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Processing and Characterisation of Bulk Melt-Textured YBCO Monoliths and Function Elements

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Abstract

Melt-textured YBCO in high quantity and good quality is prepared in a batch process. A mean trapped field >1.1T at 77K is achieved in batch processed material. Studying the microstructure is a necessary tool to understand the growth mechanisms and thus to opimise the material. From the growth induced structures in the material the anisotropy in growth speed is 1.37. From batch processed material function elements for different cryomagnetic applications are constructed. Motors with an output power >200 kW at 77 K and bearings that can lift more than 200 kg were equipped with melt-textured YBCO.

Keywords : Melt-textured YBCO, magnetic characterisation, magnetic bearing, motor

I. YBCO Batch Processing

Melt-textured YBCO in reproducible material properties and in high number of pieces are prepared by a well established IPHT–batch-process [1]. From this material function elements for different cryomagnetic applications are constructed. As starting material we use commercially $YBa_2Cu_3O_{7-x}$ powder (Solvay). Y_2O_3 and CeO_2 [2] powder to a standard composition of $Y_{1.5}Ba_2Cu_3O_{7-X}$ + 1wt.% CeO_2 are added. No further chemical doping is deployed.

For one batch 2~3 kg thoroughly mixed precursor powder is pressed uniaxial to cylindrical, quadratic or rectangular shaped compacts with sizes up to 90 mm. The compacts are processed in a modified melt-textured growth process [3]. We place the blocks in a six sides heated and controlled furnace with quasi isothermal temperature distribution that guarantees identical growth conditions of each YBCO block. Routinely we fabricate reproducible dependent on the size up to 30 cylindrical, 16 quadratic or 8 rectangular YBCO blocks per batch (Fig. 1).

For monoliths up to 60 mm size a $SmBa_2Cu_3O_x$ seed is placed in the middle on the top of the sample for larger monoliths we apply a multi-seeding technique.

By a separate procedure the oxygen annealing treatment takes place in a gastight furnace. In this furnace more than 100 YBCO monoliths are placed in flowing oxygen. The SmBCO seed preparation was optimised and rationalised [4]. At first single grain SmBCO bulks (ø 20 mm) with a starting composition of $Sm_{1.5}Ba_2Cu_3O_{7-X}$ are grown by an MTG process in air using MgO as seed. After oxygenation the single grain bulk is cleaved along the a-b-plane in discs with a thickness of 2 mm. After checking the crystal orientation the SmBCO disc is cut into a multitude of seeds. Thus about 100 SmBCO seeds with a size of about 2 × 2 × 2 mm^3 are achieved per monolith with reproducible quality, uncomplicated and cost-efficient (Fig. 2).

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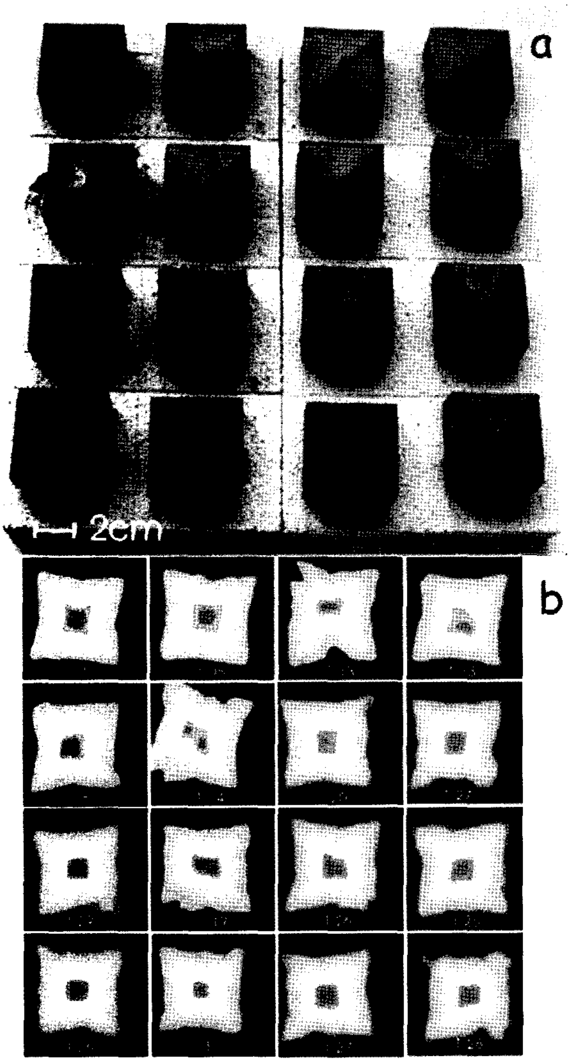

