
Project Title:	Development of Coated Conductors by Inclined Substrate Deposition
Organization(s):	Argonne National Laboratory
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FY 2004 Funding:	\$470 K

Project Purpose and FY 2004 Objectives: The purpose of this project is to develop high-performance YBCO-coated conductors for electric power applications by the inclined substrate deposition (ISD) technique. To achieve this goal, we are applying advanced characterization tools to understand texture formation and current-transport issues for ISD-based coated conductors and relate them to fabrication parameters. ISD, characterized by its fast deposition rate and good tolerance to substrate surface roughness, is an excellent candidate for cost-effective fabrication of high-performance coated conductors. In order to realize the great potential of the ISD process, our objectives in FY2004 were to: (1) understand and control fabrication parameters (including layer thickness and inclination angle) for reduced film surface roughness and enhanced biaxial texture formation in the ISD-MgO template films; (2) develop simplified buffer layer structure for the fabrication of coated conductors using ISD-MgO architecture; (3) measure and model residual strain/stresses in coated conductors and evaluate their strain tolerance to characterize the effects of various processing parameters on their mechanical reliability; and (4) assist our industrial partners in their efforts to develop practical methods for fabricating long-length coated conductors. These objectives all focus on the primary goal of DOE's second generation wire program, which is to develop the technology necessary for U.S. companies to scale-up continuous production of coated conductor with sufficient quality for industrial-scale commercial manufacturing.

FY 2004 Performance and FY 2005 Plans: We focused our fabrication effort in FY 2004 on improving the texture and critical current of ISD-based coated conductors using SrRuO₃ (SRO) as the buffer layer. This approach is based on the demonstrated improvement in biaxial texture using perovskite buffer layers and on our goal to develop a simplified architecture that takes full advantage of the simplicity and efficiency of ISD. In this activity, YBCO was deposited directly on SRO that was on MgO, which decreased the number of layers in the conductor and simplified its fabrication. Some effort was also devoted to the deposition of thicker YBCO films to enhance the critical currents. By closely coordinating the fabrication process with multiple characterization efforts, we improved our understanding of the ISD fundamentals and achieved a nearly three-fold increase in I_c . As a result, we produced short-length samples with transport $J_c > 0.75$ MA/cm² and $I_c \approx 100$ A/cm-width (at 77 K in self-field) for YBCO on ISD MgO substrates with a single-layer SRO buffer. This coordinated effort involved Raman microspectroscopy in systematically examining YBCO films to develop metrics for correlating conductor performance with deposition methodology and parameters; studies of epitaxial growth and interfacial reactions between buffer layers at Argonne's Electron Microscopy Center (EMC), funded by the DOE-Office of Science; and focused ion beam (FIB) analyses at both ANL-EMC and the University at Albany to examine the thickness and crystal chemistry of different layers of the ISD architecture. Processing improvements were also aided by extensive microstructural characterization and texture evaluation that were performed using an atomic force microscope (AFM) and a General Area Diffraction Detection X-ray unit. Due to these coordinated efforts, we can now reproducibly fabricate ISD-MgO-based coated conductors with improved performance and sharpened in-plane (ϕ -scan FWHM $\approx 5^\circ$) and out-of-plane texture (ω -scan FWHM $\approx 3^\circ$).

The FY 2005 plans are to: (1) utilize our coordinated characterization approach to identify the key current-limiting features in ISD-based coated conductors; (2) understand and optimize individual processing steps in the deposition of buffer and superconductor layers to further improve current carrying capability on short-length ISD-based samples; (3) use chemical and microstructural analyses to guide improvement of J_c for YBCO films with thickness > 2 μ m; (4) investigate Dy-123 as the superconductor coating on ISD architecture; (5) apply the ISD process to moving substrates; (6) continue measurement and modeling of residual stresses/strains and evaluation of strain tolerance to characterize the effects of

various processing parameters on the mechanical reliability of coated conductors; (7) continue collaboration with our industrial partners to solve critical issues in coated conductor scale-up (e.g., by integrating magneto-optical imaging, electron microscopy, Raman and X-ray methods to establish a characterization protocol).

