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STUDY OF THE ANISOTROPIC PROPERTIES OF $YBa_2Cu_3O_7$ SINGLE CRYSTALS BY MICROWAVE ABSORPTION

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Abstract. – Microwave absorption at 16.8 GHz has been measured on an epoxy sample containing 15 % in volume of superconducting single crystals $YBa_2Cu_3O_7$ aligned in a magnetic field during resin solidification. The absorption data are found anisotropic and they have been studied as a function of the magnetic field up to 8.5 Teslas. They are discussed in relation to already available information on transport properties and magnetic susceptibility.

The transport properties of $YBa_2Cu_3O_7$ single crystals have been shown to be quite different from the ones encountered in sintered samples. The resistivity, for example, is found to be highly anisotropic [1] with respect to the crystal c-axis. In good quality crystals, the resistivity in the plane of the Cu-O layers is low and decreases linearly with temperature down to T_c where it abruptly goes to zero; along the c-axis, the resistivity generally shows a maximum at T_c before it goes to zero. Only slight variations of this overall behavior are actually observed on various crystals. We have previously shown [2] that microwave absorption may be used to get information on the normal and superconducting states of ceramic superconductors. Similar experiments were also performed on single crystal flakes of $YBa_2Cu_3O_7$ by Rubin *et al.* [3] which have used many flakes to maximize the sample surface and get enough sensitivity.

Since transport measurements on sintered pellets do not give access to the anisotropic properties, one has to find a way to actually measure them on single crystals, even if they are very small. The sample studied here consist of very small $YBa_2Cu_3O_7$ single crystals (15 % of volume) embedded in a Stycast 1266 resin and aligned in a 7.8 Teslas magnetic field during the resin solidification. The alignment of the sample relative to the c-axis was better than $\pm 3°$ as confirmed by the X-ray rocking curve. According to a SEM picture the crystals showed various geometries of average size 5 μm. The susceptibility measurement indicated a $T_c = 90$ K. A cavity perturbation technique [4] has been used to measure the magnetic component of the micro wave absorption at 16.8 GHz as a function of temperature (4-300 K). The electric component will not be discussed for the moment as the epoxy matrix is dominating in that case; the same matrix is however not absorbing in the microwave magnetic field. According to this technique the variation of the quality factor $\Delta(1/2Q)$ and shift of the resonance frequency δ, after sample insertion at location of the maximum magnetic field (TE_{102} resonance mode), are registered at each temperature for two field orientations relative to the c-axis (parallel and perpendicular). For the parallel configuration, a static magnetic field (0-8.5 Teslas) was also applied perpendicular to the microwave field.

The data for the microwave field oriented along the c-axis are shown in figure 1. The cavity frequency shift δ (Fig. 1a) is slightly negative and constant for $T > 90$ K. At 90 K, the onset of the superconducting transition, the shift drops abruptly and saturates below 40 K. The quality factor variation $\Delta(1/2Q)$ (Fig. 1b) shows a very sharp maximum at $T_c = 90$ K with different temperature behaviors for $T > T_c$ and $T < T_c$. When a static magnetic field is applied, the frequency shift is only weakly modified even with a field of 8.5 Teslas. The quality factor variation is unaffected for $T > 90$ K and strongly enhanced below; the cusp amplitude increases and is displaced toward lower

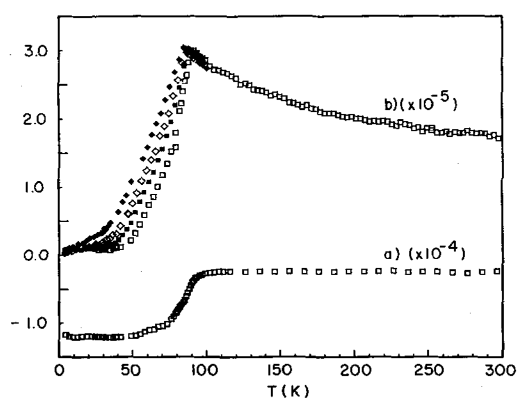

Fig. 1. – Frequency shift $\delta(a)$ and quality factor variation $\Delta(1/2\,Q)$ (b) for the parallel configuration: $H = 0$ (▫), 1.53 (▪), 3.54 (▫) and 8.59 (▪) Teslas.

