
Project Title:	RABiTS Substrates Research and Development
Organization(s):	Oak Ridge National Laboratory
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Project Purpose and FY 2004 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 2004 were:

- 1) Utilize rolling mill with clean room facility to develop a better understanding of experimental parameters affecting surface finish and texture development in Ni-based alloys.
- 2) Work with outside vendors to obtain improved coils with reduced defects.
- 3) Fabrication of long lengths of Cu-based substrates and development of suitable architectures for Cu-based substrates which can support high- J_c , thick YBCO films.
- 4) Perform percolation calculations using experimentally achievable texture in RABiTS substrates and perform such calculations as a function of applied magnetic fields.
- 5) Develop methods aimed at separating the a-axis and c-axis tilt components from the total misorientation measured in EBKP to better understand how misorientation at GB's affects J_c .
- 6) Continue magnetization studies aimed at a better understanding of AC losses in low alloy (alloys which are not completely nonmagnetic) substrates.
- 7) Develop robust, reel-to-reel buffer architectures on NiW substrates with optimized buffer layer thicknesses.
- 8) Develop high-rate, solution based buffer layers on NiW RABiTS substrates.
- 9) Fabricate double-sided RABiTS-based substrates.

FY 2004 Performance and FY 2005 Plans: In FY 2004, most milestones were achieved as planned. The ORNL rolling mill facility with a class 1000 clean room was made fully operational this year. A number of modifications were made to obtain wide, rolled substrates with good surface quality. We have worked on a limited budget with outside vendors to improve coil fabrication. We have fabricated long lengths of sharply-textured Cu substrates and new fully conductive architectures have been developed for Cu substrates. Percolation calculations using the presently achievable texture in RABiTS substrates show a reduced J_c dependence on number of grains along the width. Furthermore, the J_c dependence on width becomes even more insignificant in applied fields. We have developed crystallographically consistent methods to separate the in-plane and out-of-plane misorientation components from the total misorientation at grain boundaries. We have studied in detail processing issues which can lead to delamination of oxide buffers on powder metallurgy derived NiW substrates. We have fabricated solution-based LZO/CeO₂ buffers on NiW substrates as well as double-sided buffers.

FY 2005 plans include:

- 1) Fabrication of long lengths of Ni-5at%W substrates via the powder metallurgy route with sharp texture and transfer of technology to the industry and optimization of buffer layer thicknesses on Ni-5at%W substrates fabricated via the powder metallurgy route
- 2) Use thermal desorption as a tool to assess and control the tendency for interfacial carbon monoxide formation for various substrates fabricated using different processing routes
- 3) Research texture development in higher tungsten containing substrates, particularly the nonmagnetic, Ni-9.3at%W substrate
- 4) Research texture development in strengthened and conducting Cu-based alloy substrates

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- 5) Develop suitable all-conducting buffer layer architectures on strengthened and conducting, Cu-based substrates
 - 6) Develop simpler buffer layer architectures for NiW substrates involving either non-vacuum techniques or change in architecture
 - 7) Develop methods to separate in-plane and out-of-plane misorientations from EBKP measurements in materials with lower crystal symmetry such as YBCO and correlate J_c with grain boundary assemblages in YBCO films on RABiTS in terms of in-plane and out-of-plane misorientations
 - 8) Perform filament subdivision studies using laser-scribing w.r.t. to percolation and ac losses on YBCO/RABiTS samples 10 cm to 100 cm in length. Correlate results obtained with suitable calculations involving percolation and ac losses.

FY 2004 Results: The ORNL rolling mill facility with a class 1000 clean room was completed. Significant research and subsequent modifications to the mill were required to perform rolling at high speeds and still maintain an excellent surface quality. Technical staff from AMSC routinely visited ORNL to perform week-long rolling runs. All of AMSC's substrates for scale-up to a 4-cm-wide process were slit from substrates fabricated using this facility in FY 2004. We have worked with outside vendors to develop improved powder metallurgy based Ni-3at%W and Ni-5at%W starting coils.

We have fabricated long lengths of Cu substrates of various thicknesses using our rolling mill facility. Approximately 1000 m of 1-cm-wide Cu substrates were fabricated. Conductive buffer layer architectures have been developed for use in Cu-based substrates.

