ORNL/HTSPC-9

OAK RIDGE NATIONAL LABORATORY

LOCKHEED MARTIN

ORNL Superconducting Technology Program for Electric Power Systems

Annual Report for FY 1997

SUPERCONDUCTIVITY FOR ELECTRIC POWER SYSTEMS

A GOVERNMENT/INDUSTRY PARTNERSHIP

MANAGED AND OPERATED BY
LOCKHEED MARTIN ENERGY RESEARCH CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL-27 (3-96)

ORNL/HTSPC-9

ORNL Superconducting Technology Program for Electric Power Systems

Annual Report for FY 1997

This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors form the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (423) 576-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ORNL/HTSPC-9

ORNL SUPERCONDUCTING TECHNOLOGY PROGRAM FOR ELECTRIC POWER SYSTEMS

ANNUAL REPORT FOR FY 1997

Compiled by
R. A. Hawsey
A. W. Murphy

Edited by
W. S. Koncinski
L. M. O'Hara

Manuscript Completed: January 1998
Date Published: March 1998

Prepared for the
Office of Utility Technologies
Office of Energy Efficiency and Renewable Energy
U.S. DEPARTMENT OF ENERGY
(EB 50 01 00 0)

Prepared by
OAK RIDGE NATIONAL LABORATORY
P.O. Box 2008
Oak Ridge, TN 37831-6285
Managed by
LOCKHEED MARTIN ENERGY RESEARCH CORP.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-96OR22464

Contributors

D. B. Beach
J. D. Budai
D. K. Christen
J. A. Demko
R. Feenstra
A. Goyal
R. A. Hawsey
E. Hatfield
Q. He[1]
H. Hsu[2]
D. R. James
H. R. Kerchner
D. M. Kroeger
V. Lasrado[1]
D. F. Lee
F. A. List
J. W. Lue
P. M. Martin
J. E. Mathis[3]
B. W. McConnell
D. P. Norton
M. Paranthaman
C. Park[3]
I. Sauers
S. W. Schwenterly
A. Sheth[1]
C. J. Simon[1]
V. K. Sikka
A. Singhal[3]
E. D. Specht
J. P. Stovall
E. Y. Sun
D. T. Verebelyi[3]
R. K. Williams

[1]The University of Tennessee
[2]Imtech Corporation
[3]Postdoctoral research fellow

Contents

LIST OF FIGURES v

LIST OF TABLES ix

ACRONYMS AND INITIALISMS xi

EXECUTIVE SUMMARY xiii

HIGHLIGHTS FOR FISCAL YEAR 1997 xv

TECHNICAL PROGRESS IN WIRE DEVELOPMENT 1-1

BIAXIALLY TEXTURED $YBa_2Cu_3O_{7-\delta}$ CONDUCTORS ON RABiTS™ WITH CRITICAL CURRENT DENSITIES OF 2–3 MA/cm^2 1-1

PULSED-LASER DEPOSITION OF OXIDE BUFFER LAYERS AND YBCO ON ROLLED-TEXTURED (001) Ni 1-5

HIGH J_c YBCO FILMS ON BIAXIALLY TEXTURED Ni WITH OXIDE BUFFER LAYERS DEPOSITED USING ELECTRON BEAM EVAPORATION AND SPUTTERING 1-9

GROWTH OF BIAXIALLY TEXTURED MgO BUFFER LAYERS ON ROLLED-Ni SUBSTRATES BY ELECTRON BEAM EVAPORATION 1-13

DEMONSTRATION OF HIGH CURRENT $YBa_2Cu_3O_{7-y}$ COATED CONDUCTORS ON ROLLED-Ni SUBSTRATES WITH THIN BUFFER LAYERS 1-15

DEVELOPMENT OF HIGH-J_c HTS COATINGS BY PRECURSOR-DEPOSIT APPROACHES 1-17

FIRST DEMONSTRATION OF A LONG-LENGTH RABiTS™ 1-21

OXFORD CRADA: Bi-2212 CONDUCTOR DEVELOPMENT 1-21

GROWTH OF $TlBa_2Ca_2Cu_3O_{9-y}$ SUPERCONDUCTING FILMS ON HIGH-STRENGTH SUBSTRATES USING A SPRAY PYROLYSIS TECHNIQUE 1-23

