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14. ABSTRACT Investigate issues affect Ics in thick film HTS coated conductors and develop schemes to improve the Ics * Understand the physics associated to the deparing current density Jd in HTS films * Develop diagnostic tools for investigation of instability of HTS coated conductors This three-year project started on July 1, 2006 and finished on June 30, 2009. This final report summarizes the major progress made during the three year project period. Two students equivalent were supported during the reporting period. Research on the three objectives has been carried out in parallel with progress made summarized in the following. The details of the progress made can be found in a book chapter, 22 published papers and a pending patent.					
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Material Science and Physics in High- I_c Coated Conductors

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Final Report

July 1, 2006— June 30, 2009

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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
- * Understand the physics associated to the depairing current density J_d in HTS films
- * Develop diagnostic tools for investigation of instability of HTS coated conductors

This three-year project started on July 1, 2006 and finished on June 30, 2009. This final report summarizes the major progress made during the three year project period. Two students equivalent were supported during the reporting period. Research on the three objectives has been carried out in parallel with progress made summarized in the following. The details of the progress made can be found in a book chapter, 22 published papers and a pending patent.

Objective 1: Critical current in thick HTS coated conductors

Objective 1 has been focused on understanding the physics responsible for the thickness dependence of J_c in the HTS thick film coated conductors, and from which to develop schemes to eliminate it. In a systematic study of J_c -thickness behavior over a large range of temperature and magnetic field, we have confirmed that the weak collective pinning by native point defects in YBCO films is a dominant mechanism responsible for the observed J_c reduction with increasing thickness (Wang and Wu, PRB76, , 184508 (2007)). The central point is the thickness dependent pinning force per vortex length F_p in the point defect case. To achieve a constant F_p so as to eliminate the thickness dependence of J_c , a possible solution is to replace “native” point defects with through thickness linear defects as shown in Fig. 1. Two schemes have been explored in details. One is to chop vortices to shorter pieces in a multilayer YBCO/CeO₂ structure. The insertion of an insulating layer between two YBCO layers decouples the long vortices into shorter segments than can be pinning independently [Wang, APL88, 062513(2006)]. This scheme leads to $F_p(\text{thick})=F_p(\text{thin})$ so J_c -thickness will take the red curve shown in Fig. 1(a). Although no thickness dependence of J_c will occur, the J_c value is low and fabrication procedure will be complicated for growth of additional insulating layers. The other scheme explored in this project is to grow through thickness linear defects such as nanotube pores (NTPs) in YBCO films and BaZrO₃ (BZONRs) nanorodes. In both cases the thickness dependence of J_c is either eliminated or much reduced (See Fig. 1(b)). In the YBCO/NTP case, the effect of the NTPs on the thickness dependence of J_c is only limited to low magnetic fields below 0.1-0.2 T, which is attributed to low density of NTPs in YBCO films since the matching field of NTPs is on the order of 0.1-0.2 T. However, NTPs seem to cause less stress on the YBCO lattice so the overall

J_c values are high in the low field region where NTPs are efficient (Wang and Wu, *Phys. Rev. B* 77, 144525 (2008)). At higher fields, the collective pinning style thickness dependence of J_c is resumed, suggesting higher density NTPs are necessary to extend the effect of NTPs to higher field. In the case of BZONRs, no thickness dependence of J_c was observed at magnetic fields up to 5T, which is our measurement limit (Wang and Wu, preprint). It should be pointed out that the matching field of 2% vol BZONRs is approximately 5-10 T, so the benefit of BZONRs on the J_c -thickness behavior is expected to extend to even higher fields. One issue that must be addressed is the degradation of the J_c values in YBCO/BZONRs films, which is typically 50-100% lower than that YBCO control samples. Since high stress is generated by insertion of BZONRs, a counter mechanism must be developed to reduce the stress so as to reduce the J_c degradation. This work is underway currently.