temperatures with increasing field intensity, in agreement with the expected field variation of T_c in the case of type II superconductors. When the microwave field is aligned in the a-b plane of the crystals, the absorption is much smaller. The temperature dependence of the frequency shift data (Fig. 2a) is similar to the one observed for the parallel configuration and the superconducting onset is still at 90 K; the shift δ is slightly positive for $T > T_c$ and negative below. The absorption (Fig. 2b) is however quite different; a maximum is rather seen around 80 K and the data saturate for $T > T_c$. No external magnetic field effects have been studied since the absorption is very small.

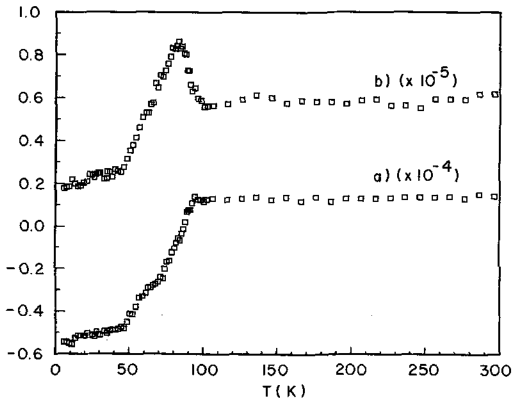

Fig. 2. – Frequency shift δ (a) and quality factor variation $\Delta\,(1/2\,Q)$ (b) for the perpendicular configuration: $H = 0$.

We know from microwave experiments on magnetic structures that the frequency shift δ is the image of the real part of the complex permeability, so to speak, the susceptibility. The data of figures 1a and 2a show the same temperature behavior as the susceptibility; the values are also negative and thus consistent with the diamagnetic character of the superconducting state. The absorption $\Delta\,(1/2Q)$ is rather related to the imaginary part which usually consist of magnetic and eddy current losses. For $T > T_c$, if the latter are dominating, the absorption should be the image of the normal state resistivity. In the parallel configuration, eddy currents are in the a-b plane and the temperature dependence of the resistivity does not usually show a maximum at T_c [1]; the resistivity should rather be linear in T. Here the normal stae absorption decreases as $T^{-0.5}$ and the resulting resistivity according to the skin depth approximation will thus vary as T^{-1}, a result which is far away from the expected one. So eddy current losses cannot explain alone the observed absorption; magnetic losses consistent with a negative frequency shift for $T > T_c$ may possibly be present. These losses are however measured at 16.8 GHz and thus likely frequency dependent. For the perpendicular configuration, the situation is more complicated as eddy currents are expected along the c-axis and in the a_b plane. In the superconducting state, $T < T_c$, the absorption for both configurations decreases exponentially in $1/T$, even for temperatures very near T_c. For the parallel configuration, the absorption is highly field dependent and two activation energies are deduced. A first activation energy is highly field dependent: 310, 253, 182 and 132 K respectively for $H = 0$, 1.53, 3.54 and 8.59 T; the second one is small, 3.3 K, and field independent. For the perpendicular configuration, the activation energies at zero field are 202 and 3 K. In the microwave range, Rubin *et al.* [3] have measured similar activation energies. Finally the absorption maximum at 80 K observed for the perpendicular configuration is not understood; it could be the result of a peculiar behavior of magnetic losses in the superconducting state or to unexpected effects produced by an effective medium (epoxy+crystals) where the microwave field is not homogeneous.

Our microwave results thus confirm the anisotropic character of $YBa_2Cu_3O_7$ single crystals. Even if the transition temperature is the same along both directions, the observed temperature dependence of the losses are different, mainly in the normal state. In the superconducting state, two exponential regimes are found for both directions and one is highly magnetic field dependent. In similar experiments [3], the presence of two gaps have been suggested; if the same argument is retained here we would get $2\,\Delta\,/\,k_b\,T_c =$ 3.45 and 0.03, a factor of 100 between the two values, the first ratio being strongly magnetic field dependent. Finally we have found that eddy current losses may not explain by themselves the observed temperature behavior of the microwave losses; one has probably to invoke direct magnetic losses to understand the observed behaviors.

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