EPITAXIAL GROWTH OF $BaZrO_3$ ON SINGLE CRYSTAL OXIDE SUBSTRATES USING SOL-GEL ALKOXIDE PRECURSORS 1-24

GROWTH OF EPITAXIAL $LaAlO_3$ FILMS ON $SrTiO_3$ (100) SUBSTRATES USING A DIP-COATING PROCESS 1-27

GROWTH OF EPITAXIAL $YBa_2Cu_3O_{7-x}$ FILMS ON SINGLE CRYSTAL OXIDE SUBSTRATES USING METAL ORGANIC DECOMPOSITION PRECURSORS 1-28

THE GROWTH OF EPITAXIAL BUFFER LAYERS ON SINGLE CRYSTAL OXIDE SUBSTRATES USING SOL-GEL ALKOXIDE PRECURSORS 1-30

HIGH-RESOLUTION TEM/AEM CHARACTERIZATION OF EPITAXIAL OXIDE MULTILAYERS FABRICATED BY LASER ABLATION ON BIAXIALLY TEXTURED Ni 1-31

TECHNICAL PROGRESS IN APPLICATIONS DEVELOPMENT 2-1
SUPERCONDUCTING TRANSFORMER PROJECT (INTERMAGNETICS GENERAL CORPORATION/ORNL/WAUKESHA ELECTRIC SYSTEMS/ ROCHESTER GAS AND ELECTRIC COMPANY) 2-1

HTS UNDERGROUND CABLE PROJECT WITH SOUTHWIRE COMPANY 2-4

SUMMARY OF TECHNOLOGY PARTNERSHIP ACTIVITIES 3-1
BACKGROUND 3-1
RELATIONSHIP TO THE DOE MISSION 3-1
FUNDING 3-1
TECHNOLOGY PARTNERSHIP APPROACH 3-2
PROGRAM MEASURES 3-7

FY 1997 PRESENTATIONS AND PUBLICATIONS 4-1

List of Figures

Figure		*Page*
1.1	XRD azimuthal (ϕ) scans indicating the in-plane alignment of YBCO/YSZ/CeO_2 films on thermomechanically textured Ni substrate	1-3
1.2	Variation in zero-field I_c as a function of temperature for the three deposition temperatures	1-3
1.3	J_c vs H for sample C and for a YBCO film grown epitaxially on $SrTiO_3$ alongside the RABiTS™	1-4
1.4	SEM photograph of the YBCO layer showing the dense surface morphology	1-4
1.5	Plot of J_c for various YBCO/buffer layers/Ni samples	1-5
1.6	XRD ϕ-scans for YBCO films deposited on RABiTS™ with and without CeO_2 cap layers	1-5
1.7	Cross-section TEM image of YBCO/YSZ/CeO/Ni structure	1-6
1.8	Plan-view Z-contrast scanning electron microscopy image of a YBCO grain boundary for a *c*-axis oriented film deposited on rolled-textured (001) Ni	1-6
1.9	Bend strain tolerance for two YBCO/buffer layers/Ni tapes measuring (*a*) compressive and (*b*) tensile stress	1-7
1.10	XRD rocking curves for YBCO/YSZ/CeO_2 oxide architecture on a 25-µm-thick rolled-textured Ni tape	1-8
1.11	(*a*) Scanning electron micrograph of a YBCO film deposited on exclusively e-beam buffered nickel. (*b*) Scanning e-beam micrograph of a YBCO film deposited on e-beam/sputtered buffered nickel	1-10
1.12	(*a*) X-ray phi scan of a YBCO film on RABiTS™ in which the buffers were put down exclusively by e-beam evaporation and (*b*) X-ray phi scan of Ni	1-10
1.13	(*a*) X-ray phi scan of a YBCO film on RABiTS™ in which the buffers were put down by a combination of e-beam evaporation and sputtering and (*b*) X-ray phi scan of Ni	1-11
1.14	(*top*) In-plane orientation map of a YBCO film deposited on e-beam/sputtered buffered nickel (*middle*) The dark and light areas are regions of YBCO with cube-on-cube orientation and 45° rotated orientation, respectively. (*bottom*) Corresponding (111), (100), and (110) pole figures	1-12
1.15	Temperature (*a*) and magnetic field dependence (*b*) of J_c for YBCO films on buffer layers prepared by PLD, sputtering/e-beam, and e-beam on biaxially textured nickel	1-12

