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The pinning force density in polycrystalline $Bi_{1.8}Pb_{0.4}Sr_2Ca_{2-x}Y_xCu_3O_y$ multiphase systems

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ABSTRACT

ac susceptibility measurements as a function of temperature T and the *ac* magnetic field amplitude, H_{ac}, have been performed on five superconducting $Bi_{1.8}Pb_{0.4}Sr_2Ca_{2-x}Y_xCu_3O_x$ polycrystalline samples ($x = 0$, 0.005, 0.04, 0.15 and 0.36, and with the volume fraction of the $Bi_2Sr_2Ca_2Cu_3O_y$ (2223) phase, $f \approx 100\%$, 100%, 64%, 0% and 0%, respectively. By using the Müller model for granular superconductors, we found that the pinning force density obtained from the imaginary peak of $\chi''(T)$ is strongly dependent on the doping level. To describe this dependence we adopted the multilayer model (a stack of superconducting, S, and normal, N, layers) of a superconductor. In the framework of this model, we demonstrated that (a) the yttrium addition influences the degree of coupling between the adjacent S layers (and thereby, the pinning strength) through the modification of the carrier concentration and of the effective thickness of the N layers, and (b) the intergrowth of $Bi_2Sr_2CaCu_2O_\delta$ (2212) layers within the 2223 grains has an important influence on the thickness of N.

1. Introduction

The Bi-based high-temperature superconductors (HTS) are of great interest for both fundamental investigations and practical applications. Due to the large anisotropy resulting from their laminar structure and the very small superconducting coherence length, the vortex dynamics in Bi-based HTS is very sensitive to thermal fluctuations. Thus, the flux-pinning effect in these materials at 77.3 K and above is weak and it is reflected in the fast drop of the critical current density J_c with increasing temperature T and the external magnetic field H. However, the same strongly pronounced two-dimensional (2D) character of Bi-based HTS makes them to remain the most suitable materials for fundamental investigations (especially those related to quasi-2D effects) through HTS.

To solve the problem of the limitation of J_c and for a better understanding of the factors that affect the important superconducting parameters, the method of additions and substitutions is frequently used. One possibility is to substitute Y^{3+} for Ca^{2+}. The most significant feature of this substitution in $Bi_2Sr_2CaCu_2O_\delta$ (2212) is the decrease of the average valence of Cu (or the hole concentration, p) [1,2] and the decrease of T_c [3], or its parabolic-like behaviour [1,2,4–6] with increasing Y content. As regarding $(Bi,Pb)_2Sr_2Ca_{2-x}Y_xCu_3O_y$ system, the volume fraction of the 2223 phase decreases whereas the volume fraction of the 2212 phase increases with increasing x [7]. One of the main factors which influences the superconducting parameters of Bi-Sr-Ca-Cu-O (BSCCO) ceramics is the 2223/2212 ratio. However, a clear correlation between the superconducting parameters and the 2223/2212 ratio has not been observed, owing to the aspects related to the effects of 2212 and 2223 intercalations.

The influence of additions in polycrystalline BSCCO was mainly studied in connection with the changes at the inter-granular contacts. As regarding the intra-granular properties, the inclusion of various elements in the unit cell of the host material will act merely as point defects, thought to be not very effective as pinning centres in the high-T region. Since BSCCO are strongly layered superconductors, it is expected that in the high-T domain the inclusions will affect the superconducting parameters by changing the anisotropy rather than by creating new pinning centres.

The Y doping into our $(Bi,Pb)_2Sr_2Ca_2Cu_3O_y$ system should influence the anisotropy through the variation of the carrier concentration and/or the change of the thickness d of the N blocks. We found that d is dominated by the variation of the number of the intercalated 2212 layers into 2223 crystal grains, supported by High-Resolution SEM analyses.

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2. Experimental

$Bi_{1.8}Pb_{0.4}Sr_2Ca_{2-x}Y_xCu_3O_y$ samples were prepared by the conventional solid state reaction method and the final sintering thermal treatment was performed in air at 850 °C for 500 h, with an intermediate grinding. Details of the sample preparation are given in Ref. [7]. X-ray diffraction (XRD) measurements were performed using the CuK_α radiation. The volume fraction *f* of samples 1, 2, 3, 4, and 5 ($x = 0$, 0.005, 0.04, 0.15 and 0.36) is 100%, 100%, 64%, 0% and 0%, respectively, in agreement with XRD measurements. High-Resolution SEM analyses were performed using an electron microscope TITAN 80-300 FEI from FEI Application Laboratory, Eindhoven. *ac* susceptibility measurements were performed with an Oxford Instruments MagLab 2000 System cryostat, with H_{ac} between 0.25 and 35 Oe and the frequency $\nu = 1$ kHz. In order to distinguish between the doping with Y and the doping state determined by the total number of holes in the CuO_2 layers, we describe the first situation by “substitution” and the second one by “doping”.

3. Results and discussions

Fig. 1a–c illustrate the results for the fundamental harmonic (χ_1' and χ_1'') measurements in the case of samples 1, 3 and 4, consisting of 100%, 64% and 0% 2223 phase, respectively, in agreement with the XRD analyses. The curves registered at lower *H* values display the typical behaviour of polycrystalline samples: two steps in $\chi'(T)$, one at higher *T*, corresponding to the diamagnetic signal of the 2223 grains for samples 1 and 3 (2212 grains for sample 4), and another one, at lower *T*, generated by the diamagnetic shielding of the sample through the weak links between the grains.