Fig. 1. Batch of melt-textured YBCO. a): Photo taken after texturing process. b) Trapped field distribution.

Precursor, seed-material, melt-texturing, and oxygennation have to be adapted to each other for high quality material with reproducible properties.

II. Structures

The micro-structure of single domain YBCO material is not homogeneous. Scanning electron microscopy and especially polarisation microscopy [5,6] are used for investigations of cracks, inclusions, oxygen content and other features. The size and the distribution of the 211 inclusions are influenced by precursor material and the temperature program during melt-texturing. The crack density and distribution also depends on the precursor but also on the oxygen annealing.

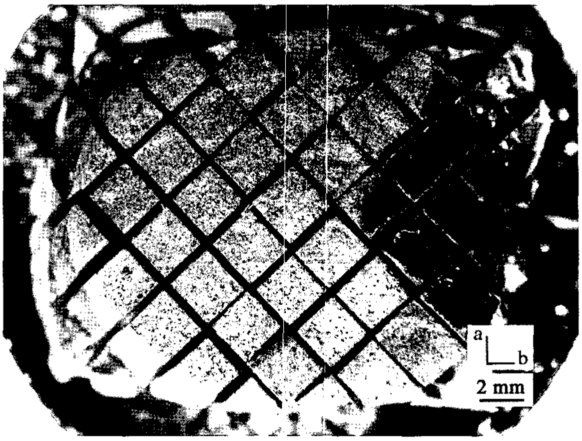

Fig. 2. Melt-textured SmBCO cut for seeds.

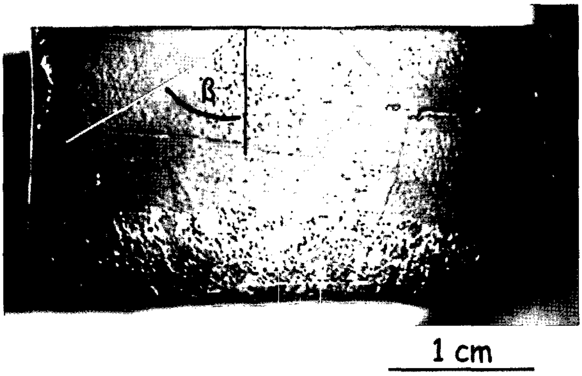

Fig. 3. Growth sectors in melt-textured YBCO. From the angle ß the anisotropy of the growth speed can be calculated.

Another feature in single domain material are so-called growth sectors [5]. In polarised light the sectors are visible (Fig. 3). The density of 211-inclusions within the sectors is different, so there is a contrast. Due to the different micro-structure of the sectors other properties like current density differ from a- to c-sector.

The border-line between a-sector and c-sector is defined by the growth mechanism. The angle ß between the border line and the c-axis of the monoliths gives the ration of the growth rate:

tan ß = v_a / v_c, v_a is the growth speed in a-, v_c the growth speed in c-direction.

In Fig. 3 the angle is defined. This monolith shows ß = 54°. Thus $v_a = 1.37\ v_c$. In contrast to single crystals the growth of melt-textured material is nearly isotropic.