1.16 The X-ray ω and ϕ scans for post-annealed 200-nm-thick MgO on Ag-Pd-buffered Ni substrates 1-14

1.17 The X-ray ω and ϕ scans for as-deposited 200-nm-thick MgO on Ag-Pt-buffered Ni substrates 1-15

1.18 The ϕ scans for a 0.76-µm-thick YBCO deposited on 1400-Å-thick YSZ-buffered Ni at 780 °C 1-16

1.19 The temperature dependence of both I_c and J_c values for a 0.76-µm-thick YBCO film . . 1-17

1.20 The J_c at liquid nitrogen temperatures as a function of film thickness for epitaxial YBCO on $SrTiO_3$, processed by the ex situ technique described 1-19

1.21 The J_c measured in self-field 1-19

1.22 The magnetic field dependence of J_c, for field orientations both parallel ($H \| ab$) and perpendicular ($H \| c$) to the film plane, for the two temperatures 64 K and 77 K spanning the useful LN_2 range 1-20

1.23 (*a*) The XRD (102) pole figure of a Tl film on RABiTS™, showing the epitaxial co-existence of 1223 and 1212 phases. (*b*) The J_c in low field determined from magnetization hysteresis 1-20

1.24 First demonstration of an ~30-cm-long CeO_2-buffered Ni substrate using a rotating cylinder in the e-beam evaporator 1-21

1.25 Differential weight loss for Ag encapsulated carbonates in flowing He 1-22

1.26 Differential weight loss for Ag encapsulated carbonates in air 1-23

1.27 The deposited conductor geometry of high-strength substrates 1-23

1.28 The in-field dependence of J_c for $H \| ab$ and $H \| c$ orientation of 3-µm-thick $TlBa_2Ca_2Cu_3O_{9-y}$ films grown on high-strength substrates at 77 K 1-24

1.29 Flowchart for the preparation of $BaZrO_3$ precursors 1-25

1.30 DTA analysis of the pyrolyzed $BaZrO_3$ gel in air (△) and in oxygen (◇) 1-25

1.31 The room-temperature powder XRD for 300-nm-thick $BaZrO_3$ films grown on sapphire substrates 1-26

1.32 The room-temperature powder XRD for 300-nm-thick $BaZrO_3$ films grown on $LaAlO_3$ (100) substrates 1-26

1.33 A typical ϕ scan featuring the epitaxial nature of $BaZrO_3$ films on $SrTiO_3$ (100) substrates 1-26

1.34 A typical $BaZrO_3$ (220) pole figure for a 300-nm-thick $BaZrO_3$ film on $SrTiO_3$ (100) substrates 1-26

1.35 A typical ω scan featuring the epitaxial alignment of $LaAlO_3$ films on $SrTiO_3$ (100) substrates 1-27

1.36 A typical ϕ scan featuring the epitaxial nature of $LaAlO_3$ films on $SrTiO_3$ (100) substrates 1-27

1.37 A typical $LaAlO_3$ (202) pole figure for a 100-nm-thick $LaAlO_3$ film on a $SrTiO_3$ (100) substrate 1-28

1.38 Flowchart for the preparation of YBCO films 1-29

1.39 The powder XRD for a 400-nm-thick YBCO grown on a $LaAlO_3$ (100) substrate 1-29

1.40 The resistivity plot for a 400-nm-thick YBCO film grown on a $SrTiO_3$ (100) substrate . . 1-29

1.41 The SEM micrograph for a 400-nm-thick YBCO film grown on a $SrTiO_3$ (100) substrate 1-29

1.42 θ-2θ scan of $GdAlO_3$ on a $SrTiO_3$ (100) single crystal 1-30

1.43 $GdAlO_3$ (220) pole figure 1-31

1.44 (*a*) General interfacial microstructure of the biaxially textured multilayer substrates and SAD patterns collected from (*b*) the YSZ layer, (*c*) the adjacent CeO_2, and (*d*) the Ni substrate 1-32

