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DEVELOPMENT OF TEXTURED YBaCuO BULK WITH ARTIFICIALLY PATTERNED WALLS

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Abstract: The recently reported superconducting $YBa_2Cu_3O_y$ (Y123) *with artificially patterned holes* is highly interesting for improving the material quality and then promising a wide variety of applications. It is well known that the core of plain bulk superconductors needs to be fully oxygenated and the defects like cracks, pores and voids must be suppressed in order that the material can trap high magnetic field or carry high current densities. To minimise these defects, we have used the Top Seeding Melt Textured Growth (TSMTG) and Seed Infiltration Growth (SIG) to prepare the single domains of $YBa_2Cu_3O_y$ (Y123) bulk superconductors with multiple holes. The samples have been processed and the ability of this novel geometry as a superconducting magnet will be discussed. The thin wall bulk superconducting permanent magnet on extruded shape is also introduced.

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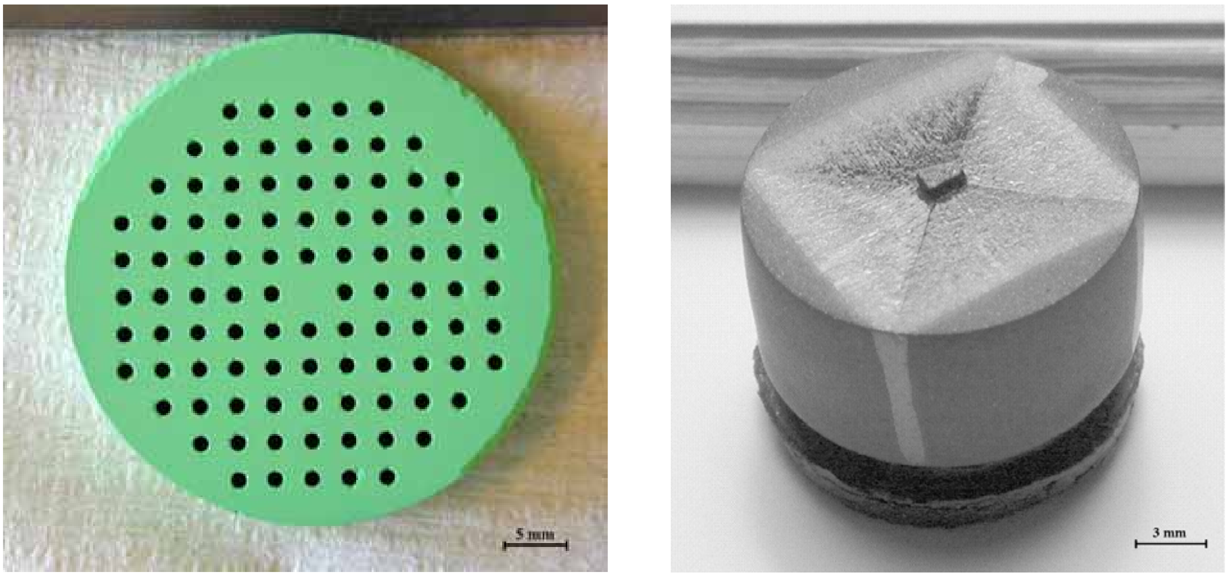
1. INTRODUCTION

Nowadays the batch [1,2] of textured $YBa_2Cu_3O_y$ (Y123) or GdBaCuO materials can be reproducibly processed. But, shaping the materials after processing without introducing cracks or defects remains one of the objectives to reach, in view to use the Y123 bulk ceramics in some devices for practical applications. It is well known that in the conventional melt processing [3,4], the Y123 phase is decomposed above its peritectic temperature, where it incongruently melts into solid Y_2BaCuO_5 (Y211) and liquid phases. The melting is accompanied by the liquid phase losses, a change in the sample dimensions such as shrinkage up to 25% [5] and cracks. The Seed Infiltration Growth (SIG) process [6-9], can be used to reduce the shrinkage and cracks into the bulk sample. On the other hand, the crystalline disorientations or chemical inhomogeneities at the grain boundaries create weak links. The grain boundaries should be also avoided for a practical use of Y123 materials. Therefore, the processing of single domains in Y123 bulk pellets by using Top Seeding Melt Texturing technique (TSMG) has been intensively developed [1,2,10,11].

