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GRANULARITY EFFECTS IN TRANSPORT PROPERTIES OF 123 SUPERCONDUCTING THIN FILMS

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ABSTRACT

Superconducting 123 thin films have been produced by RF sputtering with different morphologies. A study is presented of the transport properties (J_c(T,H)) and the AC diamagnetic screening characteristics for the different samples. Granular films show critical currents two orders of magnitude smaller than textured films at 77 K. This has been explained in terms of the presence of oxygen deficient phases in the intergranular regions.

1. INTRODUCTION

Critical current densities J_c in bulk $YBa_2Cu_3O_{7-x}$ superconductors are strongly dependent on the microstructure of the material. It is generally accepted that, in contrast to conventional superconductors, J_c is limited by the weak link properties of the grain boundaries [1]. It has often been claimed that the high density of coherence-length size defects intrinsic to the growth of thin films might explain why critical current densities of epitaxial thin films of $YBa_2Cu_3O_{7-x}$ can be more than two orders of magnitude higher than in single crystals [2]. As we shall see, the differences between the values of J_c in textured structures and in granular samples are also evident for thin films.

The effect of the intergranular coupling has been studied in c-oriented $ReBa_2Cu_3O_{7-x}$ (Re=Y, Dy) thin films grown by RF sputtering on (100)YSZ and (100)MgO substrates [3],[4] by means of transport measurements (J(H,T)) and AC mutual inductance response. The morphology of the films has been found to depend on the thickness of the films: it varied from the highly textured thin samples (< 1500 Å) to the granular thick samples (> 1 μm) with an average grain size greater than 1 μm as observed by SEM.

2. EXPERIMENTAL

The crystal structure and the effect of the granularity on the texture of the $ReBa_2Cu_3O_{7-x}$ films were characterized by X-Ray Diffraction. Critical currents were measured at variable temperature across a photolithographically defined 20 μm wide bridge using the 1 μV/cm criterion. Resistance and critical current characteristics are measured in presence of a DC magnetic field ranging from 0 to 2 T. A two coil mutual inductance technique has been designed to determine through an impedance analyzer the diamagnetic response of the superconducting films [4]. The samples were sandwiched between two coils: an AC magnetic field (0.1 Oe amplitude) perpendicular to the surface of the film is produced by the excitation coil and the mutual inductance signal $j\omega Z$, where $Z = R_s + i\omega L_s$ is detected in the pick-up coil at variable temperature. The mutual inductance contains the information of the AC susceptibility response of the film: L_s and R_s are proportional to χ' and χ'' respectively.

3. RESULTS AND DISCUSSION

While DC resistive characterizations showed in all cases sharp transitions (T_c = 89.0 ± 0.5 K for films grown on YSZ and T_c = 83.0 ± 0.5 K for films grown on MgO) reflecting the presence of a superconducting path between the voltage contacts, intergranular coupling was only evident with other characterization measurements such as J_c(T) and χ(T).

3.1 Textured thin films:

Figures 1a and 1b show the temperature dependence of the critical current at different magnetic

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fields parallel and perpendicular to the substrate of a typical 1000 Å $YBa_2Cu_3O_{7-x}$ film grown on YSZ. The temperature dependence with no applied magnetic field is almost linear and can be described in terms of a flux creep model [5].

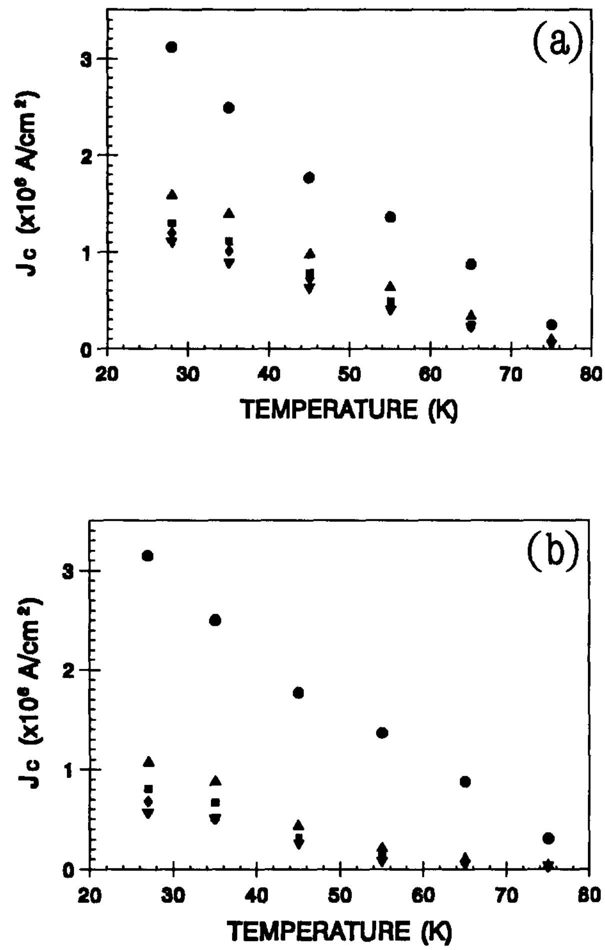

Figure 1: J_c vs T at different magnetic fields for a $YBa_2Cu_3O_{7-x}$ textured film. (a) Longitudinal and (b) Transversal. (●) 0 T; (▲) 0.4 T; (■) 0.8 T; (◆) 1.2 T; and (▼) 1.8 T.

