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This three-year project started on May 1, 2003 and the report is the final report covering the whole project period. The overall goal of the project in to identify and eliminate current limiting factors in thick films HTS coated conductors and to develop novel tools for mapping nonuniformity of HTS coated conductors. Two students equivalent were supported during the reporting period and' one student has completed her MS thesis. Research on the two objectives has been carried cut in parallel and exciting progress has been made, as summarized in the following. Details of our results may be found in 1 pending patent and 22 papers (19 published/accepted and 3 submitted).				
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Material Issues in High- I_c Coated Conductors

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Final Report

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OBJECTIVES

- * Investigate issues affect I_c s in thick film HTS coated conductors and develop schemes to improve the I_c s
- * Develop diagnostic tools for mapping non-uniformity of HTS coated conductors

STATUS OF EFFORT and FOCUS OF FUTURE EFFORTS

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Our prior AFOSR project supported two graduate students equivalent for three years with one equivalent (Emergo 50% and Wang 50%) working on study of microstructure and J_c of YBCO thick films and the other (Aga up to 2004, Dizon since May 2005 and Mishra for 3 months in summer 2005), on development of near-field scanning probe microscopy (SPM). Aga received his Ph.D. in Dec. 2004 and is current a research faculty in Fost University. Dizon completed his MS in July 2006 and continues on the PhD study here. Both Wang and Emergo are expected to complete their Ph.D. in next six to twelve months. Undergraduate Jesse Noffsinger, who received 2005 NSF graduate scholarship and was admitted to UC Berkeley recently, was also supported for his research in the second topic.

Objective 1: Critical current in thick HTS coated conductors

■ Objective 1 has been focused on the J_c s issue of the thick film coated conductors. The goal is to understand the mechanisms that are responsible for the observed J_c -degradation at large thickness and from that to seek ways to improve the J_c in thick film coated conductors. Graduate student Xiang Wang's work has been focused on study of this mysterious J_c -thickness behavior of HTS films at different temperatures and magnetic fields. It has been found that the J_c reduction with increasing thickness occurs only at self and weak magnetic field below

approximately 0.5-1.0 Tesla. An upper-turn occurs in the J_c -thickness curve at higher fields. One interesting experiment that sheds light on this matter was to insert an insulating layer between two YBCO layers. In these tri-layered YBCO/insulator/YBCO samples, J_c increases monotonically with the thickness of the insulator while the thickness of the YBCO layers was each fixed at 0.25 μm . At 20 nm of the insulator thickness, the J_c of the trilayered samples saturated to that of 0.25 μm YBCO films [Wang and Wu, APL **88**, 062513(2006)]. This further confirms the correlation between the J_c -thickness behavior and the variation of magnetic pinning with increasing thickness and suggests that inter-layer decoupled vortices could be pinned more efficiently. Further investigation on the mechanism of the J_c -thickness behavior is underway and several manuscripts are under development.

Emergo's work has been on growth and characterization of vicinal YBCO films of varying thickness from 0.2 to 3.0 μm and variable vicinal angle up to 15 deg. The goal is to seek ways to improve the J_c in YBCO coated conductors via microstructure engineering. The much improved J_c in the porous structured YBCO vicinal films [Emergo *et al*, APL **85**, 70(2004) and Polyanski, Emergo *et al*, PRB **72**, 174509(2005)] seems counter-intuitive to our perception that a dense structure superconductor carries maximum current because of maximized current cross-sectional area. Most pores in these vicinal YBCO films have their dimension on the order of tens or few hundreds of nanometers. This raises a fundamental question on what is the desired microstructure for YBCO to carry higher J_c approaching its theoretical limit of the depairing J_c . Motivated by this question, a preliminary experiment to insert 211 nanoparticles into the vicinal YBCO films was carried out recently, resulting in more porous microstructure and further improved J_c [Emergo *et al*, APL**87**, P232503(2005)]. Significantly improved J_c , especially in applied magnetic field has also been obtained in these porous YBCO films. The pores run through most part of the film thickness as shown in the TEM (transmission electron microscopy) and ion milling experiment [J. Wu *et al*, preprint and reported in CCA2005]. This means that they are "nanotubes" along the c-axis in YBCO. Since the insertion of nanoparticle and nanopores can be controllably made via growth, this work provides a promising approach for engineering microstructure of YBCO coating and a US patent application has been submitted. In the proposed research objective 2, we plan to quantify the effect of pore pinning using as-made porous films and also YBCO bridges with artificially generated nanotube pore arrays. We will continue our investigation of growth mechanism, aiming at achieving uniform aligned nanotube pores of designed dimension and density in YBCO.

