PROJECT TITLE:	**ORNL-SuperPower CRADA: Development of IBAD-MOCVD-Based 2G Wires**
ORGANIZATION:	**Oak Ridge National Laboratory/SuperPower**
PRESENTERS:	**Dominic Lee, Robert Duckworth (ORNL), and Venkat Selvamanickam (SuperPower)**
FY 2006 FUNDING:	**$ 800 K at ORNL**

Project Purpose and FY 2006 Objectives: The purpose of this CRADA research is to assist SuperPower in the development of high performance IBAD-MOCVD-based 2G wires for the commercial application of HTS technology. Approaches include the development of basic material science understanding of the fundamental issues related to the fabrication of IBAD-MgO templates as well as MOCVD-based YBCO layers for high critical current YBCO coated conductors. In addition, HTS conductor design optimizations with respect to stability and protection issues, as well as ac loss characteristics of YBCO coated conductors are also being emphasized. This understanding is critical to the development of a reliable, long-length manufacturing process based on IBAD-MgO/MOCVD-YBCO. Research activities of this CRADA are designed to be flexible and need-based such that the most urgent issues can be investigated in order to accelerate the development of commercially viable 2G wires. FY 2006 objectives were:

1. ORNL assistance to SuperPower in transferring the LMO technology from short lengths to pilot-scale type production lengths.
2. Simplify buffer structure for IBAD MgO (in conjunction with LANL CRADA) suitable for MOCVD. Demonstrate an I_c of > 300 A/cm on LMO type buffers.
3. Produce robust, delamination free IBAD-MgO/LMO templates in 250 meter lengths by performing several annealing studies with each IBAD-MgO template layers to understand the role of each layers.
4. Characterization and optimization of pinning mechanisms in 1-3 μm MOCVD-HTS films produced on IBAD-MgO templates.
5. SuperPower assistance to ORNL in transferring the MOCVD equipment to establish YBCO deposition capabilities at ORNL.
6. Understanding the role of copper (Cu) stabilization in the operational, stability limits and ac loss in non-filamentized and filamentized YBCO coated conductors.
7. Evaluate ac loss in stacks of narrow width YBCO coated conductors with different compositions and compare to equivalent 4 mm wide YBCO.
8. Determine if improvement observed in the high voltage performance of copper surround stabilized YBCO tapes translates from fundamental geometries to practical geometries.

FY 2006 Performance and FY 2007 Plans: The CRADA work has provided an improved understanding of the fundamental properties of the IBAD-MgO template including Al_2O_3 and Y_2O_3 nucleation layers, LMO buffers and also MOCVD-YBCO. The activity is closely coupled to SuperPower's YBCO scale-up program and has assisted SuperPower in implementing a robust manufacturing process. To simplify the IBAD-MgO architecture, specifically, amorphous low-cost MOD buffer layers were deposited on electropolished Hastealloy substrates to possibly eliminate both Al_2O_3 and Y_2O_3 layers and subsequent IBAD layers with good texture were obtained at LANL. This work will be further extended in FY07. In addition, ORNL assisted SuperPower in materials issues related to the behavior of LMO buffer, and contributed to the long-length fabrication of uniformly textured IBAD-MgO/LMO templates. This led to the achievement of a World Record performance of long-length 2G wire by SuperPower. Encouraging results were also obtained in this CRADA research where epitaxial LMO cap layer was directly deposited on IBAD-MgO. The results point to the possibility of eliminating the homo-epitaxial MgO layer, and show the potential exists for simplification of the IBAD-MgO substrate architecture and increasing the throughput. In the area of MOCVD HTS development, magnetic and transport critical current characteristics have been measured on samples with various stoichiometric and doping variations. The results revealed that simple changes in starting precursor stoichiometry can result in substantial enhancement in the 2G wire performance. This finding points toward the need for additional effort in stoichiometry and doping studies. To accomplish this within the CRADA research, ORNL has worked with SuperPower to transfer the MOCVD technology, and has established the "SuperPower" MOCVD-HTS deposition capability at ORNL. For FY 2006, the quench dynamics of single YBCO tapes with different thicknesses of Cu surround stabilizer were determined at 77 K using over-current pulses and constant currents for sample lengths of 0.2 - 1.0 m. The ac losses were measured in as a function of field for a set of stacked 2-mm wide SuperPower conductors and were compared to those for a 4-mm wide conductor with similar critical current density.

