01 Jan 1993

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Recommended Citation

M. Strasik and F. Dogan and J. Liu and M. Sarikaya and K. Y. Blohowiak and D. F. Garrigus and T. S. Luhman and K. E. McCrary and I. A. Aksay and W. B. Hicks, "Evaluation of $YBa_2Cu_3O_{7-x}$ Bulk Superconductors for High Field Magnet Applications," *IEEE Transactions on Applied Superconductivity*, vol. 3, no. 1, pp. 1049-1052, Institute of Electrical and Electronics Engineers (IEEE), Jan 1993.
The definitive version is available at https://doi.org/10.1109/77.233880

IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 3, NO.1, MARCH 1993

EVALUATION OF $YBa_2Cu_3O_{7-x}$ BULK SUPERCONDUCTORS FOR HIGH FIELD MAGNET APPLICATIONS

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Abstract--Processing of YBCO single crystals was carried out by solidification of semi-liquid YBCO composition using a seeding technique. Microstructural characterization of the pinning centers was investigated by TEM. Characterization of single crystals was carried out, relating grain size and shape to the corresponding flux profiles. Current densities were calculated based on measured trapped fields. Once circulating currents were established, flux pumping and quenching experiments were conducted. These large single crystals will be incorporated into electromagnetic forming devices for use in the military and commercial aircraft manufacturing and service industries.

I. INTRODUCTION

The objective of our program is to develop improved processing and fabrication methods to produce YBCO monoliths for flux-trap magnets with enhanced critical current densities in strong magnetic fields. Engineering designs for electromagnetic devices for flux-trap magnets are being devised to demonstrate the capabilities of the magnets and provide a forum for the utilization of these materials and devices.

Manuscript received August 24, 1992

II. MATERIALS SYNTHESIS

In order to grow oriented YBCO single crystals, $SmBa_2Cu_3O_{7-x}$ (SBCO) seeds were used to induce crystallization during the melt-growth process, similar to that demonstrated by Murakami, et al. [1] The SBCO seeds were grown with the a-b plane parallel to the surface. Disks made from melt quenched powders were melt-processed, yielding single crystals extending to the edge of the samples. No low angle or high angle grain boundaries were observed in good samples as determined by SEM, high resolution TEM, and x-ray analysis. Crystals up to 5 cm in diameter were grown using this technique, Figure 1.

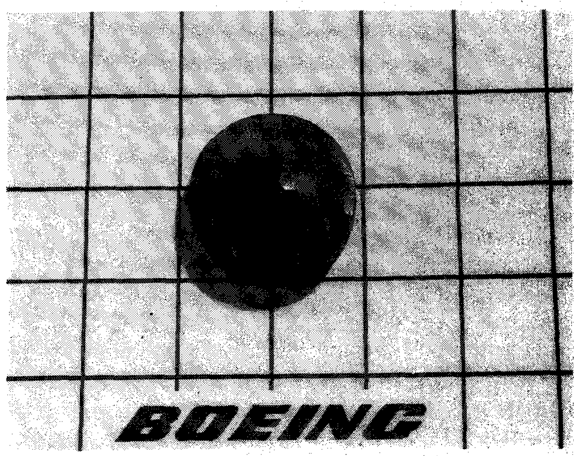

Fig. 1 Single crystal YBCO sample; grid = 1".

Previous studies from other groups have indicated that melt quenched powders were necessary in order to grow large single crystals. However, our recent results show that this is not the case. EDS and WDS analysis by SEM on the polished single crystals, prepared from melt quenched powders revealed that platinum rich inclusions were trapped throughout the sample. This indicates that the powders contain a small amount of Pt dissolved during melt quenching from platinum crucibles.

In order to study the effect of platinum on the growth kinetics of crystals, platinum was added to non-melt quenched powders in the processing of the samples. Platinum metal is used to limit the particle growth of the yttria-rich phases at the high temperatures, as well as providing flux pinning sites in the finished material.[2] In the melt-quenched powders, platinum is obtained through dissolution of the platinum crucible by the liquid melt. Since this is not possible in the non-quenched powders, a fine platinum powder is added prior to melt quenching. The size of the platinum particles most likely plays a role in determining the properties of the final material. The addition of colloidal platinum is currently being explored, as a means of mimicking the dissolved platinum phase.

Samples prepared by this method yielded large single crystals extending to the edge of the disk. These results indicate that melt quenched powders are not necessarily needed to be able to grow single crystal grains by the seeding technique.

Addition of excess 211 phase may help in the crystal growth kinetics. At the higher temperatures, the sample consists of a liquid phase plus 211 particulates. As the crystal nucleates, the grain begins to grow and 123 solidifies, consuming most of the 211 phase. However, some of the 211 particulates become encapsulated before they are consumed. Thus, an excess of 211 is necessary to continue grain growth over a large area. If excess 211 is not present, the growth is arrested by depletion of the necessary elements prior to 123 formation.

The objective of TEM characterization is to identify the nature of the pinning centers and to understand the mechanism of the growth process. The approach is to study the microstructure and the composition of the material as a function of position across the sample and as a function of different crystallographic orientation. The microstructural observations were also performed on samples prepared by different processing routes to understand the influence of the melt-quenching step and other processing parameters.

We observed that there are some fine structural defects in the melt quenched powders, which are not present in powders through the non-melt process. First, fine nanometer sized precipitates of 211 are observed. Anisotropic strain contrasts are also observed. In these powders, the twin structures are usually not well defined. However, annealing the materials at high temperature tends to reduce the density of the defects. In all of the samples, planar defects perpendicular to the c-axis were observed. These defects are usually associated with a high density of strains. Streaking of the diffraction indicates that the defects are like "stacking faults" in the a-b plane. The fine precipitates, planar defects, and strains may be responsible for high flux trapping [3]. However, the planar defects can also cause the sample to crack along the a-b plane.

