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| **Project Title** | **Wire Development Group: Understanding and Enhancing the Performance of Bi-2223 Wire** |
| **Organization(s):** | **Argonne and Los Alamos National Laboratories**<br>**American Superconductor Corporation**<br>**University of Wisconsin at Madison** |
| **Presenters:** | Alex Malozemoff (AMSC), Eric Hellstrom (UW), Vic Maroni (ANL), Terry Holesinger (LANL), and David Larbalestier (UW) |
| **FY 2003 Funding:** | |

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| ANL | $350 K | |
| LANL | $225 K | |
| UW | $750 K | |
| AMSC | | $575 K |

**Project Purpose and FY 2003 Objectives:** The Wire Development Group (WDG) is a unique collaborative effort that develops the materials science foundations of advanced HTS wires for energy and magnet applications in the US and international marketplace. It has been primarily focused on multi-filamentary Bi-2223 composite wire but recent discussions have encouraged us to plan to incorporate a YBCO-CC component next year. The group brings together two DOE national laboratories (ANL, LANL) and a leading university program in applied superconductivity (U Wisconsin-Madison) with the world's leading entrepreneurial company developing and manufacturing HTS wire and wire products (American Superconductor–AMSC). Robust, long-length Bi-2223 multifilamentary wire is commercially available from AMSC today at performance levels unequalled by any other source. The challenge of the last year was to further significantly advance Bi-2223 technology with the following specific objectives

1. Evaluate new approaches for multi-filamentary composite Bi-2223 wire
2. Refine structure-property-processing-chemistry understanding
3. Translate materials breakthroughs, understanding, and new process development into higher $J_c$ Bi-2223 research tapes with at least a 20% increase in performance at the 77 K, 0.1 T benchmark.

**FY 2003 Performance and FY 2004 Plans:** All WDG objectives have been met. New process approaches including Over-pressure processing (OP) and alternative post heat treatments have been evaluated. They both have showed significantly enhanced performance compared to conventional processing at AMSC. New characterization techniques have been applied to a wide range of high performance tapes to study the current limiting mechanisms. Our success in increasing $J_c$ by reducing 2212 intergrowth density has been proven by several characterization methods, including a SQUID magnetization technique, irreversibility field ($H_g$ & $H_K$) measurements, electron microscopy (SEM and TEM), and through-tape, transmission XRD analysis. Our focus in FY04 for both multi-filamentary composite Bi-2223 and, now, coated conductor YBCO, further amplifies our unique knowledge, special capabilities and proven collaboration effectiveness:

1. Optimization of performance enhancements for Bi-2223 developed in FY03 and their introduction into long-length processing, and
2. Use of new composite designs and measurement techniques to explore completion of the Bi-2223 phase transformation and the refinement of local probes of current flow and dissipation such as magneto optical (MO) imaging combined with low temperature scanning laser microscopy (LTSLM) to differentiate between models of current flow in Bi-2223 (and YBCO wires) and identification of new ways to understand and increase performance headroom.
3. Application of our combined capabilities to YBCO coated conductors, specifically by analyzing the temperature, field and angle-dependence of the critical current density so as to identify key current-limiting mechanisms and enhance the deposition process for improved CC performance.

**FY2003 Results:** Key results include:

- Major increase of superconducting performance in multifilamentary Bi-2223 wire. Critical current density $J_c$ at the benchmark condition 77 K, 0.1 T has increased by ≈ 35% from 22 to 30 $kA/cm^2$.
- Over pressure processing has been systematically studied. The new $J_c$ record was produced by this method, combined with a new heat treatment profile and new method to prevent sheath leakage.
- A major current limiting factor- 2212 intergrowths- has been firmly proven by several methods through strong collaboration within the WDG. The strong correlation of $J_c$ to 2212 intergrowth content was observed in a wide range of tapes with variable $J_c$ (1000-70000 $A/cm^2$ at zero field).
- Success in reducing the time required for the 2nd phase-reduction, thermal-slide heat treatment (TSHT) to values near that of the standard AMSC process and with somewhat better performance.
- Electron microscopy was used to determine spatial variations in Bi-2212 intergrowth density, examine the formation of intergrowths, and examine changes in the growth front morphology of the Bi-2223 phase, thus helping us identify causes for grain misalignment, chemical segregation, and variable phase conversion efficiency.
- Transmission x-ray diffraction (T-XRD) measurements performed on key specimens from the Bi-2212 intergrowth studies helped distinguish the various forms of 2212 – intergrowths, single grains within colonies or whole colonies – as sources of current-limiting 2212 in fully processed wires.
- The spatial uncertainty of the MO image developed in current reconstruction mode (MO-CR) with respect to SEM images has been carefully evaluated using FIB cuts to the level at which it is about 1 μm, significantly less than the spatial averaging, ~5 μm, of the technique. To add to this capability we have performed careful test experiments at the University of Erlangen (Professor Alexey Ustinov) on the Erlangen LTSLM to understand current limiting mechanisms on scales down to about 1 μm. Based on these experiments we are constructing an LTSLM in Madison.

We anticipate that these new probes of the current limiting mechanisms will move our understanding of CLM from the several-micron scale, where gross obstacles like secondary phases predominate, towards the sub-micron scale. Thus, we are closing in on the real secret of what limits the current density in Bi-2223 wires and thus potentially unlocking paths for more significant progress.

**Research Integration:** The WDG remains an outstanding, vibrant example of inter-institutional, university-lab-industry collaboration, which has helped an American company establish unquestioned world leadership in HTS wire. Trimesterly meetings, frequent individual visits, emails, phone calls, and intra-organizational sample exchanges make possible rapid coordinated progress by exploiting the unique skills at the different sites. A sensible balance of proprietary technology and publishable results is maintained. An atmosphere of trust supports a positive and enthusiastic esprit de corps. Key lab and university results are tech-transferred effectively to American Superconductor's manufacturing plant, enabling rapid introduction of new developments to the AMSC process for making robust long-length wire.