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Physica C 341–348 (2000) 1879–1880

PHYSICA C

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Magnetoresistivity in Strongly Underdoped $YBa_2Cu_3O_x$ Single Crystals *

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We report magnetoresistivity measurements on $YBa_2Cu_3O_{6.36}$ single crystals in applied magnetic fields $H||c$ up to 14 T. We observe several unusual features: the out-of-plane magnetoresistivity $\Delta\rho_c/\rho_c$ is negative at high temperatures T and becomes positive for $T < 150$ K. The in-plane magnetoresistivity $\Delta\rho_{ab}/\rho_{ab}$ is positive and displays a maximum at $T \approx 180$ K. There is a direct correlation between the sign and T-dependence of magnetoresistivities and the corresponding temperature coefficients of resistivities; i.e. $\Delta\rho_{c,ab} \sim d\rho_{c,ab}/dT$ over the measured T range for the in-plane component and for $T > 150$ K for the out-of-plane component.

The anomalous properties of the in-plane ρ_{ab} and out-of-plane ρ_c resistivities in layered cuprates are a main challenge to the understanding of these materials. Magnetoresistivity is a sensitive and important probe of the conduction mechanism. We present data on magnetoresistivities (MR) $\Delta\rho_c/\rho_c$ and $\Delta\rho_{ab}/\rho_{ab}$ obtained on $YBa_2Cu_3O_{6.36}$ single crystals. The main emphasis of this work is on the correlation between the magnetoresistivities and the temperature coefficients of the resistivities (TCR) $dln\rho_{c,ab}/dT$. We find that $\Delta\rho_{ab}/\rho_{ab}$ and $dln\rho_{ab}/dT$ correlate over the measured T range (100 $K < T <$ 275 K). A similar relationship exists between $\Delta\rho_c/\rho_c$ and $dln\rho_c/dT$ for $T >$ 150 K. However, for $T <$ 150 K, $\Delta\rho_c$ changes sign while $d\rho_c/dT$ remains negative.

In-plane and out-of-plane resistivities were measured by a flux transformer method [1]. The data were corrected for the Hall voltage by performing measurements in both negative and positive H and retaining only the even components of the primary V_p and secondary voltages V_s: $\Delta V^+_{p,s} \equiv 1/2[\Delta V_{p,s}(H) + \Delta V_{p,s}(-H)]$. The temperature sensor was carefully calibrated to account for its magnetoresistance.

Figures 1(a) and 1(b) show the H-dependence of $\Delta\rho_{ab}/\rho_{ab}$ and $\Delta\rho_c/\rho_c$, respectively, for $H||c$ and different T. Both MR components display a H^2 dependence, as expected in the weak field regime. If we do not correct for the Hall effect, the apparent MR shows a mixture of linear and quadratic field dependences.

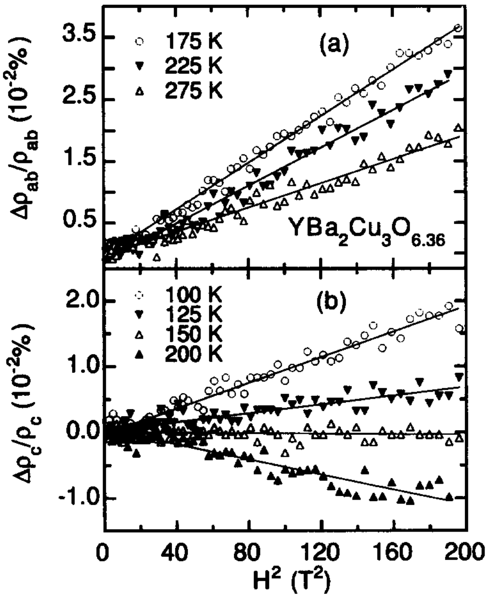

Figure 1. *Field H dependence of magnetoresistivities: (a) $\Delta\rho_{ab}/\rho_{ab}$ and (b) $\Delta\rho_c/\rho_c$ for several temperatures. Lines are guide to the eye.*

The T-dependences of $\Delta\rho_{ab}/\rho_{ab}$ and $\Delta\rho_c/\rho_c$ in $H = 14$ T are presented in Figs. 2(a) and 2(b), respectively. The insets show the respective TCR vs T. A comparison between the main panels and

*The work at KSU was supported by the National Science Foundation under Grant No. DMR-9801990

