Processing of MgB_2 and BSCCO 2212 Superconductors

Timothy Noble, Boston College

Center for Advanced Power Systems (CAPS)

National High Magnetic Field Laboratory (NHMFL)

Overview

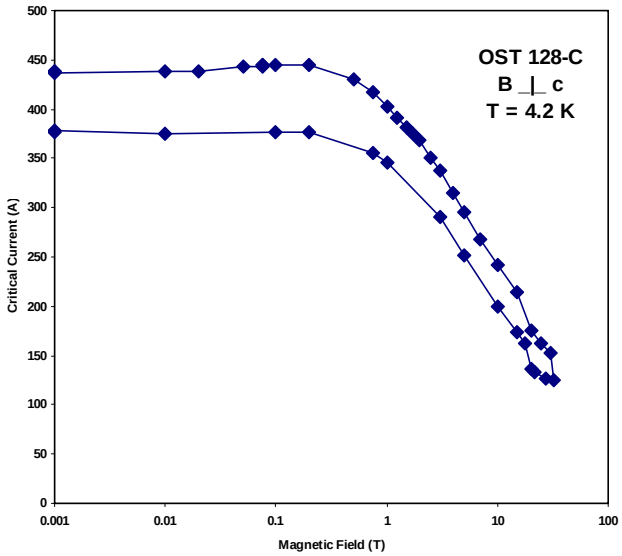
Type II superconductor Magnesium Diboride is one of the most promising new superconducting materials currently being researched. With a Tc of roughly 40K and the relatively high abundance of Mg and B on Earth, large-scale production of MgB_2 could serve as a cheap and effective replacement to more exotic NbTi and Nb_3Sn superconductors. The widespread use of MgB_2 in superconductor technology, however, is limited by its electrical and mechanical properties: relatively low critical field Hc, critical current density Jc, and brittleness characteristic of all high Tc superconductors. These limitations must be overcome if MgB_2 is to become a feasible alternative to type1 and exotic high Tc superconductors. A very similar material is Bismuth Strontium Calcium Copper Oxide, or BSCCO, a high Tc superconductor with a Tc of 77.3K for BSCCO 2212 and approximately 110K for BSCCO 2223; like MgB_2, BSCCO is a granular, brittle solid with a high melting point superconducting along CuO planes in roughly the same manner as MgB_2 conducts along central boron planes. My studies of the material properties and production methods of MgB_2 and my research into infield processing of BSCCO 2212 {$Bi_2Sr_2CaCu_2O_8$} tapes indicates that perhaps the most appropriate means to enhancing Jc in MgB_2 is through a combination of vanadium doping and infield heat-treatment.

Introduction

The creation of MgB_2 from pure magnesium and boron powders is most easily accomplished using a simple mortar, pestle and heat-treatment. Optimization experiments previously pursued at the Nation High Magnetic Field Laboratory in Tallahassee, Fl indicate that there are several avenues to the enhancement of MgB_2 superconducting and mechanical properties. The first topic considered was the behavior and production of small superconducting samples of MgB_2. In small samples, e.g. 1 gram pellets, optimization of superconducting traits may be most easily achieved by changing the Mg/B stoichiometry to 1.2:2. This addition compensates for Mg loss, occurring during heat-treatment at and above temperatures of 600K; this also inhibits the creation of unwanted phases such as MgB_4 that form in the presence of excess boron. Typically samples are wrapped in non-reactive Ni foil and heated in Ar gas to minimize the formation of MgO impurities which otherwise disrupt the homogeneity and thereby the electrical conductivity of the substance. Doping, likewise, has proven to be an effective method of enhancing the critical properties of high Tc superconductors in tapes and wires as well as in small samples. Doping MgB_2 with vanadium has proven to enhance flux pinning properties and Jc, while densifying the material and reducing the brittleness endemic to most superconducting tapes. The stoichiometry of the superconducting samples we produced was modified from 1 magnesium: 2 boron in order to create $Mg_{1.2-X}B_2V_X$ where X=(0, 0.05, 0.10, 0.15, 0.20); X remains a variable as the optimum amount of vanadium for flux pinning has yet to be determined. Likewise, tests

have yet to be made on the critical current density of vanadium-doped wires and tapes; despite the relative recentness of the discovery of MgB_2 superconductivity, it is already a simple matter to create samples with extremely high critical current density. A great deal of research has already been completed on the subject of enhanced current in small samples, and papers are readily available detailing quantitatively the enhancement of Jc in the aforementioned cases.

