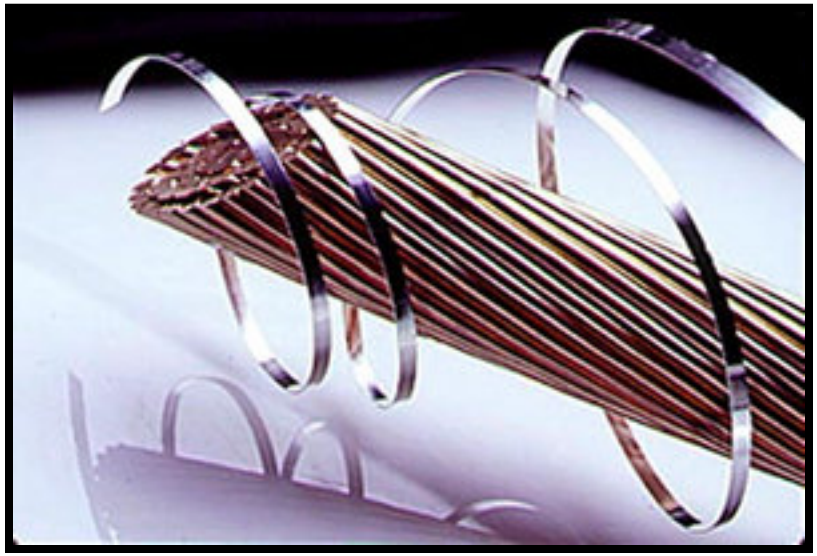
The Wire Development Group (WDG): Teaming Up To Make High-Temperature Superconducting (HTS) Wire



AMSC

American Superconductor

ornl

University of Wisconsin

ARGONNE NATIONAL LABORATORY

Los Alamos

Superconductivity Technology Center

History of High Temperature Superconductivity

- **Discovered in 1986 by Bednorz and Mueller →Nobel Prize**
- **Broad research support in the USA started almost immediately (DOE, DOD, NSF, industry, state governments)**
- **DOE laboratories, top notch corporate research labs (e.g., Bell Laboratories), and several universities led the way**
- **Argonne became a center for basic and applied research on HTS**
- **It was clear from the outset that a multidisciplinary approach was required to transition the discovery to useful products**
- **After nearly two decades of R&D, an HTS industry is on the verge of becoming a profitable reality**

Such discoveries provide a spring board to new funding, discipline application, career development, collaboration.

History of the Wire Development Group (WDG)

- **Started in 1991: AMSC, ANL, LANL, ORNL, and UW (instigated by collegial accord and backed up by binding agreements)**
- **Mission:**

  Establish the materials science foundation needed to enable the development and commercialization of HTS conductor for electric power devices and related applications
- **Program Approach:**

  Establish and sustain an aligned multi-year partnership between a U.S. company, three DOE labs, and a university focused on a high-performance, cost-competitive, broadly marketable product
- **Collaboration Format:**

  Formal Cooperative Research and Development Agreements (CRADAs) between industry and laboratories

These are some of the answers to the “why” and “how” questions about multidisciplinary research collaborations.

WDG People

Principals:

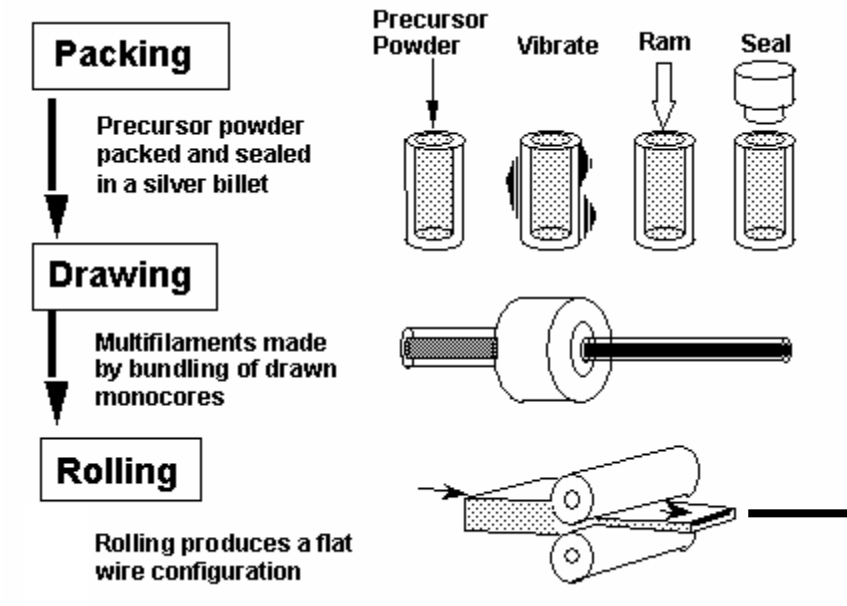
Li, Riley, Rupich, Malozemoff	**AMSC**
Bingert, Holesinger, Willis	**LANL**
Kroeger, Lee	**ORNL**
Maroni, Dorris	**ANL**
Larbalestier, Hellstrom	**UW**