0921-4534/00/$ – see front matter
PII S0921-4534(00)01237-5

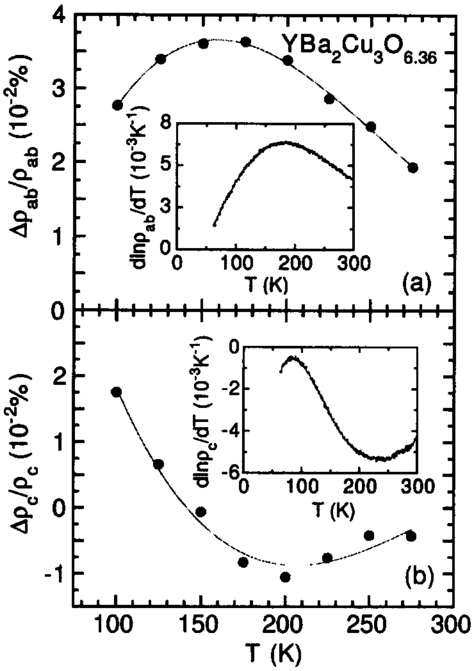

Figure 2. *Temperature T dependence of (a) $\Delta\rho_{ab}/\rho_{ab}$ and (b) $\Delta\rho_c/\rho_c$ in a field $H||c$ of 14 T. Insets: T-dependence of the temperature coefficients of the resistivities: (a) $dln\rho_{ab}/dT$ and (b) $dln\rho_c/dT$*

the corresponding insets reveals a direct correlation between MR and the respective TCR, both in sign and T-dependence, over the measured T range for the *ab* component and for $T > 150\ K$ for the *c* component. For $T < 150\ K$, $\Delta\rho_c/\rho_c$ becomes positive while $dln\rho_c/dT$ remains negative.

The correlation between magnetoresistivity and TCR can be understood as a consequence of incoherent interlayer transport. When interlayer transitions are incoherent, as is the case with $YBa_2Cu_3O_{6.36}$ [2], the out-of-plane phase coherence length $\ell_{\varphi,c}$ is T-independent, equal to the interlayer spacing ℓ_0. As a result, the in-plane conductivity σ_{ab} is only a function of the in-plane phase-coherence length: $\sigma_{ab} = f(\ell_{\varphi,ab})$ [3]. In anisotropic systems, the ratio of the conductivities is given by the ratio of the phase coherence lengths in the respective directions: $\sigma_{ab}/\sigma_c = \ell^2_{\varphi,ab}/\ell^2_{\varphi,c}$ [4]. Therefore, $\sigma_c = f(\ell_{\varphi,ab})\ell_0^2/\ell^2_{\varphi,ab}$. Hence, the T and H dependence of both conductivities appears only through that of $\ell_{\varphi,ab}$. Then,

$$\frac{\partial\sigma_{c,ab}}{\partial H} = Q\frac{\partial\sigma_{c,ab}}{\partial T}; \quad Q \equiv \frac{\partial\ell_{\varphi,ab}/\partial H}{\partial\ell_{\varphi,ab}/\partial T}. \tag{1}$$

Since $\partial\ell_{\varphi,ab}/\partial H < 0$ and $\partial\ell_{\varphi,ab}/\partial T < 0$, the sign of each magnetoresistivity is given by the sign of the corresponding TCR. The coefficient Q may have a certain T-dependence, but this dependence should be rather weak due to a partial cancellation of the T-dependences of $\partial\ell_{\varphi,ab}/\partial H$ and $\partial\ell_{\varphi,ab}/\partial T$. Therefore, $\Delta\rho_{ab}/\rho_{ab}$ and $\Delta\rho_c/\rho_c$ should closely reproduce the T-dependence of the respective TCR as, indeed, is the case at high temperatures [see Figs. 2(a) and 2(b)].

The out-of-plane magnetoresistivity $\Delta\rho_c/\rho_c$ deviates from the behavior described by Eq. (1) at $T < 150\ K$ [$\Delta\rho_c/\rho_c$ becomes positive while $dln\rho_c/dT$ remains negative]. This indicates that the condition of interlayer incoherence is not fulfilled at these temperatures in $YBa_2Cu_3O_{6.36}$. As a result, $\ell_{\varphi,c}$ becomes T-dependent, increasing beyond the interlayer spacing, and thus changes in applied magnetic field due to spin ordering effects. It appears likely that the transition to partial coherence in the c-direction is related to the antiferromagnetic transition that takes place in $YBa_2Cu_3O_{6.36}$ at $T_N \approx 40\ K$. Recently, a positive $\Delta\rho_c/\rho_c(T)$ was also observed in strongly underdoped $YBa_2Cu_3O_x$ single crystals over a wide T range above T_N and was attributed to the antiferromagnetic fluctuations [5].

REFERENCES

1. C. N. Jiang et al., Phys. Rev. B **55**, R3390 (1997).
2. D. N. Basov et al., Science **283**, 49 (1999).
3. C. C. Almasan et al., J. Low. Temp. Phys. **117**, 1307 (1999); C. C. Almasan et al., Int. J. Mod. Phys. B **13**, 3618 (1999).
4. G. A. Levin et al., Phys. Rev. Lett. (submitted).
5. A. N. Lavrov et al., Phys. Rev. Lett. **83**, 1419 (1999).