Evaluation of current transport properties of $Gd_1Ba_2Cu_3O_{7-\delta}$ coated conductors over a wide range of temperature and external magnetic fields

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Abstract. We have carried out detailed measurements on the electric field vs. current density (*E-J*) characteristics of $Gd_1Ba_2Cu_3O_{7-\delta}$ (GdBCO) coated conductors (CC) in a wide range of temperature and external magnetic fields. Four probe measurements were performed in a 20 T superconducting magnet system, which allows systematic measurements on temperature-, magnetic field- and angular-dependences of the *E-J* characteristics. Applying a constant electric field criterion (1 μv/cm), we have evaluated critical currents and *n*-values as a function of the temperature, the magnetic field and the field angle. Those results are relevant for the understanding of the practical performance of the tapes, and therefore to improve the process conditions effectively. The GdBCO CC was fabricated by the reel-to-reel PLD methods on the IBAD-MgO based substrate. The Self-field critical current of the tape was 400 A/cm-w at 77 K. The results were also compared with our previous results on YBCO CC obtained from the similar process. It is noted that the critical current of GdBCO CC is superior to those of previous YBCO CC over a wide range of practical external field and temperature.

1. Introduction

Nowadays, a large variation on different high performance second generation superconductor wires is available. Aside from the well described $YBa_2Cu_3O_{7-\delta}$ (Y-123, YBCO) coated conductors, SmBCO [1], HoBCO [2] and GdBCO [3] coated conductors with similar or better superconducting properties can be produced. Apart from their superconducting properties, the potential application of coated conductors strongly depends on their production speed, costs, available lengths and mechanical strength. Recently significant progresses have been made in improving the production process for all sort of coated conductors and therefore their production time, costs and mechanical strength get more comparable to each other. Current investigations are focused on improving the critical current density (J_C) and on reducing the anisotropy of the conductors at high temperatures and magnetic fields. The "new" coated conductors seem to have higher potential to reach these targets compared to the "classic" YBCO coated conductors. Especially the last-mentioned, $Gd_1Ba_2Cu_3O_{7-\delta}$ coated conductor`s show a significant advantage due to YBCO conductors at high temperatures.

In this study, we investigated the current transport properties on a high-I_c GdBCO coated conductor (I_C > 400 A at 77 K and self field) over a wide range of temperature and magnetic field. The E-J characteristics were measured carefully over four orders of electric field range and the major transport superconducting parameters were determinate from these measurements. The critical current density (J_C) as well as the anisotropy was compared with our previous results on YBCO coated conductors obtained from the similar production process.

2. Experiment

2.1. Sample Specification

The GdBCO sample consists of a simplified 4-layered buffer architecture and was developed by the SRL group [4]. The buffer layers are arranged from the substrate to the superconducting layer as follows: $Gd_2Zr_2O_7$ (GZO), IBAD-MgO, $LaMnO_3$ and CeO_2. This new buffer architecture is comparable with the conventional 5-layered IBAD-MgO buffer technique but the production speed was increased and the cost reduced. On a polished Hastelloy substrate (100 µm), the GZO layer (110 nm) was deposited by an ion beam sputtering system. The second layer, a 4 nm thick textured IBAD-MgO layer, is the key layer which forms biaxial grain alignment by ion beam assisted deposition. Subsequently a $LaMnO_3$ layer (19 nm) was deposited by RF sputtering and the CeO_2 layer (500 nm) was deposited by Pulsed Laser Deposition (PLD). The GdBCO layer (1.2 µm) was formed by a reel-to-reel pulsed laser deposition technique with a multi-plume and multi-turn deposition method (MPMT-PLD) [5].

The YBCO coated conductors were produced by SRL-NCCC [6] and show high critical currents (I_C) of 245 A/cm-w at 77 K and self field on a length of 216.6 m. The 2.25 µm thick YBCO layer was deposed by the same technique with the GdBCO conductor. The Hastelloy substrate is coated by 2 buffer layers, $Gd_2Zr_2O_7$ by ion-beam assisted deposition (IBAD) and CeO_2 by PLD. Previous measurements showed the excellent properties of this sample over a wide range of field and temperatures [7].

