

## Magnetic properties of the spin glass PrAu<sub>2</sub>Si<sub>2</sub>

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# 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 ( $\tau^{-1}$ ) makes the direct observation of the temperature dependence of  $\tau^{-1}$  inaccessible to standard FIR methods. The accuracy of these methods decreases for frequencies below  $10 \text{ cm}^{-1}$ , 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  $\text{NdGaO}_3$  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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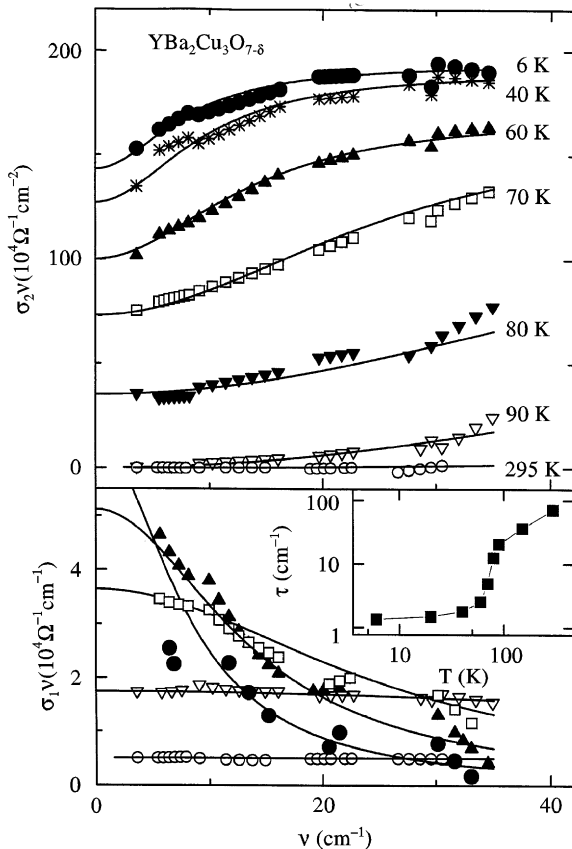


Fig. 1. Frequency dependence of the complex conductivity of  $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$  (film at different temperatures. Upper panel: the product  $\sigma_2 \cdot \nu$ , lower panel:  $\sigma_1$ . The lines are fits according to Eq. (1). The inset shows the temperature dependence of the quasiparticle scattering rate  $\tau^{-1}$  as extracted from the fits to the conductivity data.

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

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

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  $\tau$  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  $20 \text{ cm}^{-1}$  at  $T_C$  to  $1.8 \text{ cm}^{-1}$  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.

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