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Irreversibility and critical lines in textured high temperature superconductors: effects of processing on the magnetic phase diagram

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Abstract.

ac initial susceptibility of sintered, field textured, zone melted polycrystals and single crystals has been studied in the low field limit. Critical dynamic fields (h_c*) and relative position of irreversibility line (I.L) and critical line (C.L) are consistent with the creation of strong pinning sites. High anisotropy is observed in the case of field textured samples.

1. Introduction

Fabrication techniques involving melting at some stage e.g. partial melting, zone melting or melt processed melt growth (MPMG) lead to an improvement of electrical and magnetic properties of HTSC. The melting processes have the advantage of both dissolving impurities present mainly at the grain boundaries and creating defects with high activation energies such as 211 inclusions. Texturing is obtained in the MPMG process by applying a temperature gradient. More recently, it has been shown [1] that another way of texturing can be obtained by solidification under a magnetic field: at sufficiently high temperature the force due to anisotropic magnetic susceptibility overcomes other forces (thermal agitation, shape anisotropy) and, in the case of 123 compounds, leads to an alignment of the c-axis with the applied field.

2. Experimental

Details for the preparation of the field oriented samples were already given elsewhere [2]. Field textured sample T1 was submitted to an additional thermal treatment under flowing oxygen at 900°C for 30 minutes. The temperature was then reduced at a rate of 20°C/h down to 420°C where a plateau was maintained for 72 h. The cooling down to room teperature was also achieved at a rate of 20°C/h.

The study described here was achieved on millimeter sized samples with cubic or parallelepipedic shape. The measurements of susceptibility were performed with a Harsthorn bridge operating in the 10^2Hz-10^4Hz range, associated with a lock-in amplifier. Applied ac fields could be varied from some mOe to about 200 Oe.

3. Magnetic phase diagram in the low ac field limit

Pinning of flux lines by defects or impurities is very efficient at low temperature, but depinning occurs at higher temperature and lead to energy dissipation. The limit between the two regimes is given by the irreversibility line (I.L.) corresponding to a crossover from reversible magnetization and zero critical current (j_c) to irreversible magnetization and finite j_c. Existence of I.L. is subject to controversial discusssion and the various proposed theoretical models belong either to the giant flux creep and thermally assisted flux flow models (TAFF), where flux lines undergo a transition from slow to fast dynamic, or to the melting models, where I.L. corresponds to the crossover from either an ordered vortex lattice or a vortex glass to a vortex liquid state.

Experimental results involve various techniques and lead to some discrepancies; they include magnetoresistance, field cooling (FC) and zero field cooling (ZFC), loss peak of the imaginary part of the ac susceptibilty (χ"), ultrasonic attenuation, muon-

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spin rotation experiments, etc...(see E.H. Brandt [3]). ac susceptibilty measurements have been widely used but also require some care because of the strong influence of numerous parameters, e.g. size effects appear to some extent in the intergrain loss peak of bulk samples [4] and in thin films for thicknesses below 1000 Å [5].

The critical dynamic fields h_c^* obtained from ac susceptibility (imaginary part χ'') in the low ac field limit (without dc magnetic field) measure the ac field induced strengh of the I.L. shift in the (h_{ac}, T) plane. h_c^* is related to the activation energy [6] . HTSC exhibit similar characteristics both for j_c and h_c^*, e.g. single crystals and polycrystals fabricated by processes including a molten stage lead to much higher values than sintered polycrystals. As will be discussed below, high h_c^* values have to be ascribed to the appearance of strong pinning centers.

There is, finally, no sharp transition at the irreversibility line and some authors wonder about the validity of considering the maxima of χ'' data as a depinning line [7]. It was furthermore observed that dissipative motion of vortices exists even below I.L. and the limit of the dissipative regime is actually given by the appearance of linear χ' (real part) dependence upon ac field and leads to a critical line (C.L.) below I.L. in the (h_{ac}, T) plane [8].

4. Experimental results and discussion

As a first indication we obtain critical dynamic fields deduced from χ'' for T1 and T2 samples which range between 200 Oe and 300 Oe both for non-oxided and oxided samples, which is of the same order of magnitude as the values obtained for intragrain material and significantly higher than in single crystals ($h_c^* \approx 50$ Oe) [9].

The understanding of the effect of pinning on the position of the I.L.s and C.L.s (and on the increase of critical current) has been clarified by means of irradiation experiments: an increase of the number of weak pinning sites improves j_c but has no effect on the I.L., whereas the creation of strong pinning sites leads both to an increase of j_c and to an I.L. shift to higher values [10].

Sintered HTSC have low j_c and their I.L. are located well below those of e.g. single crystals (figure 1). The strengh of the I.L. shift associated with critical current increase, as observed in the field oriented samples, is therefore indicative of the creation of strong pinning centers. It can also be assumed that no significant amounts of additional defects with high activation energy are introduced by thermal treatments such as those applied to sample T1.