III. Magnetic Characterisation

The increased production rate of melt-textured YBCO needs an adapted characterisation technique. Magnetic characterisation is suitable both for quality control and for detailed investigations. Fig. 1 presents a batch of 16 quadratic YBCO monoliths directly after melt-texturing. Each block was characterised by integral levitation force at 77 K (SmCo magnet ø = 25 mm, distance 0.5 mm) and field mapping. For the field mapping the monoliths were cooled in a field of about 2 T at 77 K. After switching off the field and a delay time of 30 s the trapped magnetic field is detected by scanning the surface with hall sensors in a distance of 0.6 mm. The results in Fig. 1 show, that single domain monoliths are prepared reproducible. In this batch a mean maximum induction from 1.21 ± 0.07 T was achieved. Routinely a mean peak induction from 1.1 T to 1.2 T are reached and guaranteed in a batch. Peak maximum induction values > 1.4 T for quadratic single domain YBCO monoliths were trapped at 77 K (Fig. 4).

A trapped magnetic field of 2.5 T at 77 K was measured between two single domain monoliths in a gap of 1.5 mm. In every single domain block a maximum induction of 1.3 T at 77 K was frozen. Figure 5 shows the relaxation for different activation fields. The activation field of 2.5 T did not saturate the mini-magnet arrangement. For higher activation fields the well known exponential relaxation is observed.

Levitation force measurements are strongly dependent on the experimental set-up. In levitation applications, for example fly-wheels, high forces and high stiffness are requested. For example combinations of iron and permanent magnets can be used. They may smooth magnetic inhomogeneities and create of steep magnetic field gradients. Figure 6 and 7 show the comparison of field mapping and levitation force measurements with a sampler unit with three poles and a maximum induction of about 1 T on the middle pole. Sample A is single domain, sample B is multi-domain material. Even the material is different, the levitation forces (zero field cooled) are nearly identical. The maximum force that can be achieved is defined by the permanent magnets. It is given by measuring repulsive forces between identical magnets. This experiment represents a

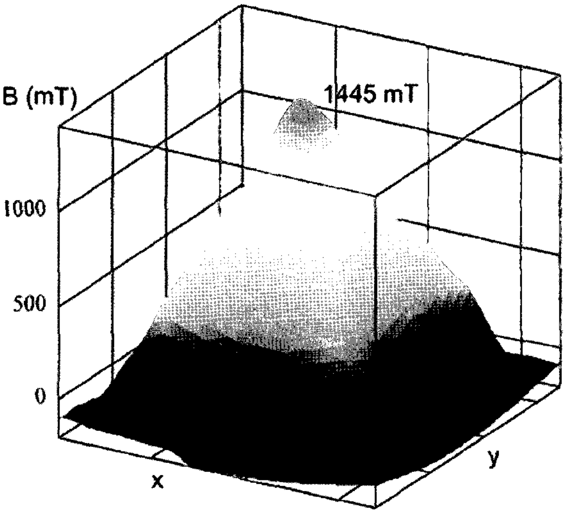

Fig. 4. Trapped field distribution of a single domain YBCO monolith at 77K.

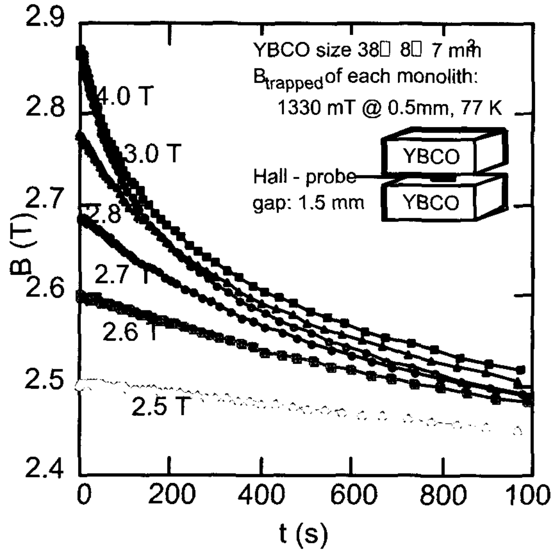

Fig. 5. Trapped field measured between two YBCO monoliths at 77K.

