# $a b$-plane anisotropy in single-domain $\mathrm{Bi}_{2} \mathrm{Sr}_{2} \mathrm{CaCu}_{2} \mathrm{O}_{8}$ high-temperature superconductors 

M.A. Quijada, ${ }^{1}$ D.B. Tanner, ${ }^{1}$ R.J. Kelley, ${ }^{2}$ and M. Onellion ${ }^{2}$

${ }^{1}$ Department of Physics, University of Florida, Gainesville, FL 32611, USA
${ }^{2}$ Department of Physics, University of Wisconsin, Madison, WI 53706, USA
The anisotropy of the $a b$-plane optical conductivity and dc resistivity of single-domain $\mathrm{Bi}_{2} \mathrm{Sr}_{2} \mathrm{CaCu}_{2} \mathrm{O}_{8}$ crystals has been measured between 20 and 300 K . There is a modest normal-state anisotropy, optical anisotropy below $T_{c}$, and an unexpected anisotropy in the resistive transition.

## 1. INTRODUCTION

A key structural element of the high- $T_{c}$ superconductors is the quasi-two dimensional $\mathrm{CuO}_{2}$ plane. In materials like $\mathrm{Bi}_{2} \mathrm{Sr}_{2} \mathrm{CaCu}_{2} \mathrm{O}_{8}$, this layer is nearly square, and thus should have almost isotropic electrical and optical properties. However, there is a weak superlattice distortion ${ }^{1}$ (generally associated with defects in the BiO layer), and hence the structure is formally orthorhombic, which permits anisotropic behavior. We have measured the optical conductivity and resistivity along the $a$ and $b$ axes of single domain crystals of $\mathrm{Bi}_{2} \mathrm{Sr}_{2} \mathrm{CaCu}_{2} \mathrm{O}_{8}\left(T_{c}=83 \mathrm{~K}\right)$ as a function of temperature.


Fig. 1. The optical conductivity along the $a$ axis of a single-domain $\mathrm{Bi}_{2} \mathrm{Sr}_{2} \mathrm{CaCu}_{2} \mathrm{O}_{8}$ crystal.

## 2. OPTICAL CONDUCTIVITY

Figures 1 and 2 show the optical conductivity, obtained by Kramers-Kronig analysis of reflectance; the $a b$ plane is anisotropic both above and below $T_{c} .{ }^{2}$ In the infrared, the normal-state conductivity is higher for $\vec{E} \| a$ by about $10 \%$. Fits to a two-component picture find that this difference can be attributed to anisotropy of the scattering rate $1 / \tau$; the Drude plasma frequencies are nearly the same.

Below $T_{c}$ there is a definite anisotropy to the far-infrared conductivity. As the frequency dccreases below $\sim 400 \mathrm{meV}$, the conductivity for $\vec{E} \|$ $b$ increases. The $a$-axis conductivity, in contrast,


Fig. 2. The optical conductivity along the saxis of a single-domain $\mathrm{Bi}_{2} \mathrm{Sr}_{2} \mathrm{CaCu}_{2} \mathrm{O}_{8}$ crystal.


Fig. 3. Resistivity along the principal axes of a single-domain $\mathrm{Bi}_{2} \mathrm{Sr}_{2} \mathrm{CaCu}_{2} \mathrm{O}_{8}$ crystal. The zero-frequency extrapolation of optical conductivity is shown as the open symbols.
is decreasing, giving a factor of two difference in $\sigma_{1}(\omega)$ at the lowest frequency. This anisotropy could be due either to anisotropy of the superconducting gap or to anisotropy of the midinfrared component of the optical conductivity. ${ }^{3}$

## 3. RESISTIVITY

The anisotropy in the $a b$ plane resistivity, measured by the van der Pauw method, ${ }^{4}$ is shown in Fig. 3. At $300 \mathrm{~K}, \rho_{b} / \rho_{a} \approx 1.15$, as determined by both infrared and transport measurements. From the linear slopes of the temperature dependence of $\rho_{a}$ and $\rho_{b}$, we deduce coupling constants of $\lambda_{a} \sim .35, \quad$ and $\lambda_{b} \sim$.31. Linear extrapolations to zero temperature yield a zero intercept for the $a$ axis, while for the $b$ axis this intercept is finite. Note that our resistivity differs from that of Martin et al., ${ }^{5}$ who reported a larger resist.vity along $a$ but in is accord with the results of Yamaya et al. ${ }^{6}$

There is also an unusual anisotropy in the resistive transition, illustrated in Fig. 4. Note that this shows the resistance, not resistivity. When the current flow is predominately along $a$, the resistance falls to near zero about 3 K higher than when the current flow is predominately along $b$.


Fig. 4. Expanded view of resistance versus temperature.

This effect has been seen in several samples and is independent of measuring current for a factor of 100 or so in current. The $c$ axis appears to have its resistive transition at the same temperature as $a$. At present, we have no explanation for the effect.

Research supported by National Science Foundation grants DMR-9101676 (Florida) and DMR8911332 (Wisconsin).

## REFERENCES

1. S.A. Sunshine, T. Siegrist, L.F.Schneemeyer, D.W. Murphy, R.J. Cava, B. Batlogg, R.B. van Dover, R.M. Fleming, S.H. Glarum, S. Nakahara, R. Farrow, J.J. Krajewski. S.M. Zahurak, J.V. Waszczak, J.H. Marshall, P. Marsh, L.W. Rupp Jr., and W.F. Peck Phys. Rev. B 38, 893 (1988).
2. D.B. Romero, G.L. Carr, D.B. Tanner, L. Forro, D. Mandrus, L. Mihaly, and G.P. Williams, Phys. Rev. B44, 2818 (1991).
3. M.A. Quijada, D.B. Tanner, R.J. Kelley and M Oncllion, Z. Phys. B, in press.
4. L.J. van der Pauw, Philips Res. Repts. 16, 187 (1901).
5. S.Martin, A.T. Fiory, R.M Fleming, L.F. Schneemeyer, and J.V. Waszczak, Phys. Rev. Leti. 60, 2194 (1988).
6. K. Yamaya, T. Haga, T. Honma, Y. Abe, F. Minami, S. Takekawa, Y. Tajima, and Y. Hidaka, Physica C 162-164, 1009 (1989).