At the same time, the two peaks in $\chi''(T)$ are attributed to the losses in the 2223 grains for samples 1 and 3 (2212 grains for sample 4), at higher *T*, and to the losses in the inter-granular network, at lower *T*. As H_{ac} increases, the peak and the diamagnetic signal corresponding to inter-granular losses shift more rapidly to lower *T* than those corresponding to the losses in the grains, in such a way that for $H_{ac} > 5$ Oe these are located below 65 K. This is because the supercurrent transport properties are better in the grains than in the weak-link network. At the same time, the amplitude of the intra-granular peak (‘nucleated’ at 1 Oe–5 Oe within the limit of experimental errors) increases with increasing H_{ac}.

As described in the upper inset of Fig. 1a, the $\chi''(T)$ curves for the sample 1 show a small peak at $T \approx 71$ K. The small peak behaves as an intra-granular one, since its shift towards lower *T* with increasing H_{ac} (even in the high-*H* range) is less pronounced, and would correspond to the losses in the 2212 grains. As estimated from the $\chi'(T)$ curve measured at $H_{ac} = 5$ Oe shown in the lower inset of Fig. 1a, the fraction of the drop in $\chi'(T)$ at $\sim$71 K is about 4–5%, which is close to the sensitivity limit of XRD, $\sim$3%. This is the reason why the 2212 phase was not seen in XRD. The estimated fraction of the same drop in $\chi'(T)$ at $\sim$71 K for sample 2 is about 6–7%, in contrast with the XRD results. (It is worthy to note that the XRD patterns were registered in the 2θ range 15°–60° with a step of 0.025° and 1 s/step; in these conditions the sensitivity limit of XRD may decrease). This contradiction can be explained by assuming that very thin 2212 layers intergrowth into the 2223 matrix.

It was suggested (indirectly, from magnetic measurements) that regardless of the 2212 ratio the dominant configuration of the superconducting phases in the grains of polycrystalline (Bi,Pb) SrCaCuO/2223 samples is the alternation of 2212 and 2223 layers [8]. It is also well known that 2212 intergrowths at the grain boundaries in 2223/Ag-sheathed tapes (see for ex. [9]). The HREM investigation (work in progress) of our 2223 single phase (according to XRD measurements) in (Bi,Pb)SrCaCuO/2223 polycrystalline system sustains the above statement. Indeed, Fig. 2, which shows the lattice image projected along the [110] direction of the 2223

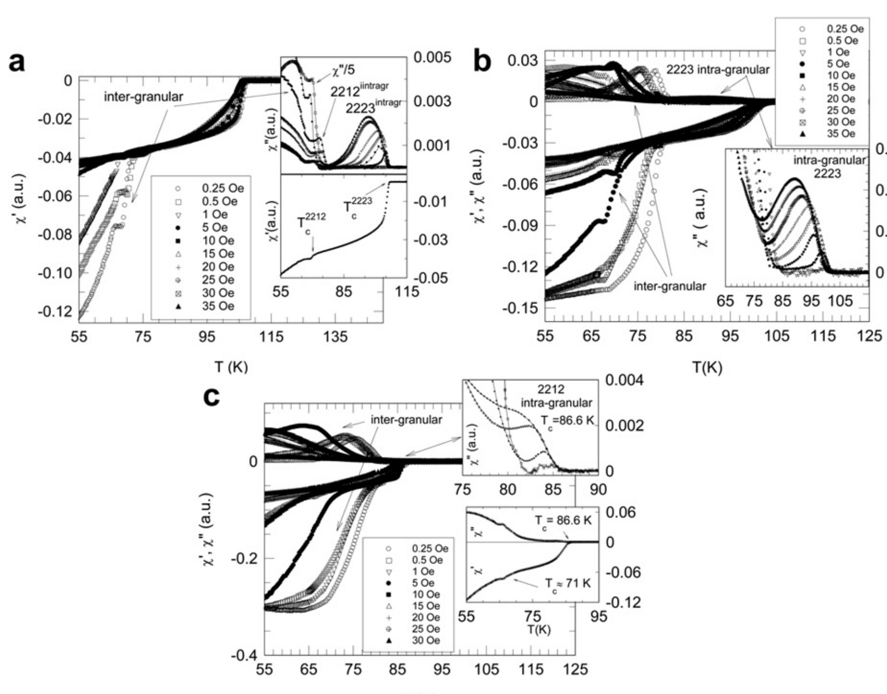

Fig. 1. Real part, $\chi'(T)$, and the imaginary part, $\chi''(T)$, of the *ac* susceptibility measured with an *ac* field amplitude $H_{ac} = 0.25$–35 Oe and frequency $\nu = 1000$ Hz for the: (a) pristine ($x = 0$) single 2223 phase sample 1. The upper inset shows the $\chi''(T)$ curves. The lower inset illustrates $\chi'(T)$ measured at $H_{ac} = 5$ Oe; (b) sample 3 with 64% Bi2223 phase ($x = 0.04$). Inset: $\chi''(T)$ curves corresponding to the losses in 2223 grains; (c) single 2212 phase sample 4 ($x = 0.15$). The upper inset shows several $\chi''(T)$ curves corresponding to the losses in 2212 grains ($T_c = 86.6$ K). The lower inset illustrates $\chi'(T)$ and $\chi''(T)$ measured at $H_{ac} = 15$ Oe.