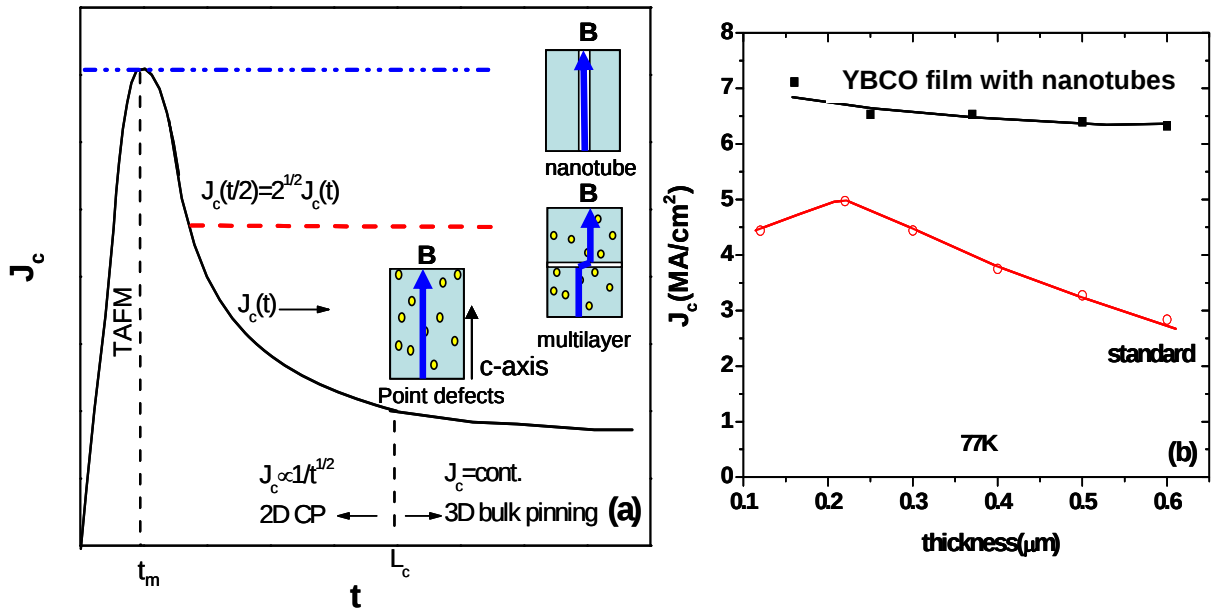


Figure 1(a) Schematically shown is the typical J_c - t of standard YBCO films (black) which can be interpreted as interplay between CP and TAFM²⁵. The TAFM dominated region is typically below 0.1 μm for T less than 77 K but expands with increasing T. The 2D collective pinning region is located between t_m and L_c where J_c follows the dependence of $J_c \propto t^{-1/2}$. Less J_c - t is expected as t exceeds L_c due to the recovered flux line elasticity. Insets show a vortex with length $t < L_c$ collectively pinned by randomly distributed point defects (black), decoupled into two identical segments in a trilayered YBCO/CeO₂/YBCO (red) and an ideal solution to eliminate J_c - t by overpowering the point defects with linear pinning centers. The resultant thickness independent J_c with high value can be achieved (blue); (b) experimental J_c - t curve measured on YBCO with NTs (black) is compared with that on standard YBCO (red).

Objective 2: Approach the depairing J_c in HTS films

Objective 2 focuses on enhancing the J_c in practical HTS coated conductors to J_d . It should be realized that the best J_c on optimized YBCO films is still an order of magnitude lower than the J_d predicted theoretically. This issue has been challenging our understanding of the underlying physics of J_c . In conventional superconductors, J_d was achieved in thin narrow bridges with both transverse dimensions much smaller than the London penetration depth. To address this issue, we have developed a novel process to make highly porous YBCO films. Nanopores have a

unique advantage over their nanoparticle counterparts for vortex pinning due to the chemical-contamination free interface with HTS matrix, which is critical to achieve the optimized pinning potential energy and not to degrade the HTS matrix. Motivated by this, we have developed a PONSE process (**P**ores by **n**anoscale **s**train **e**ngineering, US patent pending). Nanopores have been obtained via nanoparticle (NP)-facilitated strain manipulation on YBCO lattice. In our process, a large number of NPs are inserted either near the film/substrate interface or during the YBCO film growth. The local tune of the strain by the inserted NPs over the globally strained YBCO lattice on vicinal substrates plays a critical role in pore nucleation and evolution. A large number of pores of dimension from few to hundreds of nanometers formed uniformly via self-assembly growth. The density of the nanopores in the range of 5 ± 3 pores/ μm^2 corresponds to an accommodation field $H_m \sim 4.1\text{-}16.6$ mT. Significantly enhanced J_c up to 8.3 MA/cm^2 at 77K and SF has been obtained on these samples, which is twice of the standard YBCO film's J_c and $\sim 17\text{-}20\%$ of J_d , the highest so far achieved in YBCO films (Wu *et al.*, APL **93**, 062506 (2008)). A close correlation between J_c and the magnetic pinning potential U_p of the nanopores has been demonstrated below the accommodation field H_m , confirming that nanopores are strong pins on the magnetic vortices (Fig. 2). This work was featured as a Technology Update on the IOP Nanotech Web on October 17, 2008. To improve the overall J_c , especially in high B field of several Teslas, we have collaborated with AFRL to add nanoparticles (211 and BZO) into the porous YBCO films and several manuscripts have been submitted/written. Overall enhanced J_c s have been obtained by combining nanopores and nanoparticles.

