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Flux pinning in two-dimensional high temperature superconductors

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Flux pinning in two-dimensional high temperature superconductors

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Various types of high temperature superconducting single crystals (Tl-2223, Bi-2212, and Y-123 with oxygen contents between 6.4 and 6.64) were investigated by SQUID magnetometry. Both materials show very "low" lying irreversibility lines (H||c), which follow an exponential law and rise rapidly below $T/T_c \approx 0.5$. High critical current densities are found only at low temperatures, e.g. J_c is about $2.7 \cdot 10^{10}$ Am^{-2} at 1 T and 5 K in Tl-2223. A comparison of the condensation energy provided by different types of defects with the thermal energy gives evidence for pinning of individual pancakes by the as-grown defect structure.

1. INTRODUCTION

"Standard" $YBa_2Cu_3O_x$ with an oxygen content of $x \approx 6.92$ ($T_c \approx 92$ K) behaves three dimensionally, has an anisotropy factor of $\gamma \approx 5$, high critical current densities J_c at ~77 K, and "high" irreversibility lines (IL) at high temperatures and fields for H||c as well as for H||ab. However, if x decreases, the system gets more and more two dimensional and finally behaves like Tl-2223 or Bi-2212 superconductors. In this paper we present a comparison of J_c and the IL's of Tl-2223, Bi-2212, and oxygen deficient Y-123 single crystals.

2. EXPERIMENTAL

Single crystals with the nominal composition Tl-2223 and Bi-2212 were grown according to ref. [1] and [2]. Y-123 single crystals with oxygen contents between 6.4 and 6.64 were obtained from fully oxygenated crystals after annealing in an O_2/N_2 atmosphere at certain temperatures for several hours [3]. The crystals are platelets with dimensions of 670-2804 µm and 815-1407 µm in the basal plane, and 65-330 µm along the crystallographic c-axis. For the measurements in SQUID magnetometers, the single crystals were mounted onto small U-shaped aluminum plates, which were inserted into an aluminum sample holder with the c-axis oriented parallel to the field. Hysteresis loops were measured in a non commercial 8T-SQUID magnetometer up to 8 T. Field cooled (FC-) measurements were carried out both in the 8 T and in a commercial 1 T SQUID magnetometer in fields between 0.01 T and 8 T. The superconducting transition temperature T_c was measured in a field of 1.1 mT (Tl-2223 and Bi-2212) and 1 mT (Y-123) with H||ab.

3. RESULTS AND DISCUSSION

T_c was determined by fitting the FC-curves near T_c to an exponential expression [1]. We find 121.5 K for Tl-2223, 85.4 K for Bi-2212, 21.8 K for Y-123 (x=6.4), 59 K for Y-123 (x=6.64), and 49 K for Y-123 (x=6.5).

An anisotropic Bean model which takes demagnetization effects into account, was used to calculate J_c in the ab-plane as a function of the local induction B [4]. The hysteresis loops are strongly irreversible at low temperatures, but become reversible at low fields already at temperatures above $\sim T_c/2$. Fishtails were found for Y-123 (x=6.5) and Y-123 (x=6.64), but not for the other superconductors. $J_c(B)$ at 5 K is plotted in Fig. 1a. J_c at 1 T and 5 K is $2.8 \cdot 10^{10}$ Am^{-2} in Tl-2223, $2.1 \cdot 10^{10}$ Am^{-2} in Bi-2212, $5.2 \cdot 10^{9}$ Am^{-2} in Y-123 (x=6.64), and $5.3 \cdot 10^{9}$ Am^{-2} in Y-123 (x=6.5). J_c in Y-123 (x=6.4) is about $0.5\text{-}3 \cdot 10^{8}$ Am^{-2} below 0.5 T and zero above. In all samples, J_c is strongly field dependent. $J_c(B=0.5\ T)$ is plotted as a function of reduced temperature $t = T/T_c$ in Fig. 1b. At small t, J_c is high. However, it decreases rapidly with increasing t. Between 0.25 and 0.3, all J_c's become negligible. A similar behaviour is observed for higher inductions.

