Melt textured YBCO bulks with artificially patterned holes

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Abstract : In this paper, we report the preparation of artificially patterned millimetre-sized holes in $YBa_2Cu_3O_x$ (Y123) bulk superconductors. Drilled sintered Y123 pellets have been successfully melt textured and single domain monoliths of 16 mm diameter were obtained. Texture was evidenced by XRD pole figure measurements. Flux mapping was used to verify the homogeneity of the samples and to investigate the field trapping capacity. The trapped magnetic field measured with Hall sensor at 77K is comparable to the hole free parent sample, which has the same thermal history.

1. Introduction

Much effort has been devoted to the development of texturation processes [1] of bulk high temperature superconducting components with high critical current densities in the last decade. The complete oxygenation of the bulk sample (e.g. $YBa_2Cu_3O_x$ -Y123), the mechanical reinforcement and the hot-spot problem are still existing difficulties to overcome. Recently, the superconducting ceramic foams preparation of the Y123 phase has been reported [2] and can provide solutions for such problems. An alternative to foam-like structures would be to use a Y123 bulk with artificial holes already patterned [3]. This approach would allow a better reproducibility in the elaboration of the holes which would make accessible modelled experiments. In this paper we demonstrate that this latter approach can be used to obtain Y123 bulks exhibiting microstructures, textures and properties under magnetic fields similar to the usual bulks of the literature.

2. Experimental procedure

The Y123 ceramic samples were prepared from commercial powders. Y123, 25mol% Y211 and dopants 0.5wt% CeO_2 + 0.25wt%SnO_2 were well mixed and pelletized uniaxially and then sintered at 920°C during 24 hours. The formation of holes by a mechanical process, such as drilling, has been made. The holes were machined (0.5-1 mm) into the sintered bulk sample prior to melt processing. Details concerning the top seeding melt-texture growth process are given elsewhere [4]. The as-processed perforated samples were subsequently annealed in flowing oxygen at 450°C for 100 hrs. The texture characterisation was determined from XRD diffraction analysis using an experimental set-up and methodology detailed in a previous paper [5]. The sample was oscillating during the acquisition in order to increase the irradiated area up to several mm^2. The Orientation Distribution (OD) refinement was calculated using the Beartex program [6] and the {005/014/104} pole figures. Optical and scanning electron microscopies (SEM) were used to investigate the surface morphology. Additionally trapped field experiments were performed on polished samples with a Hall probe in order to verify the homogeneity of the samples and to investigate the field trapping capacity. The Hall probe measures the magnetic field in a 0.4 mm radius area approximately. Scanning steps of 0.2 mm in the 2 directions (x and y) were chosen. The sample was field cooled in liquid nitrogen with a NdFeB magnet of 15 mm diameter and 0.4T surface field.

3. Growth and microstructure

Optical micrographs of as-grown samples with 0.5 and 1 mm holes are shown in figure 1. Figure 1a shows the top surface of the formed single domains, grown from the Sm123 seeds. Seed-induced growth lines are visible up to the edge of the samples. The single domain growth occurs completely throughout the total height of the samples (Figure 1b) as was demonstrated previously using neutron bulk texture analysis [7]. The growth lines of faceted growth on the surface of the perforated single domain are clearly analogous to the ones observed on top-seeded melt-textured bulks processed in the same conditions but with no artificial holes. This shows that the pre-formed holes do not seem to disturb the growth of the monodomain, which is confirmed by the video of the melt growth process of other perforated samples prepared by X. Chaud et al. [8].

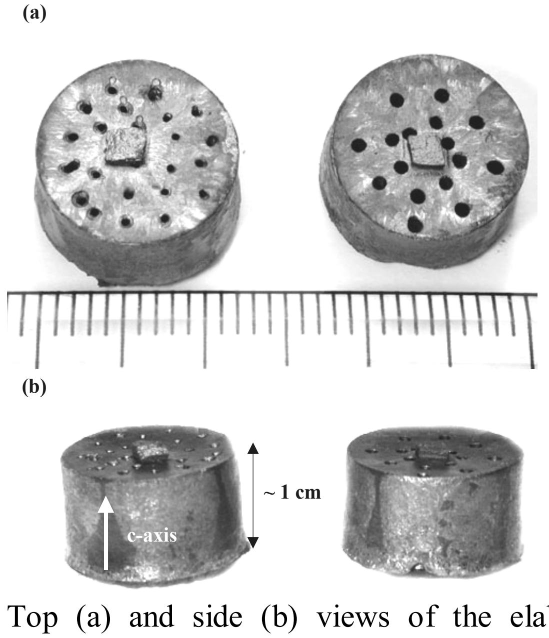

Figure 1. Top (a) and side (b) views of the elaborated samples. The averaged c-axis of the crystallite distribution is shown.

