
Project Title:	RABiTS Substrates Research and Development
Organization(s):	Oak Ridge National Laboratory
Presenters:	Amit Goyal and Dominic F. Lee
FY 2003 Funding:	\$700 K (DOE to ORNL)

Project Purpose and FY 2003 Objectives: To develop a basic understanding of fundamental issues related to coated conductor development for high-temperature and high-field applications based on the RABiTS process. The primary objectives for FY 2003 were:

1. Consideration of “true” versus measured in-plane texture in correlating superconducting properties in materials epitaxially grown on RABiTS type substrates
2. Measure texture homogeneity during fabrication of wide substrates up to 6-in. wide
3. Further developments in fabrication of higher tungsten alloy substrates via powder metallurgy
4. Robust fabrication of standard RABiTS buffered substrate using reel-to-reel systems
5. Development of copper-based RABiTS substrates
6. Development of a superior percolation model which takes into account the grain size distribution in the substrate
7. Experimental verification of the developed percolation model on continuously fabricated, meter long substrates

FY 2003 Performance and FY 2004 Plans: In FY 2003, all milestones were achieved as planned. Considerations of texture characterizations in RABiTS type substrates have led to the understanding of using the true in-plane texture as opposed to the measured in-plane texture. The measured in-plane full-width-half maximum of the texture is not a representative value since it depends both on the out-of-plane texture in the substrate (or in the relevant epitaxial layer) as well as on the actual reflection used for the measurement. Depending on the out-of-plane texture and the reflection used for the characterization of the in-plane texture, the measured in-plane texture can vary by large amounts even though the true in-plane texture is the same in each case.

Fabrication of Ni and NiW alloys in widths up to 6 in. has been accomplished. It is found that the texture along the width is fairly homogeneous with the true in-plane texture being within ± 0.5 degrees along the width. For a 4-in.-wide strip, ten 1-cm-wide substrates can be obtained by slitting. Using outside vendors, 1.2 km of Ni-3at%W substrates were fabricated by slitting a 120-m-long, 4-in.-wide strip.

There is great interest in the fabrication of higher tungsten containing substrate materials made via powder metallurgy. This is primarily so because in powder metallurgy processed materials, the secondary recrystallization temperature can be shifted to very high temperatures and a finer grain size in the final product is more easily achieved. We have fabricated Ni-5at%W alloys via the powder metallurgy route. As expected these substrates are stronger than Ni-3at%W substrates. Also the Curie temperature is lower for Ni-5at%W and hence losses at the same temperature are lower than for Ni-3at%W substrates.

Robust fabrication of the standard buffer layer structure on Ni-3at%W substrates has been achieved in continuous processing in reel-to-reel systems. The standard buffer layer structure comprises Ni (2 μm)/Y₂O₃ (20 nm)/YSZ (200 nm)/CeO₂ (20 nm). Experimental parameters resulting in reproducible fabrication were identified.

A new percolation model was developed which takes into account the deficiencies of all previously developed models. In particular, a grain size distribution similar to what is found in RABiTS substrates was first simulated using a Monte Carlo simulation. This is followed by using a new algorithm to calculate the critical currents. Experimental verification of the percolation model was also done by actual experiments on RABiTS-type substrates.

FY 2004 plans include:

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1. Fabrication of long lengths of Ni-5at%W substrates via the powder metallurgy route and transfer of technology to the industry
 2. Perform a detailed study of experimental parameters to obtain better textured materials in new rolling mill facility
 3. Optimization of buffer layer thicknesses for YBCO films of different thicknesses on Ni-3at%W substrates using experiments of continuously processed wedge samples
 4. Fabrication of long lengths of Cu-based substrates with better textures and optimization of buffer layer architectures on Cu-based substrates to sustain thick YBCO films
 5. Fabrication of thick, high I_c YBCO films on Ni-5at%W and Cu-based substrates

FY 2003 Results: It is important to find a method to properly characterize the sharpness of texture. Moreover, such a method is required to compare one sample with another. It is found that the full-width-half-maximum (FWHM) of the measured in-plane texture is highly dependent on the out-of-plane texture in the sample and on the reflection used to measure the texture. An expression is derived which compensates for both the out-of-plane texture and the reflection used to measure the in-plane texture, resulting in a true in-plane texture.

We have investigated the dependence of texture along the width of RABiTS tapes. Previously we had reported that the texture was fairly constant along the length of 1-cm-wide substrates. Substrates, 4-in. and 6-in. wide, were fabricated using reel-to-reel rolling. It is found that the texture is fairly homogeneous across the width within about 0.5 degrees in the in-plane texture for Ni-3at%W samples. This is indeed good news since it means that a single wide strip of metal can be rolled which can subsequently be slit to form 1-cm-wide substrates.