Enhancement of critical current is also easily accomplished by the process of infield processing. This technique involves the heat-treatment of superconducting samples in the presence of a constant magnetic field and depends primarily upon reduction of material anisotrophy. By creating a partial melt in a sample, individual grains become free to move independently of their neighbors; from the laws of statistical mechanics and thermodynamics we know that in the presence of a magnetic field such grains will, given a certain magnetic moment, tend to align in the direction of lowest energy, or parallel to the applied field. While it is statistically improbable that the entirety of the grains in the crystal will align in the same direction, especially when heated to over 800 Kelvin, nonetheless the majority of grains will align and thereby increase the uniformity of the material and improve its ability to carry current in the superconducting regime. The sample will retain an average grain misalignment, which is easily calculated. In the case of field-processed BSCCO 2212 tapes and wires produced by S. Pamidi and colleagues, critical current values have been measured between 300 Amps and 500 Amps at 4.2K for field applied perpendicular to the c-axis.



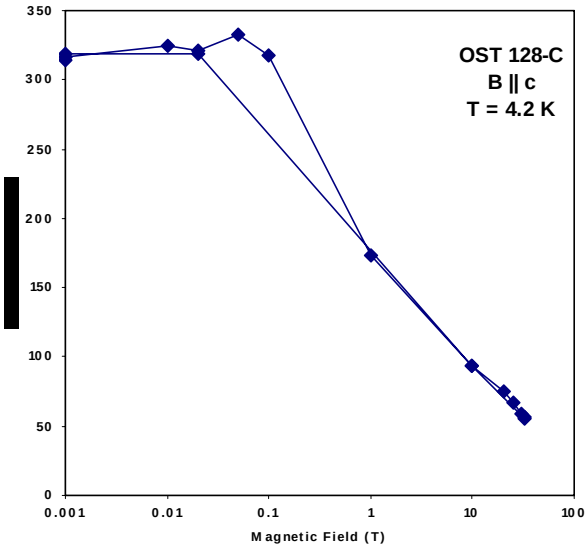
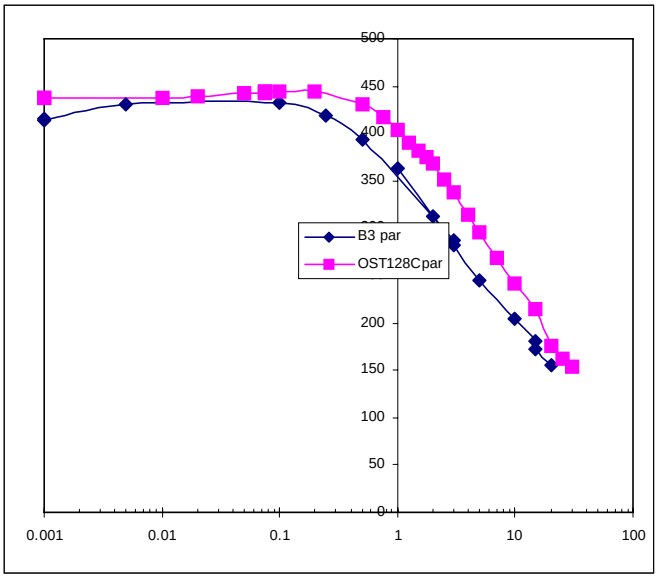


Fig. 1 Critical current measurements of BSCCO 2212, 80um tapes in zero-field treated samples. Assumed avg. grain misalignment angle 5.5 degrees. OST 128C. P.V.P.S.S. Sastry, U.P. Trociewitz



