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Magnetoresistance and Conductivity Fluctuations in $(Tl_{0.5}Pb_{0.5})Sr_2(Ca_{1-x}Y_x)Cu_2O_7$ Superconductors

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Abstract

We have studied magnetoresistance R(H) of the $(Tl_{0.5}Pb_{0.5})Sr_2(Ca_{1-x}Y_x)Cu_2O_7$ high-T_c superconductors, with x=0.1, 0.2, 0.3, 0.4 at $T < T_c$ in a magnetic field H up to 12 T. For H > 1T, the magnetoresistance can be successfully fitted by the Larkin two-dimensional superconducting fluctuation expression with only two adjustable parameters (A(T) and $H_\Phi(T)$) per each R vs H curve. This indicates that a large part of the resistive transition broadening in applied magnetic field is related to the giant conductivity fluctuations in these ceramic samples. The first scaling parameter A(T) is determined by the fluctuation amplitude. For x =0.1, the temperature dependence of A(T) follows the behaviour of the $\beta(T)$ function introduced by Larkin. For larger x, the deviation of A(T) from $\beta(T)$ is observed which may be attributed to an additional scattering caused by the $Y^{3+} \rightarrow Ca^{2+}$ substitution. The second parameter H_Φ, corresponding to the phase coherence breaking field, shows a good agreement with the the recent theoretical prediction by Reizer.

1. Introduction

The observations of the Lorentz-force independent dissipation in the mixed state of the high T_c superconductors [1], and the deviation from the conventional flux flow $R \propto H$ model [2] of the magnetoresistance at higher resistivities, has caused some doubts on the interpretation based on the concept of flux motion for the peculiar characteristics of the resistive transition broadening in an applied magnetic field of high T_c superconductors. It opened up the possibility of the explanation based on the effect of superconducting order parameter fluctuations. Several theories in this framework have shown a good fitting of magnetoresistance data below T_c, for example, the theoretical study of magnetoresistance by considering the renormalization effect due to interactions between one-dimensional fluctuations of the order parameter in magnetic field [3] , and the scaling of the magnetoresistance in high field by the Ginzburg-Landau fluctuation theory for $YBa_2Cu_3O_x$ [4].

Recently it has been reported that the Larkin 2D fluctuation expression [5] can successfully describe the magnetoresistance data of the $Bi_2Sr_2CaCu_2O_8$ c-oriented thin films [6], single crystals [7] as well as YBCO/PrBCO superlattices thin films. These results have demonstrated the validity of the Larkin expression over a broad temperature and magnetic field range.

In this paper we report a systematical study of the magnetoresistance R(H,T) in $(Tl_{0.5}Pb_{0.5})$-$Sr_2(Ca_{1-x}Y_x)Cu_2O_7$ (x=0.1, 0.2, 0.3, 0.4) superconductors. The scaling R(H,T) results reveal the applicability of the Larkin 2D fluctuation expression [5] for our experimental R(H,T) data over a broad temperature and magnetic field range. The analysis of the scaling parameters shows that, for x=0.1 compound, the temperature dependence of A(T) follows the behaviour of the $\beta(T)$ function introduced by Larkin. For larger x the deviation of A(T) from $\beta(T)$ is observed which may be attributed to an additional scattering caused by the $Y^{3+} \rightarrow Ca^{2+}$ substitution.

2. Sample preparation

Samples of $(Tl_{0.5}Pb_{0.5})Sr_2(Ca_{1-x}Y_x)Cu_2O_7$, with x=0.1, 0.2, 0.3, 0.4 were prepared by solid state

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reaction. High purity $CaCO_3$, Y_2O_3, $SrCO_3$ and CuO powders were calcined in the appropriate stoichiometric proportions at 970 °C for 12 H in air. These precursors were then mixed with Tl_2O_3 and PbO, ground and pressed into pellets, then wrapped into gold foil to prevent loss of thallium and lead during heating. The samples were then sintered at 950 °C for 3h in flowing oxygen, followed with a cooling rate of 5 °C/min to room temperature. The powder X-ray diffraction (XRD) measurements and Time-of- flight neutron powder diffraction measurements were performed to examine the samples structural and chemical properties. Details of the preparation method and structural examination of the samples are described in Ref.[8]. A standard four-probe method was applied in the resistive measurements. The magnetoresistance measurements were performed at fixed temperatures $T < T_c$, with a slowly varying magnetic fields of 600G/min and perpendicular to the applied current.