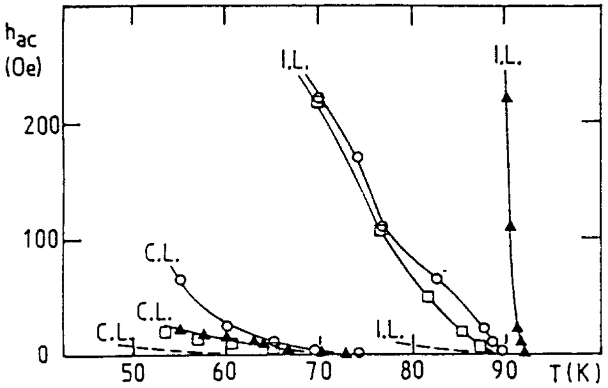

Figure 1. Irreversibility lines (I.L.) deduced from the loss peak of the imaginary part $\chi''(T, h_{ac})$ and critical lines (C.L.) deduced from linearity breakdown of the real part $\chi'(T, h_{ac})$ for $YBa_2Cu_3O_{7-\delta}$ compounds (f = 330 Hz, hac // ab). ▲ : field textured polycrystal (Tc = 91.8K). O : single crystal (Tc = 89.9K). — — — : sintered polycrystal (Tc = 88.5K) and ☐ for BiSrCaCuO ZM (Tc=93.0K). The straight lines are guides to the eye.

For a given sample it appears, moreover, that C.L. lies considerably lower than I.L, both for field textured and single crystal samples, when comparing with sintered polycrystals [8].

Measurements for h_{ac}// ab and $h_{ac}\perp$ ab show orientational effects and reflect the anisotropy induced by field texturing. Results obtained for field textured samples can be compared with those obtained by others processes creating an anisotropy too. For that purpose, it is convenient to introduce the anisotropy factor A (taken at a given temperature) which is either the ratio $H_{irr//}(T_M)$ / $H_{irr\perp}(T_M)$ in the (H_{dc}, T) plane or $h_{irr//}(T_M)$ / $h_{irr\perp}(T_M)$ in the (h_{ac}, T) plane. Figure 2 gives the temperature dependence of A near T_c for field textured sample (T2) together with some results quoted from literature.

The anisotropy coefficient A obtained in the low ac field limit for field-textured samples ($2 < A < 2.5$) is of the same order of magnitude as value obtained from magnetization under high dc fields ($2 < A < 3$)

[2], but is lower than the value obtained from j_c angular field dependence ($A \approx 5$ for $B = 6T$) . The anisotropy coefficient A approaches the values reported for MPMG samples ($A \approx 3$ for a sample with weak temperature dependence [10]). The values we obtain for field textured samples are also only slightly below the values obtained for single crystals where $A \approx 6$ [10].

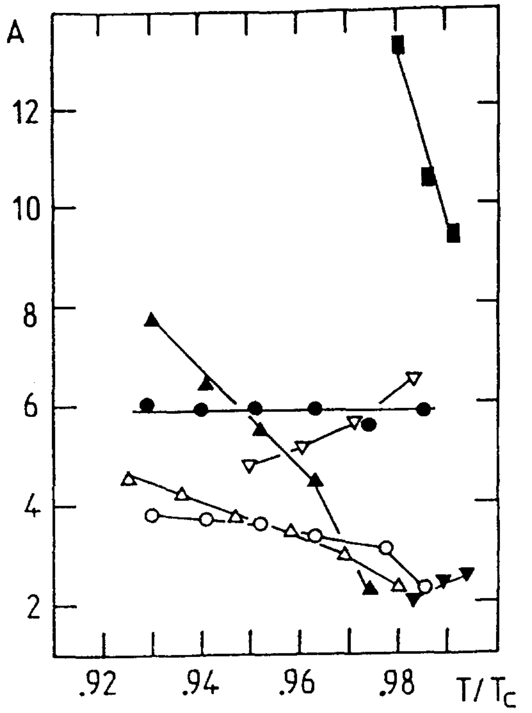

Figure 2. Anisotropy coefficient (A) defined by $H_{irr//}(T_M) / H_{irr\perp}(T_M)$ or $h_{irr//}(T_M) / h_{irr\perp}(T_M)$ for respectively d.c and a.c magnetic fields vs reduced temperature $t = T/T_C$. O: melt processed melt growth (MPMG) sample [11]. ▲ (unirradiated) and Δ (irradiated) melt processed melt growth (MPMG) sample [12]. ∇ : quench and melt growth (QMG) sample [14]. ▼ : field textured sample (this work). ● : single crystal [11]. ■ : single crystal [13].

Finally, we point out that the relative position of C.L. are consistent with the degree of anisotropy in our samples as the C.L. for a field textured sample (intermediate orientation) lies between the C.L. of polycrystals (random) and single crystals ("ideally" oriented) .

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