

**2010 Advanced Cables and Conductors Peer Review  
Project Summary**

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<b>Project Title:</b>	Current limiting mechanism studies of coated conductors
<b>Organization:</b>	Applied Superconductivity Center, National High Magnetic Field Laboratory, Florida State University
<b>Presenters:</b>	David Larbalestier, Dmytro Abraimov and Alex Gurevich
<b>FY 2010 Funding:</b>	\$400,000 (about \$150,000 used for WDG support in FY10)

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**Overall Project Purpose and Objectives:**

Our overall goal is to understand and ameliorate the current-limiting mechanisms (CLM) of coated conductors (CC), recognizing that the drive for CC performance improvement in cost and  $I_c$  always drives conductors into territory where enhanced vortex pinning and YBCO thickness is compromised by degraded connectivity. We use a unique suite of tools of great breadth to understand and compare the latest coated conductors to model samples. Synergistic microscopies (SEM with EDS, EBSD and FIB, TEM, LTLSM and MOI), theory and extensive superconducting characterizations aimed towards magnet applications have been emphasized.

**2010 Approach and Results:**

There have been several components to our work in FY10.

1. Within the Wire Development Group we have made detailed studies of the temperature dependent pinning and of the operative CLMs in the latest generation of MOD-RABiTS. We have been able to distinguish domains of T, H and  $\theta$  in which correlated pins such as stacking faults and intrinsic, CuO *ab*-planes control the vortex pinning. At 77 K, *ab*-plane stacking faults and randomly distributed RE<sub>2</sub>O<sub>3</sub> pins control  $J_c$ , while at 30 K intrinsic pinning and SFs are important. An interesting case concerns the role of voids produced during the decomposition part of the MOD *ex situ* process. They are often 15-20 vol.% and 100-200 nm diameter, thus being able both to significantly block current and produce strong magnetic pinning. The strong pinning effects are indeed observed in tracks cut within single grains which yield  $J_c(77K, SF)$  values of  $> 4.5 \text{ MA/cm}^2$ . CLMs are of various types, of which grain boundaries remain an essential and easily observable component. GBs reduce  $J_c(77K, SF)$  from intragrain values of  $\sim 4.5$  to about  $3 \text{ MA/cm}^2$  but their effect at 77K generally disappears above 2 T. Other factors which control the non-uniform through-thickness  $J_c$  and various forms of scale-up local defects compromise present values of  $I_c$  but understanding and reducing them provides the opportunity for considerable increase in  $I_c$ , even for YBCO thicknesses of  $1 \mu\text{m}$ , which is the present standard.

2. Work on an *ex situ* non-F process was concluded at end of 2010 with graduation of the student and his passage to a post-doctoral position at Texas A&M University. Although substantial enhancements of  $J_c$  and pinning force  $F_{pmax}$  in films  $< 0.5 \mu\text{m}$  were obtained using random BaZrO<sub>3</sub> (BZO) particles with this process, we were not able to show that thick YBCO films were any more accessible by this route than the standard MOD-TFA process.

3. NSF funded the fabrication of a 32 T, 40 mm bore, all superconducting user magnet for the NHMFL. This magnet will provide a field more than one third higher than any previous all-superconducting magnet and enable experiments that presently require use of 20 MW resistive magnets costing about \$125,000 in power per week. The stresses within such a magnet exceed 400 MPa, making the high-strength Hastelloy IBAD-MOCVD conductors especially valuable. Extensive study of the high field  $J_c(\theta)$  in fields up to 31 T has been made this year using NSF support, but an additional component of the work has involved evaluation of such conductors over the domain of interest to OEDER applications. We have found that the ability to add BZO

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nanorods by the *in situ* MOCVD process has interesting effects too in the lower temperature regime, even when the clear signature of correlated, quasi-c-axis pinning is no longer so clear below about 30 K. In this domain the overall  $J_c$  is nevertheless raised significantly by what we infer is point pinning induced by the strong strain effects induced by BZO particles. The correlated pinning effects of the BZO nanorods make major contributions to  $J_c$  at all temperatures for H over a wide angular range around the c axis.

**2011 Plans and Expectations:**

Plans for 2011 were significantly affected by the January 2011 decision of the President's budget to zero out ongoing R&D. Thus a major part of our plans for FY2010, namely rebuilding of our milling chamber was cancelled and funds transferred to keeping the personnel and ongoing activities in place through end of 2010 calendar year (our funding year is at present off cycle, ending June 30). As we write, it seems likely that the OEDER program will continue and will emphasize enhancing the performance of coated conductors. We believe that our kind of integrated CLM analysis will continue to be of value. Especially in the context of raising  $I_c$  performance and better optimizing pinning in all domains of interest, we plan to emphasize:

1. We will rebuild our milling chamber in FY11 so as to make study of the thickness dependence of  $J_c$  a renewed central thrust of our work. We will complement this  $z$ -dependence of  $J_c$  with studies of its  $x$ - $y$  dependence too, using low temperature laser scanning (LTLSM) and magneto-optical (MO) microscopy.
2. An important thrust of the LTLSM work has been to address the specific role of real GBs in limiting the  $I_c$  and  $J_c$  of MOD-RABiTS conductors. Although at 77K, the domain of GB limitation is relatively small, mainly below about 2 T, high  $I_c$  at smaller fields appears to be generated by the strong pinning effects of stacking faults and voids for allowing high- $I_c$  performance in cable applications. At low temperatures, especially in the 30 K, 1-3 T domain for FCL, transformer and generator applications and for  $ab$ -plane, not just  $c$ -axis GB degradation of  $J_c$  is more likely. The LTLSM with 5 T capability built by Abraimov beautifully enables such studies.
3. More generally we plan a long-term investigation of GB effects since it is the current-blocking effects of GBs that impose the strong biaxial texture of the coated conductor architecture that makes filamentization and low AC loss performance difficult. Filamentary architecture in a round wire with high  $J_c$  (but only at 4K) is indeed possible in overdoped conductors made from Bi-2212 and we believe that it is time to address the possibilities within the 123 compounds too.

**Technology Transfer, Collaboration, Partnerships:**

All aspects of our work are collaborative. Within our own program it Larbalestier, Hellstrom and Gurevich possess decades of strong interactions on conductors, ceramic processing and theory of vortex pinning. The unique CLM analysis provided by Abraimov (LTLSM) and Polyanskii (MO imaging) strongly amplifies this effort. We were founder members of the WDG and still do a significant portion of our work within it (AMSC, ANL, LANL, ORNL and FSU collaboration). Outside the WDG, we are leveraged both by major new magnet applications of coated conductors where collaborations with Superpower are strong and by work with ORNL where studies of strong vortex pinning of PLD samples (Goyal), of the irreversibility field and its angular dependence (Christen and Thompson), and using MO imaging to investigate novel methods of filamentization (Duckworth).