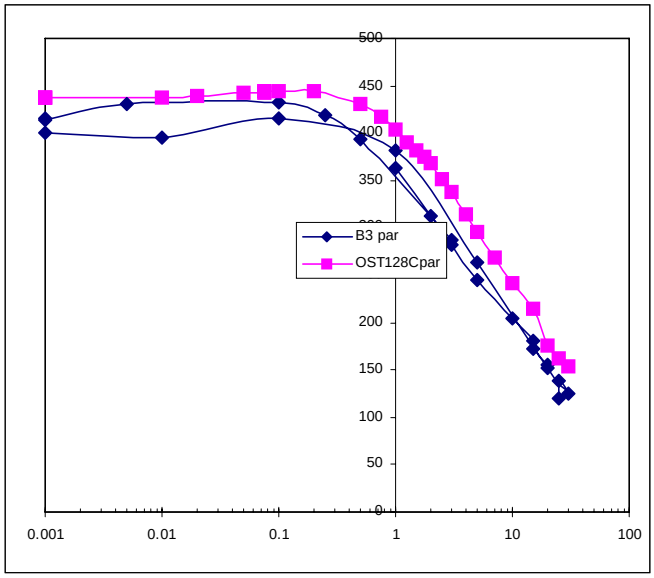


Fig. 2 Critical current measurements in field-process samples (note: second graph mislabeled. B3 perp, OST128C perp)

Sample B3. P.V.P.S.S. Sastry, U.P. Trociewitz

Experimental Methods

Production of Pure and Vanadium-doped MgB_2

Alfa Aesar 99.8% magnesium and 99.99% boron powders were combined in a 1.2:2 molar ratio. The powders, optionally doped with Vanadium to create $Mg_{1.2-X}B_2V_X$ where X=(0, 0.05, 0.10, 0.15, 0.20), were then mixed for 20 minutes using a mortar and pestle and pressed into approx. 1 gram pellets under 2 metric tons of pressure. The pellets were then wrapped in Ni foil to minimize Mg loss and heated in flowing argon. X-ray analysis afterward demonstrated that the samples contained only trace amounts of MgO and MgB_4.

Drawing of MgB_2 Wires

Using the same magnesium and boron powders combined in a pure 1:2 molar ratio, pure MgB_2 wires were manufactured using the powder-in-tube method. Pure samples were considered due to the relative isolation of the powder from oxygen during heating due to the containment facilitated by the sheathing material. Two sheathing agents were selected for testing based on their low probability of reaction with the powder during heat treatment, stainless steel and monel (CuNi); both materials, however, appear to be limited in utility by work-hardening, especially in the case of stainless steel, and complicate the manufacture of small-diameter wires. As I was only consulting on this project and aiding in the machining process, I neither possess any data regarding critical current measurements, nor am I certain if such measurements have been attempted at the present date.

Infield Processing of $Bi_2Sr_2CaCu_2O_8$ Tapes (BSCCO 2212)

Pre-made BSCCO tapes of 70-80um thickness were placed inside of a heating coil furnace positioned within the 95mm diameter bore of a 20 Tesla superconducting magnet. 6 wires and 6 tapes were placed in a container, oriented with the vertical field perpendicular to the c-axes of the tapes, and subject to a 10K temperature difference over the vertical length of the container. For each trial the 12 samples were heated to a partial melt in flowing O_2 gas, with the maximum temperature varying between 890K and 900K, for a period of 5 hours. Though the examination of the samples is not yet complete, we anticipate discovering enhanced texture within the samples and significant increases in Jc at 4.2K. Unfortunately, a large portion of my data is corrupted or illegible, so I am presently unable to offer any adequate detailed interpretation of the results. Short of examination with the ESEM, little can be definitively stated about texturing; without legible data, even less can be stated about Jc enhancement.

Conclusion

MgB_2 and BSCCO, as stated in the overview, are fairly similar high temperature superconductors. Very little experimentation, however, has presently been done in regard to infield processing of MgB_2. Given the relative ease with which one can manufacture MgB_2 in comparison to BSCCO, it should be easy to design an experiment to test the effects of infield processing upon critical current density, critical applied magnetic field, and grain alignment. While Tc is significantly lower in magnesium diboride than in BSCCO 2212 or 2223, given the proper combination of doping and field processing, the

critical superconducting properties of MgB_2 may be sufficiently enhanced as to replace not only type1 conductors, NbTi, and Nb_3Sn, but also the more expensive BSCCO superconductors as well.