Other Key Contributors:

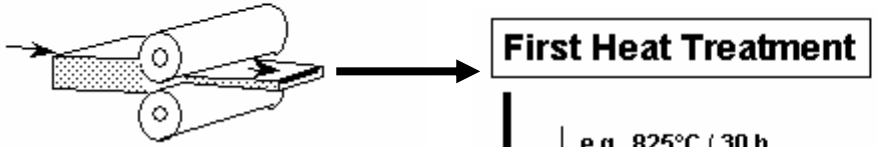
Teplitsky, Fleshler	**AMSC**
Maley, Coulter	**LANL**
Goyal, Paranthaman	**ORNL**
Merchant, Fischer, Miller	**ANL**
Cai, Polyanski, Parrella, Babcock	**UW**

Senior level scientists and engineers, young up-and-coming scientists and engineers, university faculty, postdoctorals, graduate and undergraduate students are involved.

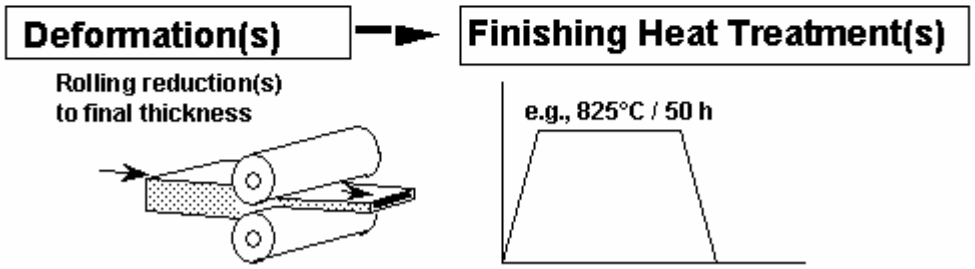
Initial WDG Focus: Optimize the Technology for Making First Generation (1G) HTS Wire—The Powder-In-Tube Process

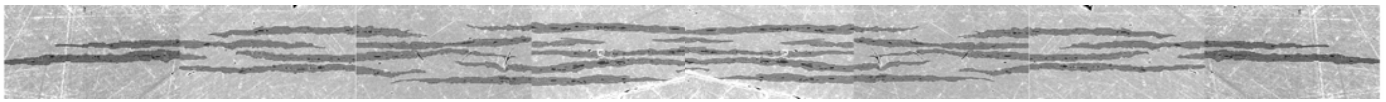


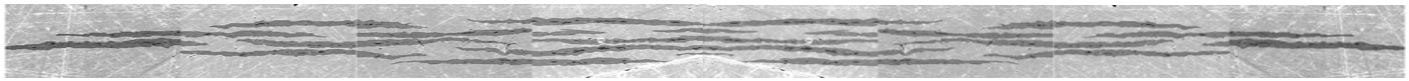
- powder stoichiometry/ synthesis
- deformation mechanics



