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Physica C 408–410 (2004) 748–749
PHYSICA C
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Reflectivity of optimally doped and underdoped $Pr_{2-x}Ce_xCuO_{4-\delta}$

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Abstract

We present optical reflectivity data in optimally doped and underdoped PCCO thin films. The optical conductivity of the underdoped sample presents an unconventional increase around 2000 cm^{-1} when lowering the temperature. Spectral weight is transferred from low (0–3000 cm^{-1}) to high (3000–6000 cm^{-1}) energy, suggesting a decrease in the low energy density of states.

Keywords: Optical reflectivity; Optical conductivity

1. Introduction

The $Pr_{2-x}Ce_xCuO_{4-\delta}$ (PCCO) system is part of the high T_c electron-doped superconductor family $ReCeCuO_{4-\delta}$ (Re = Nd,Pr,Sm,Eu). The doping region is restricted to $0.11 < x < 0.22$, with a T_x^{max} of 21 K for $x = 0.15$. Optical reflectivity has been measured for various doping levels in NCCO and PCCO, still very little has been done changing the temperature [1]. Indeed when cooling the sample, the relative variation of the reflectivity is small and comparable to the signal to noise ratio in single crystals. However, in the last few years, the preparation of thin film samples of PCCO was achieved [2] making possible high resolution optical spectra.

A search for a possible signature of a pseudogap in hole-doped Bi-2212 cuprates [3] did not uncover any transfer of spectral weight above T_c from low to high energies. This was assigned to the optical conductivity being mostly sensitive to the (π, π) direction in the Brillouin zone due to the anisotropy of the Fermi velocity, whereas the pseudogap opens up in the $(\pi, 0)$ direction. In electron-doped cuprates, recent ARPES measurements [4] suggest that a pseudogap opens, however with a momentum dependence different from hole-doped cuprates. Our study is a first attempt to measure the optical response vs. temperature above T_c, for the electron-doped PCCO thin films optimally doped and underdoped.

2. Experimental

Two c-axis oriented epitaxial thin films were prepared by pulsed-laser deposition on a $SrTiO_3$ substrate [2]—optimally doped (OPT, $T_c = 21$ K), underdoped (UND, $T_c = 15$ K), thickness ≃300 nm. The reflectivities were collected with a Bruker IFS 66v interferometer from 40 to 25000 cm^{-1} (5 meV to 3.1 eV). The spectra were measured for 11 different temperatures in the normal state, from 300 K down to 23 K. Fig. 1(a) and (b) present the reflectivity at a few selected temperatures. Using a standard thin film model [3] to eliminate the contribution of the substrate, the optical conductivity of the superconductor can be retrieved. Two boundary conditions were imposed: (i) the extrapolation of the optical conductivity at zero frequency must match the DC resistivity previously measured; (ii) the spectral weight at 3 eV must be conserved for each temperature.

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doi:10.1016/j.physc.2004.03.076

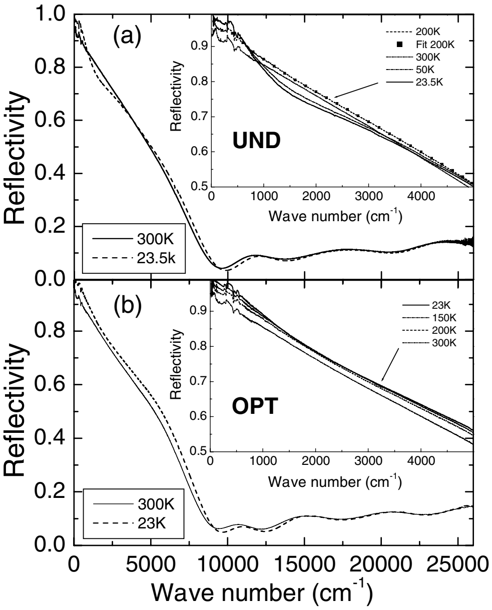

Fig. 1. Reflectivity of (a) underdoped and (b) optimally doped PCCO film. We can resolve 0.1% changes. An example of the fit of the reflectivity to eliminate the substrate contribution is shown for the underdoped sample at 200 K.

