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Author(s):
P.N. Arendt, MST-7
S.R. Foltyn, STC
J.R. Groves, STC
R.F. DePaula, MST-7
P.C. Dowden, STC
J.M. Roper, STC
J.Y. Coulter, STC

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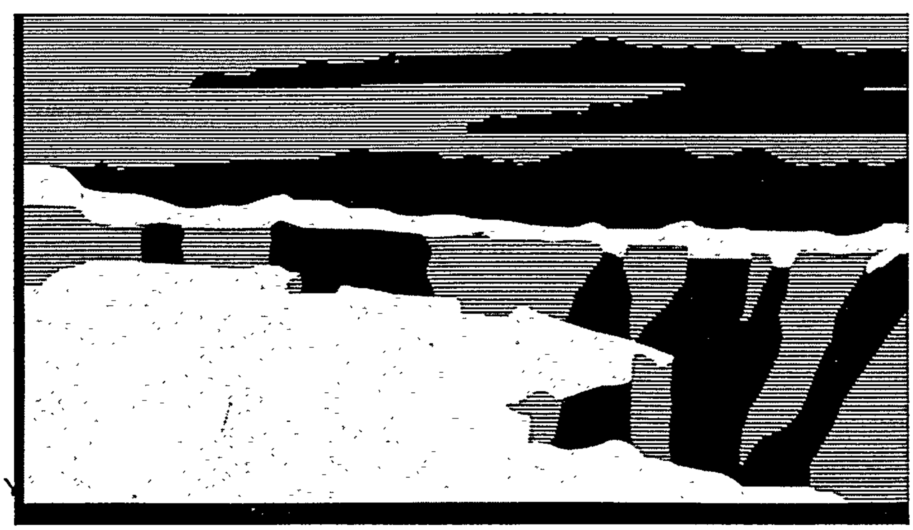

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YBCO/YSZ COATED CONDUCTORS ON FLEXIBLE Ni ALLOY SUBSTRATES

P. N. Arendt, S. R. Foltyn, J. R. Groves, R. F. DePaula, P. C. Dowden
J. M. Roper, and J. Y. Coulter

Materials Science and Technology Division
Los Alamos National Laboratory
Los Alamos, New Mexico, 87545, USA

ABSTRACT

A coating system for the deposition of in-plane oriented yttria-stabilized zirconia (YSZ) template films on 1 cm wide flexible metal substrates is presented. In static mode, the system is capable of producing high quality template films on 20 cm substrate lengths. In a continuous coating mode, the system is capable of producing good quality template films on 1.1 m substrate lengths. Superconducting $YBa_2Cu_3O_{7-\delta}$ (YBCO) films subsequently deposited onto these template films have demonstrated critical currents (Ic) of 200 A (1.5 cm length), 70 A (12 cm length), and 4 A (1 m length).

INTRODUCTION

There have been many reports on the production of high critical current density (Jc) superconducting YBCO films on small area metallic substrates.[1-6] However, only two laboratories have produced films with technically important total transport critical currents (Ic) exceeding 100 A.[7,8] These have been produced on 1 cm wide films which were under 5 cm in length. Figure 1 illustrates our best Ic attained for such short lengths. At 75 K and in self field, the Ic is 199 A with a Jc of 9.9×10^5 A/cm^2.

One key element which defines the quality of the Ic of such a YBCO film is the in-plane texture of the YSZ template film.[7] Because technically important Ic values well exceeding 100 A were obtained for short lengths of film on these YSZ templates, it was determined that a logical next step in our program was to attempt to obtain high critical currents for film lengths exceeding 10 cm. This was enabled by replacing our small 2.5 cm diameter ion assist gun with a 23 cm long ion assist gun, resulting in a template film deposition length capability of 20 cm in static mode. Also our YBCO coating capabilities were scaled up from small area batch mode processing to a continuous loop tape coating capability. Results for YBCO films obtained on the template layers made in this system have been of sufficiently good quality (70 A over a 12 cm length between voltage taps)[9] to prompt our next scale up attempt for these template layers to a 1.1 m length scale.

