DEVELOPMENT OF COMMERCIALLY VIABLE HIGH-T_c Bi-2223 SUPERCONDUCTOR TAPES*

U. Balachandran and C. A. Youngdahl
Materials and Components Technology Division
Argonne National Laboratory
Argonne, IL 60439

P. Haldar
Intermagnetics General Corp.
Guilderland, NY 12084

L. R. Motowidlo
IGC Advanced Superconductors, Inc.
Waterbury, CT 06704

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ABSTRACT

Long lengths of flexible Ag-clad Bi-2223 Superconductors have been fabricated by the powder-in-tube technique using prereacted, poly-phase, Pb-doped Bi-Sr-Ca-Cu-O powders. At liquid helium (4.2 K) temperature, improved process conditions yielded transport critical current density (J_c) values greater than 10^5 A/cm^2 at zero field; at liquid nitrogen (77K) temperature, the J_c values of short tape samples exceeded 4 x 10^4 A/cm^2. Rolled tapes are cut into lengths up to 2 – meters long and are used in parallel to fabricate small superconducting pancake coils by the "wind-and-react" technique. The coils are characterized at 77K and 4.2 K. The J_c of the coils are up to 80% of the short, rolled sample result at 77 K. The coils exhibited these results even after being cooled and warmed several times between ambient, 77 K and 4.2 K, indicating their stability following thermal cycling.

INTRODUCTION

A great deal of effort has been made over the last few years in improving the properties of Ag–clad Bi–2223 superconductor wires and tapes fabricated by the powder–in–tube technique [1–5]. This approach, because it utilizes processing similar to that currently used in the manufacture of low–temperature superconductors, appears to be a promising industrial method for fabricating long lengths of flexible high temperature superconductors. The goal is to apply this technology to devices currently use low–temperature superconductors or for new devices capable of operating in higher temperatures and/or magnetic fields. Bi–2223 superconductor tapes show significantly higher transport critical current densities (J_c) than NbTi and Nb_3Sn superconductors at 4.2 K and high applied magnetic fields. Recently, we have reported J_c's exceeding 4×10^4 A/cm^2 in short, pressed Bi–2223 samples and $\approx 3 \times 10^4$ A/cm^2 in short, rolled tape samples [at 77 K]. Control of the parameters of the thermomechanical process makes it possible to achieve a high degree of uniformity, texture, density, and phase purity and results in high J_c's over long lengths of composite tapes. Using a two step rolling and heat treatment procedure we have processed long lengths of Ag–clad Bi–2223 tape conductors and fabricated small prototype pancake coils. In this paper, we report the fabrication of the tapes, coils, and their transport properties.

EXPERIMENTAL

Ag–clad tapes were prepared by the conventional powder–in–tube technique. Appropriate amounts of Bi_2O_3, PbO, $SrCO_3$, $CaCO_3$, and CuO were mixed and calcined at 800 – 850°C in air for ≈50 h with intermittent grinding. The partially reacted precursor powders were packed into 10 to 15 cm long Ag tubes, lightly swaged and drawn through a series of dies, and then rolled to final thickness of ≈0.1 mm. 20 to 30 meters of tapes have been produced by this technique. Short lengths (≈4 cm) of tapes were cut and heat treated at ≈850°C in air with intermittent uniaxial pressing. Although uniaxial pressing and heat treatment cycles produced the highest J_c's in short samples, this procedure is not amenable to the fabrication of long lengths of tape. Unlike pressing, repeated rolling of dense composites introduces crack in the ceramic core due to non-uniform stresses that are imparted to the superconductor. However, if a series of shaping operations that progress from a round to a rectangular geometry is carefully implemented before rolling, it is possible to obtain superconductor cores that have uniform cross sections [6]. Pancake coils were fabricated using long lengths of rolled tapes. An intermediate heat treatment at ≈850°C was performed prior to the final rolling step. One to 2 meter lengths of the rolled tapes have been co-wound with insulation to make small prototype pancake coils which were reacted and tested at 77 K and 4.2 K.

RESULTS AND DISCUSSION

The DC four-probe J_c's of short-tape samples were measured as a function of temperature in the range of 4.2 to 77 K and applied magnetic fields up to 20 T. The magnetic field was applied parallel or perpendicular to the tape surface. The criterion for determining critical currents (I_c) was 1 μV/cm, and J_c's were determined for the superconducting cross-sectional areas. For the samples reported here, I_c's ranged from 40 to 50 A, corresponding to J_c's > 4×10^4 A/cm^2 at 4.2 K and self field. By using a repeated uniaxial pressing and heat-treatment operation, we were able to improve transport properties of short tapes.