FY 2007 Plans include:

1. Continue ORNL assistance to SuperPower in fabricating robust IBAD-MgO templates in a pilot-scale production level.
2. Development of improved buffer architectures leading to improved IBAD-MgO template performance and/or reduced manufacturing cost.
3. Continue characterization and optimization of pinning mechanisms in 1-3 μm thick Y,SmBCO films produced in the manufacturing system.
4. Investigate the efficacy of pinning enhancement in MOCVD REBCO through RE and other cation doping/addition.
5. Transfer the knowledge learned from the MOCVD system regarding REBCO thick film growth located at ORNL to SuperPower.
6. Over-current testing and ac loss measurements and identification of stability and protection issues related to filamentary YBCO/IBAD tapes.

FY2006 Results: Key Results from the past year include:

- A single $LaMnO_3$ (LMO) has been identified as an excellent cap layer for ion-beam assisted deposition (IBAD)-MgO template because of its excellent compatibility with IBAD-MgO and YBCO, high deposition rate, thinner layer, and wide process temperature window. ORNL has assisted SuperPower in the understanding of LMO layer deposition on homo-epi MgO, and contributed to the fabrication of LMO buffers with highly uniform texture on IBAD-MgO by SuperPower. These substrates enabled the achievement by SuperPower of its World Record 2G wire performance: 322 meters of 2G wire carrying 219 A/cm-width that resulted in an I_c x L value of 70,520 amp-meters.
- Lab-scale samples with highly-textured LMO deposited directly on IBAD-MgO, thereby eliminating the homo-epitaxial MgO layer.
- Microstructure-processing-property correlations have led to massive improvements in the performance of thick MOCVD films on IBAD templates. Correlated transport, TEM and X-ray characterization was performed. Variations in precursor stoichiometry which can result in significant changes in transport properties were investigated and correlated with microstructure.
- Established the "SuperPower" MOCVD-HTS deposition capability at ORNL.
- The quench dynamics of constant current and over-current pulses of a series of 4-mm wide, 30-cm long YBCO conductors with 20 μm and 38 μm of Cu surround stabilizer was compared to un-stabilized YBCO conductor. Both 20 μm and 38 μm of Cu surround stabilizer improved the ability of the conductor to operate in an insulated 77 K bath at a fixed current by more than 20%. It was also observed that for 0.25 s current pulses, followed by a constant current below the sample I_c, ratio of peak current to I_c went from 1.20 for the un-stabilized YBCO conductor to 3.74 (6.40) for a YBCO conductor with 20 (38) μm of surround Cu stabilizer. Normal zone propagation speeds between 0.2 cm/s and 0.7 cm/s were observed in Cu surround stabilized conductors.
- A pair of electrically insulated 2-mm wide SuperPower YBCO conductor had lower ac losses as a function of perpendicular ac field than a single 4-mm wide SuperPower YBCO conductor with the same I_c. These were compared to spliced 2-mm YBCO wide conductors with low resistance solders to see how electrical coupling of the 2-mm wide conductors and segmentation of the conductor could decrease the ac loss.
- When YBCO tapes are vacuum epoxy impregnated in Stycast W19 in a turn-to-turn geometry, the presence of Cu surround stabilizer in 4-mm wide YBCO tapes decreased the probability of breakdown as a function of voltage when compared to as-slit, 4-mm wide tapes.

Technology Integration: Close collaboration and interaction between ORNL and SuperPower has resulted in significant advancement in process understanding and subsequently in the development of a robust manufacturing process at SuperPower. The collaboration functions through weekly conference calls, frequent sample exchanges, joint development and joint materials evaluation and testing. Technical staff from SuperPower routinely visited ORNL to perform IBAD-MgO/LMO buffer evaluation studies and detailed YBCO characterizations. ORNL staffs also visited SuperPower in planning and training activities in order to transfer the SuperPower research MOCVD capability to ORNL. Several joint publications and joint invention disclosures have resulted from this work.