3. Experimental results and discussion

Fig.1 shows the magnetoresistance R(H,T) of the $(Tl_{0.5}Pb_{0.5})Sr_2(Ca_{0.8}Y_{0.2})Cu_2O_7$ ceramic superconductor, with $T_{c0}(H{=}0) \simeq 103K$, measured at temperatures $T < T_c$. These magnetoresistance data display the following features: (1) at low temperatures the R(H,T) value increases slowly with increasing field in the resistance range much smaller than the normal resistance R_n, (it is often ascribed to the thermally activated flux motion [11]). (2) When the temperature rises, these curves show a steeper variation with the increasing fields. (3) In high fields, the R(H,T) value

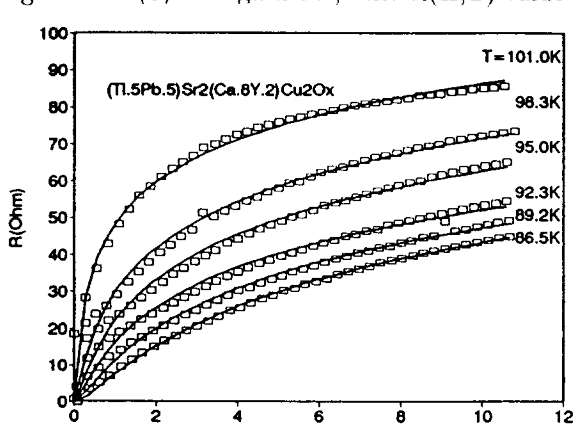

Fig. 1. The field dependence of the resistance, R(H), measured at temperatures $T < T_c$ for the $(Tl_{.5}Pb_{.5})Sr_2(Ca_{.8}Y_{.2})Cu_2O_7$ superconductor.

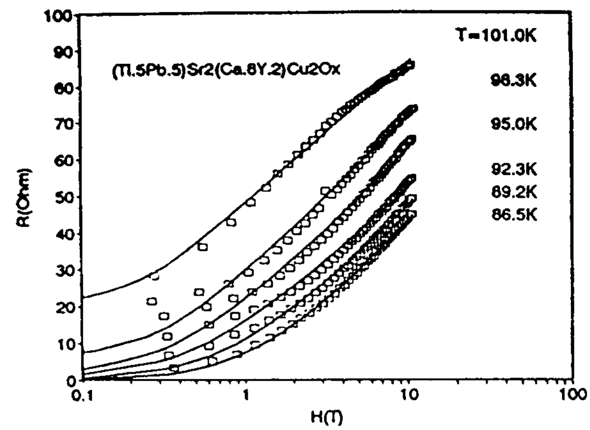

Fig. 2. Comparison between the experimental data (open squares) and the theoretical curve (Eq.1, solid line) for the $(Tl_{0.5}Pb_{0.5})$- $Sr_2(Ca_{0.8}Y_{0.2})Cu_2O_7$ superconductor.

varies logarithmically with field. This behaviour of R vs logH is observed in a wide high field range as shown in Fig.2, and it deviates from the Bardeen and Stephen flux flow model [2] which predicts a linear $R(H) \propto H$ dependence deviates. The magnetoresistance data for x=0.1, 0.3, 0.4 also display the same characteristics. Besides, we also notice some abrupt jumps of the resistance in the beginning of the field sweeps rising fields, which is typical for a ceramic sample.