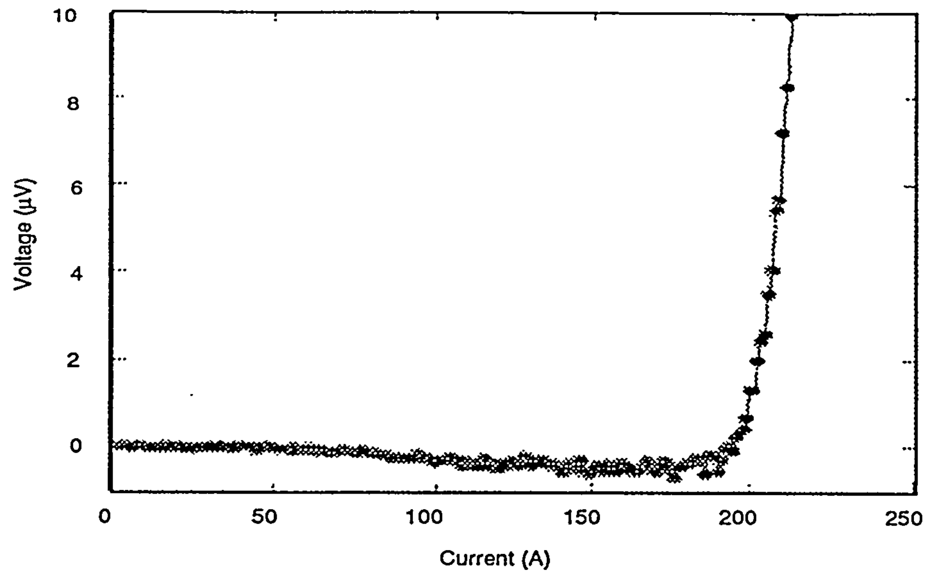

Figure 1. I-V curve for a 1 cm wide x 2.0 µm thick YBCO film on IBAD YSZ/Ni Alloy. The measurement was done at 75 K in self field. The distance between voltage taps is 1.5 cm. The total critical current is 198.7 A using a 1 µV/cm criterion. The corresponding Jc for this film is 9.9×10^5 A/cm^2.

EXPERIMENTAL PROCEDURE

Substrates

The metal substrates used in this work are a 100 µm thick, nickel based alloy, Inconel 625. The substrate surfaces are characterized using a WYCO laser heterodyne profilometer. The dimensions of the scan areas are typically 600 x 450 µm. As received from the vendor, the substrates have a surface roughness (Ra) of 100 to 300 nm and a peak to valley roughness of 1 to 2 µm. They are mechanically polished by passing them under a buffing wheel loaded with 1 µm diamond paste. Ra's achieved using this method are 10 to 30 nm. After polishing, the substrates are cleaned with soap and water followed by a solvent rinse. The substrates are then mounted in the YSZ ion-beam assisted deposition (IBAD) system.

YSZ Film Deposition System

The YSZ IBAD system is schematically illustrated for static mode depositions in Figure 2. The long axes of the substrates are mounted parallel to the long axis of the assist ion gun. Up to four 1 cm wide by 22 cm long tapes may be coated simultaneously during a deposition run. The ion probe is a Faraday cup which translates along the long axis of the substrates in order to map the ion current density as a function of position. The vapor probe is a quartz crystal monitor which remains fixed. The assist ion beam voltage is 250 eV and the sputter ion 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 µA/cm^2/(0.5 Å/sec). The total YSZ film thickness is ~ 0.5 µm.

The coater may also be operated in a continuous mode using a tape drive system. For simplification, a loop mode is used instead of reel-to-reel tape transport. Lengths of tape 1.1 m long are spliced into loops and mounted on the tape drive. Two 1 cm wide tapes may be 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 outside of 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 1.1 m tape.

