# Superconductivity for Electric Systems 2006
# Project Summary

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| **PROJECT TITLE:** | Expanding the set of tools for investigating and improving vortex pinning |
| **ORGANIZATION:** | **LANL-STC** |
| **PRESENTERS:** | Boris A. Maiorov |
| **FY 2006 FUNDING:** | $200 K |

**Project Purpose and FY 2006 Objectives:**

This presentation is part of the project "Understanding and pushing the limits of critical current in coated conductors". Complementary results in the same project will be presented by Foltyn-Civale (previous talk). With the overall objective of improving the performance of and commercial prospects for coated conductors (CC), this project has been focused on raising the critical current density ($J_c$) and critical current ($I_c$) of $YBa_2Cu_3O_7$ (YBCO). A large portion of our effort has been devoted to increasing our general understanding of flux pinning in YBCO coatings.

Measuring the angular dependence of $J_c$ (a work pioneered at LANL) is now a well-established technique to understand and characterize vortex pinning in CC. Initially, our studies have focused on measurements at liquid nitrogen temperatures (T=79K-65K) to investigate new pinning enhancement routes. However, realistic applications such as magnets or motors are expected to operate at lower temperatures. Last year (FY05) we added magnetization measurements to our set of tools to characterize and help improve CC. As a first step, we used this tool to study $J_c$ in standard Pulsed Laser Deposited YBCO CC as a function of temperature and field. During FY06 we extended these studies to films with different pinning centers engineered for $J_c$ enhancement.

Also, all our transport measurements so far were performed in the *maximum Lorentz Force* configuration (*i.e.*, with the current *I* always flowing perpendicular to the applied magnetic field *H*). However, this is not the actual situation in most applications such as cables, inserts or motors, where the magnetic field is partially or totally aligned with the current, namely in a Variable Lorentz Force or Force-Free configuration, respectively. Therefore, we decided to expand our experimental capabilities to study $J_c$ of CC in these more general current-field configurations. The goals are to identify the relevant pinning centers and mechanisms and, if possible, to devise ways to increase $J_c$ in realistic configurations.

As part of the FY06 goals in the Foltyn-Civale FY05 presentation, we applied the above mentioned techniques to research the causes of elevated $J_c$ in CC. In addition to working with American Superconductor in the understanding and enhancement of vortex pinning in ex-situ films, we have studied other ex-situ samples from ICMAB-Barcelona (in a thickness dependent study) and thick samples from Brookhaven National Lab.

**FY 2006 Performance and FY 2007 Plans:**

During FY06 we performed $J_c(\Theta,H)$, where $\Theta$ is the angle between **H** and the tape normal, studies at lower temperatures for YBCO films with the most promising types of engineered structures for pinning enhancement, such as random pinning from rare-earth mixtures $Y_2BaCuO_5$ (211) inclusions and correlated defects from $BaZrO_3$(BZO)-doping. We found that at T~75 K and intermediate fields these methods produce comparable results, but at lower temperatures the correlated defects become more effective at pinning the vortices, inducing a bigger increase in $J_c$ relative to the plain YBCO. This led us to focus on BZO-doped films. We had previously found that the $J_c$ enhancement at T=75K in BZO-doped samples was mainly due to correlated defects, and that the pinning due to the nano-particles themselves could be disregarded. However, our new studies show that the relevant pinning mechanism changes around T~40K, with both the power-law regime in $J_c(H)$ and the characteristic peak centered at the c axis vanishing at lower temperatures. Comparative $J_c$ angular and field dependent studies at 4K in BZO-doped samples with and without correlated defects showed that random disorder becomes more important at lower temperatures and dominates the field and angular dependence.

As a way to further understand pinning in ex-situ films, we performed $J_c$ angular and field dependence studies in record thick $BaF_2$–route films from Brookhaven National Laboratory and in MOD-TFA films from ICMAB (Barcelona).

Variable Lorentz Force experiments yielded the unexpected result that, for certain samples, $J_c(H)$ in the Force-Free configuration ($H//I$) is higher than $J_c$ at self-field, maintaining this condition up to several tesla. We have investigated this matter by studying samples with different thickness and microstructures and found that this increase is due to the presence of strong pinning at the ab planes that stabilizes the helical vortices present in the Force-Free configuration.

For FY07 we plan to extend our Variable Lorentz Force and Force-Free measurements to CC provided by different sources (companies and collaborators). We will also study the change in the pinning regime at lower temperatures in CC from companies and others with a variety of microstructures. We also intend to extend our present measurement capabilities and explore the irreversibility line up to 60T.

**FY 2006 Results:**

- Completed comparative temperature studies of $J_c$ behavior for different pinning enhancement routes (correlated *vs* random). Correlated pinning outperforms random as temperature is decreased.
- Grew BZO-doped YBCO without extra correlated defects, resulting in a different $J_c$ enhancement mechanism.
- Determined the $J_c$ temperature dependence of BZO-doped samples with different amounts of c-axis correlated pinning.
- Determined the change in pinning mechanisms at T~40K in BZO-doped samples.
- Study and understanding of the influence of pinning centers in the Force-Free configuration. Increase of $J_c$ for the Force-Free configuration.
- Performed pinning studies of YBCO with 211 inclusions as a function of interlayer distance and at different temperatures (Wright Patterson Air Force Research Lab)
- Studied the angular and field dependence in record thick $BaF_2$–route films (Brookhaven Nat. Lab.).
- Thickness dependence of MOD-TFA samples (ICMAB, Barcelona).
- Performed pinning studies in different Hybrid Liquid Phase Epitaxy (HLPE) samples (Cambridge).

**Research Integration:**
We continued our collaboration with American Superconductor in the investigation of pinning mechanisms in their baseline and doped MOD CC. We started a collaboration with ICMAB Barcelona to study the thickness dependence in MOD-TFA coated conductors. We continued our collaborations with Univ. of Cambridge concerning samples grown by HLPE and with in-plane rotations. We collaborated with the Air Force Research Lab. in the pinning studies of 211 inclusions. We continued our participation in the Wire Development Group (American Superconductor, Oak Ridge National Lab., Univ. of Wisconsin-Madison, Argonne National Lab.). We also collaborated with Brookhaven National Lab., MetOx and Superconductor Technologies, Inc. These collaborations resulted in joint publications and conference presentations. The information learned from these collaborations is critical for studying and understanding the pinning mechanisms arising from different pinning enhancement routes.