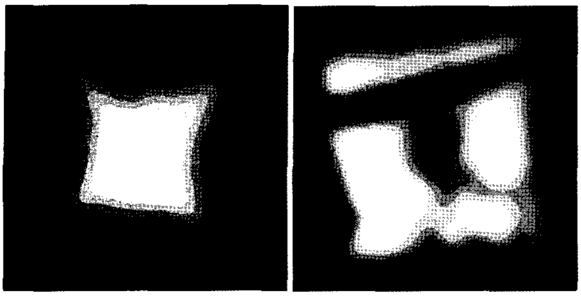

Fig. 6. Trapped field of a single domain (left) and a multi-domain monolith (right) at 77K.

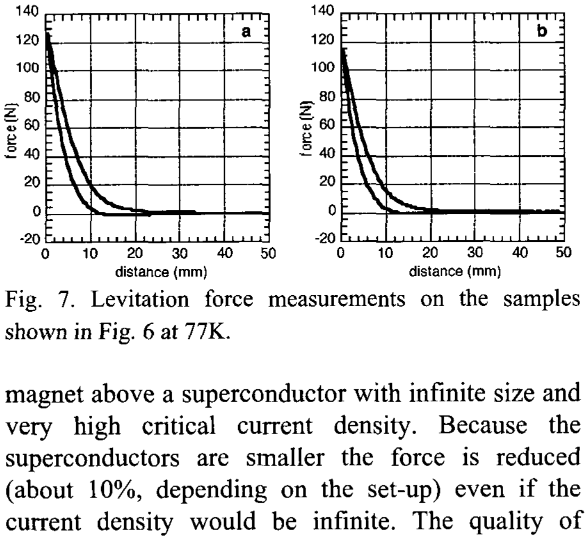

Fig. 7. Levitation force measurements on the samples shown in Fig. 6 at 77K.

magnet above a superconductor with infinite size and very high critical current density. Because the superconductors are smaller the force is reduced (about 10%, depending on the set-up) even if the current density would be infinite. The quality of melt-textured material even if it is not single domain was good enough to achieve about 80% of this limit. Single domain material at 77K reaches about 85-90% of the maximum force.

The comparison was made to demonstrate difficulties in the quality control.

IV. Applications

Function elements for HTS electric motors, magnetic bearings and levitation systems are constructed from batch processed YBCO. The function elements were prepared in several working steps. Corresponding to different requirements of the applicaton YBCO blocks were cut, machined and partly bonded with a special epoxy adhesive. Precision machining to the final dimension and passivation by paraffin vacuum impregnation against moisture completes the construction.

We constructed a levitation system that can stabilise more than 200 kg in a gap of 2 cm and so persons can levitate. During several exhibitions and shows the system was presented and tested by several 100.000 visitors. More than 200 times it was cooled and warmed up in air and it still operates. Thus we can demonstrate the long-term stability of our YBCO material.

For a Russian MAGLEV demonstrator we manufactured YBCO monoliths with a trapped field at 77K > 1.0 T. About 40 kg superconducting material levitates a vehicle for two persons with a weight of more than 200kg above a rail made of NdFeB permanent magnets. The air gap between rail and vehicle is 6 cm, the distance between rail and superconductor about 10 cm [7].

In co-operation with German industry and research institutes a demonstrator with a stored energy of 10 kWh will be realised for the fly-wheel system “DYNASTORE”. This fly-wheel energy storage system will be tested for local energy tuning of the electrical grid. Our tasks are to optimise the material for minimised bearing losses and to prepare material for the demonstrator. We prepared 100 single domain quadratic YBCO monoliths with a trapped field > 1.1 T. These blocks were cut to the final shape, then characterised with a field-cooled integral levitation force similar to the operation in the bearing.