Objective 2: Development of an advanced SPM system and investigation of current flow in coated conductors

■ Objective 2 has been focused on development of advanced characterization tools and the goal is to be able to map the physical properties of coated conductors at both microscopic scale for understanding the underlying physics and macroscopic scale for reel-to-reel quality control of coated conductors. We have further developed our microwave microprobe for mapping the electrical current distribution in a metallic film and demonstrated a spatial resolution of ~ 5 -10 μm on a 150 μm wide metal strip. In addition, several maps can be taken simultaneously using the microwave microprobe at resolution of 0.5-1.0 μm for identification of various defects in conducting films of variable thickness. We have obtained interesting results on YBCO films and

made simulation of the microwave induced local heating in conducting films. In next project period, we will focus on mapping YBCO films with known defects and investigate the current distribution in both normal state and superconducting state.

Aga, Dizon and Noffsinger have been focused on development of dual-channel scanning probe microscopy including near-field scanning microwave/optical (NSMM/NSOM) probe and NSOM/STM (scanning tunneling microscopy) probe. The goal is to be able to map the physical properties of coated conductors at both microscopic scale for understanding the underlying physics and macroscopic scale for reel-to-reel quality control of coated conductors [Aga *et al*, APL**84**, 1979 (2004)]. We have further combined our NSMM/NSOM with IV measurement for mapping the electrical current distribution (J-mapping) in a conducting film and demonstrated a spatial resolution of $\sim 5\text{-}10\ \mu\text{m}$ on a $150\ \mu\text{m}$ wide metal strip in j-mapping [Aga *et al*, APL**86**, 234101(2005)]. In addition, several microwave maps can be taken simultaneously using the NSMM at resolution of $\sim 1.0\ \mu\text{m}$ for identification of various defects in conducting films of variable thickness. To apply this technique for quantitative J-mapping, simulation of the microwave induced local heating in conducting films has been carried out and excellent agreement between theory and experiment has been obtained [Mishra *et al*, submitted to JAP]. Recently, J-mapping on YBCO films with known defects has been made at room temperature and a spatial resolution of $\sim 100\ \mu\text{m}/4000\ \mu\text{m}$ -current path width has been obtained (Dizon *et al*, submitted to APL), which is significantly better than the best $\sim 60\ \mu\text{m}/100\ \mu\text{m}$ -width reported earlier by other groups. Implementation of our SPM system to a low-temperature vacuum system was just completed and several experiments to be carried out in this low-temperature SPM (LTSPM) system.

Patents:

1. (Patent pending) J.Z. Wu, R. Emergo, T. Haugan and P. Barnes, "Fabrication of porous ceramic films"

Publications:

1. H. Zhao and J.Z. Wu, "Converting Hg-1212 to Tl-2212 via Tl-Hg Cation Exchange in combination with Tl cation intercalation", submitted to APL.
2. Jonathan R. Dizon, Xiang Wang, Roberto S. Aga, Jr., and Judy Z. Wu, "Combining Near-field Scanning Microwave Microscopy with I-V Measurement for Imaging Current-obstructing Defects in HTS Films", submitted to IEEE Trans. Appl. Superconductivity.
3. Hua Zhao, Jonathan R. Dizon, Rongtao Lu, Wei Qiu, Judy Z. Wu, "Fabrication of Three-Pole $\text{HgBa}_2\text{CaCu}_2\text{O}_{6+\delta}$ Hairpin Filter and Characterization of Its Power Handling Capability", submitted to IEEE Trans. Appl. Superconductivity.
4. R.T. Lu, R. Vallejo and J.Z. Wu, "Development of textured MgO templates on nonmetallic flexible cereflex", to appear in APL (06)
5. Shramana Mishra, Jonathan R. Dizon, Roberto S. Aga Jr and Judy Z. Wu, "A comparative study of simulated and experimentally obtained electrical current distribution in conducting films, to appear in JAP (06).
6. Z.W. Xing, H. Zhao and J.Z. Wu, "Reversible exchange of Tl and Hg cations on superconducting "1212" lattice", *Advanced Materials* **96**, 2136 (2006)

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14. H. Zhao and J.Z. Wu, "Pinning lattice: effect of rhenium-doping on the microstructural evolution from Tl-2212 to Hg-1212 films during cation exchange", *J. Appl. Phys.* **96**, 2136 (2004)
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