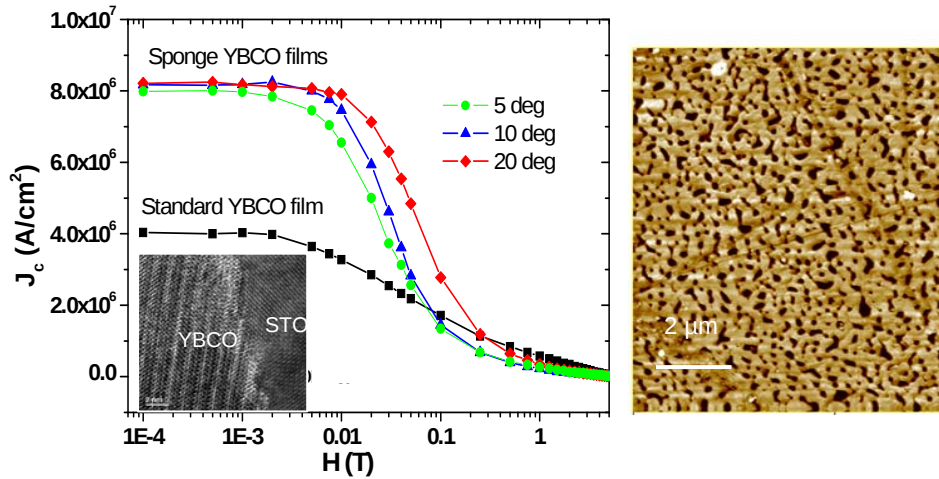


Fig. 2. Left: transport J_c measured on several YBCO sponge films in comparison with a regular one made using the same YBCO target under the same processing condition. Right: AFM image of an YBCO sponge film and lower-inset: a TEM image of the film/substrate interface of a porous YBCO film on a 15° STO substrate.

Objective 3: Development of an advanced SPM system and investigation of current flow in coated conductors

Objective 3 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 near-field microwave microprobe (NSMM)

for mapping the electrical current distribution in a metallic film and demonstrated a spatial resolution of $\sim 5\text{-}10\text{ }\mu\text{m}$ on a $150\text{ }\mu\text{m}$ wide metal strip. In addition, several maps can be taken simultaneously using the microwave microprobe at resolution of $0.5\text{-}1.0\text{ }\mu\text{m}$ 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. Recently, we have completed assembling and testing of our low-temperature chamber for NSMM and have made investigation of dissipation and instability in YBCO microbridges with and without grain boundaries (GB) using a combination of NSMM and electrical transport measurement. The NSMM measurement shows low level dissipation development at 3-4 orders of magnitudes lower than the detection limit of the transport measurement. The dissipation increases more or less linearly with applied bias current until the threshold voltage for determination of J_c is reached, as shown in Figure 3. The presence of GB on the microbridge causes much higher dissipation as compared to the case without GB, suggesting GB is indeed a high dissipation area which could lead to thermal instability of superconductor devices.

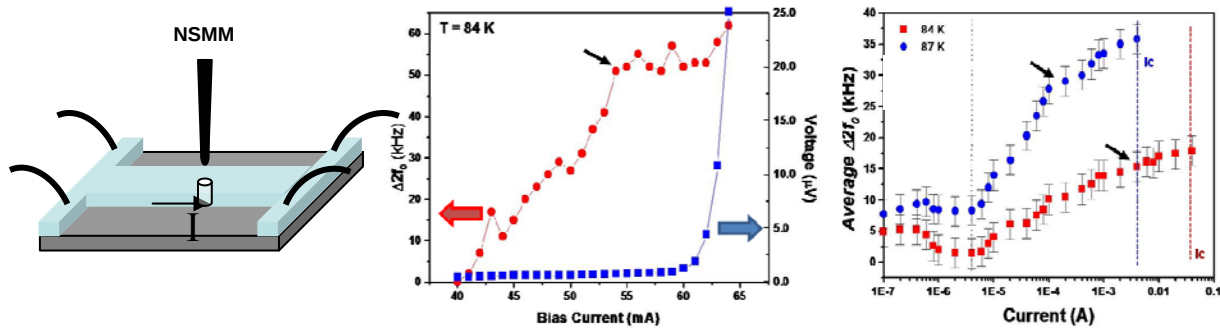


Fig. 3. Left: schematic description of the combined IV-NSMM setup; middle: comparison of dissipation detected simultaneously with IV (blue) and NSMM (red) on a YBCO microbridge; and right: dissipation detected using NSMM at 84K (red) and 87K (blue) on a YBCO microbridge. The detection limit of IV measurement is shown as a dashed line labeled " I_c ".

Patents:

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

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