1.45 (*a*) A reaction layer formed at the Ni/CeO_2 interface, and (*b*) EDS spectrum collected from the reaction layer 1-33

1.46 High-resolution images of (*a*) the Ni/NiO interface and (*b*) the NiO/CeO_2 interface 1-33

1.47 (*a*) Three distinct morphologies observed in the CeO_2 layer: (A) an equiaxial structure, (B) a columnar structure, and (C) again an equiaxial structure through the rest of the layer; (*b*) Ce profile along the line-scan across the three different structures from A to C as indicated by the arrow in (*a*); and (*c*) O profiles collected along the line-scan across the three different structures from A to C as indicated by the arrow in (*a*) 1-34

1.48 (*a*) The interface between the CeO_2 and the YSZ layer and the columnar structure in the YSZ layer; and (*b*) a high-resolution image showing the periodic dislocations at the CeO_2/YSZ interface and revealing no orientation variation between adjacent columns in the YSZ . . 1-35

2.1 Test setup for measuring the thermal performance of bushings under simulated operating conditions 2-2

2.2 Tests of conventional bushings show no damage to terminal at 249 K and to shield at 276 K 2-2

2.3 Liquid nitrogen tank high-current feedthrough 2-3

2.4 Liquid nitrogen shield 2-3

2.5 HTS cable design process 2-4

2.6 Prototype cable setup for both dc and ac measurements 2-7

2.7 Current voltage characteristics of the inner pair of prototype 5 2-8

2.8 Current voltage characteristics for three voltage taps on the outer pair of prototype 5 . . . 2-8

2.9 Current distribution in HTS transmission cable prototype 5 under ac and dc conditions . 2-8

2.10 Data on ac loss for cables 3, 4, and 5 as a function of the root mean square current 2-9

2.11 Comparison of the ac loss data with a theory by Dresner 2-9

2.12 Tape testing apparatus 2-10

2.13 Sheet testing apparatus utilizes a stainless steel chamber 2-11

2.14 Haefely-Trench 500-kV impulse generator 2-11

2.15 HTS cable cryogenic system 2-12

List of Tables

Table		*Page*
2.1	Percentage of scatter in I_c of suppliers' tapes	2-5
2.2	Percentages of vendor-specified (pitch=0) critical currents for suppliers' tapes	2-5
2.3	Prototype cable construction parameters and measured I_c	2-7
3.1	Superconducting Technology Program funding: authorization and outlay by fiscal year	3-2
3.2	Superconductivity Program: Summary of Cooperative Agreements as of September 30, 1997	3-3
3.3	Superconducting Technology Program invention disclosures (FY 1997)	3-8

Acronyms and Initialisms

ac	alternating current
AEM	analytical electron microscopy
ASC	American Superconductor Corporation
BKD	backscatter Kikuchi diffraction
CRADA	cooperative research and development agreement
dc	direct current
DOE	U.S. Department of Energy
DOE-HQ	DOE Headquarters
DTA	differential thermal analysis
DTA/TGA	differential thermal analysis/thermogravimetric analysis
EDS	energy-dispersive spectroscopy
FEG	field emission gun
FWHM	Full width half maximum
HTS	high transition temperature superconductivity/superconductor/superconducting
HV	high voltage
IBAD	ion-beam-assisted deposition
I_c	critical current
IEC	International Electric Commission
IGC	Intermagnetics General Corporation
J_c	critical current density
J_e	engineering critical current density
K_c	critical current per unit width of conductor (I_c/w)
LANL	Los Alamos National Laboratory
LN_2	liquid nitrogen
MOCVD	metallo-organic chemical vapor deposition
MOD	metal organic decomposition
ORNL	Oak Ridge National Laboratory
PLD	pulsed-laser deposition
RABiTS™	rolling-assisted biaxially textured substrates
RBS	Rutherford Backscattering Spectroscopy
RF	radio frequency
RG&E	Rochester Gas and Electric Company
rms	root mean square
RTA	rapid thermal annealer
SAD	selected area diffraction
SEM	scanning electron microscopy
STEM	scanning transmission electron microscopy
SUNY	State University of New York
T_c	critical temperature/transition temperature
TEM	transmission electron microscopy
TGA	thermogravimetric analysis
WES	Waukesha Electric Systems
XRD	X-ray diffraction
YBCO	yttrium barium copper oxide
YSZ	yttria-stabilized zirconia
Z-STEM	Z-contrast scanning transmission electron microscopy