The mutual inductance response shows a sharp and symmetric peak (≈ 1 K) in the in-phase component R_s (i.e. χ'') and an onset in the out-of-phase component L_s (i.e. χ') which coincides with T_c of the resistive transition. Figure 2 shows these characteristics for a 1500 Å $YBa_2Cu_3O_{7-x}$ film grown on (100)MgO.

The R_s peak is located at a temperature T_p which shifts towards lower temperatures when the frequency of the AC magnetic field is decreased. The dependence is roughly logarithmic and has usually been explained in terms of thermally activated flux motion models [6].

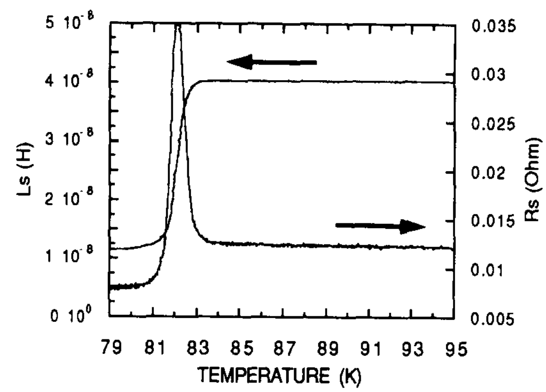

Figure 2: Series resistance (R_s) and series inductance (L_s) components of impedance (Z) for a textured $YBa_2Cu_3O_{7-x}$ film grown on (100)MgO substrate. Field frequency is 500 kHz.

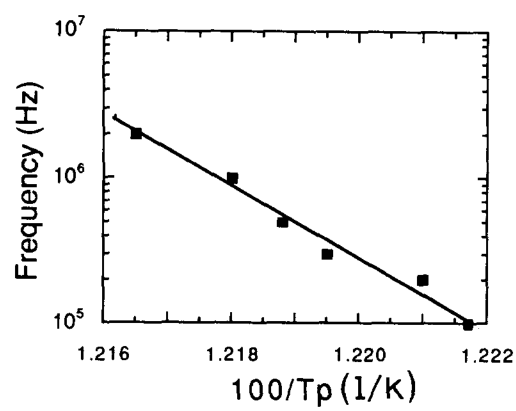

Figure 3: Log(f) vs $100/T_p$ where f is the field frequency, for the same sample of figure 2. The solid line represents the best fit (see text).

Figure 3 shows the evolution of the in-phase peak position T_p for frequencies ranging from 100 kHz to

2MHz. The slope of the Arrhenius plot Log(f) vs $1/T_p$ yields an activation energy of 4.8 eV within the experimental error. This value is well in the range 1.2 eV [7] to 12 eV [8] reported for bulk samples.

It is worthwhile to comment that the sharpness of the mutual inductance transition points to a high degree of texture and well connected grains as shown by relatively narrow rocking curves (FWHM of 0.35° of the (003) peak). Moreover, measurements of DC resistance versus temperature in different magnetic fields ranging from 0 to 2 T parallel to the substrate plane and applied perpendicular to the current showed a slight broadening, suggesting that coupling between grains in the (ab) plane took place with a minimum misorientation between them. This supports the well textured growth of the films and shows the presence of a high intrinsic pinning. Further details about this point will be published elsewhere.

We are not showing any SEM picture of the textured films since they do not present any contrast.

3.2 Granular films:

SEM analysis reveals rough film surfaces due to the presence of grains as shown in figure 4.

Figure 4: Typical SEM picture of the surface of a $DyBa_2Cu_3O_{7-x}$ granular film of thickness > 1 μm.

The effect of the intergranular coupling is reflected in the temperature dependence of the AC screening measurements: the χ'' peaks are no longer sharp and symmetric but they present a broadening at temperatures below T_p (see figure 5a) or even separated peaks between 79 K and 86 K (see figure 5b). We have attributed this behaviour to the presence of poorer superconducting phases in the intergranular regions, probably oxygen deficient with T_c between 60 K and 90 K. The large R_s peaks in these cases are the result of the superposition of the dissipation peaks of the oxygen deficient phases that have superconducting transitions at temperatures below T_p.

