

## **Multi-domain Bulk Y-Ba-Cu-O with Artificial Holes for Non-contact Torque Transfer Applications**

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**Abstract-** Bulk Y-Ba-Cu-O multi-domain superconductors have been fabricated with the aim of potential superconducting torque transferring applications. Cold top-seeded melt growth process has been employed for producing multi-domain bulk superconductors in that artificial holes were mechanically introduced into the precursor added with PVA liquid binder. Four-domain bulk Y-Ba-Cu-O superconductors with artificial holes could be obtained at the maximum temperature of 1058°C when MgO-doped Nd123 seed crystal was used.

### **I. INTRODUCTION**

We have been developing a novel machine so-called non-contact superconducting mixer by which rotational torque can be transferred from a driving motor to a rotating shaft in a closely packed vessel without any contact. This novel machine mainly relies on the superconducting torque coupling mechanism for which a bulk superconductor plays a key role of levitation and suspension in combination with permanent magnet. In operation, a driving motor attached with permanent magnets will suspend a bulk superconductor apart from the ground, and the levitated bulk superconductors will also suspend the permanent magnets floating in a mixing vessel. We apply multiple magnetic poles in both top and bottom permanent magnets facing the top and bottom surfaces of a bulk superconductor. When we turn on the driving motor, rotational torque can be transferred without mechanical contact. Therefore, we need a bulk superconductor which offers strong coupling torque force enough for practical applications. A single-domain melt-grown bulk superconductor demonstrates high field trapping ability and thus a strong coupling torque force. For engineering applications we need bulk superconductors of 60 mm in diameter that is larger than the size of 20-40mm commonly produced on a laboratory scale. However, a single-domain bulk superconductor larger than 60

mm in diameter is rather difficult to fabricate, and therefore large-sized bulk superconductors are quite expensive in the commercial market. For practical applications, the cost is always an important factor for the commercialization of novel machines, which should be borne in mind when researchers and engineers looked for technological innovation.

We have been involved in developing the melt-process of bulk high temperature superconductors, so that bulk superconductors compromise their quality and performance with production time and cost. We noticed that for superconducting torque transferring applications, a large single-domain bulk is not necessary since it faces multiple-pole magnet configurations, in that a single-domain traps multi-pole magnetic field [1]. We then started to fabricate multi-domain bulk superconductors with the domain arrangement reflecting the coupled permanent magnet configuration. Through the optimization of the melt processing parameters, we could produce four-domain bulk Y-Ba-Cu-O superconductor 62mm in diameter that exhibited comparable performance with a single domain bulk, the details of which can be found elsewhere [2].

For large bulk samples, full oxygenation is often difficult due to the fact that oxygen diffuses along the *a-b* plane, and thereby it takes a long time for full oxygenation of large-diameter samples. Cracking is often found in large samples after oxygen annealing due to the thermal stress within the grain in addition to the mechanical cracks caused by the handling process [3-5]. The green compact of a bulk superconductor is very brittle since it is simply compressed pack of raw powders. We have found that the addition of liquid PVA binder to the precursor is effective in improving the strength of the green compact. In addition we could mechanically introduce several holes into the green compact without cracking. Introducing holes into a bulk superconductor is known to reduce the amount of cracking [6, 7]. The PVA binder addition however may affect the optimal growth conditions of bulk superconductors, so that we need to optimize the melt processing parameters for binder-added superconductors. We then studied the melt processing parameters for the fabrication of large bulk Y-Ba-Cu-O samples added with CeO<sub>2</sub> and PVA liquid binder with introducing several artificial holes.