2.2. Measurement of Transport Properties

A conventional dc four-probe measurement method was used to determine the transport properties of small samples, which were cut from a longer conductor. Into the approximately 1 cm long samples, microbridges with a width of 100 µm respectively 75 µm and a length of 500 µm were etched by photolithography and wet-etching process. All measurements were performed at maximum Lorentz force configuration (field perpendicular to the current) and under helium gas flow. Pressed current contacts were used due to their lower resistivity, reproducibility and easy removability. A 1 µV/cm respectively a 10 µV/cm electric filed criterion was used to define the critical current. The external magnetic field was applied by using a 20 T superconducting magnet. The temperature accuracy was ± 0.1 K during the measurements.

3. Results and Discussions

Figure 1 shows electric field versus current density (E-J) characteristics for different magnetic fields, temperatures and field directions. The measurements were done by applying a constant current to the sample for a short time and measuring the voltage drop along the microbridge. The applied current was increased step by step by a constant factor. If the voltage exceeded an abort criterion (defined voltage) the measurement was stopped. Between the measurements, the sample temperature was monitored to exclude any self heating. This allows to detect the E-J characteristics over a wide range of electric field with a very stable temperature. From these measurements, the critical current and the n-Value were determinate by applying an electric field criterion.

The critical currents (I_C) determinate from the E-J curves for different temperatures and magnetic fields are shown in Figure 2. A maximum I_C of 4.4 A was measured at 77 K and self field for a 100 µm bridge which corresponds to a critical current of 440 A per cm width. This is in good

agreement with the measurements on the long length conductor (~400 A/cm-w). Small variation between the different samples and the measured I_C along the whole conductor can be explained by the inhomogeneity of the sample.
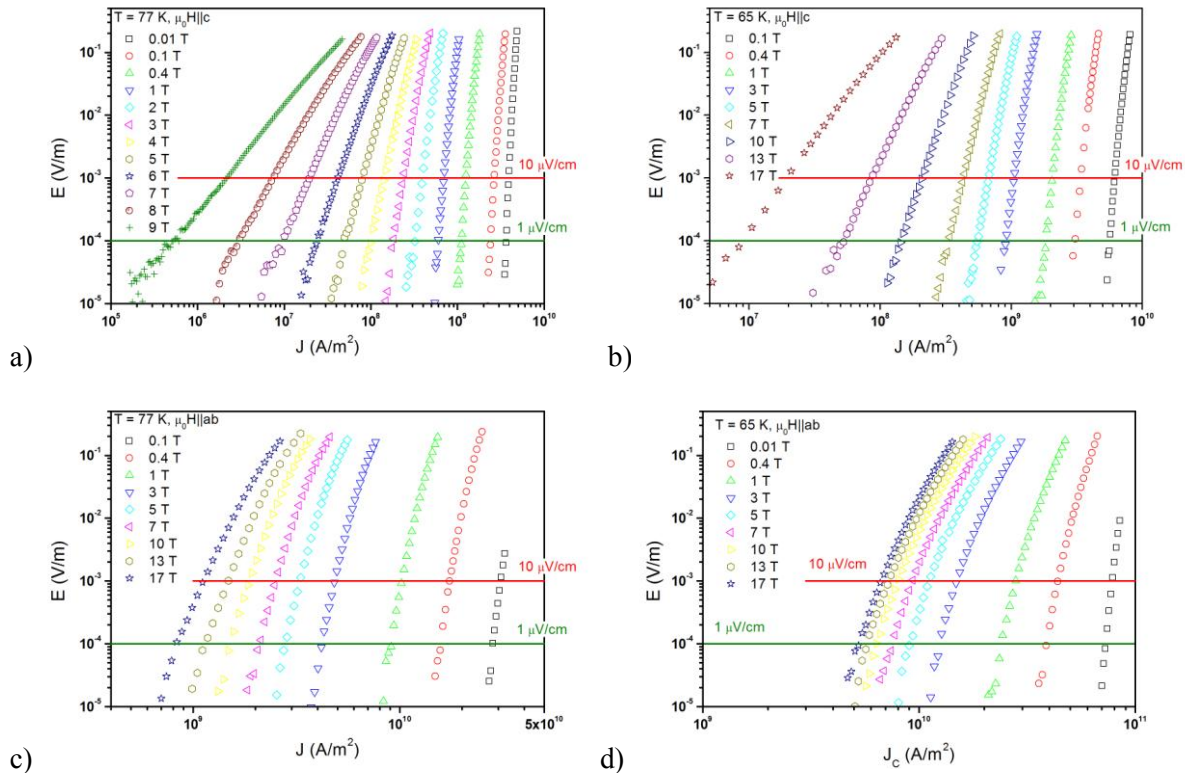

Figure 1: Magnetic field dependents of electric field vs. critical current density (*E-J*) curves at 77 K (a and c) and 65 K (b and d) for field parallel and perpendicular to the c-axis, respectively. Furthermore the two electric field criteria which were used for determining the I_C are plotted.