Figure 1 shows the temperature dependence of J_c in magnetic fields applied perpendicular to the tape surface for a short sample. At low temperatures (< 40 K) J_c's > 10^5 A/cm^2 have been measured. Moreover, with the application of high magnetic fields, a field independent behavior was observed. Detailed J_c measurements were also carried out at 77 K and pumped liquid nitrogen (64 K) temperatures and applied fields up to 3 T. By pumping liquid nitrogen down to 64 K, J_c in the field parallel to tape surface increased by an order of magnitude at 2 T compared to corresponding data at 77 K.

Long lengths of rolled Bi-2223 tape conductors were tested by winding them into pancake coils. one to six tapes of conductor were co-wound in parallel on 1-5-cm-diameter alumina formers, with ceramic insulation separating each turn, and heat treated by the "wind and react" approach. These coils were repeatedly tested for J_c at 77 K and 4.2 K. The J_c of coils containing one 1.0 m and two 1.0 m lengths of conductor approached 10^4 A/cm^2 at 77 K. J_c's at 4.2 K exceeded 10^4 A/cm^2 in fields up to 13 T [5]. The difference in J_c between samples made of long and short lengths of conductor is 60–80%, probably due to inhomogeneities and micro–cracks along certain regions of the tapes.

The I_c vs. applied magnetic fields up to 13 T at 4.2 K of a small coils that contained two 1.0 m co–wound tape conductors with 10 turns is shown in Figure 2 (using a 1.0 μV/cm and 0.1 μV/cm criterion). In zero external field, this particular coil generated a field of 450 G at 4.2 K. The I_c for the coil was 15 A at 77 K and zero field. This coil continued to exhibit these properties, even after being cooled and warmed several times between ambient, 77, and 4.2 K, indicating stability after thermal cycling.

CONCLUSION

Using the powder–in–tube method, we have processed long lengths of Bi–2223 tape conductors. By improving process conditions, it is possible to improve J_c's in short Ag–clad Bi–2223 tape. Practical J_c levels (> 10^4 A/cm^2) at 77 K, and low magnetic fields and fields up to 20 T at 20 K have been achieved. The self–field J_c of small pancake coils were found to be 60–80% of short sample results at 77 and 4.2 K.

