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INFRARED SPECTROSCOPY OF $Nd_{2-y}Ce_yCuO_4$ (y= 0-0.2) SINGLE CRYSTALS

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The data on the room temperature IR reflectivity (50-9000 cm-1) of the $Nd_{2-y}Ce_yCuO_4$ single crystals (y=[0-0.2]) are reported. The in-plane reflectivity spectra (E⊥c) were found to be extremely sensitive to the Ce content. In contrast to this, the out-of-plane reflectivity (E∥c) was found to be independent from doping. The reflectivity anisotropy of the superconducting crystals is close to that of La- and Bi-based materials, thus indicating the quasi 2D electronic structure of the above compounds. We obtained evidence that transition temperature decreases for the values of Ce content being higher than y=0.155 due to decrease of the electron-phonon coupling constant.

1. INTRODUCTION.

The importance of more profound understanding of the normal state transport properties of High Tc Superconductors stems from the fact that in conventional superconductors the same type of interaction (electron-phonon) is believed to be responsible both for scattering of the carriers at T>Tc and for pairing at T<Tc. A number of different scattering mechanisms for HTc materials were recently proposed[1-3], still, the problem is under discussion and more experimental results are necessary. In this report we introduce data, indicating that electron-phonon interaction dominates in the relaxation processes in superconducting samples of $Nd_{2-y}Ce_yCuO_4$.

2. EXPERIMENTAL.

We measured the reflectivities in E∥c and E⊥c polarizations of 5 superconducting single crystals with following values of Ce content: y=0.155 (Tc=22K), 0.16 (Tc=21K), 0.165 (Tc=17K), 0.17 (Tc=12K), 0.175 (Tc=8K) and of 4 nonsuperconducting crystals: y=0; 0.03; 0.05; 0.2.

The reflectivity measurements were carried out by means of Bruker IFS 113v FT-spectrometer, equipped with IR microscope. The Mid-IR (500-8000 cm-1) spectra were obtained with HgCdTe detector, while for Far-IR measurements (50-700 cm-1) we used He-cooled bolometer. The samples under study with typical size $3x3x0.05-0.1mm^3$ had perfect surface smoothness. The accuracy of the absolute reflectivity measurements was estimated to be better than 1% in Far-IR and better than 2% in Mid-IR.

3. THE IN-PLANE REFLECTIVITY.

3.1. EXPERIMENTAL RESULTS.

The E⊥c reflectivity ($R_\perp(\omega)$) spectra of the crystals with y=0-0.2 are plotted in fig.1. The obtained dependences resembles those of the related compound $Pr_{2-y}Ce_yCuO_4$[4]. $R_\perp(\omega)$ is extremely sensitive to y value. For y=0 the behavior of $R_\perp(\omega)$ is typical for insulators with sharp phonon structure in Far IR. Starting from y≈0.03, free carriers contribution dominates in $R_\perp(\omega)$ spectra, indicating that insulator-metal

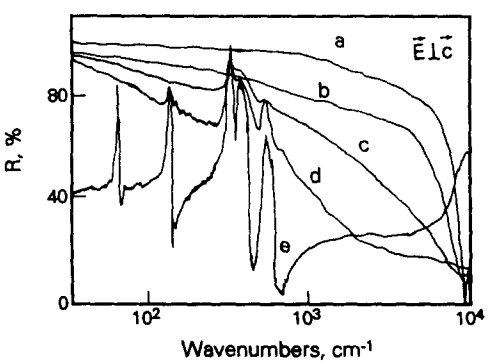

Fig.1
Reflectivity spectra of $Nd_{2-y}Ce_yCuO_4$ single crystals with different values of Ce content measured at room temperature.
Curves a-e measured in E⊥c polarization. The frequency is plotted on a logarithmic scale. Curves: a) y=0.2; b) y=0.155; c) y=0.05; d) y=0.03; e) y=0.0.

transition in the electronic structure is taking place at 0<y<0.03. For higher value of Ce content the absolute value of the reflectivity in the IR increases and plasma minimum slightly shifts to a higher wavenumber.

