OPTICAL PROPERTIES OF $(Pr,Ce)_2CuO_4$

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Abstract We studied the optical conductivity of electron doped $Pr_{1-x}Ce_xCuO_4$ from the underdoped to the overdoped regime. The observation of low to high frequency spectral weight transfer reveals the presence of a gap, except in the overdoped regime. A Drude peak at all temperatures shows the partial nature of this gap. The close proximity of the doping at which the gap vanishes to the antiferromagnetic phase boundary leads us to assign this partial gap to a spin density wave.

Keywords: Electron doped cuprates, optical conductivity, normal state gap

1. Introduction

The electron and hole doped cuprates phase diagram shows a global symmetry. However, many aspects of the electron doped compounds, including the nature of the superconducting gap, the behavior of the normal state charge carriers, and the presence of a normal state (pseudo)gap are still unclear. A pseudogap phase is now well established on the hole doped side [1]. In $Bi_2Sr_2CaCu_2O_{8+\delta}$, angle resolved photoemission spectroscopy measurements (ARPES) indicate a pseudogap opening along the $(0, \pi)$ direction in k space [2]. However, the in-plane optical conductivity does not show any direct evidence of this pseudogap [3]. The optical conductivity of non superconducting $Nd_{2-x}Ce_xCuO_4$ (NCCO) single crystals ($x = 0$ to 0.125) suggests the opening of a high energy partial gap well above T_{Neel} [4]. Low temperature ARPES reveals a Fermi surface characterized by the presence of pockets [5].

We determined the temperature evolution of the optical conductivity in a set of $Pr_{2-x}Ce_xCuO_4$ thin films. Our data reveals the onset of a “high energy” partial gap below a characteristic temperature T_W which evolves with doping.

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It is clearly detected for 0.13, it is absent down to 20 K for $x = 0.17$ and it has a subtle signature for $x = 0.15$ (optimal doping). The proximity of our samples to the antiferromagnetic phase makes a spin density wave (SDW) gap the natural interpretation for our observations, consistent with ARPES [5].

2. Experimental

The thin films studied in this work were epitaxially grown by pulsed-laser deposition on a $SrTiO_3$ substrate [6]. The samples studied are (i) $x = 0.13$ (underdoped) $T_c = 15$ K (thickness 3070 A), (ii) $x = 0.15$ (optimally doped), $T_c = 21$ K (thickness 3780 A) and (iii) $x = 0.17$ (overdoped) $T_c = 15$ K (thickness 3750 A). All T_c's were characterized by electrical resistance measurements. We checked the $x = 0.15$ sample homogeneity by electron microscopy analysis (using the micron scale X-ray analysis of an EDAX system) and found no dispersion at the micron scale in the Pr, Ce or Cu concentrations. Thin films are easy to anneal but, most important, they can be made superconducting in the underdoped regime, whereas this seems difficult for crystals [4]. Infrared-visible reflectivity spectra (at an incidence angle of 8°), were measured for all the films in the 25–21000 cm^{-1} spectral range with a Bruker IFS-66v Fourier Transform spectrometer within an accuracy of 0.2%. Typically 12 temperatures (controlled better than 0.2 K) were measured between 25 K and 300 K. The far-infrared frequency range (10–100 cm^{-1}) was measured for samples (ii) and (iii) utilizing a Bruker IFS-113v at Brookhaven National Laboratory.

3. Results and Discussion

Figure 1(a) shows the raw reflectivity (R) from 25 to 6000 cm^{-1} for a set of selected temperatures. As the temperature decreases, an unconventional depletion of R appears for $x = 0.13$. This feature, denoted by an arrow, is still visible for $x = 0.15$ as a subtle change in R. Conversely, the reflectivity of the $x = 0.17$ sample increases monotonously with decreasing temperature over the whole spectral range shown. We applied a standard thin film fitting procedure to extract the optical conductivity from this data set [3]. The real part $\sigma_1(\omega)$ of the optical conductivity is plotted in Fig. 1 (b). At low energies, for all concentrations, the Drude-like contribution narrows as the temperature is lowered in the normal state from 300 K to 25 K (Fig. 1 inset). This corresponds to a quasiparticle lifetime increasing in agreement to the metallic behavior of the resistivity. Figure 1(b) shows that the feature in the reflectivity of the $x = 0.13$ sample produces a dip/hump structure in σ_1 with a peak at ~ 1500 cm^{-1}. For $x = 0.15$ the reflectivity behavior is not clearly seen in σ_1. A similar feature was observed in NCCO single crystals only for doping levels where