In this paper, we report the preparation of Y123 bulks by using the SIG and TSMG-processes with a network of artificial holes. This new morphology seems to be an alternative way to obtain good mechanical properties/handling for the 2D Y123 fabric [12] or 3D Y123 foam [13] materials. On the other hand, Y123 material with holes can be a good candidate for increasing interfacial flux pinning if the pores can be made sufficiently small. Many other prospects are related to the holes structure like e.g. more efficient heat transfer, faster oxygenation and less microcracking, possibility of reinforcement and of interlocking connections, etc. The development of processing methods of the multi-holes textured Y123 with a high performance can open new pathways towards practical applications. In the framework of French national project, CRISMAT (CNRS), CRETA (CNRS) and CTI (Company) develop the thin wall bulk superconducting from extruded shape for portative permanent magnet applications.

2. EXPERIMENTAL PROCEDURE

The details of Seeded Infiltration Growth (SIG) and multiple holes process of $YBa_2Cu_3O_y$ (Y123) are reported elsewhere [13,17]. Basically, The $Y_2Ba_1Cu_1O_y$ (Y211) block or pellet is placed on top of the liquid phase ($3BaCuO_2 + 2CuO$) or $Ba_3Cu_5O_8$ (Y035) to allow the liquid infiltration driving by capillarity force. A $SmBa_2Cu_3O_y$ (Sm123) seed as a nucleation center is placed on the top of the Y211 preform. The holes into the preform are performed by drilling cylindrical cavities with diameter of 1 mm through the pellet. The holes are arranged in a regular network in the plane of the samples (Figure 1a). On the other hand, the thin wall and plain single domain of $YBa_2Cu_3O_y$ are grown by using the top seeding melt growth process. Details are given elsewhere [10]. The as-processed perforated and plain single domain samples are subsequently annealed in flowing oxygen. Optical and scanning electron microscopes (SEM) are used to investigate the surface morphology. Additionally, trapped field experiments are performed on polished samples with Hall probe system in order to cheek the homogeneity of the samples and to investigate the field ability. The Hall probe measures the magnetic field in a 0.4 mm radius area approximately. Scanning steps of 0.2 mm in both directions (x and y) are chosen. The bulk samples are previously magnetized at 2 T and at 77 K using Oxford Inc. superconducting coil.



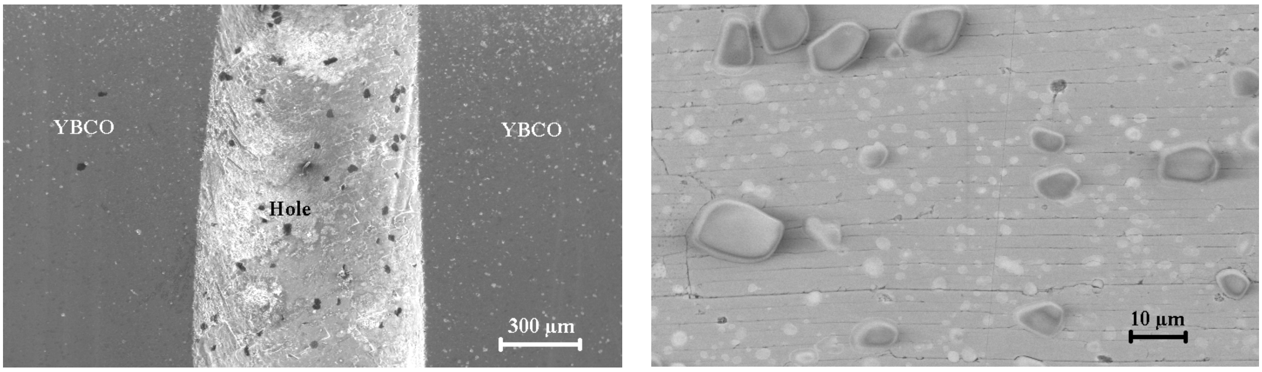
(a) **(b)**

Fig.1: **(a)** Top view of multiple holes (1 mm) Y211 preform. **(b)** Plain Y123 sample obtained from SIG-process

3. RESULTS AND DISCUSSION

A typical as-grown bulk sample obtained from SIG-process is shown in Figure 1b. The trace of the faceted growth on the surface reveals that a single-domain pellet has been successfully processed. The vertical shine trace on the side of the pellet demonstrates that the domain has grown along the whole thickness of the pellet.

