Physica C 185-189 (1991) 1015-1016
North-Holland

PHYSICA C

91/12

INFRARED CONDUCTIVITY VERSUS DOPING FROM REFLECTIVITY IN $YBa_2Cu_3O_{6+x}$ AND $Nd_{1+y}Ba_{2-y}Cu_3O_{6+x}$ CERAMICS

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We have measured the room temperature reflectivity spectra in the range 500-25000 cm^{-1} on $YBa_2Cu_3O_{6+x}$ (0<x<1) and $Nd_{1+y}Ba_{2-y}Cu_3O_{6+x}$ (0<y<0.5) polished ceramics as a function of doping (x and y). In the metallic range, in both systems, the Drude contribution and the mid-infrared band exhibit a correlated increase with hole doping level (x or y). The conductivity is compared to recent simulations of the t-J model as a function of hole doping.

1. INTRODUCTION

Systematic quantitative studies of the infrared conductivity as a function of hole doping may help to sort out the peculiar characteristics, if any, of the mid infrared absorption band (MIB) as compared to the Drude contribution in the high T_c cuprates[1], and to test some specific predictions of theoretical models. We describe our results on the infrared reflectivity of 2 sets of samples: $YBa_2Cu_3O_{6+x}$ and $Nd_{1+y}Ba_{2-y}Cu_3O_{6+x}$ (0<x<1, 0<y<0.4).

2. EXPERIMENTAL

The ceramic samples have been polished in order to achieve a mirror-like surface, a gold mirror being the 100% reflectivity reference. Reflectivity spectra have been recorded in the 500 cm^{-1}-25000 cm^{-1} range, at room temperature. A detailed discussion of the experimental conditions and of the fitting procedure to reflectivity of unoriented polycrystalline samples is given elsewhere[2,3]. For the two sets of samples, we derive typical ab plane conductivities shown in fig.1 which, for clarity, refer only to selected values of x and y. This infrared response can be described by a Drude part (represented by the plasma frequency ω_p and a carrier scattering rate $1/\tau$) and a mid-infrared Lorentz oscillator (MIB) (central frequency ω_o, damping γ). The MIB does not look by itself specific to the cuprates[4], but its origin needs to be clarified.

Several sets of parameters yield satisfactory fits of the reflectivity. The subsequent dispersion gives rise to the scatter of the experimental points displayed in fig.2.The

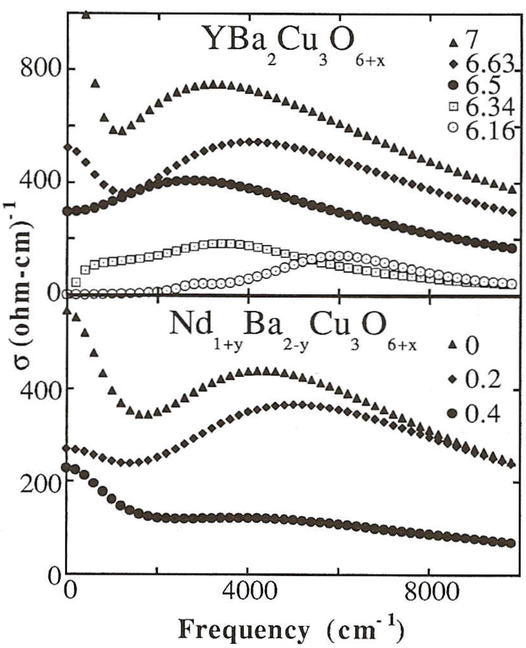

FIGURE 1
Infrared conductivities at selected x (upper panel) and y (lower panel) doping levels, derived by fitting the reflectivity spectra.

sum rule restricted to a given contribution (σ_D or σ_{MIB}) yields an effective spectral weight [5]:

$$\int_0^{+\infty} \sigma(\omega)d\omega = \frac{\omega_{eff}^2}{8} \quad (1)$$

where $\omega_{eff}=\omega_p$ for the Drude term and $\omega_{eff}=\omega_{MIB}$ for the MIB. We find a quantitative correlation between the increase of the Drude and MIB spectral weights in both sets of compounds, as shown in fig.2. Though doping is different in both materials, the infrared signature is identical. This strongly suggests that the MIB and the Drude terms share the same origin, e.g. the occurence of free carriers in the CuO_2 planes, as also infered from the optical conductivity of $La_{2-x}Sr_xCuO_4$[6].

3. COMPARISON WITH THE t-J MODEL

We have argued elsewhere that the linear dependence of ω_p^2 with the hole concentration n_h which is suggested by Fermi-liquid models[7] does not seem to apply to experimental data[3,5]. Schlesinger et al[8] have recently briefly considered the applicability of the t-J model[9,10]. Simulations of the optical conductivity in this framework[10] show that if n_h=0 (no hole doping), no infrared conductivity is seen, as observed[3]. In presence of holes, the Drude term can be identified to the coherent (quasi-particle) peaks (hence $1/\tau \sim J_\perp$), separated by a gap from an incoherent background (total width $4t\sqrt{3}$), which stands for the MIB (hence $\gamma=2t\sqrt{3}$). The spectral weight of the quasi-particle peak is of the order of J_z/t, and their effective mass is enhanced by a $t/J_\perp$ factor.

Values for t and $J_\perp$ may thus be deduced from the widths of the MIB and of the Drude peak; J_z is derived through the relative spectral weight of the Drude peak. We find for $YBa_2Cu_3O_{6+x}$ and $Nd_{1+y}Ba_{2-y}Cu_3O_{6+x}$

$$J_\perp=(0.13\pm0.06) \text{ and } (0.13\pm0.06) \text{ eV}$$
$$t=(0.31\pm0.02) \text{ and } (0.36\pm0.03) \text{ eV}$$
$$J_z=(0.08\pm0.03) \text{ and } (0.10\pm0.04) \text{ eV}$$

irrespective of x and y.

$J_z \sim J_\perp = J$ as it should, though extracted from independent parameters. The upper values are reasonable figures for t and J[9,10]. The mass enhancement that is deduced is 6±3, in agreement with earlier data[8].

It is not clear yet whether models starting from a "single hole" can be extended to intermediate doping which may be relevant to the systems considered here[10] The fact that the Drude peak and MIB spectral weights are correlated is consistent with the t-J model[9,10]. The lack of linear variation of ω_p^2 with n_h emerges more naturally in non-Fermi liquid pictures[11], which are also consistent with

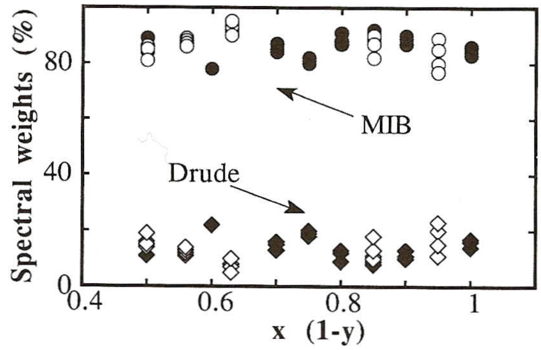

FIGURE 2
Relative weights of the Drude (squares) and MIB (circles) components for the $YBa_2Cu_3O_{6+x}$ (full symbols) and $Nd_{1+y}Ba_{2-y}Cu_3O_{6+x}$ (open symbols).

correlated growth of the Drude and the MIB contributions. We believe that such quantitative analysis as ours are of interest for a comparison of the high T_c cuprates to non superconducting metallic oxydes.

ACKNOWLEDGEMENTS

We are most grateful to Pr. M. Gabay for numerous illuminating discussions.

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