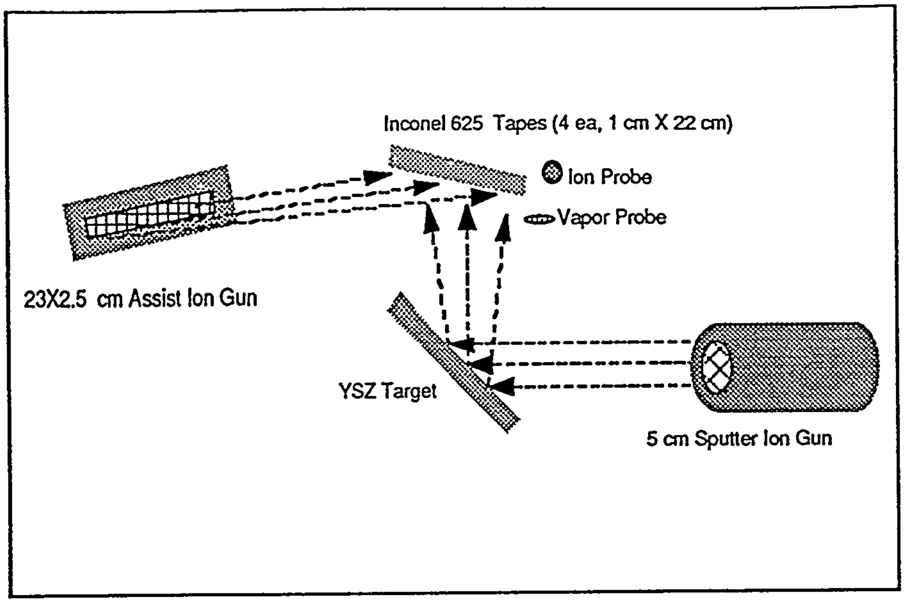

Figure 2. Schematic illustration of the YSZ IBAD deposition system used to produce the template films.

Pulsed Laser Deposition System

After the YSZ template films are coated onto the substrates, the tapes are mounted into a pulsed laser deposition (PLD) loop coating system described elsewhere.[9] Briefly, the tapes are heated on a 6.3 cm diameter disk, which also drives the tapes via an external stepper motor through a worm gear. The tape drive speeds may range from 1 mm/minute to 24 cm/minute. The typical roller temperature is 840°C, 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 and tape speed are adjusted so that 1 µm of film is deposited at a tape speed of 1.4 cm/second. After deposition, the tape rapidly cools to room temperature upon exiting the roller. The films are given a separate anneal at 450°C and 1 atmosphere oxygen to convert the YBCO to the orthorhombic phase.

Critical Current Measurement

The tapes are then transferred to a loop drive magnetron sputter deposition system and overcoated with a 2 µm thick silver film. This film serves as a protective and stabilization layer and also allows contacts for current and voltage measurements to be mounted to the superconducting film. To decrease their contact resistance, the silver films are then annealed at 550°C in 1 atmosphere oxygen for thirty minutes.

The I_c measurements are done with DC transport 4-point I-V probe techniques using a 1 µV/cm criterion. Detailed I_c measurements are done at approximately each cm position along the length of the meter long tape using spring loaded voltage contacts which are separated by 1.05 cm. The integrated I_c measurement for the entire meter of tape is done using contacts which are separated by 1 m. All measurements are done at a temperature of 75K.

RESULTS

The normalized ion current and the normalized film thickness as a function of substrate position in the YSZ IBAD system are illustrated in Figure 3. The ratios of the two quantities vary by no more than 10% for a distance about the center of approximately ± 9 cm. Thus, one may expect that the values for the in-plane texture of films, made in the static mode, will be relatively constant within this central region. Figure 4 is an illustration

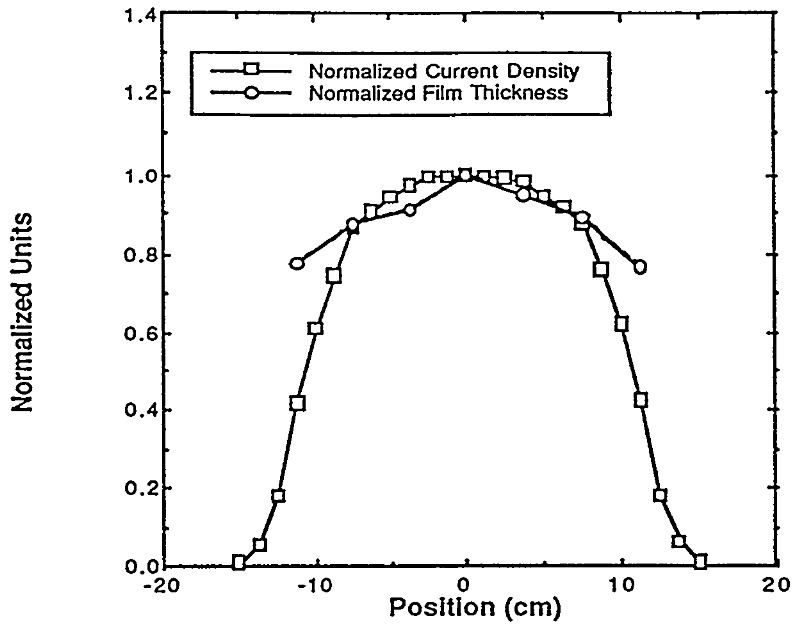

Figure 3. Normalized assist ion current distribution and film thickness as a function of substrate position. Zero cm is at the center line of the assist gun.

of the in-plane texture achieved along the length of the tape. Except for the very ends, the tape has phi FWHM values below 13°.