The multiple holes Y211 pellets were transformed into the single grain by SIG and TSMTG-processed using the configuration described elsewhere [14]. Optical macrographs of as-grown samples with 0.8 mm holes are shown in Figure 2. It illustrates the cross sections of plain and perforated samples. The porosity is drastically reduced for the drilled sample. For the plain sample, a large porosity and crack zones are noticeable. The SEM observation between two thin walls (Figure 2a) shows *(i)* the compact, free-of-crack microstructure and *(ii)* an uniform distribution of fine Y211 particles into the Y123 matrix. The single domain character of the sample was evidenced by the flux mapping measurements. This was also used to verify the homogeneity of the samples and to investigate the field ability. The three-dimensional distribution of the trapped field (as shown in Figure 3) was scanned with Hall sensor at ~ 0.5 mm above the top surface of the sample magnetized at 77 K. The trapped field value is higher in the perforated pellet (580 mT) than in the plain one (440 mT). This represents an increasing of 32% for the drilled sample than for the plain one, in agreement with our previous report [10]. This increasing of the trapped field value is probably due to: *(i)* better oxygenation and/or less cracks and porosities in the thin wall sample as illustrated on Figure 2b, *(ii)* strong pinning because the walls of the holes could act in favour of the vortices penetration *(iii)* enhancement of the cooling because the sample with holes offer larger and better surface exchange into the liquid nitrogen.



(a) **(b)**

Fig. 2: SEM images of **(a)** perforated and **(b)** plain samples

The single dome obtained after the spatial distribution of trapped field is the clear signature of a single domain and this characterization demonstrates the current loops on the entire sample. These measurements also confirm that the presence of holes does not affect the grain growth because similar flux mapping characteristics are commonly obtained for the single MTG samples [10]. Another way to demonstrate the growth of single domain from the perforated structure has been reported elsewhere [14]. In this report [14], the lines of faceted growth on the surface of the half perforated single domain are not clearly observed but exists compared to the half plain part. This shows that the pre-formed holes do not seem to disturb the growth of the single domain, which is confirmed by the video [10,15] of the melt growth process of other perforated samples prepared by X. Chaud *et al.* [10].

Thin-wall geometry has been introduced to reduce the diffusion paths and to enable a progressive oxygenation strategy [16]. As a consequence cracks are drastically reduced. In addition, the use of a high oxygen pressure (16 MPa) speeds up further the process by displacing the oxygen–temperature equilibrium towards the higher temperature of the phase diagram. The advantage of thin-wall geometry is that such an annealing can be applied directly to a much larger sample during shorter time (72 hrs compared with 150 hrs for the plain sample). Remarkable results have been obtained by the combination of thin walls and oxygen high pressure. Figure 3 shows the 3D distribution of the trapped flux mapping measured at 77 K on the perforated thin wall pellet. The maximum trapped field value of 0.8 T is almost twice the one obtained on the plain sample (0.33 T).

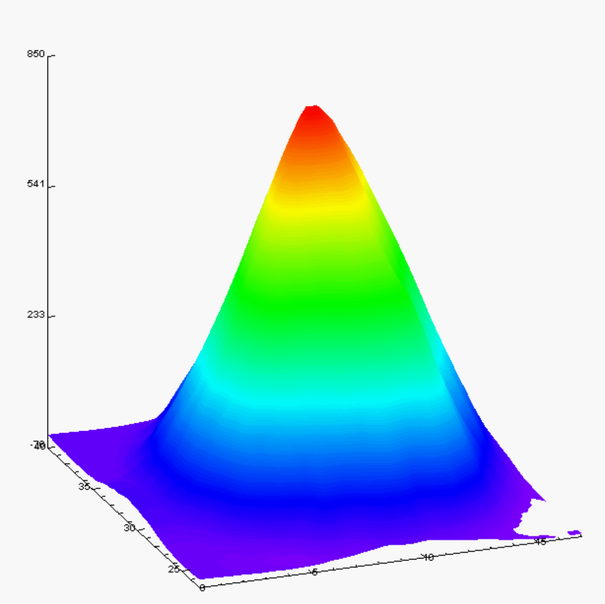


Fig .3: Flux trapped measurements of the high pressure oxygenated thin wall sample

4. OUTLOOK

Foams of conventional ceramic materials or porous structures, such as alumina and zirconia, are established components in a number of industrial applications such as filters, structures for catalysts, elements for thermal insulation and flame barriers. The combination of high specific surface with the ability to be reinforced in order to improve the mechanical and thermal properties makes the perforated YBCO superconductors interesting candidates for both: a variety of novel applications and fundamental studies. The artificial perforated Y123 bulks into desired structure [17], for example, could be a good candidates for resistive elements in superconducting fault current limiters. In this application, the low thickness of the wall between the holes allows more efficient heat transfer between drilled superconductor and cryogenic coolant during an over-current fault compared to the conventional bulk material. Superconducting bulks with artificial array of holes can be reinforced continuously with alloys [18] or high strength resins to improve their mechanical and thermal properties to overcome the forces encountered in levitation and quasi-permanent magnet applications.