FY 2004 Results: Reduced funding in FY 2004 had a significant impact on the breadth of our ISD fabrication activities. In particular, processing of long-length ISD tapes using the facilities at LANL's Research Park was completely curtailed. Key results are: (1) Studies using X-ray diffraction and AFM surface analysis showed that the optimal inclination angle for ISD MgO films is $\approx 35^\circ$. (2) Biaxial alignment was improved through the homoepitaxial MgO layer ($\approx 0.25 \mu\text{m}$) and SRO buffer ($\approx 0.1 \mu\text{m}$). We achieved in-plane texture of $\approx 5^\circ$ and out-of-plane texture of $\approx 3^\circ$ for YBCO grown on SRO buffered MgO template films. (3) Transport $J_c > 0.75 \text{ MA/cm}^2$ and $I_c \approx 100 \text{ A/cm-width}$ were measured for YBCO on ISD MgO substrates using SRO single-buffer-layer architecture. (4) We fabricated thicker YBCO films (thickness $\approx 1.6 \mu\text{m}$) with $J_c \approx 0.6 \text{ MA/cm}^2$. In FY 2003, we were depositing YBCO films that were usually $\approx 0.3 \mu\text{m}$ in thickness. (5) YBCO was grown with its c-axis tilted using SRO buffer on ISD MgO. An anisotropy of ≈ 1.6 was detected between transport J_c measured in longitudinal and transverse directions. Reproducibility of the ISD process improved. (6) We used Raman microspectroscopy to examine the onset and extent of a-axis-oriented grain growth in YBCO films. We devised Raman mapping strategies that provide both depth and spatial profiles for effects such as cation disorder, c-axis verticality, and impurity phase excretion, and we correlated these results with processing conditions. (7) We measured and numerically modeled residual stresses in YBCO coated conductors, and evaluated their effect on strain tolerance. The residual stresses in the YBCO film were measured by optical interferometric technique and were observed to be tensile in nature. A correlation of the analytically predicted and experimentally observed strain tolerance suggested that the measured tensile residual stress in the YBCO film decreases the strain tolerance of the coated conductor. The results of the modeling indicated that residual stress in the YBCO film is influenced only by the relatively thick substrate and not by the thin buffer layers. (8) In collaboration with LANL, we evaluated the angular dependent in-field performance of YBCO coated conductor fabricated using ISD-MgO architecture.

Research Integration: We have been working closely with SuperPower (SP), American Superconductor Corp. (AMSC), and Universal Energy Systems, Inc. (UES). The SP program focuses on integrating coated-conductor fabrication and characterization technologies developed at ANL and LANL with those pursued by SP. Early in the year, ISD substrates fabricated at ANL were sent to SP for YBCO deposition by MOCVD technique. Due to severe reduction in funding, MOCVD on ISD architecture was postponed. Most of our interactions with SP in FY 2004 were in the area of coordinated characterization utilizing MOI, Raman, FIB-SEM, and TEM to identify defects that influence superconducting properties in long-length tapes. Details of this interaction are given in our summary entitled "Coordinated Characterization of Coated Conductors". In our collaboration with AMSC, we worked on the optimization of their TFA precursor conversion process. Results of our collaborative effort with SP and AMSC are presented in two separate talks by our industrial partners and in ANL's talk on coordinated characterization. Our interaction with UES focuses on the ISD process. The UES program is funded by the Air Force Office of Scientific Research. In our collaboration with UES, ISD substrates were provided to UES for YBCO deposition by a MOD process. The YBCO coated samples were characterized at ANL using a variety of tools. In collaboration with LANL, we evaluated the angular dependent in-field performance of coated conductors that were fabricated using the ISD technique. Collaborations are also underway with University at Albany to evaluate the thickness and chemistry of different layers of the ISD architecture (using FIB and SIMS techniques). We also sent ISD substrates to University of Kansas (Prof. Judy Wu) for a study on the effect of miscut angle on the superconducting properties of YBCO films. Through regular teleconferences and team meetings with our collaborators, we coordinate all of the experiments, discuss the results, and establish plans for future work. ANL's program is heavily leveraged by the DOE-Office of Science's fundamental investigation of grain boundaries and by its electron microscopy center. ANL's interactions with industry and universities yielded many publications and talks at conferences during the past year.