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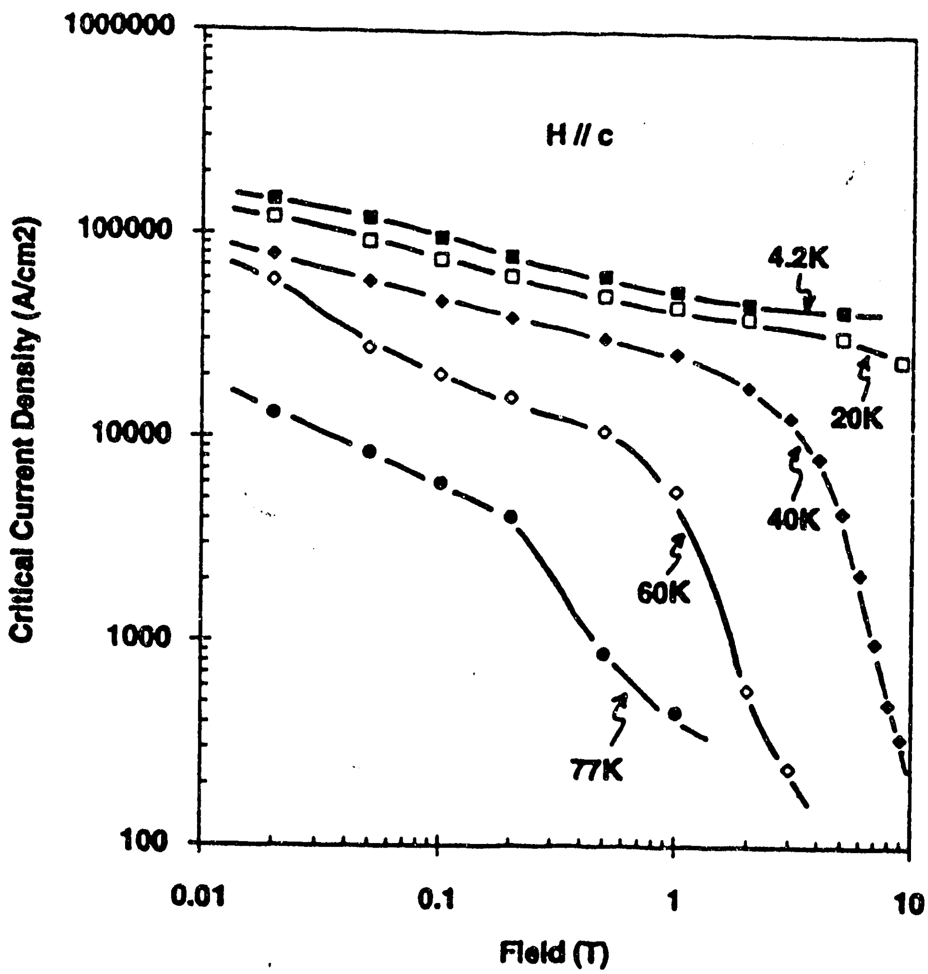
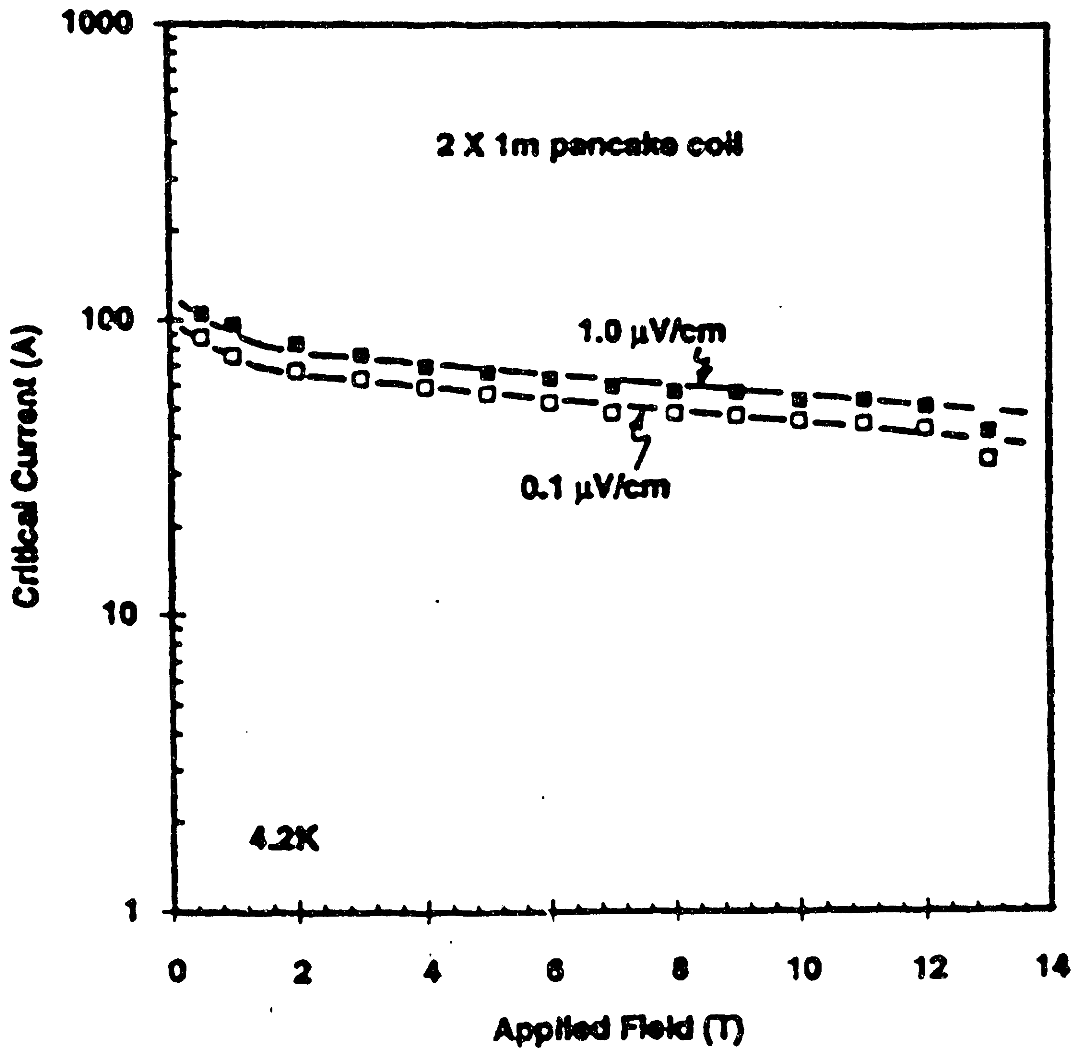
FIGURE CAPTIONS

Fig. 1 Temperature dependence of the J_c–H measurements for a Bi–2223 short–tape sample with the field applied perpendicular to the tape surface.

Fig. 2 Critical current vs. applied magnetic field for the two 1.0 m pancake coil at 4.2 K.



1000000
100000
10000
1000
100
H // c
4.2K
20K
40K
60K
77K
Critical Current Density (A/cm2)
0.01
0.1
1
10
Field (T)



1000
100
10
1
Critical Current (A)
2 X 1m pancake coil
1.0 µV/cm
0.1 µV/cm
4.2K
0
2
4
6
8
10
12
14
Applied Field (T)

END

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