- phase evolution
- microstructure development

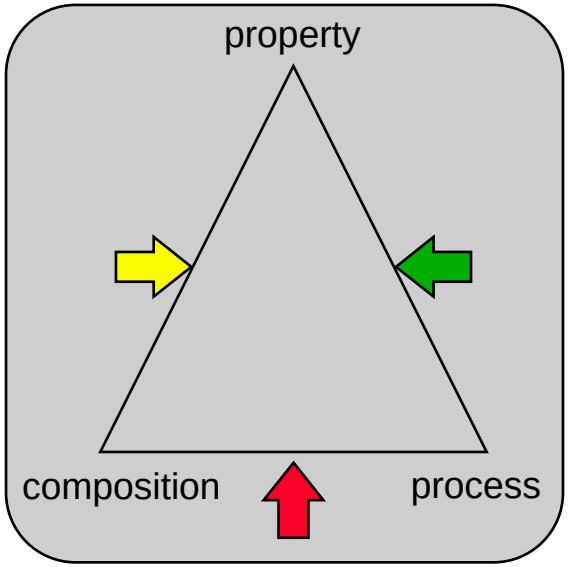


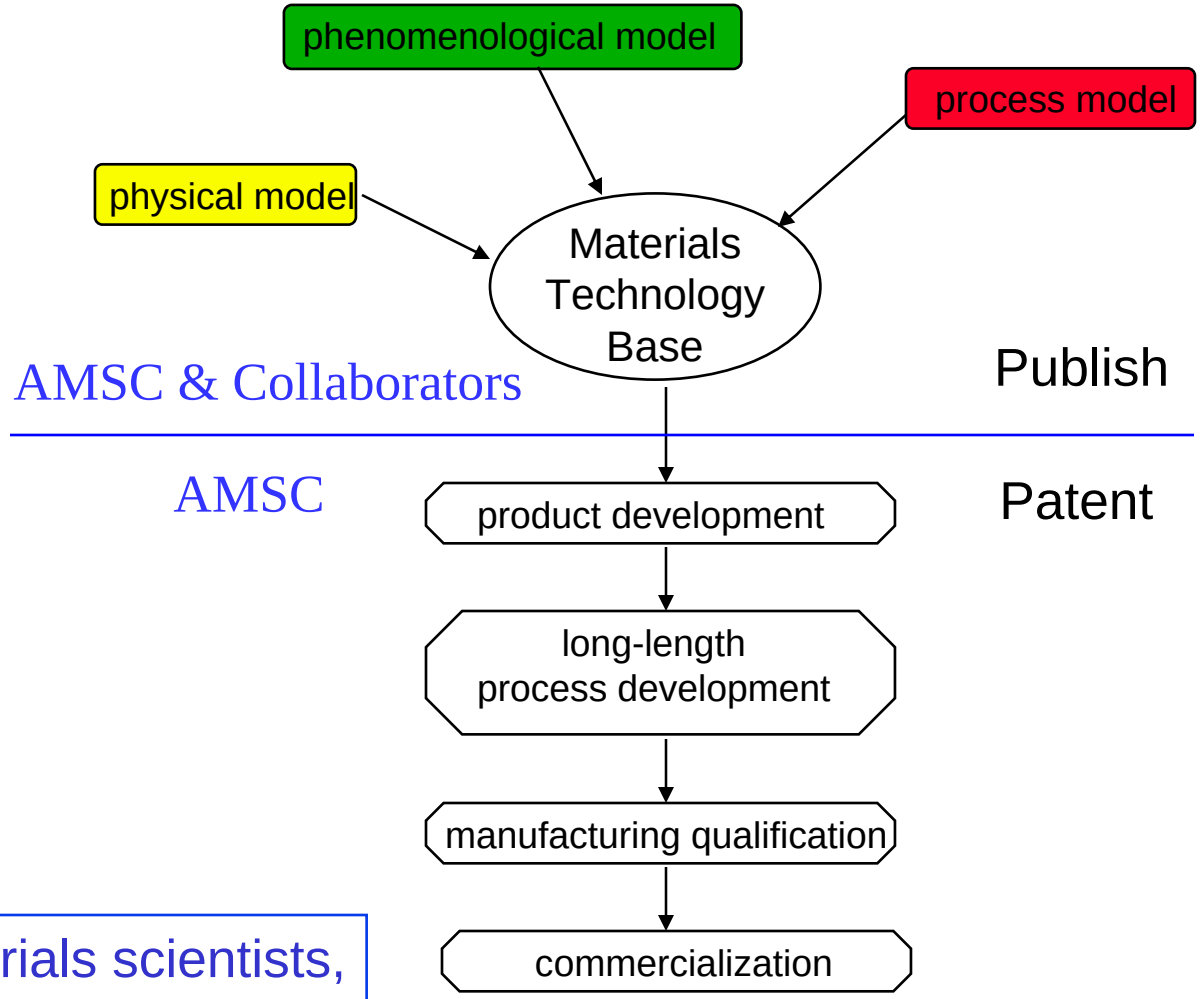




Technical Approach

Materials Science Triangle





Physicists, chemists, materials scientists, ceramists, mechanical engineers, electrical engineers, systems engineers

