Project Title:	**Development of Coated Conductors by Inclined Substrate Deposition**
Organization(s):	**Argonne National Laboratory**
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FY 2003 Funding:	$1000 K

Project Purpose and FY 2003 Objectives: The purpose of this project is to develop high-J_C coated conductors for high-temperature and high-field applications by the inclined substrate deposition (ISD) technique. To meet this goal, we are applying advanced characterization tools to understand texture formation and current transport issues for 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 fabrication of coated conductors. In order to realize the great potential of the ISD process, our objectives in FY2003 were to: (1) understand the film surface roughness and biaxial texture development in ISD-MgO as a function of thickness; (2) develop suitable buffer layer(s) on top of ISD-MgO; (3) understand the growth mechanism and orientation relationships among YBCO, buffer films, and biaxially textured ISD-MgO; (4) identify/develop, evaluate, and apply effective combinations of measurement tools for the interrogation and characterization of coated conductor embodiments; (5) measure and model residual stresses in coated conductors, evaluate strain tolerance, and predict the critical film thickness for the onset of microcracking in YBCO films; and (6) 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 2003 Performance and FY 2004 Plans: In FY2002, we reported a best transport J_C of 0.50 MA/cm^2 (77 K) and a typical J_C of ≈0.3 MA/cm^2 for short lengths of ISD-MgO-based YBCO coated conductor. This year, we gained fundamental insight into the ISD process by closely coordinating fabrication efforts with multiple characterization efforts at various institutions. As a result, we produced a best transport J_C of 1.2 MA/cm^2 (77 K) for YBCO on ISD MgO substrates. 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) analysis at the University at Albany to examine the thickness and chemistry of different layers of the ISD architecture. Processing improvements were also aided by a faster, more powerful laser (100 Hz, 60 W) deposition system and by extensive microstructural characterization and texture evaluation that were performed using a newly acquired atomic force microscope (AFM) and 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 (Ø-scan FWHM ≤9°) and out-of-plane texture (Ω-scan FWHM ≈5°).

FY 2004 plans are to: (1) 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; (2) use chemical and microstructural analyses to guide improvement of J_C for YBCO films with thickness >2 µm; (3) apply the ISD process to long-length fabrication; (4) continue our joint research activities with ORNL and LANL to develop a simplified buffer layer architecture for the ISD process; (5) continue measurement and modeling of residual stresses/strains and evaluation of strain tolerance to characterize the effects of various processing parameters on mechanical reliability of coated conductors; (6) continue collaboration with our industrial partners to solve critical issues in coated conductor scale-up (e.g., by integrating magnetooptipcal imaging, Raman and X-ray methods to establish a characterization protocol).

FY 2003 Results: (1) Studies using electron diffraction and AFM surface analysis showed that the optimal thickness for ISD MgO films on metallic substrates is 0.5-1.0 µm. (2) We achieved in-plane texture of 9°

and out-of-plane texture of 5° for MgO template films at a deposition rate of ≈40 Å/sec. (3) Roughness of the ISD-MgO surface was reduced with a homoepitaxial layer of MgO (≈0.25 µm). (4) The crystalline orientation of biaxially aligned YBCO on ISD-MgO depends on the buffer material. Biaxially textured YBCO is grown with its c-axis perpendicular to the substrate using ceria and YSZ buffers under appropriate conditions, whereas in collaboration with LANL, YBCO was grown with its c-axis tilted using $SrRuO_3$ buffer on ISD MgO. (5) In-plane textures of 11.5° and 6.5° were obtained for vertically textured YBCO (using CeO_2/YSZ buffers) and tilted YBCO (using $SrRuO_3$ buffer), respectively. Our best sample exhibited a T_c of 91 K, and transport J_c of 1.2 MA/cm^2 at 77 K. Reproducibility of the ISD process improved to give a typical J_c of ≈0.5 MA/cm^2. (6) We measured and analyzed residual strains/stresses in coated conductors and evaluated strain tolerance as a function of YBCO film thickness for a given conductor configuration. The critical film thickness estimated from the measured strain tolerance was in good agreement with analytical prediction. (7) We examined the onset and extent of a-axis growth in YBCO films using Raman microspectroscopy. 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. (8) We achieved, in collaboration with UES, Inc., an ISD MgO tape over 1-m long with average in-plane texture of ≈16°.

Research Integration: We have cooperative research and development agreements with IGC-SuperPower (IGC), American Superconductor (AMSC), and Universal Energy Systems, Inc. (UES). The IGC program focuses on integrating coated-conductor technologies developed at ANL and LANL with those pursued by IGC. In our collaboration with AMSC, we characterize grain orientations in their coated conductors using electron backscattering orientation maps and transmission electron microscopy, and we track YBCO phase evolution from amorphous precursor stage using Raman microscopy on meter-plus-length of tapes. Results of our collaborative effort with IGC and AMSC are presented in two separate talks by our industrial partners. Our interaction with UES focuses on ISD by a biased-sputtering process. The UES program is funded by the Air Force Office of Scientific Research. In our collaboration with UES, an ISD MgO tape over 1-m length has been fabricated. Through regular teleconferences and team meetings, we coordinate all of the experiments, discuss the results, and establish plans for future work. We collaborate with ORNL in developing a simplified ISD architecture. In this collaboration, a single buffer layer of $LaMnO_3$ is investigated directly onto an ISD MgO template. We are collaborating with LANL to develop a PLD protocol for depositing SRO buffer layer on ISD-MgO. Collaborations are also underway with University at Albany to evaluate the thickness and chemistry of different layers of the ISD architecture. ANL's program is heavily leveraged by programs funded by DOE's Office of Science on the fundamental properties of grain boundaries. ANL's interactions with industry and universities yielded many publications and talks at conferences over the past year.