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| **Project Title:** | **Understanding and Improving Pinning in Coated Conductors** |
| **Organization(s):** | **Los Alamos National Laboratory** |
| **Presenters:** | Leonardo Civale, Judith Driscoll |
| **FY 2004 Funding:** | \$550 K |

**Project Purpose and FY 2004 Objectives:** The objective of this project is to investigate the mechanisms that determine the supercurrent in coated conductors (CC), and to use that knowledge as a guide to explore practical methods for nano-engineering of pinning defects and process optimization of high performance CC. The approach is to characterize the transport properties as a function of magnetic field strength (H) and orientation (Θ), and temperature (T). We then correlate these properties with the structural characteristics of the samples in a variety of rare earth (RE)-123 films on single crystal substrates and CC of different architectures.

This project started in FY 2003, and that first year we focused on the comparison of the angular dependence of the critical current density ($J_c$) at liquid $N_2$ temperature in YBCO films grown by pulsed-laser deposition (PLD) on ion-beam-assisted deposited MgO (IBAD MgO) and on single crystal substrates. We identified the H-Θ regions where $J_c$ is dominated by various types of pinning centers. We found that the sources of pinning are similar in CC and films on single crystal substrates, and that the in-field $J_c$ in our CC can be higher than in equivalent films on single crystal substrates. We also performed initial studies at lower T, and on CC of different architectures provided by our industrial partners SuperPower and American Superconductor.

The goals for FY 2004 were to extend the measurements and analysis to lower temperatures, study films thinner than 1 μm, explore $J_C(H,\Theta,T)$ in CC with different architectures, perform $J_C$ measurements with current flowing in different directions in the ab-plane, grow films with rare earth substitutions, and introduce columnar defects at different angles in YBCO films on single crystal substrates.

**FY 2004 Performance and FY 2005 Plans:** Substantial progress was made on each goal. Extensive $J_c(H,\Theta,T)$ studies in the range 4 K < T < $T_c$ ~ 90 K allowed us to develop a H-Θ-T diagram of the dominant pinning mechanisms for films of thickness ranging from 0.2 μm to 6 μm. We extended our studies to CC of different architecture, mixed RE-123 compositions, second phase additions, and growth methods and conditions, on samples from Los Alamos as well as from our partners. We found systematic differences that are fingerprints of the CC processing method and architecture and that can be clearly correlated with the structural properties.

We successfully developed at Los Alamos several ways to engineer the microstructure in order to enhance the in-field $J_c$, either by introduction of additional correlated disorder (e.g., dislocations) or random pinning (e.g., strain associated with ion size variance). Our industrial partners also pursued alternative approaches to the introduction of additional pinning; we investigated $J_c(H,\Theta,T)$ in several of their samples and provided them with valuable feedback.

The last goal, the introduction of columnar defects, was modified. The reason is that we have unexpectedly been able to produce and/or study samples with additional extended defects at several orientations, generated by a variety of methods that are scaleable to industrial production. We decided that the study of the pinning due to these defects was technologically more relevant than the initially planned heavy-ion irradiations.

In FY 2005, we will continue our effort to further improve the in-field performance of CC. We will pursue this goal in several ways. One main focus will continue to be the nano-engineering of pinning-inducing defects. We expect to optimize the deposition conditions and density of $BaZrO_3$ inclusions, and explore alternative nanoparticles. We also plan to optimize our successful approach to pinning enhancement by tuning the buffer layer deposition conditions in order to create surface outgrowths. Finally, we will continue our exploration of RE substitutions, following our initial encouraging results on compositions with low variance in the RE ion size. Based on the results of the above-mentioned alternatives, we will select the most appropriate one and implement it in the continuous long-length process. In terms of measurement capabilities, we will make full use of our in-plane current rotation system, and we will incorporate measurements in non-maximum Lorentz force configurations, in order to explore the CC performance in realistic current/field distributions for various applications.

**FY 2004 Results:**

- We developed a H-Θ-T map of the dominate pinning mechanisms in PLD/IBAD MgO CC in the temperature range from $T_c$ to ~ 26 K.
- We found that $J_c$ for H//c can be scaled over wide ranges of H-T. This allows us to predict $J_c$ values for arbitrary (H,T), based on a few parameters.
- We determined the influence of the film thickness on the relative importance of the correlated and uncorrelated pinning mechanisms.
- We observed significant improvements in the in-field $J_c$ in CC of mixed RE-123 compositions grown by various methods (including samples from SuperPower and AMSC).
- We have been able to introduce epitaxial $BaZrO_3$ nanoparticles in YBCO PLD films, which generate additional c-axis correlated defects that in turn produce remarkable improvement of the in-field $J_c$.
- We introduced additional strong pinning c-axis dislocations by modifying the growth conditions of the STO buffer layer.
- We introduced tilted correlated defects by two different methods, which produce a $J_c$(H,Θ,T) that is asymmetric with respect to H//c.
- We found that the laminar growth associated with MOD films (from AMSC) results in a large density of planar defects parallel to the ab-planes, which dominates pinning in a wide angular range around H//ab.
- We demonstrated that a superstructure of $Y_2BaCuO_5$ (211) extended planar defects parallel to the ab planes produces a tunable matching pinning effect (collab. with Air Force Research Lab.).
- We explored the influence of the IBAD MgO structure on the in-plane anisotropy of $J_c$.

**Research Integration:** During FY2004 we performed measurements of $J_C$(H,Θ,T) on CC fabricated by SuperPower, Inc., American Superconductor, and the Air Force Research Laboratory, resulting in joint publications and conference presentations. The information learned from these collaborations is critical for studying the pinning mechanisms arising from different deposition techniques. During her stay at Los Alamos as a visiting staff member, Dr. Judith Driscoll was on sabbatical leave from the University of Cambridge, UK.