The critical current was twice as high for 64 K and self field (I_C = 8.7 A) compared to that at 77 K. Due to the special sample geometry (small bridge) and the measurement technique transport measurements down to 20 K was possible (Figure 2b). High I_C per cm-width (230 A/cm-w at 17 T) was determinate for 20 K and field parallel to the c-axis. For the other mean field direction (H||ab) the I_C per cm-width was above 500 A/cm-w for the whole measurement region at 40 K.
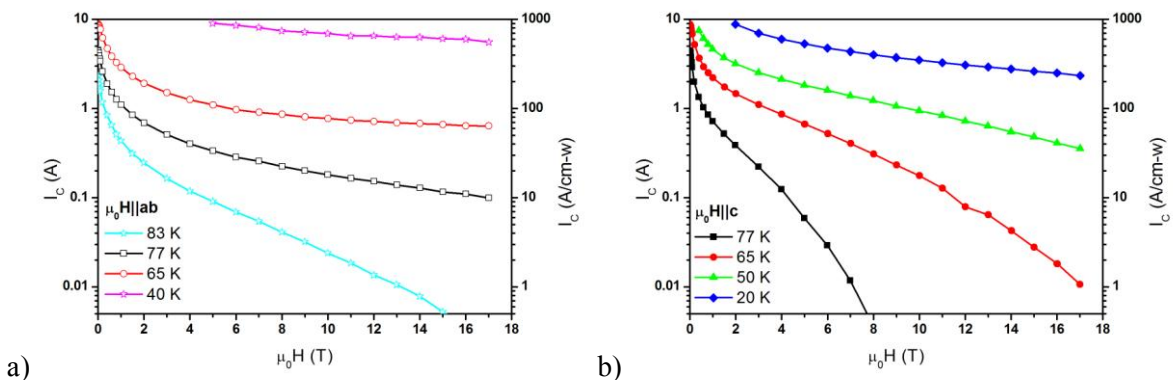

Figure 2: Critical currents and the estimated critical currents over 1 cm of width for a 100 μm wide GdBCO conductor. The results for field perpendicular to the c-axis (a) and field parallel to the c-axis (b) are shown. A 1 μV/cm criterion was used to determinate the I_C from the *E-J* measurements.

The *n*-value reflects the steepness of the transition from the loss-free to the dissipative state with typical values from 1 to 40. For application it is important to know the *n*-value because of its role in the quench behaviour [8]. Samples with higher *n*-values quench more rapidly than samples with lower *n*-values. The *n*-values of this sample shows a typical reduction from about 25 to below 7 (17 Tesla) with increasing magnetic field for field perpendicular to the c-axis and 77 K. In generally the field dependents follow those of the critical currents. With decreasing temperature the *n*-Value gets somewhat higher, up to 30 at low fields, over the whole field range.

In Figure 3 the field dependents of the critical current densities (J_C's) for the GdBCO and YBCO coated conductors are plotted for several temperatures. The GdBCO conductor shows higher J_C in the whole measurement range for field perpendicular to the c-axis. In the case of field parallel to the c-axis only at higher temperatures and low fields the performance of the GdBCO conductors are significant better in comparison to the YBCO conductors. The self field J_C at 77 K is four times higher for the GdBCO conductor ($J_C \sim 4 \times 10^{10}$ A/m^2) then for the YBCO conductor ($J_C \sim 1 \times 10^{10}$ A/m^2). The much better performance at 77 K can be explained by the higher critical temperature and irreversibility fields of the GdBCO material together with the improvement of substrate quality. This is a big advantage for application at liquid nitrogen temperatures.

