $d\rho/dT$ with temperature for samples of $CaLaBaCu_3O_{7-y}$ and $CaSmBaCu_3O_{7-y}$.

similar change of slope is observed in $CaLaBaCuO_{7-y}$ around 220 K (Peng *et al* 1989). Because of the break in the slope, the analysis of the resistivity data is limited to temperatures below 180 K. Figure 2 shows the plot of $d\rho/dT$ vs T. It is seen that there is a single sharp peak in $d\rho/dT$ indicating that the samples are single phase. A rough analysis of the data was made by estimating the background resistivity by extrapolating the resistivity from 180 K to 120 K. Such an analysis is not rigorous because it ignores the fluctuation contribution to the resistivity above 120 K. A more precise analysis was made using the procedure due to Veira and Vidal (1989). In this procedure the resistivity of the pellet at any temperature T can be written as

$$\rho(T) = \rho_0 + \rho_g(T)/p. \tag{4}$$

Here, ρ_0 is the contribution from grain boundaries and is assumed to be temperature-independent. p is a factor which represents the reduction in the effective area of cross-section for conduction arising from the mismatch of *ab*-planes of neighbouring grains. $\rho_g(T)$ is the resistivity due to the grains and is given by

$$1/\rho_g(T) = \Delta\sigma_{\mathrm{flu}} + 1/(\rho_1 + C_{2g}T), \tag{5}$$

where ρ_1 is the residual resistivity of the grains and C_{2g} is the linear temperature coefficient. The fluctuation conductivity $\Delta\sigma_{\mathrm{flu}}$ is given by equation (1).

The experimental data were fitted to equation (4) in the range $T_m + 1$ to 180 K taking into account equations (1) and (5). The parameters obtained in this analysis are collected in table 1. Figure 3 shows the fit to the resistivity data obtained both for La and Sm compounds. The rms deviations of the fit obtained for $CaLaBaCu_3O_{7-y}$ and $CaSmBaCu_3O_{7-y}$ are 0·79% and 1·65% respectively. In figure 4 is shown the variation of the fluctuation conductivity as a function of temperature for $CaLaBaCu_3O_{7-y}$. The continuous curve shows the fit to equation (1).

The parameters obtained are compared with the parameters for $YBa_2Cu_3O_{7-y}$ (Veira and Vidal 1989), Tl 2122 (Krishnan 1990) and oriented thin film of Tl 2122 (Kim *et al* 1989). It is seen that the intragrain parameters C_{2g} are comparable to the values

Table 1. The values of intergrain and intragrain parameters obtained by a fit to the model due to Veira and Vidal

		Intragrain parameters					Intergrain parameter				
Material	$\rho(300)$ mΩcm	T_{mf} K	ρ_1 mΩcm	$C_{2\theta}$ cm/K		$\xi_c(0)$ A	p $\times 10^2$	ρ_0 mΩcm	T_{czero} K	d Å	References
$YBa_2Cu_3O_{7-y}$	108·2	91·43	0	1·6	0·07	1·6	0·57	26·1	88·8	11·67	Veira and Vidal (1989)
$YBa_2Cu_3O_{7-y}$	0·9	89·93	0	0·76	0·20	2·6	28	0·09	88·20	11·67	
$Tl_2CaBa_2Cu_2O_8$	11·36	111·75	0	11·4	0·033	2·7	30	1·75	104·52	29·30	Krishnan (1990)
$CaLaBaCu_3O_{7-y}$	0·87	70·80	0	3·8	0·012	0·6	17	0·322	65·54	11·57	Present work
$CaSmBaCu_3O_{7-y}$	4·8	66·10	1·4	1·4	0·0017	0·23	16·9	1·20	63·80	11·48	

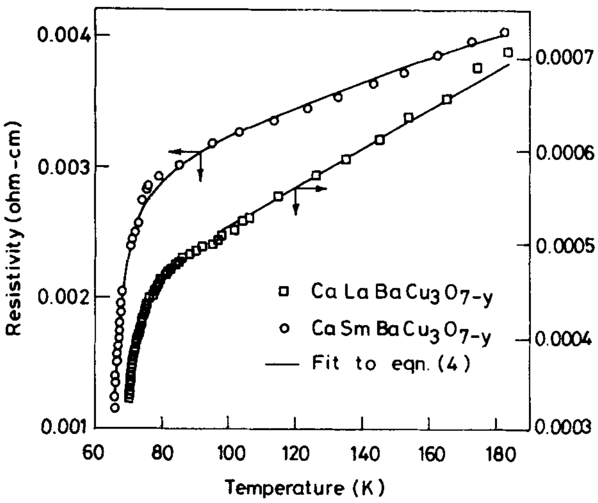

Figure 3. Electrical resistivity data for $CaLaBaCu_3O_{7-y}$ and $CaSmBaCu_3O_{7-y}$ fitted to the model due to Veira and Vidal (equation (4)).

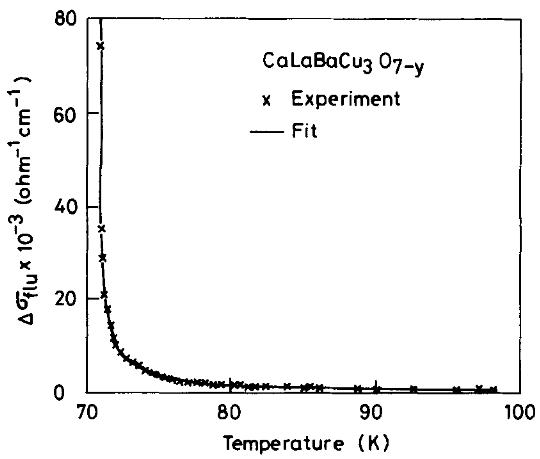

Figure 4. Variation of excess fluctuation conductivity with temperature for $CaLaBaCu_3O_{7-y}$.

obtained in single crystal and oriented films. The $\xi_c(0)$ value in $CaLaBaCu_3O_{7-y}$ is of the order of 1 Å which is similar to the value obtained for other materials. The value obtained for the parameter p is 1·73. This is obtained on the assumption that the parameter d in the LD equation (3) is the c-axis lattice parameter. If it is taken as the distance between neighbouring Cu–O planes ($\sim$ 5·8 Å), then the value of p will come out to be half the value given in table 1. It is noteworthy that in the case of $CaSmBaCu_3O_{7-y}$ the value of ρ_1 is not zero unlike in the case of other materials. This high residual resistivity in the grains of $CaSmBaCu_3O_{7-y}$ needs further investigation.

4. Conclusion

The resistivity of a pellet each of $CaLaBaCu_3O_{7-y}$ and $CaSmBaCu_3O_{7-y}$ has been measured from room temperature to T_{zero}. The resistivity showed a break in slope around 180 K in La compound and 220 K in Sm compound. The resistivity data for fluctuation effects were analysed from 180 K downwards using the procedure suggested by Veira and Vidal (1989). The intragrain parameters obtained by this analysis are comparable in values to the intragrain parameters of $YBaCu_3O_{7-y}$ and Tl 2122 compound. However in $CaSmBaCu_3O_{7-y}$ the grain appears to have a high residual resistivity and the reason for this needs to be studied further.

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