Executive Summary

The Oak Ridge National Laboratory (ORNL) Superconducting Technology Program is conducted as part of a national effort by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy to develop the science and technology base needed by U.S. industry for commercial development of electric power applications of high temperature superconductivity. The two major elements of this program are wire development and applications development. This document describes the major research and development activities for this program together with related accomplishments. The technical progress reported was summarized from recent open literature publications, presentations, and information prepared for the FY 1997 Annual Program Review held July 21–23, 1997. This ORNL program is highly leveraged by the staff and other resources of U.S. industry and universities. In fact, nearly three-fourths of the ORNL effort is devoted to cooperative projects with private companies. Interlaboratory teams are also in place on a number of industry-driven projects. Patent disclosures, working group meetings, staff exchanges, and joint publications and presentations ensure that there *is* technology transfer with U.S. industry. Working together, the collaborative teams are making rapid progress in solving the scientific and technical issues necessary for the commercialization of long lengths of practical high temperature superconductor wire and wire-using systems.

Highlights for Fiscal Year 1997

- Critical current densities (J_cs) between 2 and 3 MA/cm^2 (77 K, H = 0) have been achieved for thin YBCO films on rolling assisted biaxially textured substrates (RABiTS™). The increase in J_c over previous record values (1.2–1.4 × 10^6 A/cm^2) is believed to be the result of close control of substrate temperature during deposition and the use of thin oxide buffer layers, thus eliminating some microstructural features that limit J_c, such as micro-cracks and pores. For this, all buffer layers were deposited by industrially scalable electron beam (e-beam) evaporation or radio frequency (RF) sputtering, and the YBCO was deposited by pulsed laser deposition (PLD).

- The high-temperature superconducting (HTS) cold mass subsystem [i.e., the Intermagnetics General Corporation (IGC) primary and secondary HTS coils and the Oak Ridge National Laboratory (ORNL)-designed and procured 77-K radiation shield, support plates, and cryogenic system] for the 1-MVA demonstration transformer was assembled, leak tested, and shipped to Waukesha in September. ORNL has also tested an available cryocooler and loaned it to the project. In addition, the tank vacuum system was completed, tested, and shipped. The liquid nitrogen reservoir for the 77-K shield and the cryocooler heat exchanger were shipped directly to Waukesha from the manufacturers in late July. S. W. Schwenterly visited the Waukesha plant for uncrating and testing of the cold mass subsystem. The core has been assembled at Waukesha, and final assembly of the entire transformer is under way. Final test plans for the cryogenic and vacuum systems are being completed at ORNL with the balance of the test plans being prepared at Waukesha and IGC.

- The fifth cable in a series of prototype, 1-m uninsulated test samples was tested in collaboration with Southwire Company. The prototype consisted of two pairs of oppositely wound BSCCO-2223 tapes with the inner pair uninsulated between layers and the outer pair insulated between the layers by Kapton tape. The ac losses were measured calorimetrically. As expected, the outer pair is the predominant source of ac loss when both pairs carry current because the outer pair carries about 60% of the ac current.

- A new buffer layer architecture was developed on textured nickel substrates using the e-beam evaporation technique. Epitaxial laminates of MgO/Ag/Pt or MgO/Ag/Pd were deposited on biaxially textured nickel foils. In-plane aligned MgO buffers deposited using the e-beam process may be an industrially scalable alternative to laser-deposited films. The best in-plane alignment for MgO on Pd was ~11° full width half maximum (FWHM).

- Additional alternatives to PLD of buffer layers on textured nickel were developed. For this, an all e-beam evaporation deposited, standard CeO_2/yttria-stabilized zirconia (YSZ) architecture was produced, mimicking the PLD architecture developed last year. In addition, a substrate with the combination e-beam evaporation and sputtered YSZ buffer layers was also produced. YBCO films grown on these substrates show comparable properties to the best YBCO films grown on all-PLD buffered nickel.