The PLD YBCO film deposited on top of this static mode YSZ template film has been reported in detail elsewhere.[9] Briefly, the in-plane FWHM values of the overcoated YBCO improve, on average, by another 6°. The average I_c between voltage taps, separated by a distance of 12 cm, is 70 A. The thickness of the YBCO film is 1.7 μm. The integrated average J_c for this tape is 410 kA/cm^2.

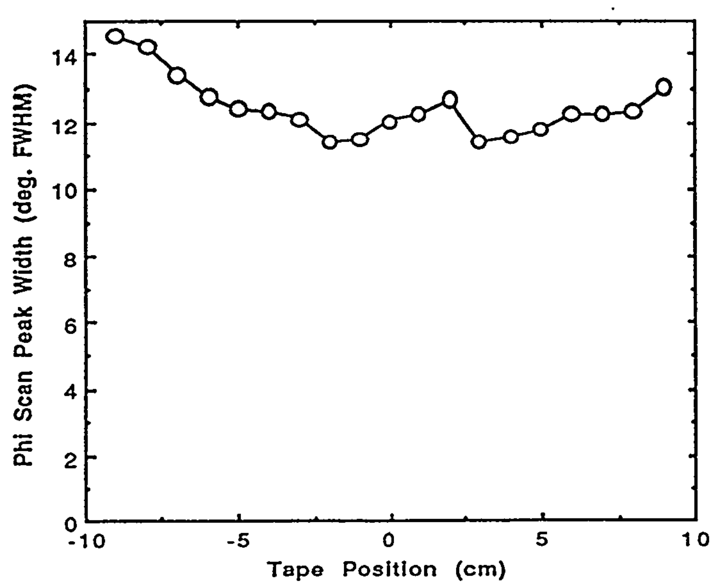

Figure 4. Illustration of YSZ film in-plane texture as a function of substrate position for a deposition done in static mode.

The IBAD YSZ films deposited on a 1.1 m tape have relatively uniform phi FWHM values along the length of the tape. A 1.1 m tape with a YSZ template film phi FWHM of 24° was overcoated with a 2.3 μm thick YBCO film. The integrated Ic(75 K) for the voltage contacts placed 1 m apart was 4 A. The Ic data for the individual 1.05 cm segments within this 1 m length are illustrated in Figure 5. The segment Ic variations along the length of the tape are over an order of magnitude apart. Four adjacent segments (84, 85, 86, and 87) with high and low Ic's were cut from this tape for detailed examination. Figure 6 shows phi scans of these adjacent segments. The YBCO films vary by a few degrees in phi FWHM but in no systematic way to elucidate variations in their Ic data. Figure 6 illustrates, however, the intensity of these individual phi scans do vary systematically in that the weaker phi peak intensities correspond to the lower value Ic segments. This weaker signal also implies that less favorably oriented material is available for accommodating the supercurrent. The YBCO film thickness' are the same for these sections so that no good explanation for the discrepancy may be advanced at this time.

CONCLUSIONS

We have constructed YSZ IBAD, YBCO PLD, and Ag magnetron tape deposition systems capable of coating flexible metal substrates which are 1.1 m long. We have also constructed a fixture with the capability to readily measure Ic's on 1.05 cm long segments along the entire length of 1 m superconducting tapes. We have achieved technically important Ic values for YBCO films on metal substrates. For measurements in self field at 75K, these are; 200 A for 1.5 cm films, and 70 A for 12 cm long films. On a 1.1 m tape the overall transport current is 4 A. Short sections within this meter tape exhibit Ic values an order of magnitude higher. Future work will concentrate on understanding and ameliorating these large variations. Also, we will endeavor to improve the in-plane texture of the YSZ template films on these meter long tapes