III. SUPERCONDUCTING PROPERTIES

A. Flux-Trapping Experiments

Flux-trapping measurements were carried out on the seeded, single crystal $YBa_2Cu_3O_{7-x}$ samples as a function of applied field and orientation of the applied field, Figure 2. Experiments were performed both on the solid monoliths as well as on cylindrical single crystals to establish amount and profile of induced circulating currents required for the operation of the electromagnetic devices.

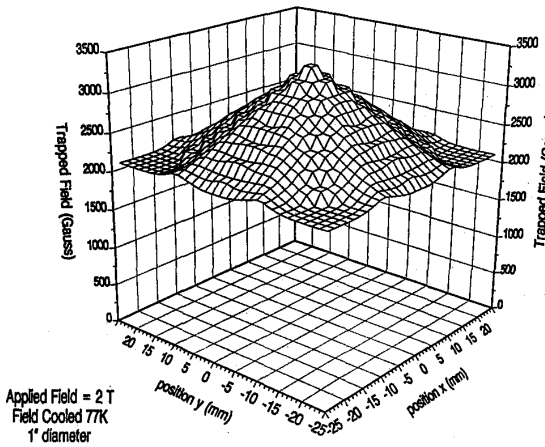

Fig. 2 Flux-trap profile of a 1"YBCO single crystal.

Fields of up to 5000 Gauss were trapped at 77K in the 1.25" diameter single crystal samples. As expected, the current density of the single crystal sample is independent of an applied field up to a tested field of two Teslas. In contrast to earlier samples, the magnetic field in the single crystals was more uniform over the surface of the sample. The flux profile clearly shows a presence of a circulating current in a one turn single crystal conductor, with macroscopic current densities exceeding $1x10^4$ A/cm^2 at 77K in an applied field of up to at least 2 Tesla.

Flux trapping with the quenched and non-quenched samples was carried out. Not enough data has yet been collected to determine which method yielded better material. However, the latest sample tested, a non-melt quenched sample with excess 211 and Pt weighing in at a mere 15 grams, gave a trapped field of 3300 Gauss. Earlier testing on this particular sample gave much lower numbers. It was not until the sample was reoxygenated for an additional period of time that the magnetic properties increased. This indicates that these samples require a considerably longer oxygenation period than earlier samples.

B. Current Density Measurements

Critical current density measurements were performed at Wright Patterson Laboratories by Dr. G. Kozlowski on 1" diameter single crystals by magnetization up to a field of 9 Tesla at temperatures ranging from 4.2K to 85K. Figure 3 shows currents densities as a function of applied magnetic field with the applied field parallel with the c-axis. The current densities measured when the field was applied perpendicular to the c-axis were lower by a factor of three. The current density exceeds $3x10^4$ A/cm^2 at 0 Tesla and 77K and $8x10^5$ A/cm^2 at 0 Tesla and 4.2K. The current densities at temperatures up to 40K are almost independent of the applied magnetic field up to a measured field of 8 Tesla. This shows that the single crystals are very pure lacking the common weak links often associated with bulk YBCO samples. The current densities calculated from the trapped flux experiments correlate well with the magnetization meas-urements. These current densities are essentially similar to those observed by Nippon Steel in their samples.

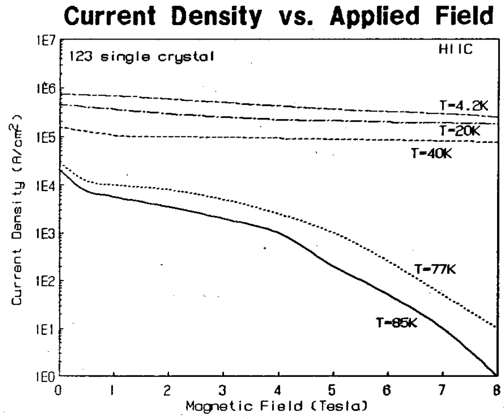

Fig. 3 Current density vs. applied field in a single crystal.

IV. APPLICATIONS

Among the potential applications for flux-trap magnets being explored at Boeing are electromagnetic forming equipment, rivet guns, dent pullers, motors, cryocirculators, generators, bearings, gyroscopes, flux pumps, and magnetic refrigerators.

Conventional electromagnetic dent pullers are very large, heavy systems, not easily transportable (2000 pounds for the capacitor unit), and potentially dangerous (495 Volts and 30,000 Amperes) in operation. They require large cables connecting the capacitors and the hand-held unit, making the accessibility of the dent puller very impractical and sometimes impossible. In the proposed high temperature superconducting system, the capacitors are replaced by magnetic energy stored in bulk flux-trapped magnets. Advantages accrued with the superconducting system include safety (during quench, the developing resistive and inductive voltages cancel), portability, simple operation under hazardous and remote conditions, and improved productivity and reproducibility.

V. SUMMARY

Large single crystals of YBCO (>5 cm diameter and 1 cm thickness) were grown using seeding techniques. The crystals were characterized by relating the grain size and shape to the corresponding flux profiles. Engineering designs for high field magnet applications were devised to utilize these high temperature superconducting magnets. Implementation plans for these devices into the aircraft manufacturing industry are being developed.

ACKNOWLEDGMENTS

We wish to acknowledge the generous funding of our customer, DARPA, Order No. 7476, monitored by the AFOSR under Contract No. F496-20-90-C-0079. Superconducting precursor 123 powders were supplied from SSC, Inc., Bothell, WA.

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