In order to analyze these R(H,T) data, we use the following expression derived by Larkin, which considers the Maki-Thompson contribution to the superconducting fluctuation conductance in a two-dimensional system [5] :

$$\Delta R = A(T) f_2(H/H_\Phi) \qquad (1)$$

$$f_2(\frac{H}{H_\Phi}) = \Psi(\frac{1}{2} + \frac{H_\Phi}{H}) + ln(\frac{H}{H_\Phi}) \qquad (2)$$

where Ψ is the digamma function, A(T) is the amplitude of the fluctuation contribution and H_Φ is the phase-coherence-breaking field. H_Φ is related to the phase coherence breaking time : $\tau_\Phi(T) = \hbar/4eDH_\Phi$, where D is the diffusion constant. The parameter A(T) is given by [5]:

$$A(T) = \frac{e^2/2}{\pi^2\hbar} R_l^2 \beta(T/T_c^*) = A_o \beta(T/T_c^*) \qquad (3)$$

where R_l is the effective fluctuating sheet resistance and T_c^* is the critical temperature of a quasi 2D superconducting layer, which is corresponding to the double CuO_2 layer in the high T_c compounds [6]. In strong anisotropic superconductors, the magnetoresistance is mainly caused by the component of the magnetic field which is perpendicular to the the a-b planes. $\beta(T/T_c^*)$ is increasing with a decreasing temperature in case of an attractive electron interaction [5] and it diverges as T_c^* is approached; $\beta(T/T_c^*)$ becomes field dependent when the e-e interaction are sensitive to the magnetic field, i.e. $H_\Phi(T) > \hbar/4eD\tau_\Phi$. The value of $\beta(T/T_c^*)$ function was tabulated by Larkin [5].

For comparing the experimental data with Eq.1, A(T) and H_Φ are taken as the fitting parameters. As shown in Fig.1 and Fig.2, the fitting results (solid line) demonstrate good agreement with the experimental data for a wide range of temperatures and magnetic fields. We also performed the same measurements and analysis of the magnetoresistance for x=0.1, 0.3 and 0.4. The results also exhibit quite good agreement with the Larkin's 2D fluctuation theory.

In order to evaluate the characteristic temperature T_c^*, we fit A(T) with Eq.(3). The value of T_c^* and A_o, obtained from the fitting, are tabulated in the insert of Fig.3. The T_c^* value decreases as Y concentration x is reduced. The normalized fluctuation contribution $A(T)/A_o$ is plotted as a function of temperature in Fig.3. The $A(T)/A_o$ is in good

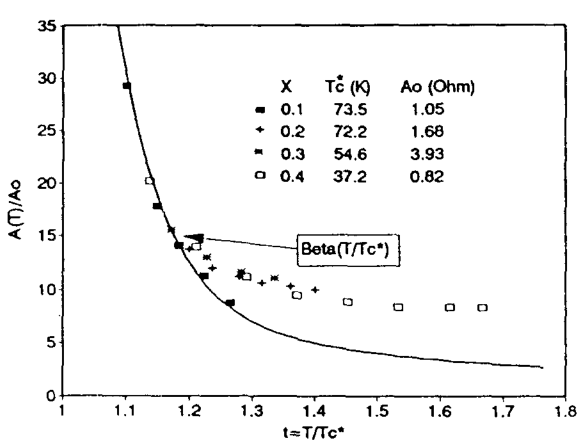

Fig. 3. The temperature dependence of the normalized coefficient $A(T)/A_o$ for x=0.1, 0.2, 0.3, and 0.4 of the $(Tl_{0.5}Pb_{0.5})$- $Sr_2(Ca_{1-x}Y_x)Cu_2O_7$ superconductors. The solid curve is the Larkin function $\beta(T/T_c^*)$. Insert shows the value of T_c^* and A_o obtained from the fitting.

agreement with the theoretical Larkin $\beta(T/T_c^*)$ function for x=0.1. However, for larger x the deviation of $A(T)/A_o$ from $\beta(T)$ is observed. It has been shown by the Hall measurements in $(Tl_{0.5}Pb_{0.5})$-$Sr_2(Ca_{1-x}Y_x)Cu_2O_7$ [8] that the Hall number per Cu decreases with an increasing x, which implies that the substitution $Y^{3+} \rightarrow Ca^{2+}$ results in the introduction of excess electrons into the conducting CuO_2 planes. The deviation of $A(T)/A_o$ from $\beta(T)$ may be attributed to an additional scattering caused by the $Y^{3+} \rightarrow Ca^{2+}$ substitution.

