

Frequency dependence of the irreversibility temperature in Y-Ba-Cu-O.

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We study the frequency dependence of the irreversibility temperature T_{irr} in single crystal, thin film and ceramic Y-Ba-Cu-O samples. T_{irr} , measured by the onset of third harmonic signal, depends weakly on frequency for crystals, moderately for thin films and strongly for ceramic samples. The data is analyzed in the framework of the flux creep and the vortex-glass models. Although we cannot rule out the flux creep scenario, the data is better described by the vortex-glass phase transition model.

We recently [1] studied the frequency dependence of the irreversible temperature, T_{irr} , identified by the onset of the third harmonic signal in the response of high-temperature superconductors (HTS) to AC magnetic fields. We measured single crystals of three HTS families: Y-Ba-Cu-O (YBCO), Bi-Sr-Ca-Cu-O (BSCCO) and Tl-Ba-Ca-Cu-O (TBCCO). For YBCO, we found very weak frequency dependence of T_{irr} (less than 0.1 K per decade of frequency). For BSCCO and TBCCO crystals the dependence is much more pronounced. The increase of T_{irr} is of the order 2.5 K and 6 K per decade for BSCCO and TBCCO, respectively. For all three systems T_{irr} show a tendency to converge to a finite temperature as the frequency approaches zero. An attempt to analyze the data using conventional theories of thermally activated vortex motion [2] failed to describe the data and yielded unphysical values for the attempt frequency f_0 and huge values of the activation energy U . We have suggested that our data may be better understood in the framework of phase transition models [3] and that T_{irr} for $f \rightarrow 0$ can be interpreted as a transition temperature separating the reversible vortex-liquid and the irreversible vortex-glass phases.

In the present work we focus on the YBCO system and investigate the frequency dependence of T_{irr} for three YBCO subsystems: single crystals, thin films and ceramic samples. The measurement technique is identical to that reported previously [1].

In figure 1 we exhibit the frequency dependence of T_{irr} normalized to the transition temperature T_c

for the three YBCO subsystems, in DC applied field of 300 Oe and AC amplitude of 0.5 Oe. The single crystal sample exhibits very weak frequency dependence, the thin film shows a moderate linear dependence on the logarithm of the frequency, and the ceramic bulk presents a relatively strong frequency dependence with a tendency for convergence at low frequencies. Very similar results were obtained for several films and ceramic samples in various DC magnetic fields.

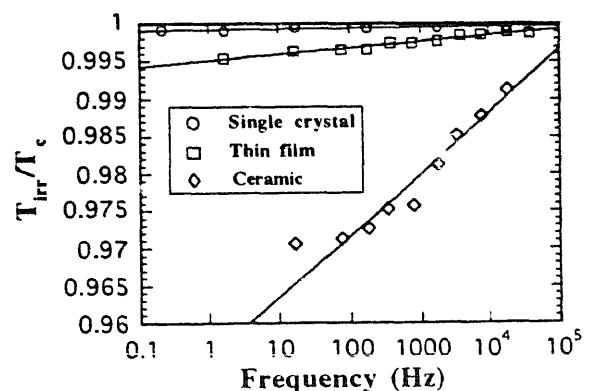


FIGURE 1. Frequency dependence of normalized irreversibility temperature. Solid lines are fits to eq. 1.

While for BSCCO and TBCCO it is plausible to assume a constant activation energy because of the

relatively large distance between T_{irr} and T_c , for the YBCO family this assumption appears simplistic. It is clear that the activation energy should vanish at T_c and therefore an attempt to fit the data of figure 1 with a simple Arrhenius law will naturally result in unphysical parameters. We therefore go one step further and assume a linear drop of the activation energy [4] of the form $U = U_c [1 - T/T_c]$ where U_c is the activation energy at $T=0$. This immediately leads to a frequency dependence of T_{irr} of the form:

$$T_{\text{irr}}(f) = T_c / (\ln(f_0/f)kT_c/U_c + 1) \quad (1)$$

where f_0 is the frequency at which $T_{\text{irr}} = T_c$.

The solid lines in figure 1 are fits to eq. 1 where f_0 and U_c are free parameters. The frequency f_0 obtained from these fits was of order MHz for all the systems and the energy U_c obtained was 2, 0.3 and 0.03 eV for the crystal, film and ceramic samples respectively. One must recall however, that the values of U_c obtained here are only a linear extrapolations of the activation energy to $T=0$. In practice, U is expected to deviate from this linear dependence on temperature and saturate for low temperatures. Thus, the high values of U_c serve as an upper limit for the activation energy and we cannot rule out the explanation of our data in the framework of flux creep models.

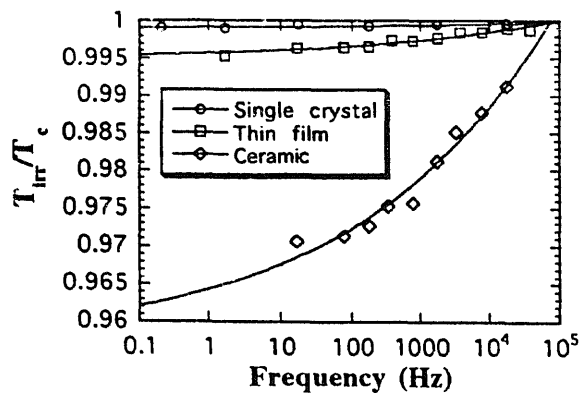


FIGURE 2. Frequency dependence of normalized irreversible temperature. Solid lines are fits to eq.2.

Another possible explanation for the frequency dependence of T_{irr} is in the framework of phase transition models [3]. These models predict a transition between the reversible vortex-liquid state and the irreversible vortex-glass state at a finite temperature T_g . Identifying T_g with T_{irr} at $f \rightarrow 0$ the expected frequency dependence of T_{irr} becomes:

$$T_{\text{irr}} = T_g + A\omega^{\nu(z-1)}, \quad (2)$$

where A is a field dependent prefactor and ν and z are the critical and dynamical exponents respectively. The solid lines in Figure 2 are fits to eq. 2 with $\nu(z-1)=6.5$ as was obtained in resistive measurements [5-7]. For the single crystal and the thin film the fits to eqs. 1 and 2 are of equal quality however, the fit to eq. 2 for the data of the ceramic sample describes much better the frequency dependence of T_{irr} than the fit to eq. 1. This gives somewhat more support to the phase transition scenario. Although the data appear to be better described by the phase transition model, we cannot rule out any other models. In order to do so, one must increase the frequency range to cover the very low frequencies where the differences between the models should be more apparent.

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