The temperature dependence of the critical currents for granular samples are markedly different than for textured films. Measurements of J_c in different longitudinal and transversal magnetic fields are shown

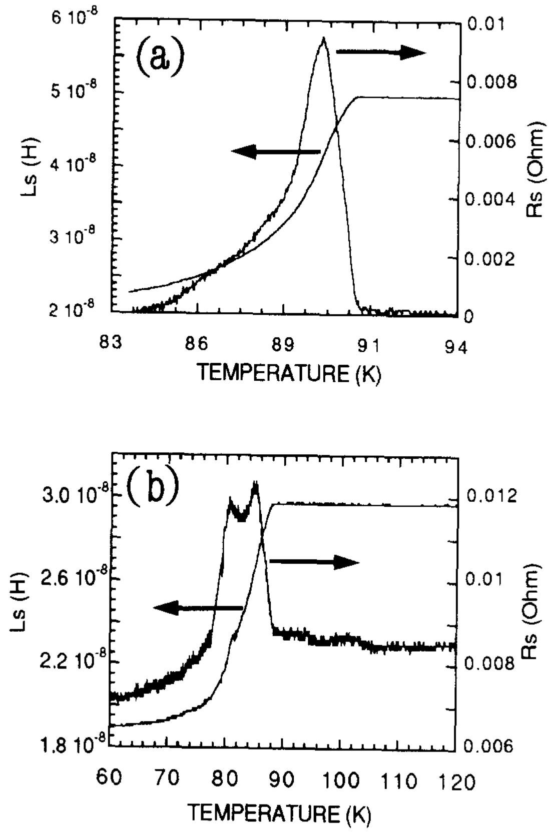

Figure 5: Series resistance (R_s) and series inductance (L_s) components of impedance (Z) for: (a) granular $YBa_2Cu_3O_{7-x}$ film; (b) granular $DyBa_2Cu_3O_{7-x}$ film. Both films are grown on (100)YSZ substrates. Field frequency is 500 kHz.

in figures 6a and 6b respectively. At the lower temperatures were the intergranular regions are superconducting a linear dependence with no applied magnetic field is again consistent with flux creep theories.

Absolute values of J_c at low temperatures (<60 K) are only one order of magnitude smaller than in textured samples. This difference might be due to the misorientation of the grains: while textured films have rocking curves with a FWHM of 0.35° of the (003) peak, granular samples have FWHM higher than 0.6°. It has been shown that misorientations in bicrystalline substrates of ≈5° can produce a drop of J_c by a factor more than 20

[1]. On the other hand, J_c values are not dramatically depressed in the presence of a magnetic field: oxygen vacancies can act as pinning sites along the boundaries. For temperatures higher than 60 K, the temperature dependence of J_c is roughly two orders of magnitude smaller than in textured films and its behaviour is probably dominated by weak coupling between grains through the mentioned poor superconducting boundaries.

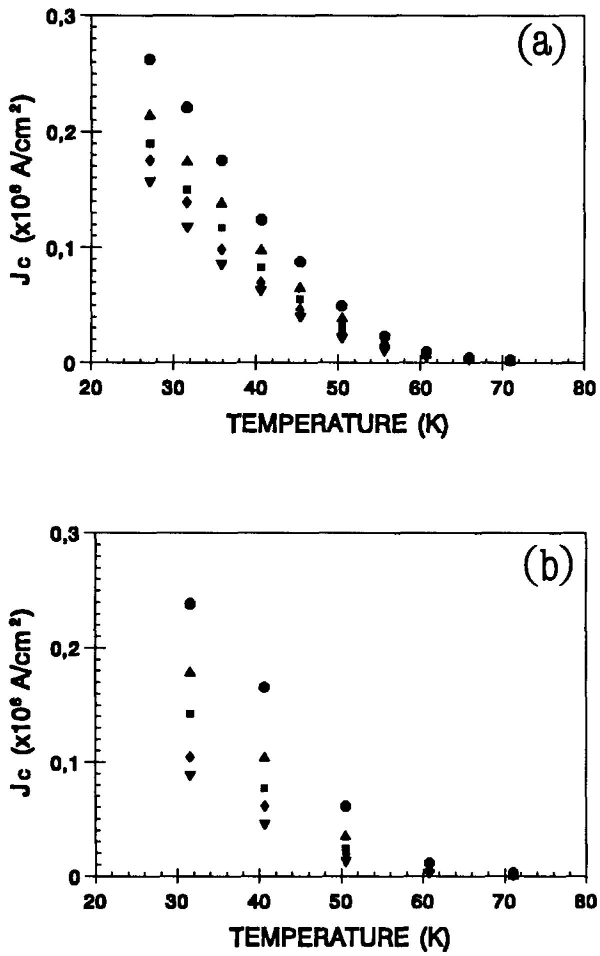

Figure 6: J_c vs T at different magnetic fields for a $YBa_2Cu_3O_{7-x}$ textured film. (a) Longitudinal and (b) Transversal. (●) 0 T; (▲) 0.4 T; (■) 0.8 T; (◆) 1.2 T; and (▼) 1.8 T.

4. CONCLUSIONS

Well textured thin $ReBa_2Cu_3O_{7-x}$ (Re=Y, Dy) films and granular thick films have been characterized using transport and two coil mutual inductance measurements. The different temperature dependence of J_c and the changes in the shape of the magnetic loss peak have been explained in terms of strong coupling between well oriented grains for the thin samples and in terms of poor superconducting oxygen deficient phases in the intergrain regions for the granular samples.

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