The IL's as a function of t are shown in Fig. 2a. The irreversible region of Y-123 decreases systematically with decreasing oxygen content, i.e. the

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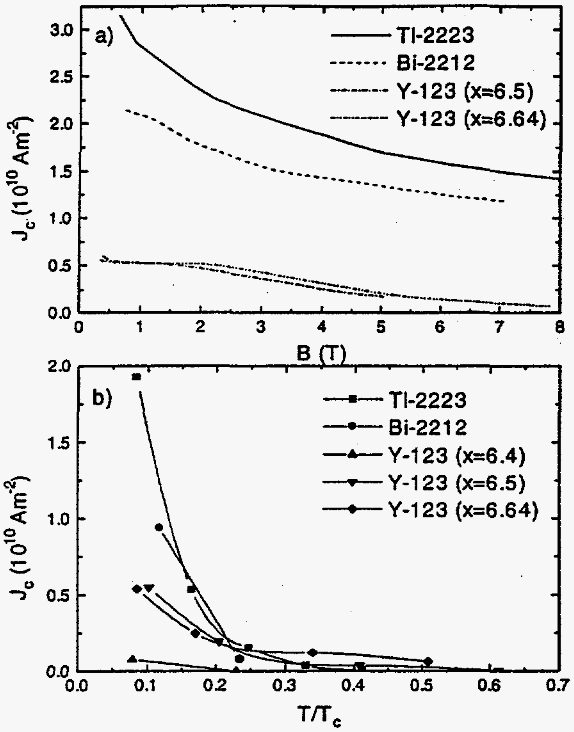

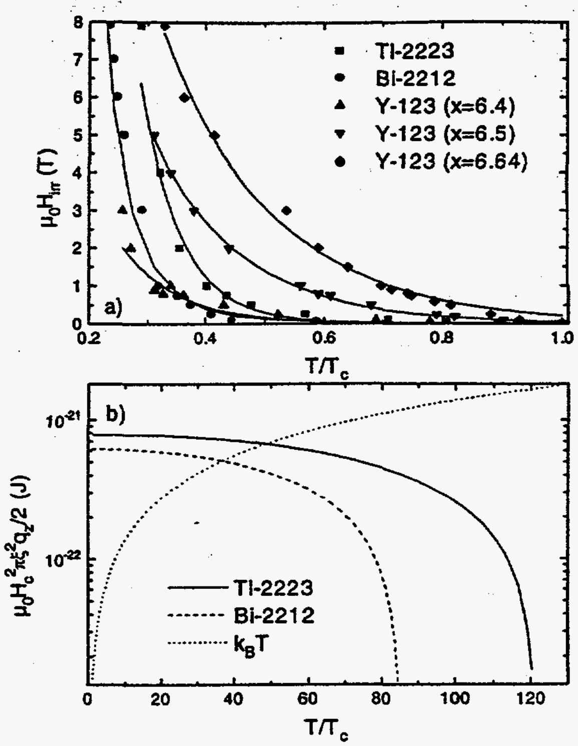

Fig. 1: a) $J_c(B)$ at 5K. b) J_c as a function of reduced temperature at 0.5 T.

Fig. 2: a) IL's and fits to an exponential law (solid lines). b) Condensation energy, q_z=0.3 nm.

IL shifts to lower fields and temperatures. In comparison to the IL of a fully oxygenated sample, the initial slope becomes flatter with decreasing oxygen content. At t≈0.3 a rapid rise occurs as in Bi- and Tl-based superconductors. All IL's can be described by an exponential law $\mu_0 H_{irr}(t)=a\cdot\exp(-bt)$. This behaviour is in agreement with experiments carried out on a series of melt textured oxygen deficient Y-123 samples [5]. Low lying IL's and the rapid deterioration of J_c with temperature and field are consequences of the layered structure. At low temperatures and fields pancakes are coupled by magnetic and Josephson interactions. At higher temperatures and fields, they decouple and each pancake has to be pinned individually. Furthermore, the number of pinning centers per plane is limited and their efficiency decreases with increasing temperature. Thus, a dissipation free current flow becomes impossible. Evidence for pancake pinning by disk shaped as-grown defects ($r \approx \xi$, q_z=0.3 nm corresponds to the thickness of one layer) is shown in Fig. 2b. The condensation energy of a pancake intersects the $k_B T$-line at positions where the IL is in fact found ($\mu_0 H_{irr}$=0.1 T at 37 K for Bi-2212, and $\mu_0 H_{irr}$=1 T at 48.5 K for Tl-2223).

4. SUMMARY

Two dimensional superconductors were investigated by SQUID magnetometry. We find strongly temperature and field dependent critical current densities, low lying IL's and evidence for individual pancake pinning.

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