We have previously reported on the fabrication of Ni-3at%W substrates with good texture. In continuation of the same work, while still far from a commercial product, we have fabricated ten 1-cm-wide, 120-m-long substrates from a single rolling. Efforts are continuing to sharpen the texture further and in obtaining longer lengths by minimizing defects in the starting coil. A Ni-5at%W substrate was also fabricated. This substrate has a higher yield strength than the Ni-3at%W substrate and also has reduced magnetism compared to the Ni-3at%W substrate. The texture obtained in 4-in.-wide strips of this material will be presented. Initial attempts at buffer layer deposition and YBCO deposition on this substrate will also be presented.

Robust fabrication of the standard buffer layer structure of Ni (1.5 μm)/ Y_2O_3 (20 nm)/YSZ (200 nm)/ CeO_2 (20 nm) on Ni-3at%W substrates has now been achieved in continuous processing in reel-to-reel systems. Experimental parameters resulting in reproducible fabrication were identified. The typical texture obtained in long lengths has a true in-plane FWHM of $\sim 4.8^\circ$.

Copper-based substrates which do not result in secondary recrystallization even at temperatures higher than 1000°C were fabricated. Previously made copper substrates had much lower secondary recrystallization temperatures and hence buffer layer depositions on these substrates was difficult. A high degree of texture has also been attained with a true FWHM of $\sim 4.1^\circ$ and with out-of-plane textures of 4.1° and 5.5° in and about the rolling direction, respectively. Both conductive and nonconductive buffer layers have been developed for Cu-based substrates with the highest J_c of over 2 MA/cm^2 in self-field. Two nonconductive buffer layer architectures, Cu/TiN/MgO/LaMnO₃ and Cu/Ni/LaMnO₃, resulted in a J_c of 1 MA/cm^2 in self-field, 77 K. The conductive buffer layer architecture, Cu/Ni/La_{0.7}Sr_{0.3}MnO₃, resulted in a J_c of 2 MA/cm^2 in self-field, 77 K.

A new percolation model was also developed which addresses the shortcomings of previous models. Previous models differed with respect to: a) conductor scale or length scales considered; b) grain shape and grain distribution considered; c) the particular expression for J_c versus misorientation angle, Dimos or otherwise; d) the basis for misorientation assignment at grain boundaries; e) the dimensionality of grains; and f) the type of limiting path algorithm used, exact or inexact. No previous study included both the grain shape and the grain size distribution along with an exact limiting path algorithm to study the

dependence of J_c in long lengths. In this study, we first simulate the grain size distribution that is typically obtained in RABiTS-type substrates using the Monte Carlo Potts method. In the final grain size distribution, grains up to three times the average grain size can be found. Grain boundary misorientations were assigned based on X-ray measurements of the global texture. An exact limiting path algorithm was employed to calculate the J_c . It is found that even after considering a more realistic grain size distribution where grains three times the average grain are present, as long as the conductor is at least 100 grains wide, percolative pinch-offs are not observed.

In order to test the results of the percolation modeling, experimental verification was obtained on continuously processed meter long samples. The average grain size in the Ni-3at%W substrates is ~ 40 μm , and so the prediction would be that for a sample containing 100 grains or 0.4-cm wide, no percolative pinch-offs would be expected. A 0.4-cm-wide, 1-m-long YBCO sample was fabricated using the ex-situ BaF_2 process. Consistent with the predictions of the percolation modeling, no percolative pinch-offs were observed.

Research Integration: Four CRADA teams are working directly with ORNL staff members to develop the science and technology base for coated conductors. These teams are led by American Superconductor Corporation, MicroCoating Technologies, Oxford Superconducting Technology, and SuperPower. Critical issues in each of these CRADA's are the development of better textured substrate materials and better characterization of the substrates with respect to texture. Cu-based substrates coupled with conductive buffer layers are also becoming an interest in light of applications requiring a stabilizer. Percolative aspects of current flow and fundamental limitations to obtaining high J_c 's in long samples is a topic of great interest to all CRADA partners as well to the superconductivity community in general.

Substrate materials fabricated in this project provide substrates for all ORNL projects. Both metal substrates and buffered substrates are sent to CRADA partners as well as many universities and national laboratories. All YBCO on RABiTS samples sent to collaborators from ORNL use substrates fabricated in this project. Sample exchanges this year include the following organizations: Sandia National Laboratories, National Renewable Energy Laboratory, Los Alamos National Laboratory, Argonne National Laboratory, University of Wisconsin, University of Houston, California State University, and University of Cincinnati. Interactions were had with the following companies: American Superconductor, SuperPower, MicroCoating Technologies, Oxford Superconducting Technology, Ametek, Hamilton Precision Metals, and N. Ferrara, Inc. This project has directly or indirectly resulted in ~ 30 publications and over 5 invention disclosures in the last fiscal year.