The preparation of the perforated samples can give rise to problems like microcrack induction during drilling of the pellets, but it seems that after melt processing there are no micropore-like defects in the microstructures. Indeed, the presence of holes in the sample seems to limit porosity around the holes in the bulk material. Figure 2 shows the typical microstructure of a single-domain of Y123 between two holes. One can clearly observe (i) the compact, free-of-crack microstructure and (ii) an uniform distribution of fine Y211 particles into the Y123 matrix.

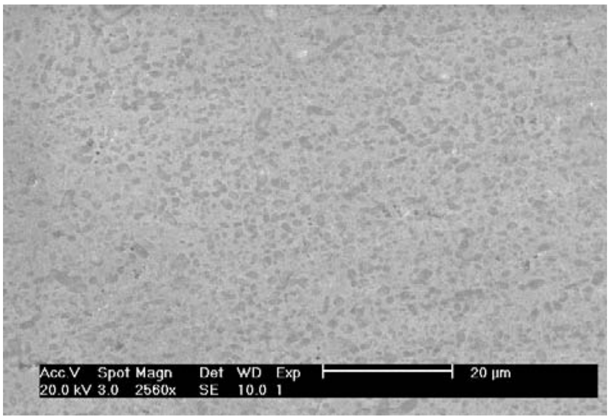

Figure 2. SEM microstructure corresponding to the area between 2 holes

4. Texture analysis

The {005/014/104} multipole figure, recalculated from the refined orientation distribution of the crystallites, is presented in Figure 3. This figure shows a very strong 005 pole at the center of the pole figure, with an orientation density 968 times stronger than the one of a random powder, indicating that the mean c-axis of the crystallites distribution is aligned with the cylinder axis of the samples. The 104/014 poles exhibit a single domain-like character showing the strong alignments of the **a** and **b** axes of the Y123 phase in the plane of the sample. These latter poles are however slightly elongated in azimuth, illustrating a small misalignment of **a** and **b** in the plane. A contribution which comes from a small domain can be seen at larger tilt angles. However, this component is lower than one percent in volume from the observed densities.

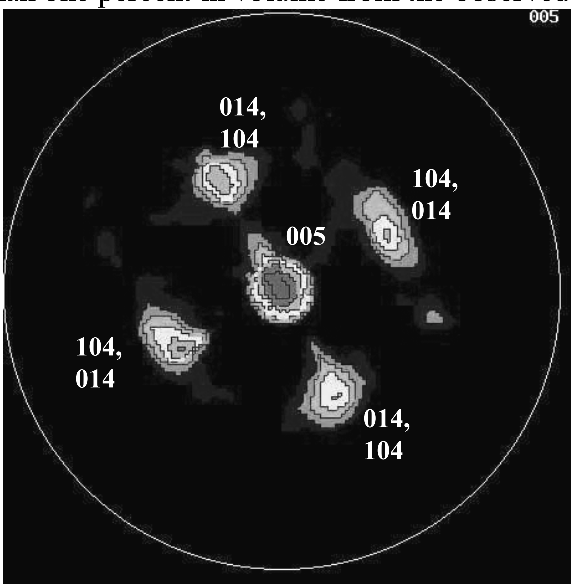

Figure 3. {005/104/014} multipole figure. Observe the single domain-like character of the sample. Schmidt projection, logarithmic density scale.

5. Trapped field

Figure 4 corresponds to the trapped field mappings at 77 K of a perforated sample (figure 4a) and of a reference sample (figure 4b), which has the same composition, same thermal treatment but without holes. The two perforated samples exhibit similar maps, indicating that there is no significant difference induced by the two hole sizes (0.5 and 1 mm) in these measurement conditions. Hence, only one map is represented. No clear effect of the holes on the trapped field can be evidenced from the mappings illustrated on figure 4: both have the same shape, with no fall of the trapped field around the holes. Note that mappings with smaller scanning steps have been performed around the holes and have given the same result. The trapped field value is similar in the 3 samples. Since the samples were cooled with a magnetic field of only 0.4 T, no optimal trapped field value can be given here. Field cooled under high fields must be performed to really compare the samples capacity in term of continuity and value of the trapped field. However, these measurements confirm that the perforated samples are homogeneous and that the hole presence has not affected the domains growth.