Percolation calculations have been updated using the presently achievable texture in long-lengths of RABiTS substrates. Typical true in-plane textures of $\sim 5^\circ$ full-width-half-maximum are now routinely obtained by AMSC and ORNL. With this sharper in-plane texture, the dependence of J_c on number of grains across the width of a conductor is reduced. We have also extended the calculations to determine the J_c as a function of number of grains in the conductor in the presence of applied fields. It is found that in the presence of applied fields, the dependence of J_c on number of grains across the width of a conductor is reduced significantly.

A long standing objective in the coated conductor community has been to get a better understanding of the in-plane and out-of-plane misorientations of grain boundaries present in coated conductors. The total grain boundary misorientation in large areas of the textured substrates has been characterized using electron backscatter Kikuchi diffraction (EBKD) for almost 10 years now. However, so far it has not been possible to separate the in-plane and out-of-plane misorientation components from the total misorientation as measured using EBKD. Using the properties of Rodrigues Space, we have successfully been able to separate the in-plane and out-of-plane misorientations in a crystallographically self-consistent manner for cubic materials. Grain boundary maps of the total, in-plane and out-of-plane misorientations in large areas of the RABiTS substrate were made. The misorientations were then correlated to both the measured true phi and the J_c of YBCO grown epitaxially on these substrates.

A study was conducted on the magnetic properties of a series of biaxially textured $Ni_{1-x}W_x$ materials with compositions $x = 0; 3; 5; 6$, and 9 at.% W. The quasi-static dc and ac hysteretic loss W was determined to support estimates of the ferromagnetic contribution to the overall ac loss in potential ac applications. The alloys were prepared by either vacuum casting or powder metallurgy methods, and the hysteretic loss tended to be lower in materials that were recrystallized at higher temperatures. Some samples were progressively deformed (0.4% bending strain) to simulate winding operations; this increased the hysteretic loss, as did sample cutting operations that create localized damage. In ac magnetization measurements, the effects of ac frequency and dc bias field on the ferromagnetic loss were determined.

Development of reel-to-reel RABiTS using powder metallurgy derived Ni-3at%W substrates was found to result in delamination of oxide buffers at the alloy/seed layer interface. A significant research effort was focused in determining the fundamental cause of the delamination. Among the factors considered were: oxygen nonstoichiometry of the seed layer, barrier layer, and the cap layer; formation of a volatile tungsten oxide at the interface of NiW and Y_2O_3 ; stresses in the film from a higher rate of deposition; and morphology of the deposited layers such as columnar grains with porosity between columns that may increase oxygen diffusion to the alloy/oxide interface. It was found that none of these factors strongly affected the delamination. The strongest correlation with delamination was found to be with the presence of carbon in the powder metallurgy derived substrates. Although the amount of carbon in the substrates was not enough to prevent ~100% cube texture formation, the level was high enough to cause delamination problems. It is found that upon annealing the PM derived NiW substrates in a low partial pressure of oxygen or water, the carbon content is significantly reduced. No delamination of buffer layers is observed on PM NiW substrates in which the carbon has been reduced significantly via appropriate annealing procedures.

Using the sol-gel alkoxide precursor route, we have grown 50-100-nm-thick epitaxial LZO layers in a single coat directly on PM derived, Ni-W substrate. Solution based processing of thin films also offers the possibility of double sided coating for enhancing the overall engineering critical current density using a reel-to-reel dip coating process. Smooth, epitaxial, crack-free buffer layers with double-sided coatings were also produced. Using the metal-organic decomposition (MOD) approach, we have successfully developed a method to grow epitaxial CeO_2 cap layers on LZO-buffered Ni-W substrates.

Research Integration: Three 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, Oxford Superconducting Technology, and MetOx. Critical issues in each of these CRADAs are the development of better textured substrate materials and better characterization of the substrates with respect to texture as well as to ac losses. 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, nature of grain boundaries in RABiTS substrates, and fundamental limitations to obtaining high J_c 's in long samples are topics of great interest to all CRADA partners as well to the superconductivity community in general.

Substrate materials fabricated in this project provide substrates for internal 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, University of Houston, California State University, and University of Cincinnati. Interactions were had with the following companies: American Superconductor, Oxford Superconducting Technology, MetOx, Ametek, Hamilton Precision Metals, and N. Ferrara, Inc. This project has resulted in a number of publications and invention disclosures in the last fiscal year.