Recent Progress in Melt Processed (RE)BCO HTS

David A. Cardwell*, Yun-Hua Shi, Nadendla Hari Babu, Anthony R. Dennis, John H. Durrell and Mark D. Ainslie

(Department of Engineering, University of Cambridge, Trumpington Street, Cambridge, CB2 1PZ, UK)

(RE)-Ba-Cu-O [(RE)BCO, where RE = rare earth element such as Y, Nd, Sm, Eu, Gd, etc.] high temperature superconductors (HTS) have significant potential for high field engineering applications at 77 K when fabricated in the form of large single grains by the so-called top seeded melt growth process (TSMG). A novel Y$_2$Ba$_4$CuM$_y$O$_{y+7}$ (Y-2411, where M = U, Zr, Hf, Nb, Ta, W and Mo) phase that is effective at pinning magnetic flux quanta in bulk (RE)BCO HTS on the nm scale has been developed recently at Cambridge with a number of desirable properties, including crystallographic compatibility with the superconducting (RE)Ba$_2$Cu$_3$O$_7$ (RE-123) phase, chemical stability at the melt processing temperature and an ability to resist coarsening during the melt process. This novel phase, which is more effective at pinning flux than the RE$_2$BaCuO$_5$ (RE-211) phase produced as a by-product of the melt growth process, has been used to the development a practical processing method for the fabrication in air of large, single grain RE-Ba-Cu-O superconductors. The process also includes a new type of generic seed crystal (Mg-doped NdBCO) that can promote effectively the epitaxial nucleation of any (RE)-Ba-Cu-O system and secondly by suppressing the formation of (RE)/Ba solid solution in a controlled manner within large (RE)BCO grains processed in air. This process has enabled fabrication of single grain samples of GdBCO that exhibit a record trapped field of 17.6 T at 26 K, as shown in Fig. 1 [1]. The recent development of multi-seeding techniques for the fabrication of larger sample of conformal geometry has improved further the prospects of these technologically important materials for practical applications, which will also be presented.


Figure 1. Record trapped field of 17.6 T at 26 K in a bulk GdBCO sample of diameter 2.5 cm.
Large, single grain YBa$_2$Cu$_3$O$_{7-x}$ bulk superconductors fabricated by seeded infiltration and growth

Namburi Devendra Kumar*, Yunhua Shi, A R Dennis and David Cardwell

Department of Engineering, University of Cambridge, Cambridge, UK

(RE)-Ba-Cu-O bulk high temperature superconductors fabricated in the form of large, single grains have considerable potential for various engineering applications based on their ability to trap large magnetic fields at technologically achievable temperatures. Top Seeded Melt Growth (TSMG) is an established processing technique for fabricating large, single grains of (RE)BCO that exhibit superior superconducting properties. However, this process often results in defects in the fully processed bulk, including shrinkage and macro-cracks in the sample microstructure. In this context, the so-called seeded infiltration and growth (SIG) process emerged as a viable alternative to TSMG. However, the growth of large single grains of (RE)BCO by this technique is difficult due to various complexities associated with the growth process itself. We have extended a recently developed method for the reliable fabrication of single grains of YBCO of up to 40 mm in diameter to include SIG, which we report in this study. The potential of various liquid phases to aid the growth of the Y-123 phase has been investigated in detail. The microstructures and superconducting properties of the YBCO bulk samples processed by SIG are compared with the properties of samples fabricated by conventional TSMG and the results discussed.
Large single grain YBCO bulk superconductors with artificial holes

C.-J. Kim, B.-H. Jun and S.-D. Park

Neutron Utilization Technology Division, Korea Atomic Energy Research Institute

Large single grain YBCO bulk superconductors with artificial holes were fabricated using a top-seeded melt growth (TSMG) process for the powder compacts with artificial holes. The special dies with a disc- or rectangular shape were designed for perforation. The artificial holes were successfully made for YBCO powder compacts without use of organic binders. No cracks were developed during die pressing. The single grain YBCO bulk superconductors with artificial holes showed the higher magnetic levitation forces and the higher magnetic flux density at 77 K than those of YBCO without artificial holes. The microstructure investigation showed that the number of pores around the artificial holes was smaller than that of the regions far from the artificial holes. The artificial holes are likely to act as effective diffusion channels of oxygen atoms during melt growth and oxygenation process.
Magnetic Field Uniformity in the Space between Face-to-Face HTS Bulk Magnets for NMR Application

T. Oka *, 1, Y. Takahashi1, T. Kanai1, J. Ogawa1, S. Fukui1, T. Sato1, K. Yokoyama2, T. Nakamura3
(1 Niigata University, 2 Ashikaga Institute of Technology, 3 RIKEN)

