FY2008 Superconductivity for Electric Systems Peer Review
Project Summary Form

PROJECT TITLE:	Raising performance of 2G wires through improved nucleation of YBCO on technical oxide buffers.
ORGANIZATION:	Brookhaven National Laboratory
PRESENTERS:	Vyacheslav Solovyovv
FY 2008 FUNDING:	$300K + $50K (April 2008)

Overall Project Purpose and Objectives:

The purpose of the project is to realize the full potential and reduce cost of 2G conductors through improvements in the structure of the $Y_1Ba_2Cu_3O_7$ (YBCO) layer. FY08 efforts have concentrated on understanding the catalytic activity of oxide buffered metal substrates and the influence of the substrate activity on structure of the YBCO layer. The catalytic activity is defined as the ability of the substrate surface to provide nucleation sites for the epitaxial phase, in this case c-axis oriented YBCO. Oxide buffered metal substrates, especially ones made in mile-length quantity, tend to have low activity, i.e. they generate fewer YBCO nuclei and the nucleation rate is lower as compared with single crystal substrates, such as $SrTiO_3$ and $LaAlO_3$. A low nucleation rate is one of the reasons for under-performance of thick YBCO layers manufactured using Metal-Organic Deposition (MOD) and Metal-Organic Chemical Vapor Deposition (MOCVD). FY09 efforts will concentrate on finding practical ways to enhance the catalytic activity of the buffered metal substrates. A separate FY09 effort will be dedicated to the development of BNL’s 3G wire concept, a new, possibly low-cost, method for manufacturing high-performance YBCO wires.

2008 Approach and Results:

Milestone 1: Establish the influence of grain size on the performance of MOD layers.
We have correlated the critical current performance of American Superconductor Corporation’s (AMSC) 2 μm thick MOD YBCO layers with specimen grain size. Transport critical current densities, J_c^T, of these conductors were observed to be inversely proportional to YBCO grain size in 5 - 40 μm size range. Analysis of magnetic hysteresis curves of the conductors and transmission electron microscopy data from a large YBCO grain revealed that the reduced J_c^T in tapes with large YBCO grain size is due to the accumulation of secondary phase precipitates within the grains near the periphery of, and in, the grain boundaries. Similar experiments, in collaboration with Vic Maroni, Argonne National Lab, performed on SuperPower’s 2 μm thick MOCVD YBCO showed that nucleation of Cu-rich secondary phases degrade the performance of the thick film YBCO conductor. We concluded that a low YBCO nucleation rate is responsible for secondary phase accumulation and low performance in both MOCVD and MOD YBCO thick films.

Milestone 2: Develop a characterization method that would predict the efficiency of the oxide buffer layer for YBCO nucleation.
In FY07-FY08 we demonstrated that it was possible to synthesize fully textured 2-μm thick MOD films. After discussion with our industrial partners in FY07 we came to the conclusion that the present processing protocol has reached its limit in improving J_c and further progress in performance requires understanding substrate conditions, such as surface activity, that promote epitaxial nucleation. In FY 08 we developed a method for reliable prediction of activity of CeO_2 buffers. The method is based on high-resolution X-ray diffraction of out-of plane reflections ([311] and [422]) of the CeO_2 layer. This allows the determination of lateral (parallel to the surface) grain size, d_x, of the CeO_2 layer. We demonstrated that substrates with $d_x < 10$ nm have very low activity, possibly due to the fact that the CeO_2 grain size is smaller than the critical YBCO nuclei size. The YBCO nuclei density was also observed to vary significantly from one Ni

grain to another, suggesting influence of Ni grain orientation on the CeO2 buffer activity. An important set of experiments aimed to clarify this issue have been conducted in collaboration with D. Larbalastier and D. Abraimov at Florida State University. The YBCO nuclei density was shown to drop significantly as the Ni grain out-of-plane tilt angle approached 7^o. We concluded that the CeO_2 buffer activity is a function of lateral grain size and out-of-plane tilt. Enhancement of the lateral grain size is identified as the most promising direction for improving the activity of CeO_2 buffers.

2009 Plans and Expectations:

CRADA with AMSC: increase the lateral grain size and the activity of CeO_2 buffered RABITS substrates by post-processing.
In FY09 we plan to conduct a systematic study of the influence of CeO_2 lateral size on the substrate activity. As deposited low activity substrates with lateral CeO_2 grain size below 10 nm will be subjected to a heat treatment in vacuum to determine the kinetics and thermodynamics of the grain growth during the post-processing. The following questions will be answered: (i) What is the minimum acceptable lateral CeO_2 grain size? (ii) Can post-processing minimize the negative effect of the out-of-plane tilt on nucleation? (iii) What is the effect of lateral strain on the substrate activity? (iv) What is the effect of surface roughness?

CRADA with SuperPower: determine impact of the $LaMnO_3$ substrate activity on properties of thick YBCO layers deposited by high-rate MOCVD process.
We plan to apply our methodology for the prediction of catalytic activity of SuperPower's Hastelloy substrates buffered with a $LaMnO_3$ layer. The effect of the activity variability will be estimated by profiling the Cu-rich phase accumulation in the film and by the YBCO nuclei density determined by high-resolution X-ray diffraction at an early stage of processing. The question to be answered is whether structural quality of thick MOCVD YBCO layers can be improved by increasing the activity of $LaMnO_3$ buffer.

BNL 3G conductor concept validation:
In FY2008 we have developed a new concept of BNL 3G conductor. The design retains the positive features of 2G tapes, such as use of inexpensive, non-toxic elements and operation at liquid nitrogen temperatures, but offers potentially greater superconducting critical current and improved conductor aspect ratio. The design also promises much lower fabrication costs due to elimination of the need for heteroepitaxial oxide buffers and a textured substrate, utilizing nucleation on oriented nano-rods as a way to achieve bi-axial texture of thick YBCO layer. In FY09 we plan to perform the following experiments aimed to validate the BNL 3G concept: (i) Achieve a high rate of YBCO nucleation on non-oriented Dy_2O_3 nano-rods and (ii) Orient high-aspect ratio nano-rods to achieve less that 10^o of out-of-plane alignment.

Technology Transfer, Collaboration, Partnerships:

1. FY08 is the second year of our CRADA with AMSC. This years effort concentrated on identifying factors influencing catalytic activity of 4 cm wide long-length buffers deposited by high-rate reactive sputtering. Three batches of samples received from AMSC were the key samples in determining the relationship between the buffer structure and YBCO nucleation rate. Additionally, buffer samples deposited by RF sputtering by Amit Goyal at Oak Ridge National Lab were used as a reference in this study.
2. In FY08 we transferred our low-angle polishing technology to Super Power. After a visit to SuperPower's facility in Feb 2008 a CRADA agreement was established to study the activity of SuperPower's buffer, $LaMnO_3$, and its influence on the structure of the YBCO layer.

3. Joint experiments with Florida State University utilized backscattered electron diffraction (EBSD) to determine influence of the tilt angle on nucleation kinetics.
4. In 2008 we have signed a collaboration agreement between BNL and National Institute of Advanced Industrial Science and Technology (Japan) to determine the effect of the out-of-plane tilt of single crystal CeO_2/Al_2O_3 substrates on the nucleation energy.

Publications: V.F. Solovyov, and H.J. Wiesmann, *Physica C:* 2007. 467(1-2): p. 186-191., V.F Solovyov et al., *Superconductor Science and Technology* 2008, accepted for publication.