Available online at www.sciencedirect.com

SCIENCE DIRECT®

ELSEVIER

Physica C 408–410 (2004) 713–715

PHYSICA C

www.elsevier.com/locate/physc

Magnetotransport properties of $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ single crystals

V. Sandu [a,1], E. Cimpoiasu [a,2], Shi Li [b], M.B. Maple [b], C.C. Almasan [a,*]

[a] *Department of Physics, Kent State University, Kent, OH 44242, USA*
[b] *Department of Physics, University of California at San Diego, La Jolla, CA, USA*

Abstract

Magnetotransport measurements of $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ ($x = 0$, 0.13, 0.2, 0.32, and 0.42) single crystals reveal two regimes in the pseudogap region for the $x \geqslant 0.20$ samples, with a crossover at a temperature $T_{cr}(x)$. For $T_c < T < T_{cr}$, there is a vortex-like response in magnetoresistivity. For $T > T_{cr}$, the results are consistent with the picture in which the origin of the pseudogap is the nearly antiferromagnetic Fermi liquid renormalized by strong superconducting fluctuations.

Keywords: Magnetoresistivity; Vortex-like excitations; Pseudogap; $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$

The charge carrier density can be modified in high temperature superconductors (HTS) either by varying the oxygen amount or by partial substitution of the rare earth ions. The partial substitution of Y with Pr in $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ system has special advantages: (i) $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ is isomorphous to $YBa_2Cu_3O_{7-\delta}$ for $0 \leqslant x \leqslant 1$; (ii) with increasing Pr content, the O2p-R4f Fahrenbacher–Rice band crosses the Fermi level, hence, the CuO_2 pdσ band is gradually depleted of holes [1]; (iii) the integrity of the CuO chains is preserved even in strongly Pr-doped HTS. Thus, by varying the Pr content, one can cover the whole range of behaviors characteristic to bilayer cuprates, from the optimally doped to the strongly underdoped regime.

It is known that a **k**-dependent *pseudogap* (PG) in the quasiparticle density of states (DOS) opens in underdoped HTS, below a temperature $T^*(x)$ [2]. The microscopic mechanisms responsible for PG are still under debate, but the d-wave symmetry of both the superconducting gap and pseudogap suggests their common origin. We performed in-plane resistivity and angular magnetoresistivity (MR) measurements on $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ ($x = 0$, 0.13, 0.2, 0.32, and 0.42) to shed more light on the physics underlying the PG.

Electrical resistivity measurements were performed using a six-lead configuration [3]. The angular magnetoresistivity was measured in constant applied magnetic field $H = 14$ T while rotating H from $H \| c$-axis ($\theta = 0°$) to $H \| (ab) \| I$ ($\theta = 90°$). The single crystal growth is described elsewhere [4].

As expected, the critical temperature T_c decreases from 92 to 39 K with increasing Pr content from $x = 0$ to 0.42, while the normal-state resistivity strongly increases. The T dependence of ρ_{ab} is linear for $x = 0.13$ and is a combination of linear and quadratic contributions for the $x = 0$ sample. For $x \geqslant 0.2$, the lower limit T^* of the linearity range shifts to higher T, moving outside of the measured T range for the strongly underdoped samples. For this concentration range and for $T_c < T < T^*$, $\rho_{ab}(T)$ exhibits a power-law dependence; i.e., $\rho_{ab}(T) \propto T^\alpha$. The exponent α changes over this T interval, indicating the existence of a crossover

* Corresponding author.
E-mail address: calmasan@physics.kent.edu (C.C. Almasan).

[1] Permanent address: National Institute of Materials, Physics, Bucharest, MG-7, R76900, Romania.

[2] Present address: Department of Physics and Astronomy, State University of New York at Stony Brook, Stony Brook, NY 11994, USA.

0921-4534/$ - see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.physc.2004.03.124

temperature T_{cr} in $\rho_{ab}(T)$, hence two subregimes located in the PG region. Specifically, $0 \leqslant \alpha < 1$ for $T_{cr} < T < T^*$, indicating an underlinear $\rho_{ab}(T)$, while $\alpha > 1$ for $T_c < T < T_{cr}$, indicating an overlinear $\rho_{ab}(T)$. The value of T_{cr} increases from 99 to 145 K with increasing Pr content from $x = 0.2$–0.42.

The presence of the two subregimes in the PG region can be understood within the framework of the nearly antiferromagnetic Fermi liquid (NAFL) renormalized by strong superconducting fluctuations [5]. Specifically, the rate of change of ρ_{ab} with T is the result of a fine interplay between two effects. On one hand, as T decreases, the **k**-dependent PG opens around the hot spots, the Fermi surface approaches the magnetic Brillouin zone, and the area of hot spots widens on the expense of the cold spots, which tends to increase the resistivity. On the other hand, the low frequency spin fluctuations, which are the main scatterers in NAFL, gradually freeze as T decreases and PG opens, an effect which decreases the resistivity. For $T_{cr} < T < T^*$, the suppression of the spin fluctuations on decreasing T is the dominant effect, thus overall $\rho_{ab}(T)$ decreases. At even lower temperatures, $T < T_{cr}$, the hot spots spread and PG increases, which decelerates the decrease in resistivity.

