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PROCESSING OF YBCO/IBAD YSZ COATED CONDUCTORS ON FLEXIBLE SUBSTRATES

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ABSTRACT

Continuous coaters capable of producing 1.1 m long x 1 cm wide tapes of $YBa_2Cu_3O_{7-\delta}$ (YBCO) on biaxially oriented yttria-stabilized zirconia (YSZ) on flexible Ni-alloy substrates have been developed at our laboratory. Using a 1 µV/cm criterion, we have achieved transport critical current (I_c) values of 29 A (75 K, self field) between voltage taps spaced 1 m apart. The corresponding critical current density (J_c) value for this tape is 290 kA/cm^2. For shorter tapes, (12 cm voltage tap separation) we have attained J_c values of 0.67 MA/cm^2. Individual 1 x 1 cm sections within these shorter tapes have attained J_c values of 1 MA/cm^2.

INTRODUCTION

Coated tapes of superconducting YBCO are considered to be the second generation of high-temperature superconducting wire. Several laboratories have reported efforts to produce wires in lengths of up to 1 m of this material. These laboratories use either of two techniques to deposit template films of biaxially oriented YSZ on polycrystalline metal substrates. These techniques are ion-beam assisted deposition (IBAD) [1] [2] or inclined substrate deposition [3]. These template films are then over coated with films of YBCO. These latter films are heteroepitaxially deposited using pulsed laser deposition (PLD) techniques. Other laboratories are employing modified bias sputtering to obtain biaxially oriented YSZ films [4] or thermomechanical processing of Ni to obtain an oriented metal template substrate [5] for subsequent YBCO depositions. These latter techniques have promise for producing long lengths of template material; however, no YBCO I_c values have been reported for conductor lengths greater than a few cm.

EXPERIMENTS

Substrates

The substrates used in these studies are 50 to 100 µm thick nickel-based alloys. These are chosen for their corrosion resistance at elevated temperatures and include Inconel 625 and Hastelloy C-276. The substrates are not polished if their as rolled surface finishes have RMS surface roughness values of 300 A, or less, as measured by a 100 µm long surface profilometry scan in the rolling direction. The substrates are cleaned with soap and water followed by a deionized water rinse and a solvent rinse. This is followed by a light vacuum bake at < 10^{-5} Torr and 650 °C for one hour. The substrates are then mounted in the YSZ IBAD system for the template coating.

YSZ film deposition

The YSZ IBAD film deposition system is configured for either of two types of film depositions. It is capable of depositing onto fixed tapes mounted in the deposition zone or onto tapes moving in continuous loops through the deposition zone. In the fixed tape mode, up to four 1 cm wide by 23 cm long substrates may be coated simultaneously. In the continuous mode, lengths of tape 1.13 m long are spliced together into loops and mounted on a tape drive. Two 1 cm wide tapes are coated simultaneously during a deposition run. Shielding is added to the tape drive system so that vapor is not coated onto portions of the tape, which are not in the ion-assist zone. The tapes are passed through the deposition zone at a frequency of 0.6 Hz. Thus, in a run of several hours, the tapes pass through the deposition zone many times resulting in a relatively uniform in-plane texture along the length of the 1.13 m tapes. The long axes of the substrates are mounted parallel to the long axis of a 23 cm long ion-assist gun. A Faraday cup ion probe translates along the long axis of the substrates in order to map the ion current density as a function of position. A quartz crystal oscillator is used to monitor the vapor deposition rate. The assist-ion beam voltage is 200 eV and the sputter ion beam voltage is 550 eV. The currents in each of these beams are set such that the ion current to film deposition rate ratio is relatively constant during a deposition run. The ratio that is used during deposition is approximately 300 $\mu A/cm^2/(0.4$ Å/sec). The total YSZ film thickness is ~ 1 µm.