- The first private sector demonstration of high J_c YBCO films on ORNL's RABiTS™ was completed by cooperative research and development agreement (CRADA) partner Midwest Superconductivity, Inc. For this, Midwest deposited an ~1-µm-thick film of YBCO on RABiTS™ using their metal-organic, chemical vapor deposition process. The J_c of the 2.8-mm-wide sample was 640,000 A/cm^2 (77 K), measured across the full sample width, and exceeds 1 million A/cm^2 at 70 K. Moreover, the field dependence of the J_c and the critical current (I_c) is as good as the films grown by PLD at ORNL.

- A $BaZrO_3$ (barium zirconium oxide) precursor solution was prepared by sol-gel synthesis through an all-alkoxide route. The work is being done to determine the feasibility of growing epitaxial buffer layers by sol-gel chemistry on metal substrates. The barium precursors were prepared by reacting barium metal with 2-methoxyethanol, and zirconium precursors were prepared by exchanging ligands between zirconium *n*-propoxide and 2-methoxyethanol. The resulting $BaZrO_3$ precursor solution was partially hydrolyzed and spin-coated on sapphire, $SrTiO_3$ (strontium titanium oxide) (100), and $LaAlO_3$ (lanthanum aluminum oxide) (100) substrates. X-ray diffraction (XRD) studies showed the presence of a single (100) cube texture for $BaZrO_3$ films on $SrTiO_3$ and $LaAlO_3$ substrates. The $BaZrO_3$ film on $SrTiO_3$ substrates had a sharp texture compared with that on $LaAlO_3$ substrates. This could be explained by the presence of a reduced lattice mismatch between the substrate and the film.

- Scale-up experiments are under way at ORNL, designed in part to provide longer lengths of RABiTS™ for YBCO deposition at ORNL, Los Alamos National Laboratory (LANL), and Midwest Superconductivity, Inc. Recently, 30-cm-long CeO_2-buffered, textured-Ni substrates were fabricated for the first time using a rotating cylinder in an e-beam evaporator. Also, we fabricated a RABiTS™ sample more than 6-cm long with a layer sequence of YSZ (1000 Å)/CeO_2 (400 Å)/Ni (125 µm) in a static mode in the e-beam system. Detailed XRD analysis on this long substrate showed that the FWHM values for the top YSZ layers were 9–10° [in-plane epitaxy; (202) ϕ scan] and 6–7° [out-of-plane epitaxy; (002) ω scan].

- A test apparatus has been constructed for testing tape dielectric samples in air and liquid nitrogen at 1 atm pressure. The test rig was designed at ORNL with an International Electric Commission (IEC) standard as a guide and was fabricated at Southwire. Checkout of the test set has begun, and preliminary tests of several dielectric materials have been done using dc and ac voltages. The design and assembly of a high pressure cryogenic test system for sheet dielectrics is also proceeding. Chamber support plates have been designed and fabricated. Design of the electrode assembly is under way. A low noise ac power supply has been ordered that will allow low level partial discharge measurements to be conducted and improved voltage control for ac breakdown.

- $YBa_2Cu_3O_{7-\delta}$ films grown on RABiTS™ carry critical current densities 10^5 to 10^6 A/cm^2 at 77 K and low applied magnetic fields. In the low-field and low-current regime, ac transport current studies show hysteresis energy loss (per cycle and per unit length) roughly the value expected for a superconductor of elliptic cross section. The I_c was deduced from observed dc and dynamic current–voltage relations. The power loss rises sharply as I_0 (the maximum current in each cycle) is raised above I_c. In the present configuration, ferromagnetic hysteresis of the Ni substrate contributes little or no loss.

- In a collaborative project with the University of Tennessee Space Institute, a dip-coating unit was assembled at ORNL for application of $LaAlO_3$ sol-gel alkoxide precursors on $SrTiO_3$ single crystal substrates. Detailed XRD studies indicated the formation of epitaxial $LaAlO_3$ films with a single cube-on-cube texture. A complex matrix of 20 different sets of growth conditions was needed to grow the films, thus providing data for future work on RABiTS™ and long-length substrates.

