Direct observation of the quasiparticle relaxation in $YBa_2Cu_3O_{7-\delta}$

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The importance of the low-frequency electrodynamics ($\nu < 1$ THz) of high-temperature superconductors was unambiguously demonstrated during the last few years [1,2]. One of the intriguing results of the recent experiments is the suppression of the quasiparticle scattering rate below T_C, which clearly demonstrates the unconventional character of the high-temperature superconductivity. The drastic decrease of the effective scattering rate (τ^{-1}) makes the direct observation of the temperature dependence of τ^{-1} inaccessible to standard FIR methods. The accuracy of these methods decreases for frequencies below $10\ \mathrm{cm}^{-1}$, the range, which become increasingly important to investigate the quasiparticle relaxation in the superconducting state. According to the theoretical calculations [3,4], the complex conductivity ($\sigma_1 + i\sigma_2$) of high-T_C superconductors reveals characteristic features in this frequency range: (i) a Drude-like peak of $\sigma_1(\nu)$ with a strongly temperature-dependent width is observed in the spectra and (ii) the imaginary part of conductivity $\sigma_2(\nu)\cdot\nu$ shows a minimum around zero frequency with a characteristic width which is directly connected to the quasiparticle scattering rate.

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In order to investigate these phenomena experimentally, we have carried out transmission measurements on $YBa_2Cu_3O_{7-\delta}$ film using submillimeter spectroscopy [5]. This method employs backward wave oscillators as monochromatic and continuously tuned sources of electromagnetic radiation in the frequency range $2 < \nu < 35\ \mathrm{cm}^{-1}$. The real and imaginary parts of conductivity are calculated from the measured complex transmission coefficient of a thin superconducting film on a dielectric substrate.

The *c*-axis oriented film was prepared by high pressure DC-sputtering from a stoichiometric $YBa_2Cu_3O_7$ target onto a (0 0 1) oriented NdGaO3 substrate. Magnetic susceptibility measurement showed a sharp superconducting transition [ΔT(10–90%) < 0.5 K] with an onset $T_C = 89.5$ K.

Fig. 1 shows the frequency dependence of the complex conductivity of the $YBa_2Cu_3O_{7-\delta}$ film at different temperatures. A well-defined minimum around $\nu \sim 0$ is observed in $\sigma_2(\nu)\cdot\nu$, which is accompanied by a Drude-like peak in $\sigma_1(\nu)$. The characteristic frequency of this process shifts to lower frequencies with decreasing temperatures. To obtain the scattering rate, the experimental data were analyzed within a simple model, that describes the quasiparticles using a Drude expression $\sigma_D(\omega)$. The influence of the superconducting component was taken into

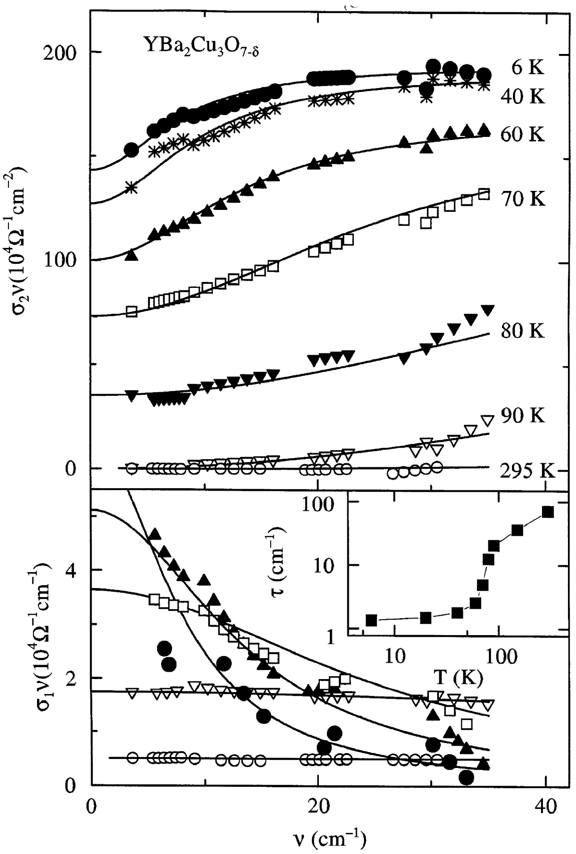

Fig. 1. Frequency dependence of the complex conductivity of $YBa_2Cu_3O_{7-\delta}$ (film at different temperatures. Upper panel: the product $\sigma_2 \cdot \nu$, lower panel: σ_1. The lines are fits according to Eq. (1). The inset shows the temperature dependence of the quasiparticle scattering rate τ^{-1} as extracted from the fits to the conductivity data.

account by an additional term $\sigma_s(\omega)$. The whole expression can be written as:

$$\sigma_1 + i\sigma_2 = \sigma_D^* + \sigma_s^* = \frac{n_n e^2}{m}(\tau^{-1} - i\omega)^{-1} + \frac{n_s e^2}{m}(\pi\delta(0)/2 + i/\omega), \quad (1)$$

where n_n and n_s represent the effective density of the normal and superconducting components. Both conductivity components were then fitted simultaneously, taking n_s and τ as free parameters. Note that we are not using the two-fluid model assumption $n_n + n_s = \text{const}$. The fits are represented by solid lines in Fig. 1.

The inset in Fig. 1 shows the temperature dependence of the scattering rate, determined from these fits. The scattering rate collapses from a value close to 20 cm^{-1} at T_C to 1.8 cm^{-1} at 40 K and then remains almost constant for further decreasing temperatures. Most probably and in accord with many other experimental findings, a gap develops in the spin-fluctuation spectrum at the superconducting phase transition temperature making the quasiparticles long-lived below T_C. From these data we can conclude that for temperatures $T > 40$ K the scattering rates are determined mainly by inelastic scattering processes from spin fluctuations. Below 40 K elastic impurity scattering processes dominate.

References

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