Pulsed laser deposition system

After the YSZ template films are coated onto the substrates, the tapes are mounted in a pulsed laser deposition (PLD) loop coating system described elsewhere [6]. Briefly, the tapes are driven over a heater, which results in a substrate temperature of approximately 790 °C. During deposition, the background gas pressure is 0.2 Torr oxygen. The YBCO deposition rate is 70 Å /sec. After deposition, the films are given a separate anneal in 1 atm oxygen at 450 °C to convert the YBCO to the orthorhombic phase.

The tapes are then transferred to a loop drive magnetron sputter deposition system and over coated with a 2 µm thick silver film, which serves as a protective and stabilization layer. To decrease their contact resistance, the silver films are then annealed at 550 °C in 1 atm. oxygen for thirty minutes.

Critical current measurement

The I_c measurements are done with DC transport 4-point I-V probe techniques using a 1 µV/cm criterion. Current leads are placed at each end of the tapes and have a total surface area of approximately $1cm^2$. Detailed I_c measurements are done at each cm position along the length of the tapes using spring loaded voltage contacts. Integrated I_c measurement for the tapes are done using contacts, which are separated by 1 m for the longer tapes or by 12 cm for the shorter tapes.

RESULTS

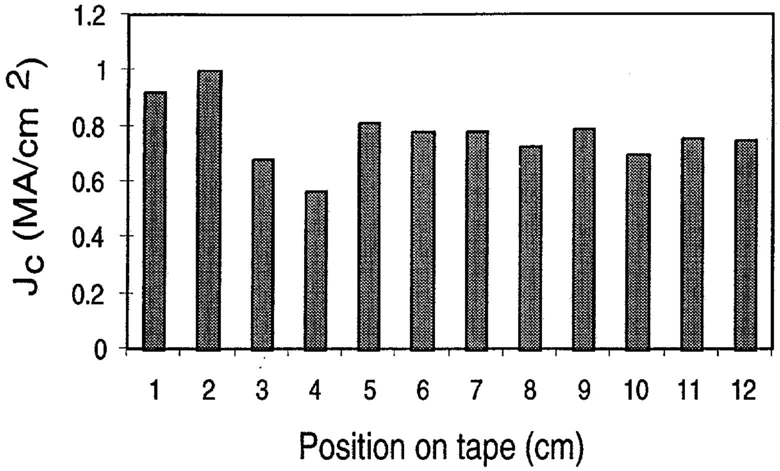

Figure 1. Individual segment J_c values for a 12 cm long 60 A tape. YBCO thickness = 0.9 μm

Detailed individual 1 x 1 cm segment I_c and J_c values (75 K, self field) for a short tape with YBCO film thickness of 0.9 μm are illustrated in Fig. 1. The overall J_c variation for the individual segments is ±25%. The integrated I_c and J_c values for the 12 cm tape length are 60 A and 0.67 MA/cm^2, respectively. Many individual segments have Jc values at or above 0.75 MA/cm^2, with one of the segments attaining a peak value of 1 MA/cm^2. The YBCO in-plane texture for this film, as determined by phi scan of the (111) peak, was 12° FWHM. These results show improvement over those we reported for these proceedings last year [6]. At that time, our best 12 cm tape had YBCO film thickness of 1.7 μm with an integrated I_c of 70 A, an integrated J_c of 410 kA/cm2, and an overall individual segment J_c variation of ± 40 %.

A study of YBCO Jc vs. its in-plane texture done by our laboratory several years ago [7] for 1 cm wide by 4 cm long strips of YBCO on both a single crystal YSZ substrate as well as IBAD YSZ on Ni-alloy substrates is illustrated in Fig. 2. For this study, the total length of the films measured within the current pads and voltage taps is approximately 1 cm. Also included in this plot are the J_c values for the individual 1 cm x 1 cm segments of the 60 A tape reported above. These most recent results show an improvement of 2.5 to 5 times in the YBCO J_c values as a function of the in-plane texture. These are attributed to improved YBCO deposition parameters and improved handling procedures within our laboratory for the tape processing.