Figure 4 shows the cross sectional view of the impregnated thin wall Y123 bulk sample. We can notice the dense and homogeneous infiltration of the wax epoxy across the hole.

In the frame work of French national project, the extruded shape of the thin wall YBCO is under development. Basically, from of Y_2O_3 and Y_2BaCuO_y preforms, the various shapes and multiple holes formed by extrusion (Figure 5) have been developed. The growth of single domain of thin wall Y123 using SIG process is underway.

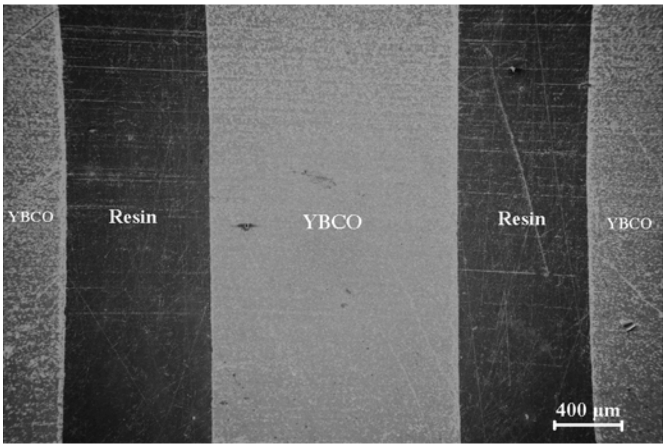
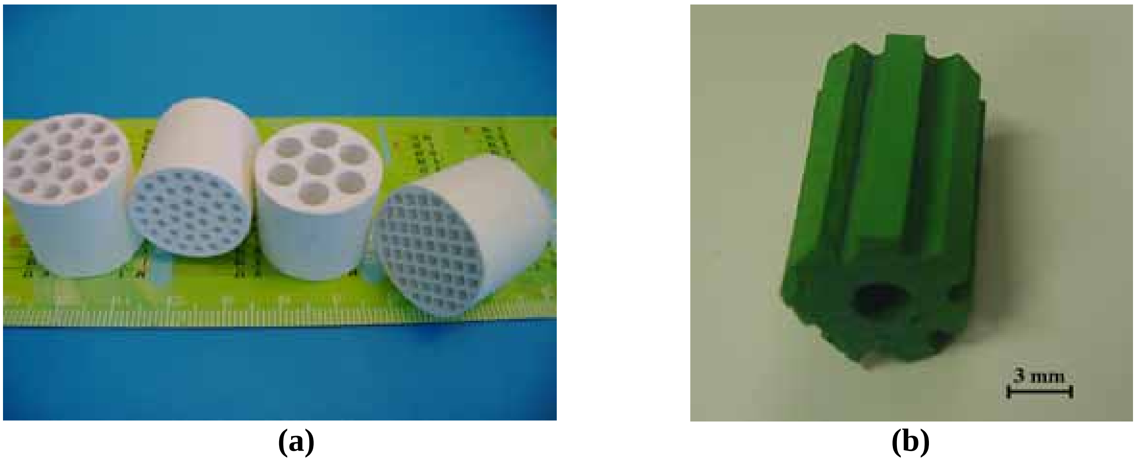


Fig.4: Reinforcement of the perforated sample: a view of cross section impregnated with wax resin



(a) **(b)**

Fig.5: Extruded **(a)**Y_2O_3 and **(b)** Y211 preforms showing various shapes and thin walls

5. CONCLUSION

Single grain Y123 superconductors have been grown by liquid infiltrating from a Y035 source into a Y211 preform. The infiltration-growth method allows processing of Y123 single domain, with a homogeneous distribution of Y211 into the Y123 matrix.

The textured Y123 bulks with multiple holes have been processed and characterized. SEM investigations have shown that the holes presence does not hinder the domain growth. The perforated samples exhibit a single domain character evidenced by single dome trapped-field distribution. This new structure has a great potential for many applications with improved performances in place of Y123 hole free bulks since it should be easier to maintain at liquid nitrogen temperature during application, avoiding the hot spot apparition. It is clear that, the Y123 bulks with an artificial pattern of holes are beneficial to evacuate porosity from the bulk and to uptake the oxygen.

The ability of the Y123 material with multiple holes to trap a high field has been demonstrated. Using high pressure oxygenation, the trapped field increases up to **0.8 T at 77 K** for the thin wall pellet corresponding to **50% larger** than the bulk material without holes. The thin wall bulks superconducting on extruded shape for portative permanent magnets are under development.

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