

Superconductivity for Electric Systems 2006 Project Summary

PROJECT TITLE:	Coordinated Characterization of Coated Conductors
ORGANIZATION:	Argonne National Laboratory
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FY 2006 FUNDING:	\$650K

Project Purpose and FY 2006 Objectives: This project is orchestrated to provide a comprehensive capability to evaluate what works well and what goes wrong in the processing of long-length coated conductors (CC) produced by our CRADA partners— SuperPower, Inc. (SP) and American Superconductor (AMSC)—and by our laboratory and university collaborators in the OE/HTS Program. Our coordinated characterization of coated conductors (C^4) is applied in a manner that addresses key performance issues for CCs. These include: (1) finding and indexing “high” and “low” performance segments of CCs by magneto-optic imaging (MOI), (2) determining local phase makeup and texture quality by Raman microscopy and x-ray diffraction (XRD), (3) examining indexed microstructures by scanning electron microscopy (SEM), (4) conducting “biopsies” using focused ion beam (FIB) methods with transmission electron microscopy (TEM), and (5) obtaining high resolution 3-D structures using SEM. Selection of issues to study and sample types takes into account what SP and AMSC view as their highest priority concerns. Performance limiting defects, desirable flux pinning defects, and precursor conversion mechanisms have been the principal focal areas in FY 2006. We work closely with SP and AMSC to maximize the pace of progress towards commercialization and believe that our characterization is the key to establishing optimum processing parameters and protocols. Individual characterization methods employed in isolation are unlikely to provide directional answers for the rapidly maturing CC technology. For this reason we have tailored our C^4 project to be the most comprehensive/integrated characterization activity in the OE/HTS Program. Our active participation in the AMSC-led Wire Development Group (WDG) continued in FY 2006.

FY 2006 Performance: Performance areas addressed in FY 2006 are listed below:

- Elucidation of flux pinning center formation and phase evolution in MOD YBCO films (with AMSC and the WDG);
- Development of generalized models for flux pinning that are applicable to MOD and MOCVD YBCO films;
- Exploration of the cause of performance variations along the length of MOCVD CCs (with SP);
- Analysis of on-line Raman data supplied by SP to test pathways for product quality tagging and feedback control;
- Implementation of new instrumentation that uses the field-angle dependence of J_c to connect our flux-pinning model to the morphology and density of pinning defects determined by our MOI-Raman-FIB-TEM analysis suite.

FY 2007 Plans: Our plans for FY 2007 embrace logical extensions of our work through FY 2006 and are summarized below:

- Work with AMSC and the WDG to optimize the flux pinning architecture of the MOD/RABiTS format for CC manufacturing through detailed study/modeling of flux pinning mechanisms coupled with measurements of in-field performance as a function of fields angle (using instrumentation now in place at ANL).
- Work with SP to (1) explore the cause(s) of a-axis grain growth in MOCVD films, (2) resolve the remaining issues concerning the effects of post-MOCVD carbon, and (3) begin to investigate pathways for flux pinning enhancement in MOCVD YBCO films through joint experimentation (with SP) and modeling.
- Extend the flux-pinning model to higher fields where the effect on J_c of multiple pinning-defect morphologies may not be simply additive.

FY 2006 Results: In FY 2006 we examined a wide variety of samples provided by our industrial partners and laboratory/university collaborators. These studies involved (in whole or in part) the application of our cadre of C^4 characterization tools to investigate specific performance limiting behaviors and to establish a sounder

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fundamental basis for elucidating and enhancing the performance features of the YBCO coated conductor. Specific examples are listed below:

- We performed extensive studies of the formation and dissipation of planar defects in MOD films produced by AMSC. This work included examinations of large numbers of through-process specimens (during precursor conversion, after YBCO formation, and during oxygen anneal). We have evidence that the planar defects nucleate from a phase that contains barium, copper, and oxygen, with some of the copper being in the cuprous state. Furthermore, we have developed an understanding of why dysprosium addition to the YBCO precursor (to boost the nano-particle pinning center density) tends to discourage the formation of the planar defects.
- We have developed a model that relates pinning center, size, shape, and number density to pinning force in YBCO films as a function of field angle.
- We have examined a series of step-milled YBCO films by Raman microscopy and electron microscopy. The results of these studies provide seminal insights about YBCO phase composition and microstructure as a function of depth into the film. We see evidence that cation disorder (as a possible point defect pinning center propagator) is correlated with improved pinning near the YBCO/substrate interface of IBAD textured conductors. In partially processed samples, we are able to map the gradient of secondary phases that participate in the formation of YBCO and to track the YBCO nucleation process from substrate to surface.
- We conducted comprehensive C^4 examinations of specimens from several of SP's long length MOCVD product tapes with the finding that (1) there is a tendency for a-axis grains to form at interfaces between passes during multi-pass MOCVD depositions, (2) the microstructure in lower performance regions tends to contain more of the a-axis grains, and (3) carbon persists in the YBCO films after MOCVD deposition but it is not clear whether/how this carbon influences I_c fall-off in long length tapes.
- In conjunction with SP we performed an extensive analysis of multi-spectral data files obtained with the Raman tool attached to SP's MOCVD deposition chamber and identified correlations between spectral characteristics and CC tape performance at both the post-deposition and post-anneal stages. A manuscript describing this work has been prepared for publication.
- Over the past year we had 14 peer reviewed publications and there are currently five manuscripts in the submission/acceptance stage.

Research Integration: The current OE/HTS program at Argonne is first and foremost committed to supporting our two CRADA collaborations—one with SP and one with AMSC. For our SP collaboration we work closely with Jodi Reeves of SP to develop work plans. Face-to-face meetings have been occurring on a quarterly basis, with frequent telephone and e-mail communication. The samples supplied by SP for C^4 analysis at Argonne are ones from their most current processing runs that have been well characterized for electrical performance properties. We also assist SP in the interpretation of data from the on-line Raman tool they have adapted to their MOCVD line. The C^4 analysis on SP films helped to improve the processing protocol and the resultant long-length J_c . Our collaboration with AMSC occurs mainly through the 2G Wire Development Group (WDG) which is led by AMSC but also includes participation by Los Alamos National Laboratory (LANL), Oak Ridge National Laboratory (ORNL), and the University of Wisconsin/Madison (UWM). The WDG meets three times a year to review research progress and plan follow-on work. The WDG members work on common sets of MOD/RABiTS samples produced mainly by AMSC. The collective results of specialized examinations at each of the participating institutions regularly produce insights that AMSC factors into its MOD/RABiTS processing methodology. We have helped to understand the mechanism of formation of the desirable planar pinning defects in their CCs. In FY 2006 we also examined specially prepared samples from LANL, UWM, and Brookhaven National Laboratory, with the focus of even this work aimed at assisting developments in MOD/RABiTS and MOCVD/IBAD process advancement.