Between 2000 - 2002 we equipped 11 HTS electric motors with YBCO rotor elements. For these elements in different size and design 600 melt-textured monoliths with a total weight of 80 kg were used. Figure 8 shows YBCO rotor plates used for a 200 kW HTS reluctance motor (Oswald Elektromotoren GmbH). Several reluctance motors with function elements of single domain YBCO were designed, built and tested at the MAI Moscow, Oswald Elektromotoren GmbH Miltenberg and IEH of the University Stuttgart. At the MAI Moscow a HTS reluctance motor with an output power of 150 kW (3000 rpm) at 77 K was achieved [8]. The Oswald Elektromotoren GmbH realised a HTS reluctance motor with an output power more than 200 kW (3000 rpm) at 77 K [9]. Plates made from melt-textured YBCO for this motor are shown in fig. 8. In comparison to conventional motors the HTS

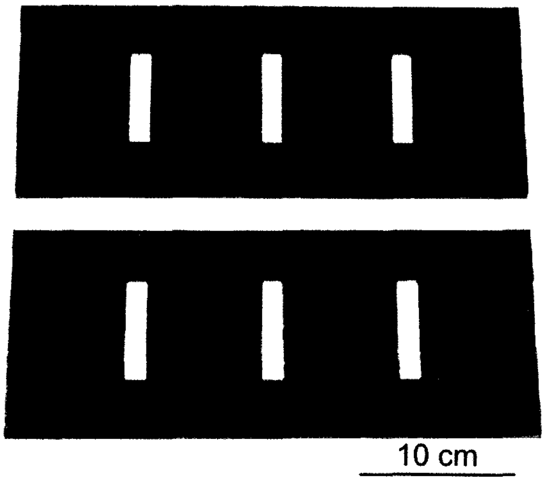

Fig. 8. Plates from melt-textured YBCO for a 200 kW HTS reluctance motor.

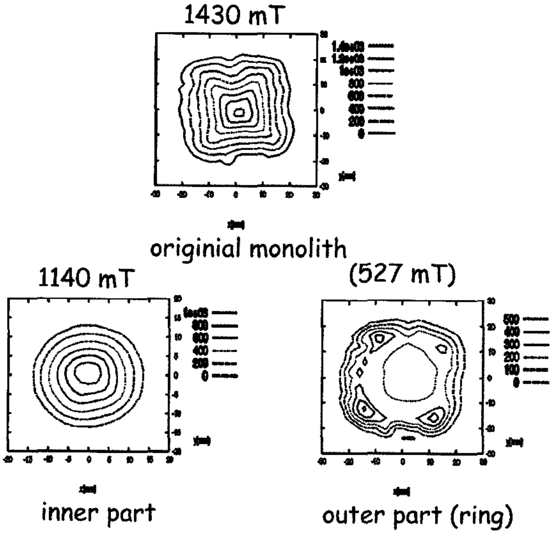

Fig. 9. Trapped field distribution of a melt-textured monolith (above). Below the inner part and the cut ring are shown.

reluctance motors are reduced in size and specific weight by a factor 3-5 [9]. Thus HTS machines show higher dynamics and new applications for electric machines are possible.

At the Budapest University fast inductive switches using bulk superconductors were designed. Rings are needed. Single domain cylindrical blocks with a diameter of 45 mm and a height of 15 mm were prepared. Using special machines the inner part was drilled out and a ring with an inner diameter of about 35 mm was prepared. Fig. 9 shows the two dimensional flux distribution of the single domain block the inner part and the ring. Cutting did not lead to degradation. The trapped field distribution of the ring is similar to coil made from conductors. In the trapped field distribution of the ring features of the growth related structures (growth sectors) can be seen.

IV. Summary

The reproducible preparation of differently shaped and sized single domain monoliths in high quantity and quality in a batch process is guaranteed. By optimising the seeding fabrication and the oxygen annealing treatment the quality of the material could be increased. The maximum induction of 1.4 T at 77 K was reached in a single domain batch processed YBCO monolith without chemical doping or further treatment. Function elements from YBCO blocks were successfully applied in HTS reluctance motors, magnetic bearings and inductive fault current limiters.

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