- High I_c Y-123 films were grown on a RABiTS™ using e-beam evaporation exclusively for the ultrathin buffer layers. For this, $YBa_2Cu_3O_{7-y}$ coated conductors were fabricated with a layer sequence of YBCO/YSZ/CeO_2/Ni. The cube (100) texture in the starting Ni substrates was obtained by cold-rolling followed by recrystallization. The CeO_2 (cerium oxide) and YSZ films were grown epitaxially on the textured-Ni substrates using an e-beam evaporation technique. The total thickness of the buffer layer was 1500 Å. The YBCO films were then grown by PLD. The biaxial texture in the YBCO layer was over 90%. A transport I_c of 1.0×10^6 A/cm^2 at 75 K was obtained on a 0.76-µm-thick YBCO film in zero field.

- We have investigated several systematics regarding the superconductive transport properties of YBCO epitaxial deposits on RABiTS™. The focus of the effort was to make a comparative study of the field- and temperature-dependent J_c among different YBCO/RABiTS™ samples and with properties of the "benchmark" materials deposited on $SrTiO_3$. In addition, a preliminary test of the bend-strain tolerance was conducted, both in compression and tension, and an assessment was made of the prospects for achieving practical current levels through this type of coated-conductor approach. YBCO films can be routinely obtained on RABiTS™ with J_c (77 K) > 0.5 MA/cm^2 and only one in-plane orientation when CeO_2 is utilized to eliminate secondary in-plane orientations. These data show that not only is YBCO the HTS material of choice for conductor applications, but also that the high-field properties of YBCO/RABiTS™ may exceed those of the prototype, YBCO/$SrTiO_3$ films. For YBCO thicknesses of ~1–3 µm, the J_c (1 T) exhibits no systematic thickness dependence, with values in the range ~100–150 kA/cm^2 at 64 K. Even though the present structures have a small superconductor fraction, the data at 64 K suggest that practical levels are accessible in the liquid nitrogen temperature range.

- Epitaxial buffer layers of $NdAlO_3$, $GdAlO_3$, $YAlO_3$, and $SrTiO_3$ have been grown on single crystal substrates using a sol-gel technique. θ-2θ scans of the films indicate *c*-axis preferred orientation, and pole figure analyses verify single cube-on-cube epitaxy. FWHM values of the rocking curve and ϕ scans are between 1 and 4°.

- IGC has delivered the HTS coils for the 1-MVA transformer to ORNL. The coils are constructed using several kilometers of IGC's low-cost, surface-coated BSCCO-2212 material. The coils are approximately 1-m diameter and 1.2-m long and are the largest volume HTS coils produced to date in the United States. The coils were pretested prior to shipment by IGC and meet specifications.

- Southwire and ORNL have signed a new cooperative agreement to develop superconducting underground transmission cable technology. Recently, Southwire and ORNL's Fusion Energy and Metals and Ceramics divisions successfully completed the first phase of research, resulting in the design and testing of four prototype, 1-m cable sections and the characterization of these cables with both dc and ac current. The new agreement provides for precompetitive research and technology development that will lead to the construction of a 30.5-m-long, three-phase HTS cable complete with dielectrics, thermal insulation, and outer enclosures. The cable will be installed between two overhead utility towers and will supply about 1250 A of current at 12.5 kV to the utility and building wire plants at Southwire Company. In this manner, the cable will be tested under real-use conditions and will verify the design of the various cable subsystems. ORNL will again be a partner in the project, supplying research, design, and testing expertise in the areas of dielectric materials, cryogenics, and superconductivity.

- Four-terminal ac impedance measurements are being carried out on superconductive $YBa_2Cu_3O_{7-\delta}$ films grown on RABiTS™ tape. The overall signal is dominated by the non-lossy component from the 1.2 µH/m self-inductance of the 1-mm-wide strips. The smaller loss voltage obeys behavior expected for magnetic hysteretic losses, including the superconductive material in the mixed state. The present results are preliminary in a study to determine the power-loss contributions, including those from the ferromagnetic Ni substrate. Comparison is planned with results from similar YBCO films grown on nonmagnetic insulating substrates, such as $SrTiO_3$.

- Testing of the Southwire HTS transmission line prototype 4 has been completed. The dc measurements indicate that the cable I_c using the 1-mV/cm criteria is about 975 A. The ac loss measurements