Fluctuation conductivity of polycrystalline Hg,Tl-1223

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Abstract

Detailed resistivity measurements were made for polycrystalline $Hg_{1-x}Tl_xBa_2Ca_2Cu_3O_{8+\delta}$ (x = 0 and 0.2) in zero field and above the superconducting T_c. The fluctuation conductivity $\Delta\sigma$ is analyzed. With decreasing temperature two crossover temperatures could be identified for each sample; i.e. T^* from two to three dimensional fluctuations in the mean field region (MFR), and T_G from the MFR to the critical region. All results are in agreement with the Lawrence–Doniach model. The c-axis coherence length and the interlayer coupling factor were obtained.

Key words: Fluctuation Conductivity; Hg,Tl-1223

1. Introduction

The series $HgBa_2Ca_{n-1}Cu_nO_{2n+2+\delta}$ with $n = 1, 2, 3...$ offers the highest superconducting transition temperature (T_c) known to date. These compounds have attracted much interest from both the point of view of fundamental science and possible applications. The thermal fluctuations give a finite probability of forming superconducting pairs and thus induce excess conductivity $\Delta\sigma$. Studies of the superconducting fluctuations are important for clarifying intrinsic properties.

$\Delta\sigma$ was calculated by Aslamazov–Larkin (AL) [1] using a microscopic approach in the mean field region (MFR) where the fluctuations are small. They obtained

$$\Delta\sigma_{AL} \propto \epsilon^{\alpha}. \quad (1)$$

Here $\epsilon = \ln(T/T_c^{mf})$ and T_c^{mf} is the mean field critical temperature. For a 2-dimensional (2D) system, $\alpha = -1$, and in 3D, $\alpha = -1/2$.

For anisotropic superconductors Lawrence and Doniach (LD) used an anisotropic mass formulation of the AL theory and found [2]

$$\Delta\sigma_{LD} \propto \epsilon^{-1/2}(\epsilon + 4J)^{-1/2} \quad (2)$$

Here $J = [\xi_c(0)/s]^2$ is a measure of the interlayer coupling strength, $\xi_c(0)$ is the c-axis coherence length at $T = 0$ K and s is the interlayer spacing. This relation predicts a cross-over from 2D to 3D at $\epsilon^* = 4J$.

In this communication we study the behavior of thermal fluctuations in the MFR of Hg, Tl-1223.

2. Experimental

Synthesis of $Hg_{1-x}Tl_xBa_2Ca_2Cu_3O_{8+\delta}$ ($x = 0, 0.2$) was performed using carefully ground mixtures of purified metal oxides which were heated twice in sealed silica tubes with intermediate regrinding. A nominal composition with $x = 0.2$ yielded a pure 1223 phase. Electrical measurements were made with a standard four probe technique in a cryostat allowing a temperature resolution of order ~ 100 μK.

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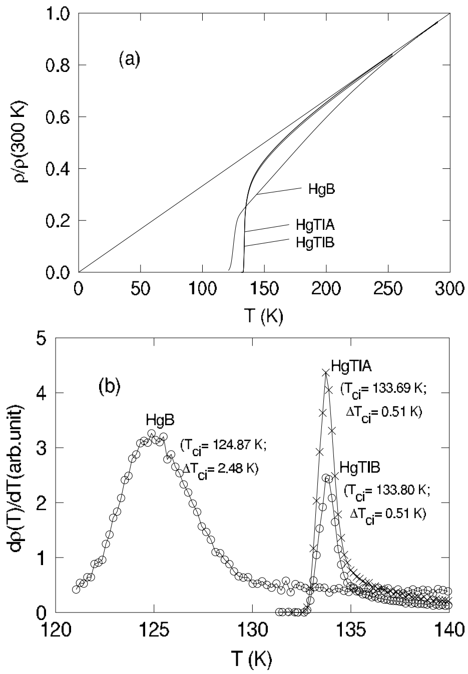

Fig. 1. (a) Normalized ρ of HgB ($x = 0.0$), HgTlA ($x = 0.2$) and HgTlB ($x = 0.2$); (b) Temperature derivative of ρ, $d\rho/dT$, around T_c.

3. Results and discussion

Fig. 1a shows the normalized electrical resistivity for three samples. A linear T-dependent resistivity which can be extrapolated to $\rho = 0$ at $T = 0$ K was observed above $\sim$ 220 K for HgTlA and HgTlB. Fig. 1b shows the temperature derivative of the resistivity, $d\rho/dT$, around T_c. A single peak at T_{ci} is observed for each sample, however HgTlA and HgTlB show higher T_{ci} and narrower ΔT_{ci}. Data are shown in the figure. These results support that Tl doping in Hg1223 is favorable for obtaining high quality single phase samples. We will focus discussion on HgTlA and B.

$\Delta\sigma$ was obtained from the measured resitivity $\rho(T)$ and the linearly extrapolated normal-state resistivity $\rho_n(T)$ by $\Delta\sigma = 1/\rho(T) - 1/\rho_n(T)$. $\rho_n(T)$ was obtained from a fit at $220 < T < 250$ K. The results were analyzed in different temperature regions as $\Delta\sigma = A\epsilon^a$, $\epsilon = \ln(T/T_c^{mf})$. The mean field transition temperature T_c^{mf} was obtained as described previously [3].

Fig. 2 shows $\Delta\sigma$ for HgTlA and HgTlB on double logarithmic scales. The three temperature regions for $\Delta\sigma$ are identified for each sample; at temperatures above ϵ^*, the value $\alpha_{1mf} = -1$, between ϵ_G and ϵ^*, $\alpha_{2mf} = -0.5$ and for $\epsilon < \epsilon_G$, α_{3mf} has a value of -0.33.

Comparing with the theoretical formulae, the LD model thus gives a consistent description of the fluctuations. The AL model can not explain the crossover from 2D to 3D.

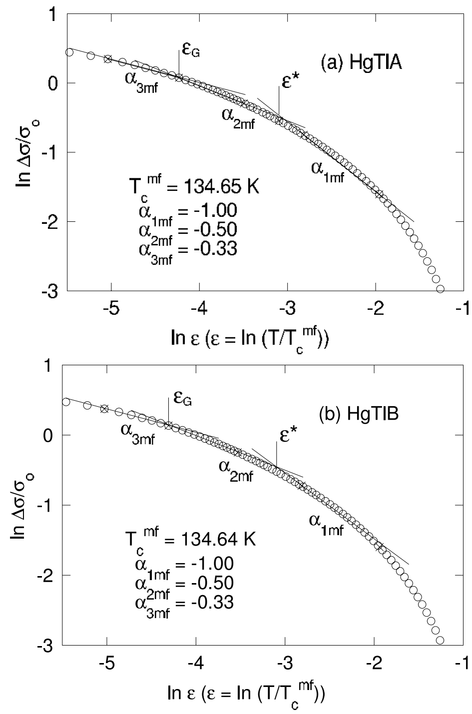

Fig. 2. Normalized $\Delta\sigma$ vs. ϵ for HgTlA and HgTlB on double logarithmic scales. Results for T_c^{mf}, cross-over temperature and exponents are given in the Figure. For clarity only a reduced set of data is shown.

From ϵ^* we can estimate $\xi_c(0)$ and J in the LD formula. $\xi_c(0)$ was found to be 1.24 and 1.30 Å and J was 5.5×10^{-2} and 6.0×10^{-2} for HgTlA and HgTlB respectively.

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