3. Results and discussion

Fig. 2 shows the real part $\sigma_1(\omega, T)$ of the optical conductivity in the UND sample at four selected temperatures. The peak in $\sigma_1(\omega)$ around 40 cm^{-1} is consistent with localization, as proposed [2] to interpret the DC resistivity upturn at low T, and was thus introduced to satisfy the first boundary condition. If ignored, the DC resistivity deduced from the fit is far too low, but $\sigma_1(\omega)$ is only changed significantly below 120 cm^{-1}. At higher energy (Fig. 2 inset), the signature of the dip noticed in the reflectivity is an increase of $\sigma_1(\omega)$ around 2000 cm^{-1} when the temperature is lowered. The OPT sample does

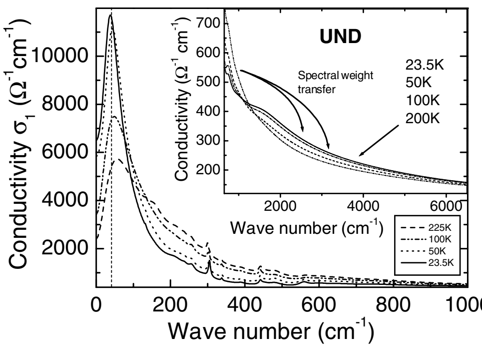

Fig. 2. Real part of the optical conductivity (from fit) of the underdoped sample. The dashed line shows the lower limit of the experimental energy range.

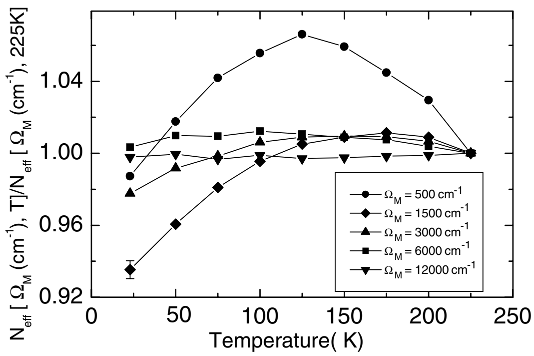

Fig. 3. Normalized spectral weight vs. temperature for the underdoped sample. Different symbols refer to different cutoff frequencies Ω_M.

not exhibit this behavior. Previous studies in nonsuperconducting NCCO show similar changes in the conductivity [1]. Integrating the conductivity up to Ω_M defines an effective carrier density, or spectral weight (SW):

$$N_{eff} = \int_0^{\Omega_M} \sigma_1(\omega)\, d\omega \qquad (1)$$

Fig. 3 displays the evolution of N_{eff} vs. T for various cutoff frequencies (Eq. (1)) in the UND sample. $N_{eff}(\Omega_M, T)$ was normalized with respect to $N_{eff}(\Omega_M, 225\ K)$, which eliminates systematic errors. For $\Omega_M = 12000\ cm^{-1}$, N_{eff} is conserved, meaning that if there is any SW rearrangement, it is confined between 0 and 12000 cm^{-1}. For $\Omega_M = 6000\ cm^{-1}$, N_{eff} is still essentially conserved. For $\Omega_M = 3000\ cm^{-1}$, and mostly conspicuous for $\Omega_M = 1500\ cm^{-1}$, N_{eff} diminishes from 175 to 23 K, showing a SW transfer from low (0–3000 cm^{-1}) to high energies (3000–6000 cm^{-1}) (see also inset Fig. 2). The energy scale of SW transfer observed in UND PCCO is much too high to be attributed to localization [5] and is also incompatible with a possible narrowing of a mid-infrared band around 2000 cm^{-1}. Finally for $\Omega_M = 500$ cm^{-1}, the SW increase from 225 down to 150 K is followed by a decrease at low temperature. This suggests a competition between the narrowing of a Drude like contribution and an unconventional electronic mechanism. The latter is consistent with a transfer of states from low to high energies, that is a pseudogap opening [1]. However, more data are necessary before such an interpretation can be proposed.

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