a)   b)
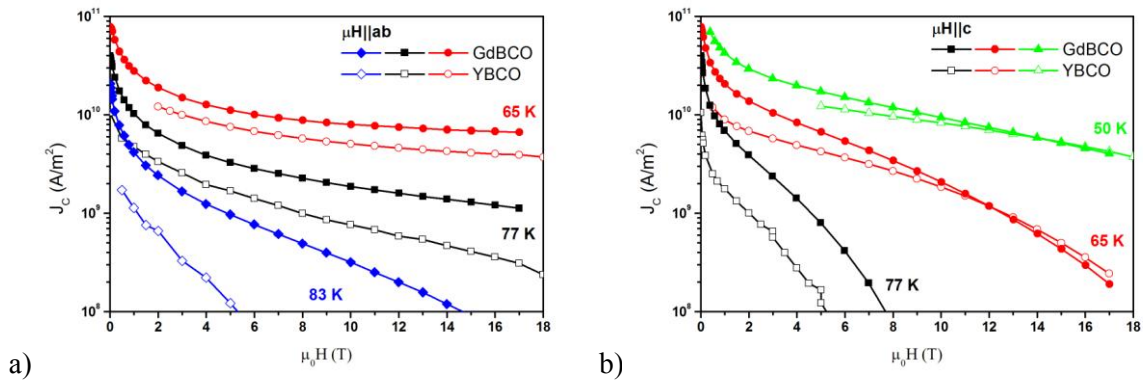
Figure 3: Critical current densities for the GdBCO and YBCO coated conductors at three temperatures. The results for field perpendicular (a) and parallel to the c-axis (b) are shown separated. A 10 µV/cm criterion was used to determinate the J_C from the *E-J* measurements.

Another relevant abandonment in current research activities is to reduce the anisotropy of coated conductors. For application the lowest I_C over all field directions is mostly decisive for the usability. The analysed GdBCO coated conductors show a significant lower anisotropy compared to the YBCO conductors at 77 K (Figure 4a).

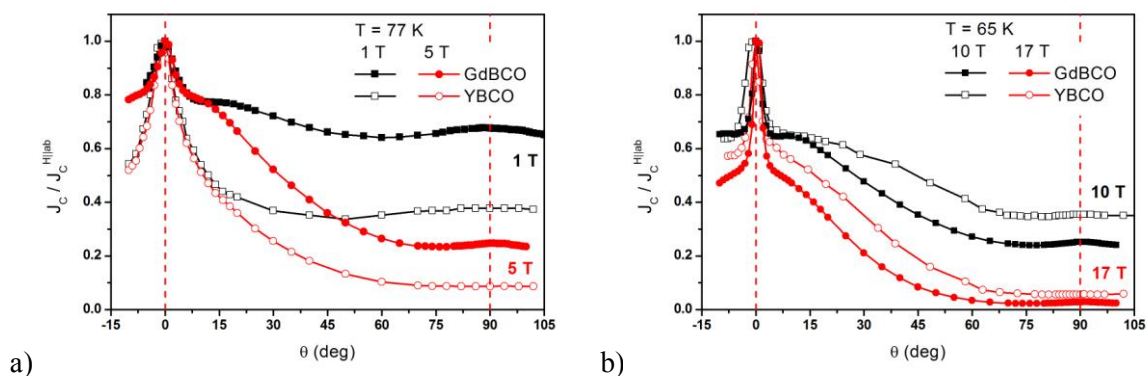a)   b)

Figure 4: Normalized critical current density as a function of the angle between the field and the a/b-planes at 77 K (a) and 65 K (b). The field was always perpendicular to the direction of the current.

The anisotropy ratio (I_C at H||ab divided by the I_C at define angel) is less than 1.48 for H||c and 1.56 for the minimum I_C at about 60 ° for a magnetic field of 1 T. With lower temperatures the anisotropy factor is getting more unfavorable for the GdBCO conductor because of the high currents for H||ab. Although the I_C of the GdBCO conductor is higher or similar to the YBCO conductor the anisotropy is higher. This is related to the intrinsic pinning originating from good alignment of the grains which appears in a sharp peak for H||ab.

4. Conclusion

We investigated the transport properties of a new $Gd_1Ba_2Cu_3O_{7-\delta}$ coated conductor at various temperatures and external magnetic fields. A self field critical current above 400 A/cm-w was determinate at 77 K. The field dependent I_C was measured up to 17 T for field parallel (H||c) and perpendicular (H||ab) to the c-axis. In the high field region excellent properties could be obtained around the temperature of liquid nitrogen ($J_c^{H||ab} > 0.1$ MA/cm^2 at 17 T and $J_c^{H||c} \approx 20$ KA/cm^2 at 7 T). This is also the region where the biggest advantage due to the YBCO conductor was observed. The anisotropy of the GdBCO coated conductor is significantly smaller and the critical current higher compared to the YBCO coated conductors. With decreasing temperature, below 65 K, the transport properties of both samples approach each other, whereas the effect is more pronounced for field parallel to the c-axis. These results are useful for engineering design of potential applications as well as for further improvements in the conductor production.

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