WDG Achievements Through 1998

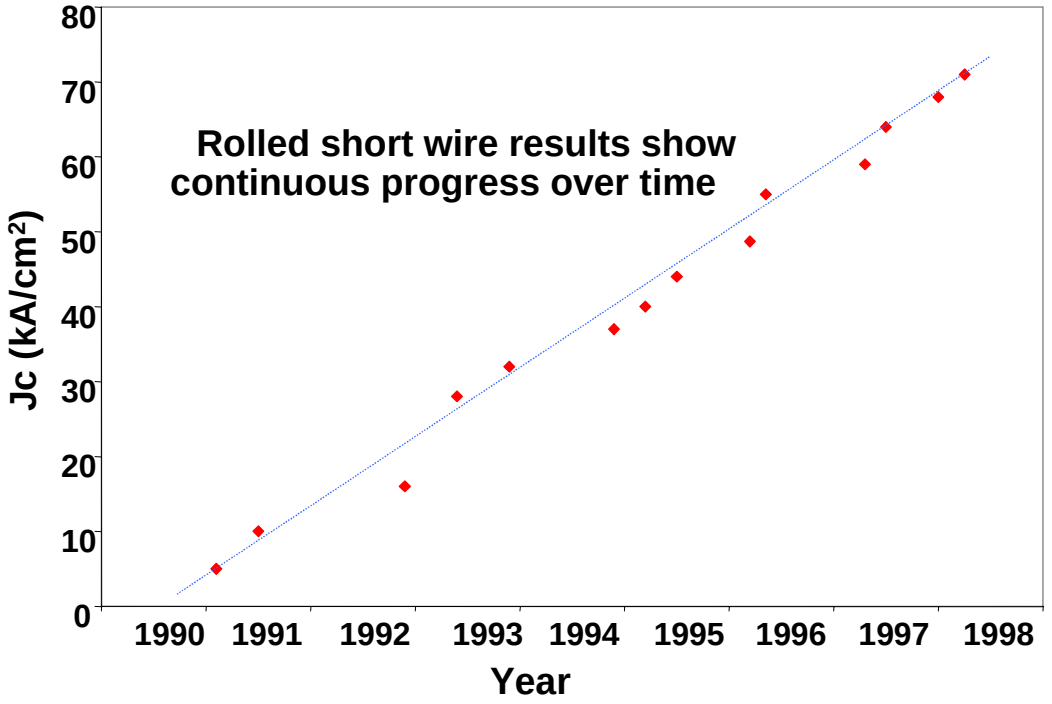
- **The WDG played a vital role in improving the performance of HTS wire**

-Contributed to fundamental understanding of key HTS phenomena

-Developed new, improved characterization techniques

-Achieved continuous enhancements in the performance of HTS wire

-Established American industry as the 1G HTS world leader



Performance metric is the kilo-amp/cm^2

21 patent applications, 10 MS & PhD theses, 175 peer reviewed publications representing one of the largest connected libraries of 1G HTS wire information available today

World's First 5,000-hp HTS Motor: July 2001

Wire produced at AMSC's Westborough, MA pilot plant

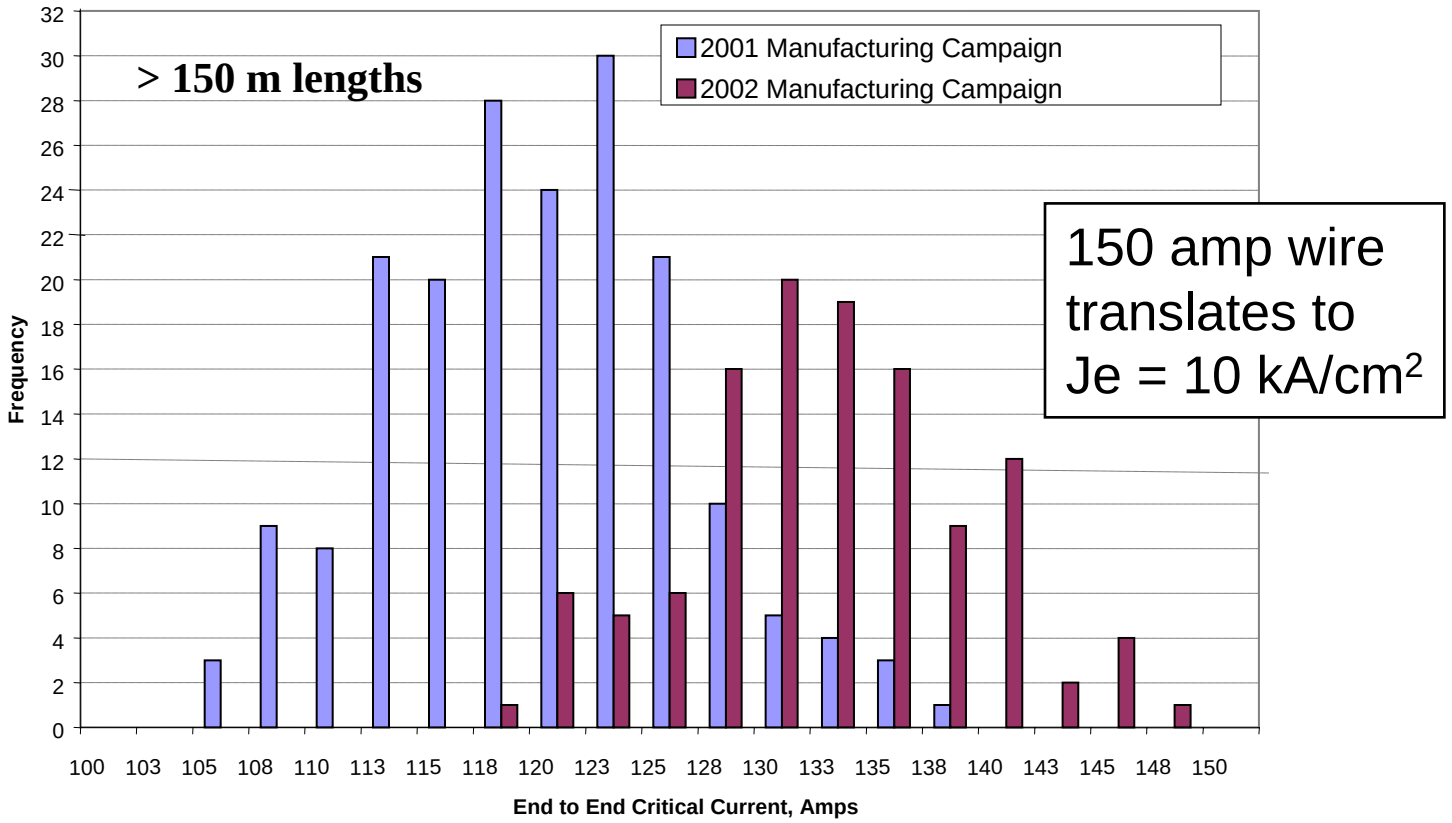
- *MFC Wire*
- *1,800 rpm*
- *97.2% Efficiency at full load*
- *7,000 hp peak load*

