

Direct observation of the quasiparticle relaxation in $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$

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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 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.

In order to investigate these phenomena experimentally, we have carried out transmission measurements on $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ film using submillimeter spectroscopy [5]. This method employs backward wave oscillators as monochromatic and continuously tuned sources of electromagnetic radiation in the frequency range $2 < \nu < 35 \text{ cm}^{-1}$. 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 $\text{YBa}_2\text{Cu}_3\text{O}_7$ target onto a (0 0 1) oriented NdGaO_3 substrate. Magnetic susceptibility measurement showed a sharp superconducting transition [$\Delta T(10-90\%) < 0.5 \text{ K}$] with an onset $T_C = 89.5 \text{ K}$.

Fig. 1 shows the frequency dependence of the complex conductivity of the $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ 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

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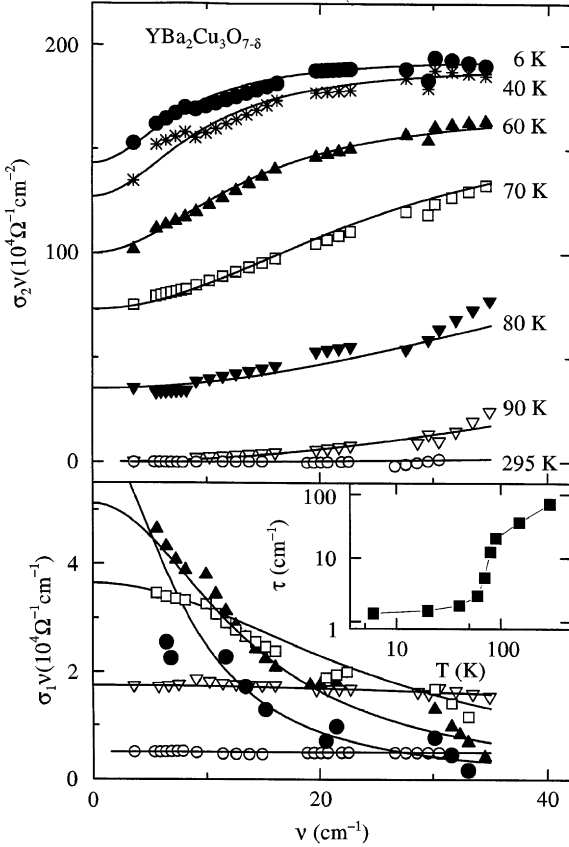


Fig. 1. Frequency dependence of the complex conductivity of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (film at different temperatures. Upper panel: the product $\sigma_2 \cdot \nu$, lower panel: σ_1 . The lines are fits according to Eq. (1). The inset shows the temperature dependence of the quasiparticle scattering rate τ^{-1} as extracted from the fits to the conductivity data.

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 $T > 40 \text{ K}$ 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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account by an additional term $\sigma_s(\omega)$. The whole expression can be written as:

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