Project Title:	**Progress in SuperPower's 2G HTS Wire Development and Manufacturing Program**
Organization:	SuperPower, Inc.
Presenters:	Venkat Selvamanickam. and John Dackow
FY 2010 Funding:	$ 1,068,280

Overall Project Purpose and Objectives:

Over the past few years, SuperPower successfully demonstrated the scale-up of 2G HTS wire technology to manufacturing. In FY09, we reported a two-pronged approach to continue to forge ahead on both the manufacturing and technology development fronts. The R&D scientists along with all R&D equipment were relocated to Houston for a total emphasis on next levels of technology advancement in collaboration with the Texas Center for Superconductivity at University of Houston. The group in Schenectady, NY was focused on advancing high-yield manufacturing of long-length, high-performance 2G HTS wires to meet near-term requirements of our customers. Emphasis was placed on rapid transfer of new technologies to manufacturing and solving production challenges.

Specifically, our objectives in FY10 were to

- demonstrate high-yield manufacturing of kilometer-lengths of 2G HTS wires with critical currents exceeding 250 A/cm
- develop scalable approaches to manufacture 2G wires with improved critical current retention in magnetic field without sacrificing throughput
- reduce cost and improve efficiency of wire fabrication using simpler processes and fewer layers in our wire architecture, and
- develop novel, scalable processes for multifilamentary 2G wires for low ac loss applications.

Overall, the program is strongly tied to the DOE-OE mission through the development of 2G HTS wires that meet all the necessary requirements (piece length, performance, cost, and manufacturing capacity) of systems that are being constructed to modernize the electric power grid and enhance the reliability and security of the energy infrastructure. The program has a *direct impact* on OE sub-program goals namely, development of prototype wire achieving 1,000,000 A-m and production of an HTS coil operating in applied magnetic fields up to 5 T at 65 K.

2010 Approach and Results:

SuperPower uses IBAD (ion beam assisted deposition) and MOCVD (metal organic chemical vapor deposition) processes in the manufacturing of 2G wire. One of the significant advantages of these technologies is high throughput. In addition, these technologies have enabled 2G wires with superior mechanical properties and low ac losses, both of which are critical for electric power applications.

In order to effectively execute our research plan on the two fronts of manufacturing excellence and technology development, we organized the effort in two distinct teams so as to enable a strong focus on both areas, but with seamless interaction between the two.

Manufacturing Excellence:

In FY09, we demonstrated world record performance level exceeding 300,000 A-m in 1000+m lengths of 2G wire. In FY10, we routinely produced kilometer lengths and focused our manufacturing operation on achieving improved performance levels over long lengths with high yield. As a result, longer wire piece lengths with higher amperage were shipped to our customers in FY10 compared to FY09. Additionally, we successfully implemented improved MOCVD processes in our manufacturing operation to routinely produce long-length wires with two-fold enhancement in in-field wire performance. Key drivers for wire cost were addressed to achieve a 20% cost reduction. Quality control and Quality Assurance have been a major focus in our production operations to achieve superior performance over long lengths. We implemented process controls to minimize deviations, as well as installed new QC tools such as on-line ellipsometry and on-line tape inspection system in our pilot buffer sputter deposition system. Also, we installed an on-line X-ray Diffraction unit in our pilot MOCVD system and obtained valuable real-time correlation between superconductor film quality and critical current uniformity. Further, we trained the on-line tape inspection system in pilot MOCVD to better predict critical current uniformity based on real-time observation of tape defects.

Enhanced In-field Performance:

In FY09, we demonstrated enhanced critical currents at high magnetic fields in the temperature range of 65 to 77 K using Zr-doped precursor chemistries in our MOCVD process. BZO nanocolumns formed by a self-assembly process were found to be responsible for the enhanced in-field performance. We had also begun transition of this enhanced process to manufacturing as well as demonstrated pancake coils made with Zr-doped wires that generated a magnetic field of 2.5 T at 65 K. In FY10, we addressed a major drawback of the process, namely reduction in the deposition rate to allow for self-assembly of BZO nanocolumns. Using modified precursor chemistries, we were able to achieve the two-fold improvement in in-field performance of Zr-doped wires, but at the same high deposition rate used for standard wires. This process was successfully transferred to our pilot MOCVD manufacturing operation and the improved pinning wires are now routinely manufactured in kilometer lengths at high speeds. Another important finding in FY10 has been the dramatic difference in the in-field performance of Zr-doped wires when the rare earth is changed from Y to Gd. The peak in critical current in the orientation of field parallel to the wire and the minimum critical current were found to steadily increase as the amount of Gd in Y-Gd mixture in Zr-doped wires was increased from 0 to 100%. We have also investigated the effect of Sm addition to Y and to Gd in Zr-doped wires.

In order to further improve and control the in-field critical current performance, we have investigated methods to direct the assembly of nanocolumnar structures rather than rely purely on self assembly. Multiple techniques have been evaluated to direct the growth of BZO nanocolumns from nucleation sites created on the surface of the $LaMnO_3$ (LMO) cap layer, on which the HTS film grows. Additionally, prefabricated nanocolumns have been created on the nucleating surface of the HTS film as an alternate pathway to control the size, distribution and orientation of pinning defects.