Designed by AMSC to Dramatically Reduce Manufacturing Costs

Devens, MA Manufacturing Plant For 1G HTS Wire: 2002

- Larger billets, process automation, longer strands, multi-dies, faster line-speed, combination of process steps
- Enables $50/kAm at full capacity
- Volume production in second half of 2002
- Full capacity is 20,000 km/year

Progress Status in 2002: 1G HTS Critical Currents Are High and Continuing to Improve



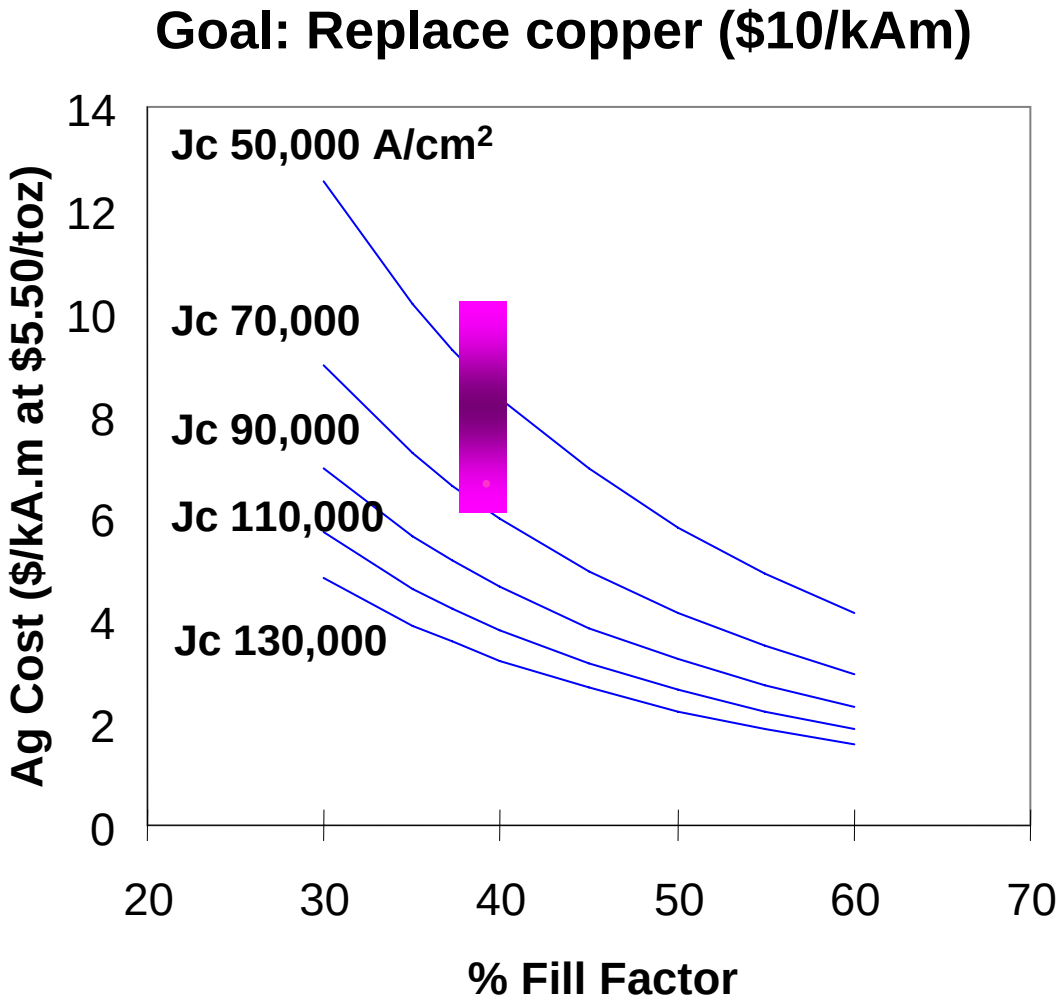
170 A also demonstrated in short, fully scalable lengths at AMSC
Robust, commercially available: This wire is for real!