## II. EXPERIMENTAL

The optimum melt processing conditions including the growth window temperature for Y-Ba-Cu-O 20 - 40 mm in diameter were systematically studied by Hinaï *et.al.* [8]. Since we are fabricating larger bulk Y-Ba-Cu-O superconductors added with PVA liquid binder, the melt processing parameters should be re-scheduled to optimize the growth mode. In this study, the mixture powders was prepared from homemade Y123 and Y211 powder in a molar ratio of 10:4 added with CeO<sub>2</sub> powder of 1wt%. After mixing raw powders for two hours, we added PVA aqueous solution of 1 wt% and mixed using a mortar and pestle for another two hours. The well-mixed powders were pressed

into the pellets 75 mm in diameter and 15 mm in thickness by uniaxial pressing at 50 MPa. Then the holes of 1 mm diameter were drilled into the green compact in prior to melt processing. For the de-binding process, the samples were subjected to the heat treatment in a box furnace at 600°C for 24 hours with a rather slow heating rate of 10°C/hr. Then the samples were slowly cooled to room temperature at the rate of 10°C/hr. After finishing the de-binding process, the samples were moved from the furnace and visually checked to see the presence of any major cracks. The de-bindered samples were then placed on an Al<sub>2</sub>O<sub>3</sub> plate with Y<sub>2</sub>O<sub>3</sub> and BaCuO<sub>3</sub> powder buffer layers. Four seeds of Nd123 were positioned on the top surface of the precursor before subjecting to the melt process. The melt processing conditions that we designed in this study were heating at a rate of 100°C/hr to the maximum temperature of 1050-1060°C and kept for three hours; rapidly cooled to 1015°C in 30 minute and kept at this stage for one hour; followed by slow cooling at a rate of 0.25°C/hr to 960°C; and cooling down to room temperature a rate of 100°C/hr. The as grown bulk samples were subjected to oxygen annealing treatment in flowing oxygen at 400°C for 160 hours. The surface morphologies of finished bulk samples were observed with an optical microscope to study the growth mode and the presence of any appreciable defects like cracking.

### III. RESULTS

Figure 1 shows the optical micrograph of bulk Y-Ba-Cu-O sample fabricated at the maximum temperature of 1050°C with generic Nd123 seeds.



Fig.1 Bulk Y-Ba-Cu-O sample melt-processed at the maximum temperature of 1050°C using Nd123 seeds, exhibiting polycrystalline structure.

The sample exhibited polycrystalline structure, and its surface morphology suggested that the maximum temperature was lower than the optimum according to the study reported by Hinai *et. al* [8]. We then slightly shifted the maximum temperature from 1050°C to 1055°C and performed melt processing again. Figure 2 shows the sample morphology melt-processed at the maximum temperature of 1055°C.



Fig.2 Bulk Y-Ba-Cu-O sample melt-processed at the maximum temperature of 1055°C using Nd123 seeds. Grains grew larger but the Nd123 seeds were dissolved.

The sample morphology of this sample revealed that melt processing parameters were not optimal yet. One can see that Nd123 seeds were dissolved at this temperature and thereby the grain growth could not be established in a good orientation. Moreover, the nucleation of small grains was also observed in the locations without seeds crystals, implying incomplete decomposition of the precursor.

To promote complete decomposition, it is necessary to increase the maximum temperature. However, Nd123 seeds were dissolved even at 1055°C. We then employed MgO-doped Nd123 seeds whose decomposition temperature is higher than pristine Nd123 by about 10-15°C [9, 10] and raised the maximum temperature to 1058°C.

Figure 3 demonstrates the surface morphology of bulk Y-Ba-Cu-O fabricated at the maximum temperature of 1058°C with MgO-doped Nd123 seeds. The surface morphology reveals four domains fully established in the entire bulk.



Fig.3 Bulk Y-Ba-Cu-O sample melt-processed with the maximum temperature of 1058°C using MgO-doped Nd123 seed crystals. One can see that four domains were fully grown in the entire bulk.

#### IV. SUMMARY

We have studied the optimal melt processing parameters for the fabrication of four-domain bulk Y-Ba-Cu-O samples that can be used for superconducting torque transferring mechanism. We have found that optimal maximum temperature in the cold-seeded melt-growth process was higher than 1055°C for relatively large green compact 75mm in diameter. Hence we used MgO-doped Nd123 seed crystals whose decomposition temperature was higher than that of Nd123 by about 10-15°C. We have then succeeded in fabricating four-domain Y-Ba-Cu-O bulk sample 62 mm in diameter added with 1wt% CeO<sub>2</sub> and 1wt% PVA liquid binder for which several holes could be introduced prior to the melt process without any damage.

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