

Detection of Josephson - Abrikosov vortex transition line in $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ polycrystalline superconductors

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Abstract

We have used an AC mutual-inductance technique based on the screening method to detect the presence of both Josephson (JV) and Abrikosov (AV) types of vortices in superconducting materials. By measuring the AC magnetic susceptibility of polycrystalline $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ for different compositions ($x=0.1, 0.5$, and 0.6) as a function of temperature, transport current and AC magnetic field, we were able to identify a JV-AV type transition in our samples.

Keywords: polycrystalline, susceptibility AC, cuprate superconductor, vortices Abrikosov and Josephson

The partial substitution of Y for Pr in the classical hole-dominated cuprate superconductor $YBa_2Cu_3O_{7-\delta}$ (YBCO) has been actively used to shed some light on the pairing mechanisms in a rapid growing family of high-temperature superconductors.

In particular, such a substitution allows to monitor the Pr induced destruction of hole-like Cooper pairs (within CuO plane) in the electron-doped superconductor $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ (YPBCO). On the other hand, the vital properties of any polycrystalline material are governed by the combination of both grain boundary Josephson weak links and relatively large grain size distribution that usually occurs in sintered YBCO. This, in turn, results in a granular material that provides a way to experimentally realize a disordered 3D Josephson junction array. Recall, that for a typical 3D Josephson network, the Josephson current between grains i and j is given by the well-known formula, $I_{ij}=I_{ij}^0 \sin(\theta_i-\theta_j-A_{ij})$. Here I_{ij}^0 is the Josephson critical current, θ_i is the phase of the grain i , and A_{ij} depends on the vector potential A as: $A_{ij} = (2\pi/\varphi_0) \int_i^j A \cdot dr$ with φ_0 being the flux quantum. In general, A_{ij} terms depend on the applied magnetic field, the sample morphology, and the effects of the shielding currents. According to the current paradigm, the so-called intergranular Josephson vortices (JVs) are assumed to sweep in and out of the weak-link network, while intragranular Abrikosov vortices (AVs) move in and out of the superconducting grains, both causing bulk pinning hysteresis losses. Remarkably, the above model predictions for the real (χ') and imaginary (χ'') parts of AC susceptibility χ_{AC} are consistent with our experimental data (see Figure 1). This allows us to deduce the important physical parameters of our polycrystalline PYBCO samples, including inter and intragranular pinning force densities, the fraction of the superconducting grains, the form of grain size distribution, and the bulk London penetration depth. Besides, according to the anisotropic Ginzburg-Landau (GL) theory, one may also take into account the intrinsic pinning peak. This, of course, assumes that the vortex pinning force density has no angular dependence. It also predicts that vortices parallel to the a - b planes are more strongly pinned than those moving along the c -axis.

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As is well-known, in type-II superconductor, the imaginary component of the χ_{AC} (see Figure 2) shows a peak at certain temperature which is routinely interpreted as a signature of the irreversibility line. At the same time, χ_{AC} experimental results are typically interpreted in the context of critical-state models associated to type-II superconductivity. In particular, the curves corresponding to the real component of χ_{AC} (Figure 2) are related to the Kim-Anderson model which is directly associated to flux creep phenomena and shows an exponential behavior of the form $E(j) = \text{sgn}(j)E_c \exp[n(|j/J_c| - 1)]$ [1].

In this work we study the influence of the transport current on the obtained (at a constant temperature) χ_{AC} curves for the above-mentioned polycrystalline PYBCO samples. We also discuss the influence of the transport current density J_c and the amplitude of the AC applied magnetic field on manifestation of both Josephson (JV) and Abrikosov (AV) vortices [2]. As usual, the anisotropy of the samples is accounted for by defining a charge carrier mass tensor [3] which has the value of m_{ab} within the a - b plane and m_c in the c -axis direction. This allows to obtain the necessary GL equations in terms of the superconducting parameters for the crystallographic directions (λ_{ab} , λ_c , ξ_{ab} and ξ_c) assuming $\varepsilon = \frac{1}{\gamma} = \frac{\lambda_{ab}}{\lambda_c} = \frac{\xi_c}{\xi_{ab}}$ as the anisotropy parameter, which is also responsible for the angular dependence $\varepsilon_{\theta}^2(\theta) = \varepsilon^2\{\cos^2\theta + \sin^2\theta\}$. In the case of the oxide superconductors, the a - b anisotropy is usually small enough and can be neglected (hence, in the most of cases, the material may be treated as uniaxial). The anisotropy between the parameters in the a - b plane and the c -axis is very large. We notice that, as could be expected, in our polycrystalline samples, the obtained results demonstrate a consequence of the superposition of this angular dependence due to the different orientations of single crystals forming a particular sample.

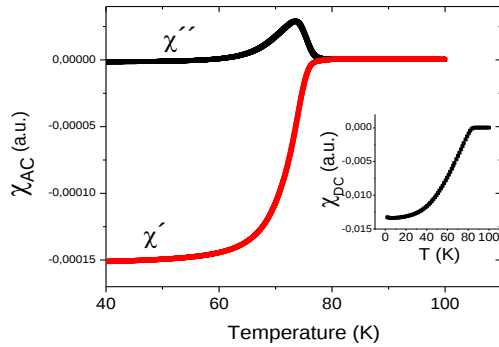


Figure 1: χ_{AC} vs. T for $Y_{0.9}Pr_{0.1}Ba_2Cu_3O_{7-\delta}$ for $h_{AC} = 0.35$ Oe and $f = 42$ kHz. Inset: DC magnetic susceptibility for an external DC applied magnetic field $H=200$ Oe.

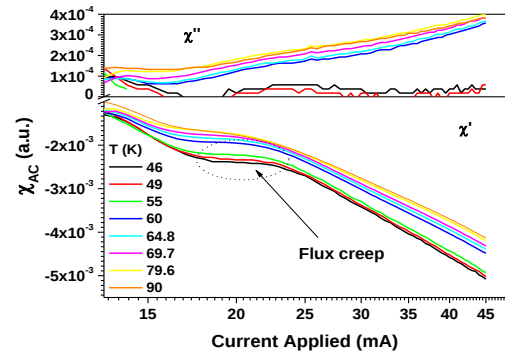


Figure 2: χ_{AC} vs. h_{AC} for $Y_{0.9}Pr_{0.1}Ba_2Cu_3O_{7-\delta}$. The real component, χ' , shows an exponential behavior characteristic for the presence of flux creep.

The authors gratefully acknowledge Brazilian agencies CNPq, CAPES and FAPESP for financial support. CS thanks CAPES (IEL Nacional – Brazil) for the fellowship.

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