The $R\perp(\omega)$ spectrum of the crystal with maximal critical temperature (Tc=22K, y=0.155) is typical for the in-plane reflectivity of all metal-oxide materials. It demonstrates rather smooth plasma minimum and relatively low value of $R\perp(\omega)$ in Mid-IR. In contrast, the dependence for nonsuperconducting crystal with y=0.2 reveal very sharp plasma edge and a high reflectivity with $R\perp(\omega)>90\%$ over a wide wavenumber range. So, Ce content increase from y=0.155 to y=0.2 results in the dramatic changes in free carriers scattering in Cu-O planes of $Nd_{2-y}Ce_yCuO_4$ single crystals.

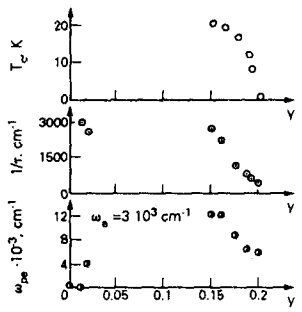

Fig.2
Critical temperature Tc, scattering rate value $1/\tau$ and plasma frequency value of the interband transition ω_{pe} as functions of the value of Ce content.

3.2. DATA FITTING.

The fitting of the obtained data was performed as follows:

i To obtain quantitative characteristic of the scattering possesses (scattering rate value $1/\tau$) in the systems under the study we performed the Drude-Lorenz model fit of the measured reflectivities.

ii We determined the scattering rate values for the crystals with different Tc values within the framework of strong electron-phonon coupling mechanism.

We used the simplest Drude-Lorenz formula with frequency independent scattering rate

$$\varepsilon(\omega)=\varepsilon_\infty - \omega_p^2/[\omega(\omega+i\tau^{-1})] - \omega_{pe}^2/(\omega^2-\omega_e^2+i\omega\gamma) \quad [1]$$

where ω_p - Drude plasma frequency, $1/\tau$ - scattering rate, ε_∞ high frequency contribution to the dielectric constant, ω_e,ω_{pe} and γ are center frequency, plasma frequency and damping of the Mid Infrared interband term respectively. The Eq.1. gives rather good fit to the experimental curves in Mid-IR.

This fit yields the values ε_∞=4, ω_e=2500 cm-1, γ=5000 cm-1. The plasma frequency ω_p increases from 12500 cm-1 in the crystal with y=0.155 to 17000 cm-1 in the crystal with y=0.2. We also obtained dependences of $1/\tau$ and ω_{pe} versus the value of Ce content plotted in fig.2. Maximal values of scattering rate ($1/\tau\approx$3000 cm-1) are observed in nonsuperconducting samples (y<0.05) and in the crystals with maximal Tc (y≈0.15). The lack of the experimental data make so far unreliable any considerations about the physical origin of the scattering processes in the nonsuperconducting samples. As for the superconducting crystals, the behavior of the scattering rate, plotted in fig.2 qualitatively agrees with well established fact for superconducting metals and alloys. Usually the high values of Tc are observed in the materials, with strong coupling, having rather poor conductivity in normal state due to high values of $1/\tau$. And, vise versa, good conductors in normal state (Al,Cu,Au,Ag) exhibit poor or no superconductivity. It is electron-phonon interaction that is believed to be responsible for free carriers scattering in normal state in superconducting metals and alloys. To get the experimental proof of electron-phonon interaction dominant role in scattering phenomena of superconducting crystals of $Nd_{2-y}Ce_yCuO_4$ we have calculated Tc as a function of scattering rate $1/\tau$.

Following the recent results[5] of tunneling study of $Nd_{2-y}Ce_yCuO_4$ materials we used a double peak approximation for the phonon density of state function $F(\omega)$ with ω_{ph1}=110 cm-1 and ω_{ph2}=300 cm-1. Within the model of phonon-mediated superconductivity the equations for the critical temperature and scattering rate are given by

$$T_c = \frac{\left(\omega_{ph1}\right)^{\lambda_1/\lambda}\left(\omega_{ph2}\right)^{\lambda_2/\lambda}}{1.45}\exp\left\{-\frac{1+\lambda}{\lambda-\mu^*}\right\} \quad [2]$$

$$\frac{1}{\tau} = \pi\cdot\left(\lambda_1\omega_{ph1}\mathrm{cth}\left(\frac{\omega_{ph1}}{2T}\right) + \lambda_2\omega_{ph2}\mathrm{cth}\left(\frac{\omega_{ph2}}{2T}\right)\right) \quad [3]$$

