Project Title:	**Development of High I_c Ex Situ Processed RBCO Coated Conductors**
Organization(s):	**Oak Ridge National Laboratory, Los Alamos National Laboratory, and The University of Wisconsin**
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Project Purpose and FY 2004 Objectives: This project represents a cross-institutional, collaborative research effort targeting the development of $YBa_2Cu_3O_7$ (YBCO) and/or RBCO coated conductors (R is a rare earth element or mixture thereof) based on the ex-situ conversion of evaporated, BaF_2-type precursors. The purpose is to generate a materials science basis for continued properties improvement in ex-situ coated conductors through structure-property-chemistry correlations. FY 2004 objectives included achieving a better understanding and control of transient liquids during the conversion process, faster conversion rates, high I_c ($\geq$400 A/cm-width) with thickness and J_c optimization, and a better understanding of the relation between flux pinning and microstructure. The last objective is closely coupled with the American Superconductor Corporation (AMSC) led Coated Conductor Wire Development Group (CC-WDG). Each of the three collaborating teams participates in this CC-WDG.

FY 2004 Performance and FY 2005 Plans: Significant progress towards FY 2004 objectives and milestones was made. Specific milestones for FY 2004 were to: 1) increase the processing rate of PVD precursors from 1-2 Å/s to 10 Å/s, and 2) raise the I_c performance of YBCO films on a metallic substrate to 400 A/cm-width at 77 K (self-field). TEM and SEM were used to characterize fully and partially processed YBCO coatings. Signatures of liquid phase formation were identified. The existence of two distinct growth modes was established. EBSD (Kikuchi electron backscatter diffraction) was used to examine in detail grain boundary structures and local YBCO orientations through the thickness of a film by repeated imaging and ion milling. The ability of YBCO to overgrow substrate grain boundaries (GBs) and create novel GB networks was discovered. A new "fast modified" process was developed for the conversion of thick PVD-BaF_2 precursors in the range of 10 Å/s. YBCO films of variable thickness were grown by the fast conversion process on RABiTS substrates provided by AMSC. A nearly linear increase of I_c with d was obtained. Angular and temperature dependent J_c measurements were performed in variable magnetic fields. It was observed that the angular dependence of J_c is processing dependent and can be controlled to reduce the anisotropy (this is covered in the CC-WDG summary).

Research plans for FY 2005 are to continue the collaborative research towards higher I_c in ex- situ coated conductors. With respect to CC-WDG objectives, an enhanced emphasis will be given to the relationships between flux pinning and the processing of PVD-BaF_2 YBCO films. The microstructural origin of the process dependent J_c anisotropy will be investigated. A promising route to study and improve flux pinning is to substitute one or more rare earths for Y. We will investigate the ramifications of these substitutions for several R elements, bearing in mind that minor variations in the overall process may have an impact on the liquid-mediated growth and I_c performance. Evaluation of the efficacy/ compatibility of R substitution is considered timely. We will attempt to raise I_c to values >500 A/cm at 77 K by increasing J_c for films of medium thickness (1.5-2 μm). Using the new through-thickness imaging capability, we will continue study of current-limiting mechanisms in YBCO coated conductors.

FY 2004 Results: Key results from the FY 2004 collaborative research are summarized below:

1) Continuation of the study of the bimodal growth process in ex-situ YBCO coated conductors showed that this growth mode is not limited to thick films (d >2 μm), but may occur in thinner coatings (e.g., 0.8 μm) as well. The bimodal structure is evidence of the variable role of transient liquids during the conversion process. Barium-rich secondary phase layers were often observed between the large, laminar YBCO grains. However, exceptions to this latter effect were observed as well. Such films still exhibited bimodal microstructures without the intercalated Ba-rich phases, had lower out-of-plane misalignments, and produced higher than average J_c values.
2) A new set of processing conditions and procedures was developed for the synthesis of thick YBCO coatings. The improvements involve all stages of the production process, starting from the precursor deposition (by electron-beam evaporation), through a newly inserted, low-temperature oxidation anneal, to the high-temperature conversion. This new process enables faster conversion rates in the range of 5-10 Å/s, compared to 1-2 Å/s previously.
3) The efficacy of this new, "fast modified" process for raising Ic was tested for YBCO films of variable thickness on ORNL and AMSC RABiTS substrates. A significantly reduced dependence of J_c on the YBCO thickness d was observed. In the range 0.5-1.3 μm, Ic increases linearly with d to values >300 A/cm (77 K). This represents a significant improvement over FY 2003's best result (240 A/cm), measured for 2.5-μm-thick YBCO coatings. The present I_c values are higher and obtained for films of half the thickness.
4) Ion milling, coupled with SEM and EBSD, has been used to visualize through-thickness, YBCO grain boundary structures in coated conductors and their registry with the underlying template. A remarkable feature of the liquid-mediated growth mode is the ability of YBCO grains to completely overgrow GB's of the substrate template, both in the case of IBAD and RABiTS. A new GB network is thus formed in the YBCO and this network may evolve through the film thickness. Analysis of this behavior for films produced by the "fast modified" process reveals interesting GB network modifications which depend on the original precursor thickness. The role of these modifications in enhancing J_c is currently under investigation.

Research Integration: This research group represents a tight inter-lab, university, and industry collaboration in YBCO coated conductor research, where each partner brings a unique expertise to the collaboration. Ex-situ conversion is a promising deposition process for large-scale commercial deployment as illustrated by our industry partner, American Superconductor Corporation. Work on flux pinning in ex-situ PVD-BaF_2 YBCO coated conductors is closely integrated with CC-WDG efforts in flux pinning of AMSC MOD-BaF_2 YBCO. Additional external collaborators include: NIST-Gaithersburg (phase development) and NIST-Boulder (strain effects), Stanford University and other participants in the MURI project (information exchange), and Institute de Ciencia de Materials de Barcelona, Spain (granularity effects).