PROJECT TITLE:	Engineered Columnar Defects for Coated Conductors
ORGANIZATION:	Oak Ridge National Laboratory
PRESENTERS:	Amit Goyal (ORNL)
FY 2008 FUNDING:	$ 425 K (DOE to ORNL)

Overall Project Purpose and Objectives:

To develop a basic understanding of introducing controlled nanoscale defects within the superconductor to result in enhanced properties of superconductors on coated conductors. U.S. HTS wire manufacturers are now in a position to produce reasonable quality coated conductors in "pilot-scale" mode. In meeting the DOE cost target, however, it is necessary to further improve the HTS transport properties, especially in the presence of high applied magnetic fields. Improvements in the properties of the HTS coating require a thorough understanding of the pinning mechanisms and control of various combination of nanostructures, in order to further improve the in-field and angular dependent properties in REBCO.

FY 2008 objectives were:

1. Continue correlation of HTS properties in thicker REBCO films with 3D, self-assembled linear nanodot arrays and extend work to film deposition by other methods such as MOCVD. *Transfer* this technology to companies to result in massive enhancements in commercial wire performance.
2. Extend experimental work to other insulating perovskite, fluorite and rock-salt structure nanodots and nanorods and relate structures observed with theoretical understanding of the self-assembly and growth process.
3. Further optimize the defect structures within the superconductor films on coated conductors to yield an overall improvement in the pinning at all field orientations. Fabricate designer materials with controlled defect structures which show what properties are possible to obtain and to guide work in CRADA's.
4. Demonstrate single layer conductors with I_c > 1,000 A/cm at 77K with enhanced in-field performance for all field orientations at 77K, 1T and 65K, 3T.
5. Further investigate performance enhancement via rare earth doping and replacement in addition to incorporation of self-assembled defects.
6. Control pinning by ordered epitaxial nucleation sites on substrate surfaces for 1-D nano-defect growth.

2008 Approach and Results:

A joint experimental, theoretical, and computational effort is ongoing at ORNL to study the simultaneous phase separation and ordering (SPSO) of embedded nanostructures in heterogeneous ceramic materials. This project aims to establish a fundamental understanding of this self-assembly process in multicomponent superconductors such as YBCO via synergistic efforts in fundamental theoretical formulations, simulations and experiments. The ultimate goal of the research is to develop ways in order to introduce controlled, engineered defect structures within the superconductor layer to optimize flux-pinning in thick epitaxial superconducting films on coated conductors. Close interaction with companies to transfer the knowledge base from the base program to the companies is ongoing.

2008 Results:

We have shown last year that vertically ordered arrays of $BaZrO_3$ (BZO) nanostructures within a YBCO matrix using PLD, result from a new process referred to as simultaneous phase separation and ordering (SPSO) during the growth of embedded nanostructures in heterogeneous ceramic materials. BZO and YBCO phase separate during the initial growth stage and BZO forms crystalline nanodots surrounded by YBCO epitaxial layers. Nanoscale BZO patterns form to minimize the combined free energy of mixing, phase boundary, and elasticity. When the BZO concentration modulates, the elastic field caused by the lattice mismatch becomes non-uniform. The resulting elastic field, in competition to the phase boundary energy, will determine an equilibrium feature size. This kinetic process is studied by a Cahn-Hilliard model with the incorporation of the elastic strain energy. It is found that a large lattice mismatch strain, slow deposition rate, large surface diffusivity, and thin spacer layer will promote the formation of well ordered BZO nanostructures in both vertical and lateral directions.

This year we have made significant strides and essentially all the FY2008 goals have been fully met. In particular the following results have been obtained:

- We have very successfully transferred the knowledge generated from this project to companies to result in massive enhancements in commercial wire performance.
- We have extended the experimental work to other insulating nanodots and related structures observed with theoretical understanding of the self-assembly and growth process.
- We have further optimized the superconductor films on coated conductors to yield an overall improvement in the pinning at all field orientations. We have fabricated designer materials with controlled defect structures which show what properties are possible to obtain and to guide work in CRADA's.
- We have fabricated single layer conductors with self-field, I_c > 1,000 A/cm at 77K with record performance at 65K, 3T.
- We have explored site substitution in the Y and Ba sites in YBCO via rare-earth doping and its effect on texture, structure and pinning.
- We have fabricated HTS films on epitaxial cap layers on coated conductors with ordered epitaxial nanoscale structures on the substrate surface for 1-D nano-defect growth.

2009 Plans and Expectations:

1. Continue technology transfer to companies to implement the creation of these columnar defects into their tapes with techniques such as MOCVD.
2. Further understand the mechanisms of 3D self-assembly of insulating nanodots of various compositions and crystal structures, resulting in engineered columnar defects, to enable still better control of defect structures.
3. Further optimize the defect structures within the superconductor films on coated conductors to yield an overall improvement in the pinning at all field orientations. Fabricate designer materials with controlled defect structures which show what properties are possible to obtain and to guide work in CRADAs.
4. Further investigate performance enhancement via a combination of rare earth doping and replacement as well as incorporation of columnar defects.
5. Further develop control of pinning by columnar defects propagated by ordered epitaxial nucleation sites on substrate cap buffer layer.

Technology Transfer, Collaboration, Partnerships:

Technology transfer to SuperPower resulted in essentially identical, self-assembled, columnar defects in MOCVD films. Key to this success was the theoretical understanding of the self-assembly process and the guidance it provided to modify experimental parameters. This project was performed in close collaboration with The University of Tennessee. Prof. Yanfei Gao, a theoretician who was very closely involved in this work through a close collaboration and partnership. Research Assistant Professor Sung-Hun Wee of the University of Tennessee performed key depositions. Work is ongoing in a joint collaboration with Winnie Wong-Ng of NIST, Gaithersburg and Timothy Haugan of AFOSR on RE doping. During the course of this FY, 1 plenary talk, 5 invited talks, 4-5 contributed talks and 5 papers have been published or submitted for publication. The project received a MICRO/NANO 25 Award in 2007 from R&D100 magazine.