where λ_1 and λ_2 are the values of electron-phonon coupling constants, and μ^* is Colomb pseudopotential. The calculated dependences of Tc and a coupling constant $\lambda=\lambda_1+\lambda_2$ as a function of scattering rate are plotted in fig.3. The agreement between the obtained dependence and experimental points is quite satisfactory. The derivation between experimental points and calculated dependence is within the accuracy of $1/\tau$ values determined by fitting measured reflectivities with Eq.1. So, within the model of phonon mediated superconductivity, there is qualitative consent between optical and superconducting properties of the crystals under the study. Taking into account the linear temperature dependence of dc resistivity at temperatures T>70K we can conclude that electron-phonon interaction dominates in the scattering processes of free carriers in Cu-O planes of $Nd_{2-y}Ce_yCuO_4$ superconductors. Following the analogy with conventional superconductors we can also

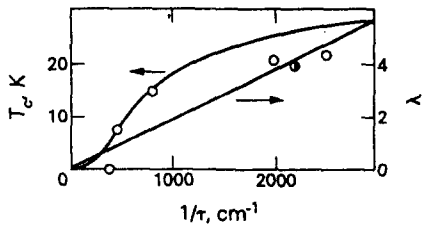

Fig.3
Solid lines - critical temperature Tc and electron-phonon interaction coupling constant λ as functions of scattering rate value 1/τ obtained within the model of strong-coupling superconductivity model Eq. 2,3. Open circles - the result for the scattering rate value, obtained by Drude-Lorentz model fitting of the reflectivity spectra of crystals with different Tc. Half-dashed circle - the same result from Ref.6.

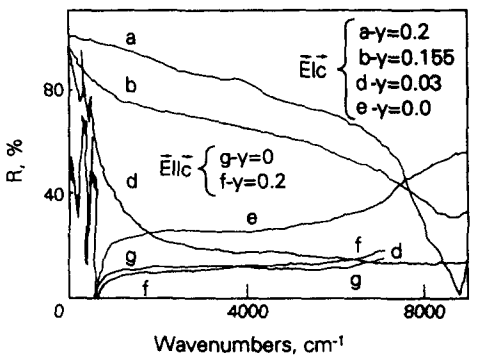

Fig.4
Room - temperture (300K) frequency - dependent reflectivity of $Nd_{2-y}Ce_yCuO_4$ for a series of Ce concentrations, y. Curves a-e measured in E⊥c polarization; curves f,g - in E∥c polarization.

conclude that electron-phonon interaction is responsible for carriers pairing at T<Tc.

4. REFLECTIVITY ANISOTROPY.

The reflectivity spectra of the crystals with y=0-0.2 measured in E∥c and E⊥c polarizations are plotted in figure 4. The R∥(ω) spectra are generally of the same character for all of the samples. They exhibit the dielectric-type behavior with R(ω) being independent from wavenumber in Mid-IR. Such behavior follows from the fact that free carriers contribution to the E∥c spectra is negligible at frequencies higher than 500 cm-1 even in the metallic phase of the material (y>0.05). Therefore free carriers appearing as the result of doping processes are localiezed in Cu-O planes. So the observed anisotropy can be considered as a consequence of quasi two dimensional (2D) nature of the electronic structure in the above compounds. The similar behavior of R∥(ω) was observed in $La_{2-y}Sr_yCuO_4$ and $Bi_2Sr_2CaCu_2O_8$ single crystals too[7,8].

5. CONCLUSIONS.

1) The reflectivity anisotropy observed in $Nd_{2-y}Ce_yCuO_4$ (y=0-0.2) single crystals close to that of $La_{2-y}Sr_yCuO_4$ and $Bi_2Sr_2CaCu_2O_8$ materials proves the quasi 2D nature of the electronic structure in the above materials.

2) Qualitative agreement between optical and superconducting properties of the crystals under the study within the model of phonon mediated superconductivity indicate the dominant role of electron-phonon coupling in the scattering processes of free carriers in Cu-O planes of $Nd_{2-y}Ce_yCuO_4$ crystals with y>0.15.

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