In order to develop the novel practical application for the nuclear magnetic resonance devices (NMR), a characteristic experimental trial has been carried out to achieve the uniform magnetic field distribution in the space between the face-to-face HTS bulk magnets. The magnetic poles were activated as 1.8 T (N) and 1.4 T (S) at 30 K by applying the pulsed magnetic fields up to 7 T, and settled face-to-face with the gaps less than 70 mm. Since the HTS magnet gives us the “cone-shape” distribution of the magnetic fields, the data become weak and uniform with increasing the gap. The uniformity required for detecting the NMR signals was less than 1,500 ppm at more than 0.3 T in the 2 x 2 mm² cross sectional plane between the magnetic poles. In this condition, highest uniformity of 3,500 ppm at 0.57 T was obtained in the 60 mm gap. Then we attached a ferromagnetic iron plate to a magnetic pole surface to change the distribution to “M-shape”, in which the peak was suppressed lower than those around it. The best uniformity of 358 ppm at 1.11 T was obtained at 9 mm distant from the iron plate surface in the gap 30 mm, which is available to detect NMR signals. When we estimated the magnetic field uniformity by the FEM calculation program which was operated with use of the compensation coil attached at the surface centre of the magnetic pole, the uniformity reached the lowest data of 30 ppm. It is inferred that the concave magnetic field distribution was compensated by the counter cone-shape field, resulting in the uniform field plane.
Critical Current Densities in Ag-added Bulk MgB$_2$

Muralidhar Miryala$^{*1}$, Kazuo Inoue$^1$, Michael R Koblischka$^2$, Masato Murakami$^1$

$^1$Superconducting Materials Laboratory, Department of Materials Science and Engineering, Shibaura Institute of Technology, 3-7-5 Toyosu, Koto-ku, Tokyo 135-8548, Japan

$^2$Experimental Physics, Saarland University, Campus C 6 3, 66123 Saarbrücken, Germany

Abstract: In the former studies, we found that the bulk MgB$_2$ contained numerous voids in various shapes and sizes. With the aim of improving the critical current density as well as the mechanical performance of disk-shaped MgB$_2$ bulk superconductors, we added Ag and optimized processing conditions. The samples with varied Ag content from 0, 2, 4, 6, 8, and 10 wt% were synthesized in pure Ar atmosphere. Microstructural observation with scanning electron microscopy confirmed that metallic Ag particles are embedded in the void regions, which will lead to the improvement of the mechanical performance. Furthermore, the critical current density ($J_c$) values were also improved with Ag addition as compared to pure MgB$_2$ bulk. The sample with 4 wt% Ag addition exhibited the highest $J_c$ of 293 kA/cm$^2$ at 20 K and self field. The respective $J_c$ values at 10K were 400 kA/cm$^2$, 300 kA/cm$^2$, and 100 kA/cm$^2$ in self field, 1T and 2T (see Fig. 1). These values are the highest records so far reported in bulk MgB$_2$ materials.

![Fig. 1. Field dependence of the critical current density (10 – 30 K) for MgB$_2$ sample with 4wt% Ag, sintered at 775 °C.](image)
Tri-axial Magnetic Alignment in ErBa$_2$Cu$_4$O$_8$ Cuprate Superconductors

Shigeru Horii*,1, Momoko Yamaki2,**, Toshiya Doi1
(1Kyoto University, 2Kochi University of Technology)

In high-$T_c$ superconductors with anisotropic crystal structure and weak link at grain boundaries, an increase in the misorientation angle between two grains leads to a serious decrease in intergrain critical current density ($J_c$) even for $c$-oriented materials. Therefore, both formation of a $c$-axis oriented microstructure and alignment of grains along the $a$- and $b$-axes directions are required for improvement of their $Jcs$. Magnetic alignment using a modulated rotation magnetic field (MRF) is a novel crystal arrangement method which realizes tri-axial crystal orientation at room temperature without epitaxial growth. In the magnetic alignment, magnetic anisotropy in materials is one of the most important factors for determining degrees of orientation and orientation axes.

In the present study, we focused on twin-free ErBa$_2$Cu$_4$O$_8$ (Er124) as an appropriate RE124 for the fabrication of tri-axially aligned cuprate ceramics from viewpoints of magnetization axes and tri-axial magnetic anisotropies. Moreover, influence of viscosity on the degrees of orientation should be taken into account in the case of MRFs induced by rotation control of “samples”. Using slurry containing fine Er124 powders, we attempted to fabricate Er124 green compacts aligned under two different MRFs shown in Figure 1; unidirectional rotation type and oscillation type.

Er124 single crystals were grown by the flux method under ambient pressure[1]. Er124 crystals were ball-milled and were mixed in ethanol as dispersd medium with poly-vinyl-butyral (PVB). Note that PVB was added in various concentrations ($x = 5\sim20$ wt.%) to control viscosity ($\eta$) of the slurry. Thus prepared slurry was slip-casted or dried in the two different MRFs of $\mu_0 H_a = 1$ or 3 T. The degrees of orientation of the obtained green compacts were evaluated from the pole-figure measurements for (017) peaks using CuK$\alpha$ radiation.

As a result of the present study, we found that the degrees of tri-axial orientation in ErBa$_2$Cu$_4$O$_8$ (Er124) green compacts aligned in MRFs depended on average diameter of pulverized Er124 powers, type of MRF, magnetic field, and viscosity of slurry. At the current stage, the degree of inplane orientation with $10^\circ$ in Er124 was achieved by rough optimization of these parameters.

This work was partly supported by the Grant-In-Aid for Scientific Research (24550236) from JSPS, Nippon Sheet Glass Foundation for Materials Science and Engineering and Iwatani Naoji Foundation.

**) current address: JECC TORISHA Co., Ltd., 2-8-52, Yoshinodai, Kawagoe, Saitama 350-0833, Japan

Figure 1. Two different rotation types as generation methods of MRF; (a) unidirectional rotation type and (b) oscillation type.