Quoted 'Champion' Performance by Industry for Multifilamentary Bi-2223 Wire: 2002

A/cm^2 at 77K, sf, 1 μV/cm	Filament Current Density (Jc shorts)	Wire Current Density (Je > 100 m)
AMSC	74,000	16,000
Sumitomo	42,000	~12,000
Siemens	40,000	7,500
Nordic Superconductor	50,000	7,000
Furukawa	39,000	6,000
IGC	25,000	6,000
Alcatel	28,000	~5,000

Through 2004 the WDG made vital contributions to AMSC's leadership position in the manufacture of high performance 1G HTS conductor.

Commercialization Model for 1G HTS Wire



Cost Model:

- **Ag-sheathed MFC Bi-2223 wire**
- **Large volume production**

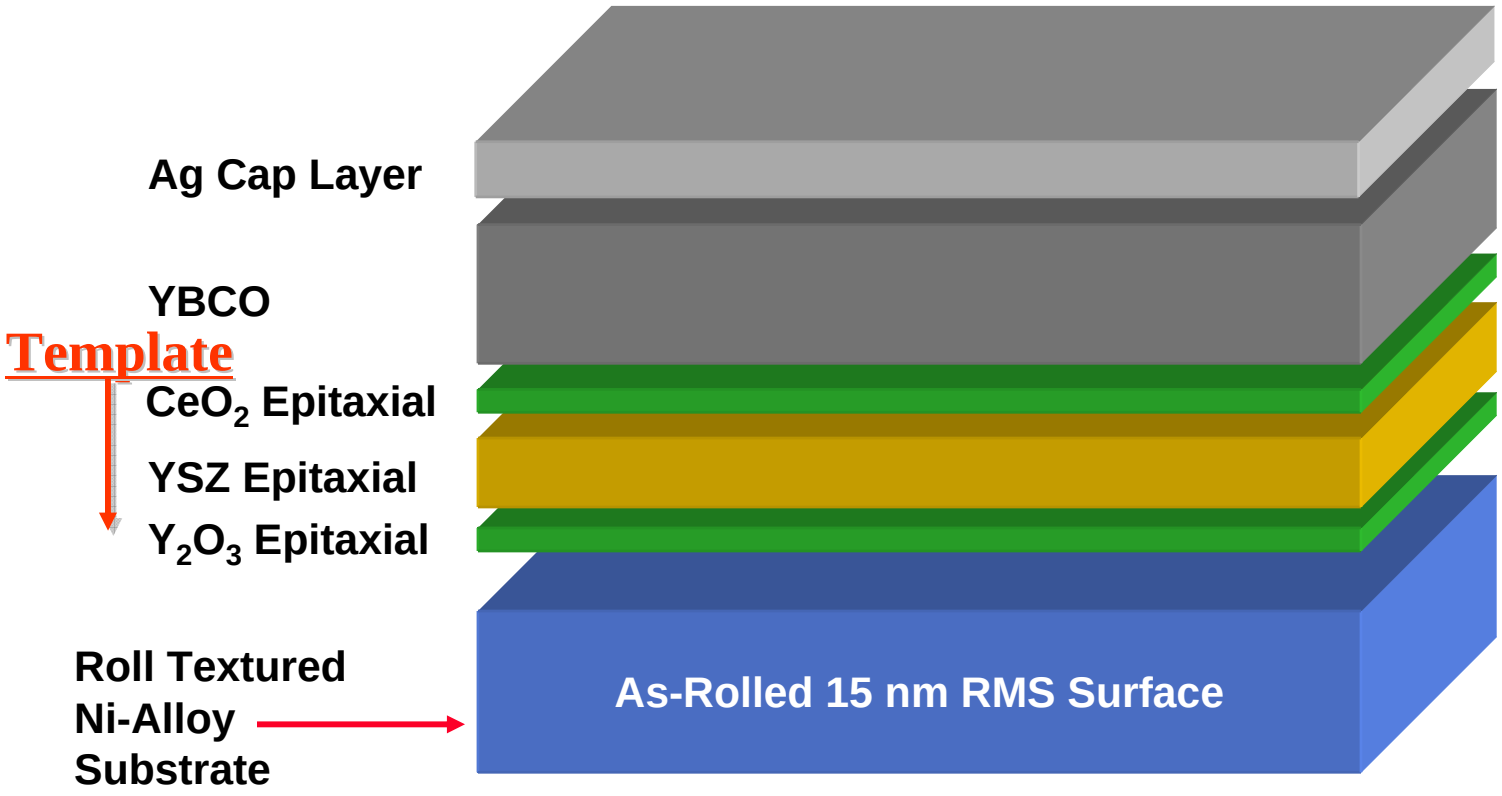
Future WDG Focus:

- **Increase Jc**
- **Increase fill factor (double benefit of improved Je and reduced Ag fraction)**
- **Replace Ag with less expensive material**
- **Move on to the YBCO coated conductor (2G)**

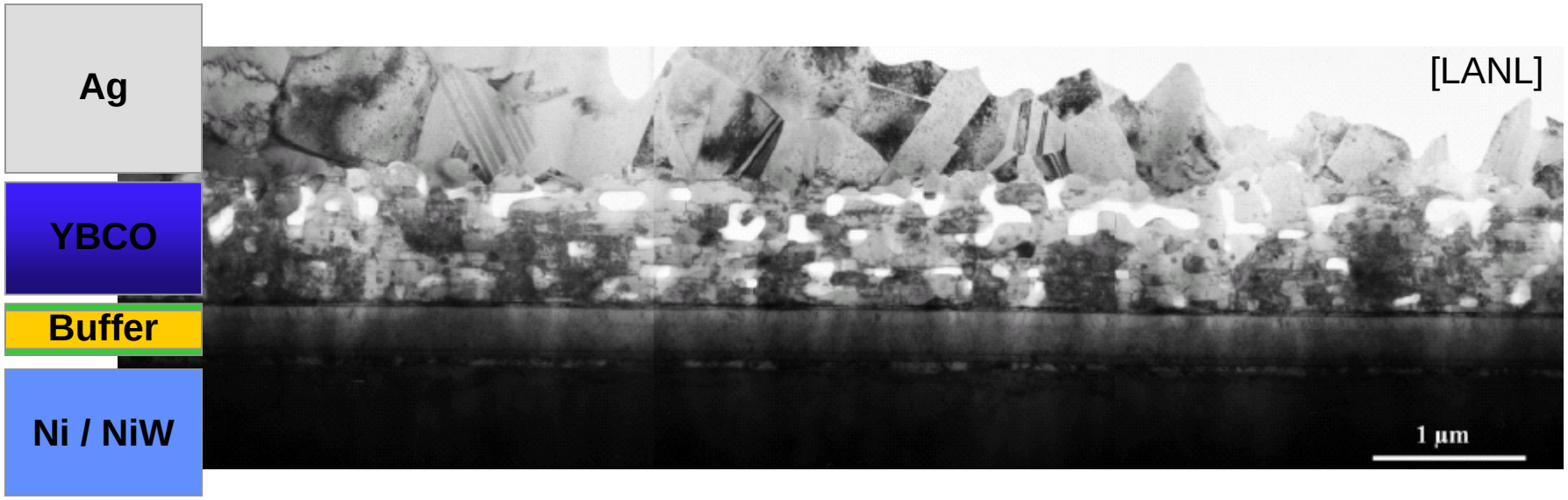
Enthusiasm gives way to reality. The Ag/Bi2223-based 1G conductor has several unique applications but is hard pressed to replace copper.

AMSC Moves on to the 2G Coated Conductor Architecture

AMSC continues 1G product manufacturing to meet needs of demonstration projects and special applications, but also opens new R&D on the $YBa_2C_3O_7$ (YBCO) coated conductor in partnership with the WDG.



