Anisotropic electromagnetic in-plane response of $La_{1.96}Sr_{0.04}CuO_4$.

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Abstract

We report on the anisotropy of the in-plane electronic conductivity examined in the weakly doped phase of the high-T_c system $La_{2-x}Sr_xCuO_4$ with infrared spectroscopy. Evidence for spin stripes in these materials is well documented. We find anisotropy of the electronic response within the CuO_2 planes with an enhancement of the conductivity by 50% parallel to the stripe direction in the limit $T, \omega \to 0$. These results uncover a complex electronic behavior due to formation of charge stripes that is beyond an idealized picture of strictly 1D charge channels.

Key words: stripe order; high-temperature superconductivity; infrared spectroscopy; doped Mott-Hubbard insulators

In many cuprates a tendency towards segregation of doped charge carriers into one-dimensional (1D) self-organized regions (charge stripes) within CuO_2 planes is observed [1,2]. The 90° shift in the direction of charge stripes in neighboring planes [1] precluded a direct investigation of the role of these 1D elements in the electronic transport through experiments probing anisotropic response. An exceptional feature of $La_{2-x}Sr_xCuO_4$ (LSCO) is the appearance of *unidirectional* diagonal spin stripes along the orthorhombic a axis in the weakly doped region $x \leq 0.055$ which are rotated by 45° from those observed in superconducting LSCO ($x > 0.055$) [3,4]. Therefore, untwinned single crystals of weakly doped LSCO can be viewed as a benchmark system to study spin and charge self organization in a compound with intrinsic real space inhomogeneities.

Single crystals $La_{1.96}Sr_{0.04}CuO_4$ were grown by the traveling-solvent floating-zone technique and detwinned under uniaxial pressure [5]. Reflectance measurements were carried out at frequencies from 20 to 48000 cm^{-1} (2.5 meV - 6 eV) in polarized light at temperatures 13 K $\leq T \leq$ 293 K. We obtained the in-plane complex conductivity $\sigma = \sigma_1 + i\sigma_2$ from the frequency dependent reflectance $R(\omega)$ using Kramers-Kronig (KK) analysis. For the low-ω extrapolation we used dc resistivity data and for the high frequency extension of our data previously published results on LSCO [6].

In Fig. 1, the in-plane optical conductivity of $La_{1.96}Sr_{0.04}CuO_4$ is shown for light polarized parallel (a axis) and perpendicular (b axis) to the spin stripes. The far-IR region ($\omega < 600$ cm^{-1}) is dominated by a nearly isotropic Drude response at 150 K and 293 K. An observation of the Drude response in $La_{1.96}Sr_{0.04}CuO_4$ suggests that the electronic conductivity even in weakly doped LSCO is band-like as well. When cooling down to 13 K, the frequency dependence of the far-IR conductivity changes significantly. The Drude-like behavior observed at higher temperatures evolves into a resonance mode located at finite frequency. A comparison of the top and bottom panel of Fig. 1 shows that $\sigma_1(\omega)$ has a distinct in-plane anisotropy in the limit $T, \omega \to 0$.

Fig. 2 focusses on this anisotropy in both dc and optical conductivities of untwinned $La_{1.96}Sr_{0.04}CuO_4$. There are distinctive parallels between both data sets: in the dc conductivity σ_{dc} the crossover from semiconducting to metallic behavior occurs at higher temperature for currents oriented perpendicular to the stripes and in the optical conductivity $\sigma_1(\omega)$ we observe a

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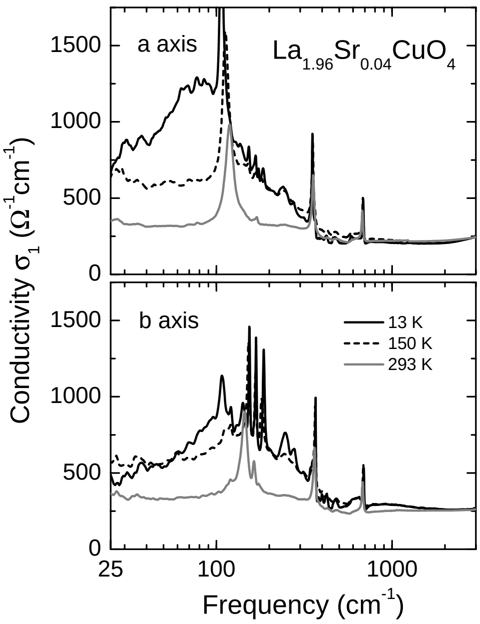

Fig. 1. Frequency dependence of the real part of the in-plane conductivity $\sigma_1(\omega)$ along the orthorhombic a and b axis in the far-IR and mid-IR frequency region.

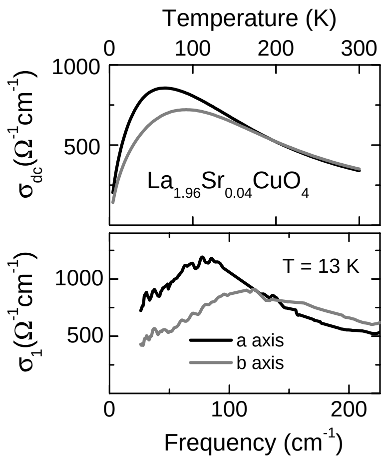

Fig. 2. Dc conductivity $\sigma_{\rm dc}(T)$ (top panel) and optical conductivity $\sigma_1(\omega)$ after substraction of the phonon modes visible in Fig. 1 at 13 K (bottom panel) parallel (a axis) and perpendicular (b axis) to the stripes.

hardening of the localization mode in b direction. The two data sets directly show that at low T and ω conductivity is enhanced for charges moving along spin stripe direction (a axis).

The peak in the optical conductivity at finite frequencies can be attributed to disorder-induced weak localization in a low-dimensional conductor [7] and has been observed in static charge stripe ordered $\mathrm{La}_{2-x-y}\mathrm{Nd}_y\mathrm{Sr}_x\mathrm{CuO}_4$, too [8]. It obvious that the difference in the localization scales for charge transport parallel and perpendicular to the spin stripes is the dominant factor defining the anisotropy of the LSCO system. To find the reasons for the anisotropic conductivity in LSCO it is important to identify a possible relationship between the 1D spin modulation in this system and experimental evidence for the charge stripes in $\mathrm{La}_{2-x-y}\mathrm{Nd}_y\mathrm{Sr}_x\mathrm{CuO}_4$ compounds [1,2,8,9]. Our results support the view that charge stripes occur as well in weakly doped LSCO materials. In this case the anisotropy detected in our dc and optical conductivity measurements (Figs. 1 and 2) can be attributed to the fact that the 1D modulation of spins is accompanied by the concurrent 1D self-organization of holes into charge stripes.

A close inspection of Fig. 2 shows that the in-plnae anisotropy of the conductivity σ_a/σ_b does not exceed a factor of two, even in the limit $(T,\omega) \rightarrow 0$. This is relatively mild compared with the anisotropy observed organic 1D conductors. Several factors may be responsible this behavior. Charge stripes may have finite width with the antiphase domain walls extending over several lattice spacings [10]. This effect creates lateral degrees of freedom within each stripe. Also, charge stripes may be meandering [11] or fluctuating [12] on relatively short time scales.

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