In a dirty superconductors, the Maki-Thompson fluctuations are related to the presence of a pair breaking scattering which leads to the destruction of the pair phase coherence. These processes are characterized by the electron phase-breaking time $\tau_\Phi(T)$, related to the phase coherence breaking field by $\tau_\Phi(T) = \hbar/4eDH_\Phi$. Reizer [9] has studied the electron phase relaxation and the Maki-Tompson correction to the conductivity in a 2D system, for $T > T_c^*$. He has obtained the following relation [9]:

$$\frac{\hbar}{\tau_\Phi(T)} = \frac{\pi^3 k_B T}{8k_F^2 ld} \frac{ln[\hbar/(k_B T\tau)]}{[ln(T/T_c^*)]^2} \tag{4}$$

where k_F is the Fermi wave-vector and $l = v_F\tau$ is the electron mean free path. For fitting $H_\Phi(T)$ with Eq.4, the expression for τ_Φ (Eq.4)

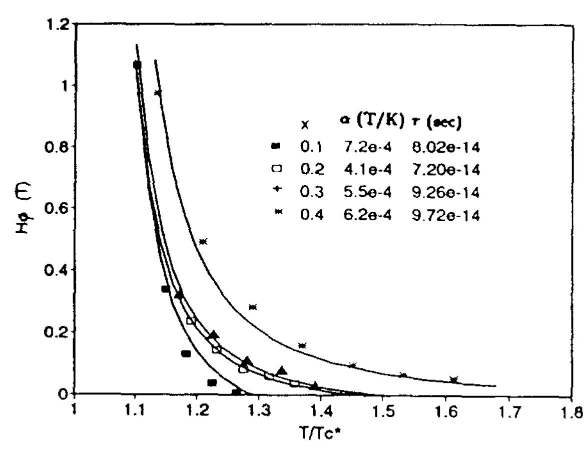

Fig. 4. The temperature dependence of the phase breaking field $H_\Phi(T)$ for x=0.1, 0.2, 0.3 and 0.4. The solid line is the theoretical curve $H_\Phi(T) = \alpha T \times \ln(\hbar/k_B T\tau) / [\ln(T/T_c^*)]^2$. The two fitting parameters "α" and "τ" are listed in the insert.

is writen as

$$H_\Phi(T) = \alpha T \times \frac{ln[\hbar/(k_B T \tau)]}{[ln(T/T_c^*)]^2} \qquad (5)$$

Taking "α" and "τ" as two fitting parameters, we are able to fit the $H_\Phi(T)$ values with the Reizer's expression. As shown in Fig.4, this fitting procedure was quite successful for x=0.2. However, there is a small progressive deviation of the $H_\Phi(T)$ data from the theoretical curve. An important point to be mentioned here is that the same characteristic temperature T_c^*, corresponding to the divergence of $A(T)/A_o$ (Fig.3), can be successfully used to describe the $H_\Phi(T)$ behaviour (Fig.4).

4. Conclusion

In conclusion, we have carried out a systematic study of the magnetoresistance in the $(Tl_{0.5}Pb_{0.5})$-$Sr_2(Ca_{1-x}Y_x)Cu_2O_7$ system. The convincing fitting results show the validity of the Larkin 2D fluctuation expression to describe the experimental R(H,T) data. This implies that the resistive transition of the normal to superconducting state transition in a magnetic field is mainly related to 2D superconducting fluctuations, rather than to a small perturbation due to the flux flow. For the very low resistivity 'tail', however, one can not exclude the possible contribution of flux motion due to quantum tunneling [10], or the thermally activated flux motion [11], and vortex-antivortex pair formation[12].

The fluctuation contribution A(T) follows the behaviour of the Larkin β(T) function. The deviation of $A(T)/A_o$ from β(T) for larger x may be attributed to the excess charge carriers induced into the conducting CuO_2 planes by the $Y^{3+} \rightarrow Ca^{2+}$ substitution, which may also cause an additional scattering. The analysis of the temperature dependence of the phase coherence breaking field, $H_\Phi(T)$ confirms the theoretical prediction by Reizer [9] for the two-dimensional electron systems.

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