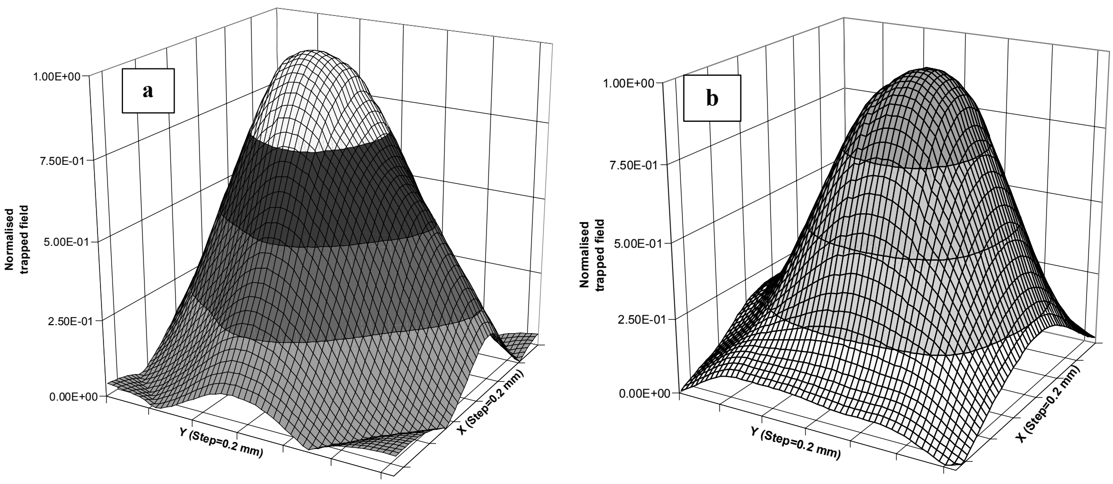

Figure 4. (a) Normalised trapped field (77K) of the perforated sample. (b) Normalised trapped field (77K) of the hole free sample.

6. Transport measurements

The temperature dependences of the resistance are shown (figure 5) for magnetic field up to 3 T applied parallel to the ab-planes and to c-axis respectively of the perforated textured material. The measurements show a transition temperature, $T_c(\rho=0) \approx 90$ K and a narrow transition width indicating the good homogeneity of the sample. The magneto-resistance curves show the high T_c when the magnetic field is applied in ab planes, corresponding to the strong pinning force in this case. We can deduce an anisotropy ratio confirming the texturation of the perforated structure sample correlated to the SEM microstructure observations, texture analysis and trapped field measurements.

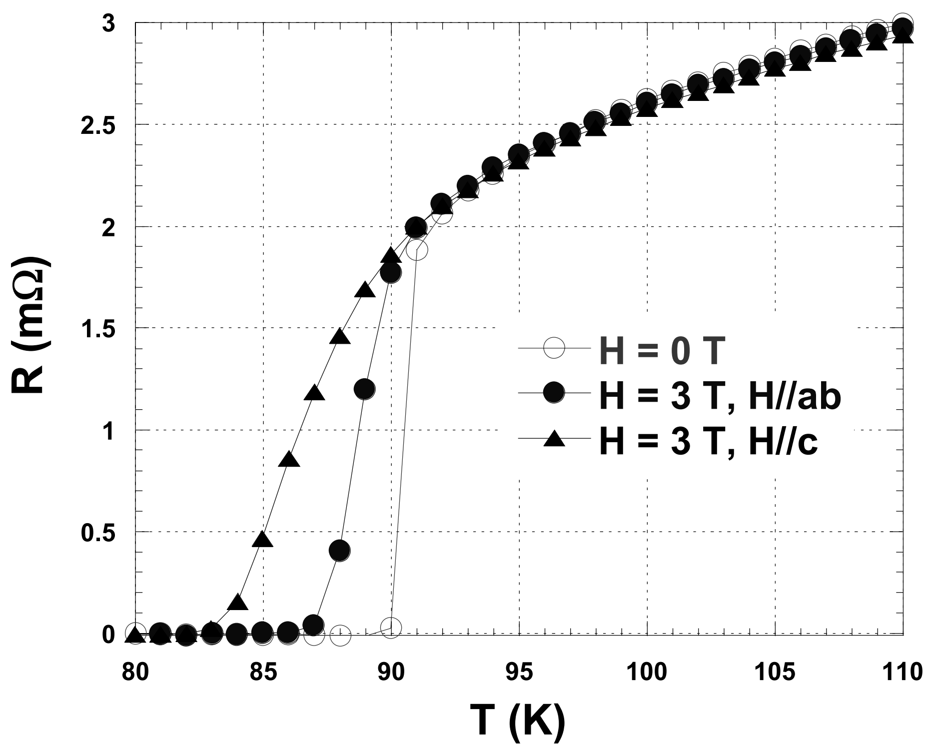

Figure 5. Temperature dependence of the resistivity of the perforated sample in magnetic field

7. Conclusion and outlook

In summary, top seeding melt textured Y123 bulks with an artificial pattern of holes have been processed and characterised. SEM studies have shown that the hole presence does not hinder the domain growth and that the classical microstructure is conserved. The perforated samples exhibit a c-axis grain orientation confirmed by pole figure and the single domain character is evidenced by trapped-field distribution and resistivity measurements. This new structure has a great potential for many applications with improved performances with respect to Y123 hole free bulks, since it should be easier to oxygenate, and to maintain at liquid nitrogen temperature during application, avoiding the hot spot apparition. Further investigations concerning oxygenation effect, transport-Jc measurements, maximum trapped field capacity and interconnected of regular holes are under way.

References

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