The YBCO Coated Conductor Presents a New Architecture with New Scientific Challenges

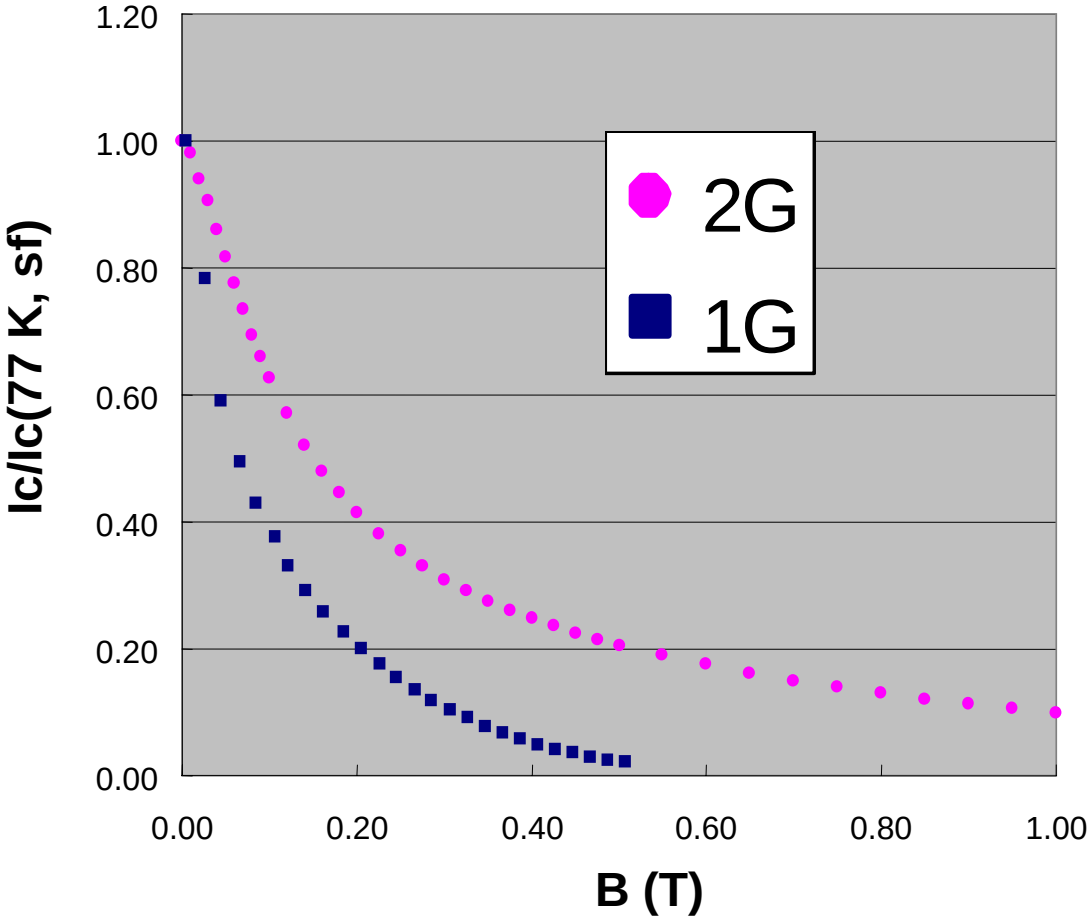


- Dense buffer layers
- High performing YBCO layer

Ic = >200 A/cm-w (77K, sf)
0.9 µm YBCO; >10 meters

Uniform microstructure over large area

The 2G Conductor Has Substantial Performance and Cost Advantages Compared to the 1G Conductor: $10/kAm is Within Reach



Normalized magnetic field dependence of 1G and 2G HTS tape critical current reveals the superior in-field behavior of the 2G coated conductor.

The WDG has made a smooth transition from the 1G emphasis to a new emphasis on development of the 2G conductor.
The WDG presentation at the FY 2005 HTS Program Peer Review received a top score.

Features of a Successful Collaboration with Industry: National Laboratory/University Perspective

- **Industry provides clear focus**
  - **-goals driven by industry needs**
  - **-industry identifies metrics for economic tenability**
- **Industry coordinates flow of materials/specimens/etc.**
  - **-all collaborators work with the same objects**
  - **-"the whole becomes more than the sum of the parts"**
- **The many intangibles:**
  - **-openness (candor)**
  - **-trust, respect, camaraderie**
  - **-new competencies**
  - **-career development**

WDG wins the Council for Chemical Research (CCR) Collaboration Success Award in 2000.