Higher efficiency Processes:

Apart from product performance, cost and availability are two main factors that limit the widespread use of 2G HTS wires. While steady progress continues to be made in cost reduction through yield improvements and in capacity increase through minimization of down time and set-up time, we are pursuing technological advancements for larger impacts. Working with NREL, we have developed a silver electrodeposition process to replace the capital-intensive silver sputtering method used so far for 2G HTS wire manufacturing. In collaboration with Los Alamos and Oak Ridge National Laboratories, we are developing planarization as an alternative to electropolishing which enables the use of less expensive, simpler and application-specific substrates. Concomitantly, a buffer layer processing step is eliminated which results in doubling of production capacity.

Advanced wire architectures:

Over the past few years, multifilamentary wires have been demonstrated by a number of groups for ac loss reduction, but have yet to be scaled up to long lengths (even 50 m of continuous single piece length has not been demonstrated). In FY10, we have been developing a scalable technique to produce multifilamentary 2G wires. Additionally, this technique enables filamentization of a thick copper stabilizer too.

2011 Plans and Expectations:

Our primary focus in FY11 will continue along the lines of our present objectives, namely high-yield manufacturing, cost-performance improvements, higher efficiency/higher throughput processes, and development of advanced wire architectures, specifically multifilamentary wires for ac loss reduction.
We will develop a radically new MOCVD system design to address the deficiencies of our current system and achieve more efficient use of precursors that will lead to lower cost and higher throughput. This new MOCVD system design is targeted to achieve a better control of temperature for thick film growth that should lead to higher current wires. Improvements to the in-field critical current performance will be a significant focus and our effort on Zr-doped wires in conjunction with rare-earth modification, directed assembly and prefabricated nanostructures will be continued. We will target at least a 50% improvement in in-field critical current over the already improved values, over a range of temperatures and magnetic fields. A new variable temperature-field-angular system capable of high current measurements will be procured and installed for a comprehensive study. We will scale up our processes to fabricate multfilamentary tapes in conjunction with silver and copper electrodeposition to achieve long-length wires with striated superconductor and stabilizers. We will scale the planarization process to long lengths to eliminate electropolishing and one of the buffer process steps.

On the manufacturing front, we will continue to increase the yield through the identification of sources of deviations in the processes through our existing on-line QC tools, as well as correlation of drop-outs in critical current performance with wire defects. In order to even more rapidly transition our technology development successes to manufacturing, SuperPower will establish a Specialty Products Facility in Houston in the Energy Research Park of the University of Houston. A pilot MOCVD system, identical to the one used for manufacturing with features such as on-line XRD and on-line tape inspection will be procured and set up in this new facility.
Deliveries of long lengths of 2G wire will continue to be made to customers worldwide for various device applications. We will continue to market our 2G wire worldwide to strengthen the customer base and meet delivery schedules on time.

Technology Transfer, Collaboration, Partnerships:

The University of Houston continues to be a major partner to SuperPower in its wire development program. Essentially all R&D equipment needed for 2G HTS wire processing has been fully transferred, installed and made functional at the University laboratories. Five SuperPower scientists work full-time in Houston alongside UH personnel to execute the technology development roadmap. SuperPower also executed a license agreement with the University of Houston in FY10 for technologies developed under the research program.

Additionally, SuperPower has committed to establishing a Specialty Products Facility at the University's Energy Research Park to expedite transition of successful technologies to manufacturing.

SuperPower continues its strong relationship with national laboratories and other universities. This effort was augmented with the research conducted at ORNL on the MOCVD system loaned by SuperPower which involved a close cooperation with ORNL staff on our proprietary process know-how. In the tenth year of our CRADA with Los Alamos National Laboratory (LANL), we jointly studied in-field critical current properties of our production wires and developed substrate planarization processes. We continued to benefit from a strong collaboration with Argonne National Laboratory (ANL) on coordinated characterization to better understand the influence of precursor chemistry in improved pinning of Zr-doped wires. In our CRADA with the National Renewable Energy Laboratory (NREL), we were able to successfully transition laboratory technology on alternate silver and copper chemistries for electrodeposition to replace the capital-intensive silver sputter deposition. We established a new CRADA with Brookhaven National Laboratory (BNL) on microstructural understanding of our MOCVD growth process using the synchrotron beam source at BNL. Other notable collaborations included microstructural and electromagnetic studies of our conductor and coil testing with Florida State University, and mechanical property measurements with the Naval Research Laboratory. Industrial partnerships guided our work on conductor engineering, such as the generator program with Baldor Electric, and the fault current limiter project of the device group at SuperPower. Most of all, we engaged our customers closely to understand their requirements and accordingly develop modifications to meet their needs. Overall, this program greatly benefited from basic research collaboration with universities, applied research technology transfer with national laboratories and application projects with our customers and industry partners.

Several visits have been made by SuperPower employees to various national labs and universities and vice versa. SuperPower employees closely interacted with the lab scientists by frequent e-mail and phone communication. Frequent sales and marketing trips were carried out around the world to meet directly with our steadily growing customer base.

The program has been reviewed this FY on site by DOE representatives.