Project Title:	**Electromechanical Studies for Superconductor Development**
Organization(s):	**National Institute of Standards and Technology, Boulder, CO**
Presenters:	Jack Ekin and Najib Cheggour
FY 2004 Funding:	$195 K

Project Purpose and FY 2004 Objectives: This project provides the electromechanical research needed to develop YBCO and BSCCO superconductors for high-field magnet and electric power applications. Stress and strain management is one of the key feedback parameters needed to move the second generation conductors to the market place. The project utilizes the expertise and unique electromechanical measurement facilities at NIST to provide performance feedback to companies and organizations developing the conductors (AMSC, SuperPower, ORNL, LANL, ANL), as well as to provide engineering design data to the SPI partners. We have achieved significant progress in our primary objectives for FY 2004:

1) **Cu stabilization:** Measure the effect of axial strain (ε) on critical-current density (J_c), at 76 K and self field, in YBCO (both RABiTS and IBAD) coated-conductors that incorporate a stabilizing Cu layer either by lamination or Cu-plating, and compare to samples without Cu stabilizer.
2) **Magnetic-field effect:** Measure the magnetic field dependence of the reversible strain effect (which we discovered last year) at 76 K and fields up to 16.5 T, to investigate any correlation of this effect to strain-induced variations of the fundamental superconducting parameters T_c and B_{c2}.
3) **Liquid-helium measurements:** Investigate the effect of axial strain on J_c in YBCO RABiTS at 4K as a function of magnetic field up to 16.5 T.
4) **Substrates:** Measure stress-strain characteristics of bare and fully coated substrates, as well as new conductor geometries.
5) **YBCO thickness:** Start preliminary tests of the effect of film thickness on the axial strain effect.

FY 2004 Performance: Key results from the FY 2004 program are summarized below.

1,5) Measurements of $J_c(\varepsilon)$ were made at 76 K and self-field in a series of YBCO on Ni-W RABiTS and IBAD Hastalloy conductors with and without Cu stabilizer. These data were obtained with our stress-free-cooling strain apparatus. In both IBAD and RABiTS samples that incorporate a stabilizing Cu layer (either by Cu-plating or lamination), the results show that the Cu stabilizer significantly increases the irreversible strain (ε_{irr}) from ~ 0.38-0.4 % to 0.52-0.6 %, probably by providing an additional pre-compression of the YBCO layer during sample cooling from room temperature to 76 K. Therefore, the impact of Cu, besides providing a good electric and thermal stability to the conductor, is also to markedly widen the strain window for applications of these composites. Furthermore, some Cu-laminated YBCO/Ni-W samples also showed a small (2%) increase of J_c as a function of strain, which peaks at $\varepsilon \approx 0.3$ %. Compared to last-year's results, ε_{irr} also maintained high values in the new higher-J_c YBCO coated conductors. Preliminary tests of $J_c(\varepsilon)$ at 76 K and self-field on thick (≥ 2 µm) YBCO coated conductor RABiTS are underway.

2) The first detailed J_c measurements in YBCO coated conductors as a function of strain and magnetic field were made at 76 K. Data, obtained for YBCO on Ni-5at.%W RABiTS, show the dependence of the newly discovered reversible strain effect on magnetic field, both at low (50 mT) and high (up to 16.5 T) field intensities. Among preliminary conclusions is that the J_c sensitivity to strain is increased with magnetic field above 3 T, and that, unexpectedly, this strain sensitivity is reduced in low magnetic field up to ~ 3T. These results will impact high-field applications such as industrial magnets, motors, and magnetic separators, as well as low-field applications such as power transmission lines, MRIs and transformers. The degradation of J_c at the irreversible strain (ε_{irr}) dramatically increases from ~ 2 % at self-field to ~ 30 % at 16.5 T. The pinning force density $F_p = J_c \times B$ is studied as a function of magnetic field and applied strain.

This opens a whole new area of study of strain effects in high-T_c superconductors in general and YBCO in particular. These materials were, for nearly two decades, thought to have no intrinsic strain effect on their transport properties at practical fields and temperatures (unlike their low-T_c superconductor counterparts). These findings provide insight into the origin of the reversible-strain effect in YBCO coated conductors and into the influence of strain both on the weak- and strong-link conduction regimes. A weak-link strain model is being developed to interpret these $J_c(B,\varepsilon)$ results that should also be useful in application design.

3) Measurements of $J_c(\varepsilon)$ were carried out in Cu-laminated YBCO/Ni-W RABiTS coated conductors at 4 K and magnetic field up to 16.5 T. In comparison to the samples of last year, J_c at 4 K and 16.5 T improved by 60 %. Furthermore, the irreversible strain effect was also found at 4 K, both in earlier RABiTS samples (~ 3.5 MA/cm^2 at 16.5 T) and new RABiTS samples (~ 6 MA/cm^2 at 16.5 T). The irreversible strain ε_{irr} at 4 K and 16.5 T has similar values compared with those measured at 76 K and self-field. These results will impact high-field magnet applications.

4) Measurements of stress-strain characteristics on bare and YBCO coated Hastalloy C-276 substrates as well as on copper-plated conductors were obtained at 76 K. These sample were supplied by SuperPower. The modulus of elasticity, yield strength, and proportional limit of elasticity were determined for these conductors and added to our database on substrate mechanical properties for feedback to the wire manufacturers. The results confirm that the mechanical properties of fully coated conductors are dominated by those of the substrate.

FY 2005 Plans: Determined in consultation with the manufacturers and a number of research collaborators within the DoE/OETD community. Direct feedback is given to the wire manufacturer within each project and then disseminated to the general wire-development and SPI community:

- Continue the extensive study of the effects of *magnetic field* strength on $J_c(B,\varepsilon)$ at 76 K in YBCO coated conductors. Provide data feedback and engineering design equations to AMSC, SuperPower, ORNL, and LANL on the performance of their conductors for use in applications at low and moderate magnetic-field intensities: power-transmission lines, rotating machinery, industrial magnets, and transformer applications.
- Acquire the first data on the effect of axial strain on the J_c of YBCO coated conductors as a *function of temperature* for applications in pumped liquid nitrogen. This will be conducted on new coated conductor geometries in collaboration with AMSC, SuperPower, ORNL, and LANL.
- Study the effect of YBCO *film thickness* on the strain response of YBCO coatings, as samples become available. This will be carried out in collaboration with ORNL, AMSC, and SuperPower.
- Add to the growing stress-strain *database* of new substrate-materials/conductor-geometries being developed by the manufacturers and DoE research laboratories.
- Design and construct a new apparatus for measuring the effects of strain on J_c as a function of magnetic-field/sample *angle*. Out-of-plane field orientations will probably play the limiting role for strain effects in most rotating machinery and magnet applications. The apparatus will be commissioned next year to enable measurements to commence as soon as possible in the following year.

Research Integration: NIST collaborates closely with researchers and managers at AMSC and SuperPower, ORNL, LANL, and ANL to implement a research program that utilizes NIST's specialized electromechanical test facilities and expertise. The resulting data provide feedback to the wire manufacturers, national labs, and SPI application developers, where they are integrated into conductor development and system design processes. Several collaborative papers with these organizations have been published or are being written.