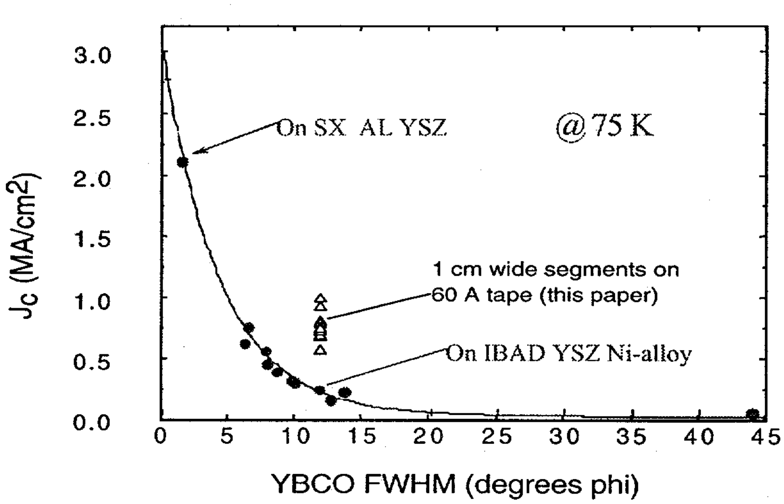

Figure 2. YBCO J_c vs. in-plane texture for 1 cm wide by 1 cm long tapes and tape segments. YBCO thickness' = 0.9 to 1.0 μm

For longer tapes, our best result, to date, is

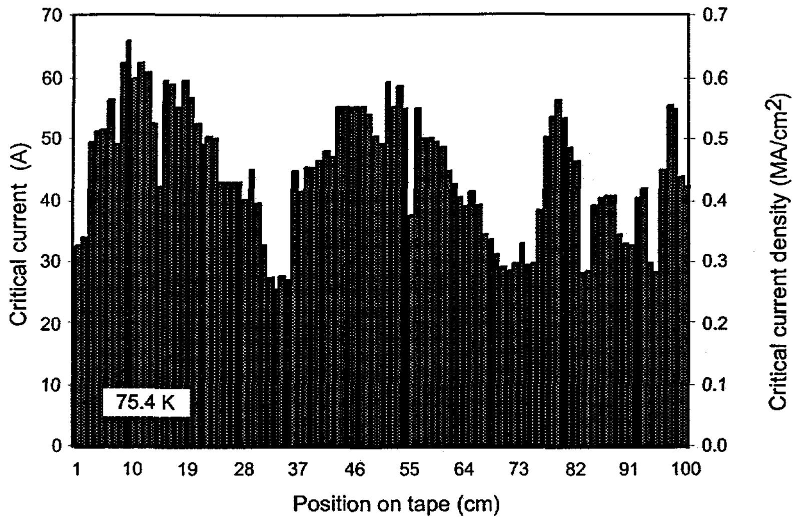

Figure 3. Segment-by-segment I_c and J_c values for 1 m tape with a 1 μm YBCO coating on an IBAD YSZ layer. The 50 μm thick substrate was coated in its as-rolled condition.

an I_c of 29 A (75.4 K, self field) over a full meter. The YBCO film thickness for this tape is 1.0 μm. Thus, the corresponding integrated J_c value for this tape is 290 kA/cm^2. Fig. 3 is an illustration of the segment-by-segment I_c variation for this tape. In this case, the highest I_c value is 67 amps, or approximately twice the end-to-end value. These results indicate that continued efforts to ameliorate the individual segment variations should result in tapes with improved integrated I_c values. Finally, it is noted that this 29 A tape was used as an exhibit at a recent conference [8] and was passed among the attendees to provide a "feel" for handling of second generation tape. Upon its return to our laboratory, the tape was again measured over 1 m and the 29 A result was confirmed.

CONCLUSIONS

We have fabricated robust, high I_c and high J_c YBCO coatings on flexible substrates using continuous coating processes. Future work will be directed at improving the Ic uniformity and improving the integrated end-to-end I_c values of our 1 m tapes.

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