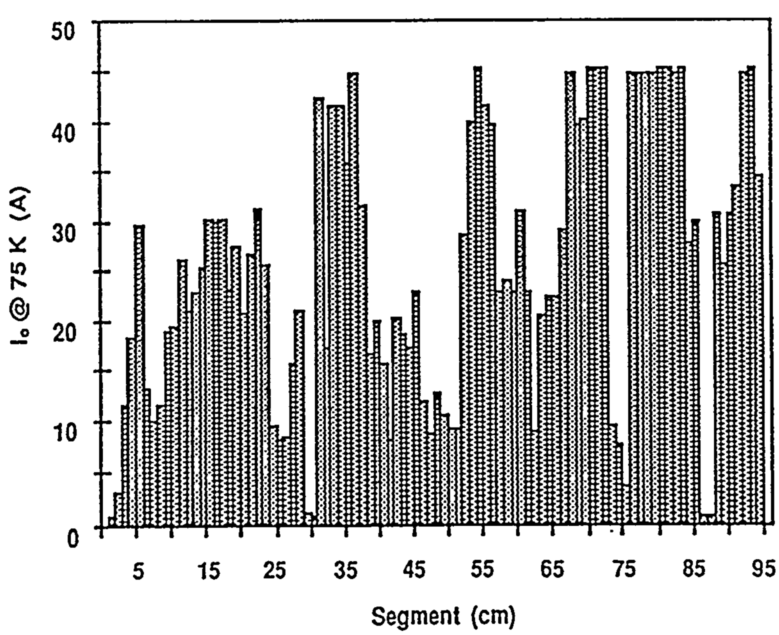

Figure 5. Segment by segment Ic measurement along 1 m tape. The measurement is done at 75 K. The YBCO film thickness is 2.3 μm.

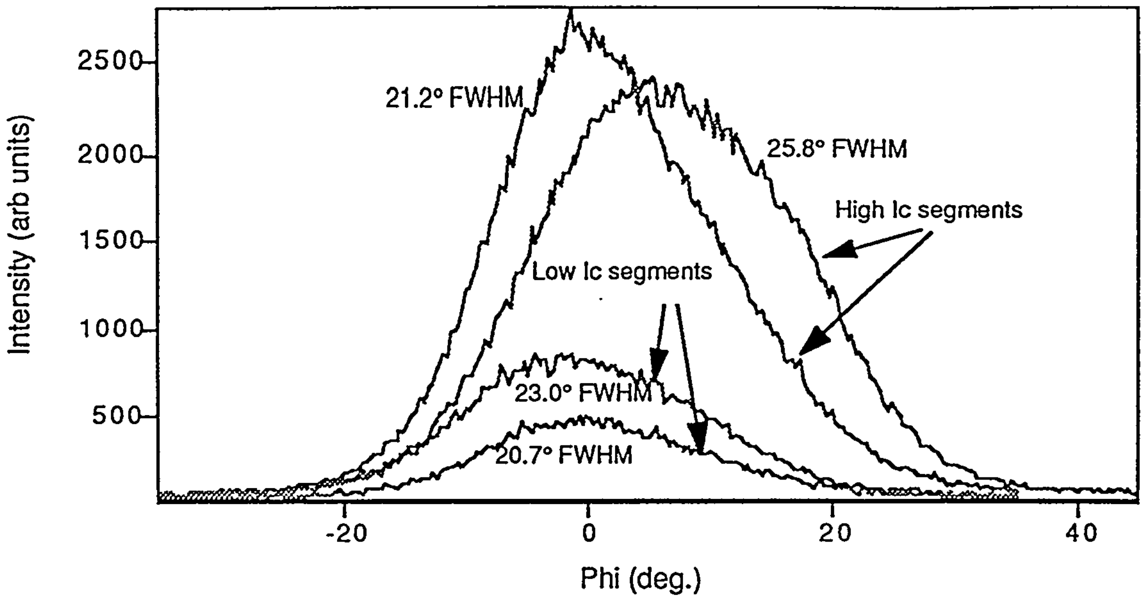

Figure 6. Phi scans for YBCO films (103 peak) for sections 84-87. The underlying IBAD YSZ template layers for these four sections have phi FWHM values of 24.2° ± 0.3 °.

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