Magnetotransport measurements reveal further aspects of the processes involved in the two subregimes. We extracted the *orbital magnetoresistivity* as $\Delta\rho^{orb}_{ab}/\rho_{ab} \equiv [\rho_{ab}(90°) - \rho_{ab}(0°)]/\rho_{ab}(0°)$, assuming that the spin contribution to MR is independent of field orientation. The magnetoconductivity $\Delta\sigma^{orb}_{ab} \equiv -\Delta\rho^{orb}_{ab}/\rho^2_{ab} \propto T^{-\beta}$ for the $x = 0$ and 0.13 samples at all T, and for the $x \geqslant 0.2$ samples at $T > T_{cr}(x)$ (see Fig. 1). The exponent β decreases from 4.6 to 3.35 as x increases from 0 to 0.42 (see inset to Fig. 1). The value $\beta = 4.6$ for the optimally-doped sample and its decrease in the PG region are in good agreement with the predictions of NAFL [6].

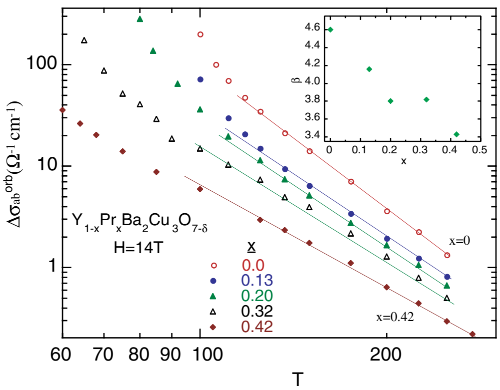

Fig. 1. Log–log plot of orbital magnetoconductivity $\Delta\sigma^{orb}_{ab}$ vs temperature T. Inset: exponent β vs Pr content x.

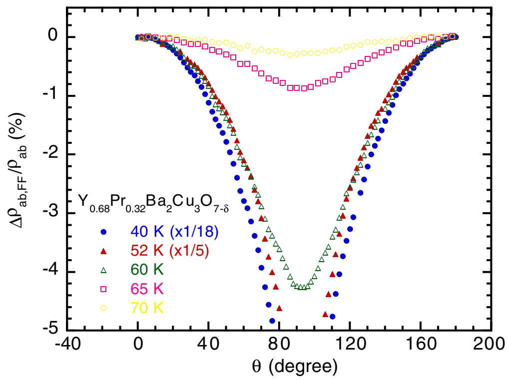

Fig. 2. Plot of flux-flow-like magnetoresistivity $\Delta\rho_{ab,FF}/\rho_{ab}$ vs angle θ of $Y_{0.68}Pr_{0.32}Ba_2Cu_3O_{7-\delta}$ measured at 60, 65, and 70 K. For comparison, $(\Delta\rho_{ab,FF}/\rho_{ab})(\theta)$ in the superconducting state (40 and 52 K) are also shown with filled symbols.

The anisotropic magnetoresistivity $\Delta\rho^{anis}_{ab}/\rho_{ab} \equiv [\rho_{ab}(\theta) - \rho_{ab}(0)]/\rho_{ab}(0)$ exhibits the expected $\sin^2\theta$ dependence only for $T > T_{cr}$. After subtracting the $\sin^2\theta$ term, the θ dependence of the magnetoresistivity is similar to the one below T_c due to flux-flow (see Fig. 2). This flux-flow-like magnetoresistivity $\Delta\rho_{ab,FF}/\rho_{ab}$ indicates the presence of vortex-like excitations at $T_c < T < T_{cr}$. Vortex-like excitations were also invoked in the explanation of data from other types of measurements performed at $T > T_c$ [7,8].

In summary, we carried out a detailed study of the charge transport in $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ within the pseudogap PG state and of its evolution with the Pr amount. We identified two subregimes in the PG region: a high temperature subregime, consistent with the model of nearly antiferromagnetic Fermi liquid, renormalized by strong superconducting fluctuations, and a low temperature subregime in which the effect of the PG is enhanced and fingerprints of vortex-like excitations could be singled out.

Acknowledgements

This research was supported by the NSF grant no. DMR-0102415 at KSU and the US Department of Energy grant no. DE-FG03-86ER-45230 at UCSD.

References

[1] A.I. Liechtenstein, I.I. Mazin, Phys. Rev. Lett. 74 (1995) 1000.
[2] T. Timusk, B. Statt, Rep. Prog. Phys. 62 (1999) 61.
[3] C.N. Jiang, A.R. Baldwin, G.A. Levin, T. Stein, C.C. Almasan, D.A. Gajewski, S.H. Han, M.B. Maple, Phys. Rev. B 55 (1997) R3390.

[4] L.M. Paulius, B.W. Lee, M.B. Mapple, P.K. Tsai, Physica C 230 (1994) 255.
[5] Y. Yanase, K. Yamada, J. Phys. Soc. Jpn. 68 (1999) 548; Y. Yanase, K. Yamada, J. Phys. Soc. Jpn. 68 (1999) 2999; (c) Y. Yanase, K. Yamada, J. Phys. Soc. Jpn. 69 (2000) 2209.
[6] H. Kontani, J. Phys. Soc. Jpn. 70 (2001) 1873.
[7] A. Lascialfari, A. Rigamonti, L. Romano, P. Tedesco, A. Varlamov, D. Embriaco, Phys. Rev. B 65 (2002) 144523.
[8] Z.A. Xu, N.P. Ong, Y. Wang, T. Kageshita, S. Uchida, Nature (London) 406 (2000) 486.