

## Superconductivity for Electric Systems 2006 Project Summary

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<b>PROJECT TITLE:</b>	<b>ORNL-AMSC CRADA: Development of RABiTS-Based 2G Wires</b>
<b>ORGANIZATION:</b>	<b>Oak Ridge National Laboratory/American Superconductor Corporation</b>
<b>PRESENTERS:</b>	<b>A. Goyal, M. Paranthaman (ORNL), and W. Zhang (AMSC)</b>
<b>FY 2006 FUNDING:</b>	<b>\$800 K at ORNL (funding from DOE-OETD and matching funds at AMSC, plus \$180 K funds-in from AMSC)</b>

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**Project Purpose and FY 2006 Objectives:** This program is focused on the development of the YBCO coated conductor technology, particularly in the areas of yield improvements and manufacturing cost reductions. The goal of this program is to establish a low-cost, high throughput, high yield manufacturing process for the commercial manufacturing 2G High Temperature Superconducting (HTS) wire. To achieve these goals, the project tasks focused on an improved understanding of the fundamental material science related to the fabrication of RABiTS templates and MOD-based YBCO layers and the detailed characterization and correlation of the 2G wire properties with process parameters. This understanding is critical to the development of a reliable, low-cost reel-to-reel manufacturing process based on a 4 – 10 cm wide strip and has been essential for the continuously improving performance of 2G wire. This program also includes defining, characterizing and understanding issues related to YBCO performance, 2G wire properties (AC losses and stability) and devices fabricated using RABiTS/MOD based 2G wires.

FY 2006 objectives were:

1. Assist AMSC personnel in manufacturing alloy substrates (4 cm wide by 100 m long) using the ORNL rolling mill facility with clean room.
2. Improvement of the RABiTS™ template manufacturing reliability through fundamental characterization of the buffer layer properties and uniformity along length and width.
3. Development of improved buffers or buffer architectures leading to improved performance and/or reduced manufacturing cost.
4. Optimization of self-field  $I_c$  and pinning mechanisms in 0.8 – 2.0  $\mu\text{m}$  YBCO films produced in AMSC's Pilot manufacturing line.
5. Demonstration of solution deposited buffer layers in a continuous process with performance comparable to AMSC's standard  $\text{CeO}_2/\text{YSZ}/\text{Y}_2\text{O}_3$  buffer architecture.
6. Development of a reel-to-reel direct printing technology for striated YBCO films.
7. Characterization and testing of 2G wires and wire products.

**FY 2006 Performance and FY 2007 Plans:** The CRADA work has provided an improved understanding of the fundamental properties of the substrate, buffers and YBCO in the RABiTS/MOD process. The activity is closely coupled to AMSC's 2G scale-up program and has assisted AMSC in implementing a robust Pilot manufacturing process. Due to the unavailability of funds and AMSC's focus on developing a commercial 2G wire manufacturing process based on the RABiTS/MOD technology, the development of a reel-to-reel direct printing technology for striated YBCO films and the fabrication and testing of 2G wire products were deferred to FY 2007. However, progress on short filamentized YBCO films using ink-jet printing will be presented in the ORNL core program presentation in the 2G session.

FY 2007 Plans include:

1. Develop methods to improve mechanical properties of Ni-alloy substrates for 2G HTS wire (increased strength, reduced magnetism, enhanced texture, etc.) and development of thermo-mechanical processing parameters.
2. Continue ORNL assistance to AMSC in manufacturing strengthened alloy substrates (4 cm wide by 100 m long) using the ORNL rolling mill facility with clean room.
3. Develop MOD buffers with metal diffusion properties comparable to PVD YSZ layers.
4. Demonstration of MOD buffer deposition on NiW substrates at a rate, cost and performance comparable to or better than the AMSC's present baseline [ $\text{CeO}_2(75\text{nm})/\text{YSZ}(75\text{nm})/\text{Y}_2\text{O}_3(75\text{nm})$ ] process.
5. Characterization and optimization of pinning mechanisms in 0.8 – 2.0  $\mu\text{m}$  MOD YBCO films produced on 4 cm wide RABiTS templates.
6. Development of a reel-to-reel direct printing technology for striated YBCO films.
7. Characterization and testing of 2G wires and wire products.

**FY 2006 Results:** Key Results from the past year include:

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- Over 10 km of 4 cm wide NiW substrate was produced in the ORNL rolling mill facility.
  - The availability of this high quality 4-cm wide substrate was essential to maintaining the pilot operation at AMSC's targeted rate.
- The quality uniformity (texture, buffer quality,  $I_c$ , etc.) and wire-to-wire reproducibility of 4 cm wide strips were characterized and the data used to improve the performance of AMSC's 2G reel-to-reel manufacturing processes.
- Process conditions were developed for preparing highly textured, epitaxial LZO barrier layers and  $\text{CeO}_2$  cap layers on NiW substrates from solution based processes.
  - The solution-based buffer process was transferred to lengths (5 meter) using a slot die coater and reel-to-reel furnace.
- Detailed microscopy, x-ray and electrical characterization of YBCO films were used to optimize AMSC's 4 cm manufacturing process to control pinning performance.
  - 124-type stacking fault formation was characterized and stacking fault densities were optimized in 2G wires to enhance pinning in the  $ab$ -plane.
  - Nanodots additions were optimized in YBCO films to improve pinning in the  $c$ -axis.
- Detailed electrical characterization was carried out on thick YBCO films to characterize and optimize performance along the wire length.
- Publications and Presentations
  - 10 presentations at national/international meetings
  - 12 publications (9 published; 3 submitted)
  - 1 joint invention filed

**Research Integration:** Close collaboration and interaction between ORNL and AMSC have resulted in significant advancement in process understanding and subsequently in the development of a robust manufacturing process at AMSC. The collaboration functions through weekly conference calls, frequent sample exchanges, CRADA meetings, joint development and joint materials evaluation and testing. Technical staff from AMSC routinely visited ORNL to perform week-long rolling runs and work on slot-die coating and inkjet printing processes. AMSC views ORNL as their fundamental RABiTS template research laboratory and a key partner in characterizing and testing 2G wires and in developing novel, low-cost technologies that will further advance the MOD/RABiTS technology. The ORNL-AMSC team also worked closely with members of the WDG to develop a basic understanding of fundamental pinning mechanisms in MOD-based YBCO films. A key to the success of the CRADA interaction is the ability to rapidly address critical manufacturing issues, identify solutions and transfer the improvements into AMSC's production process.