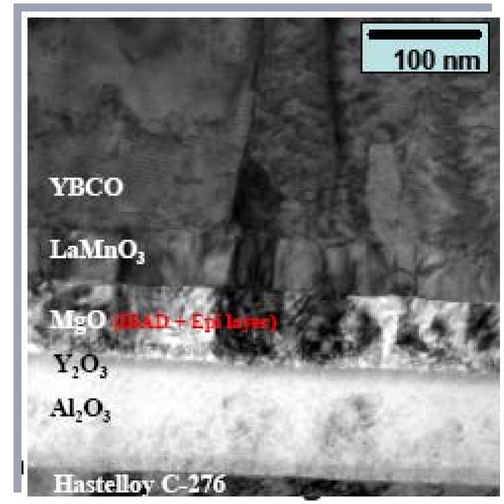
superior performance.
powerful technology.

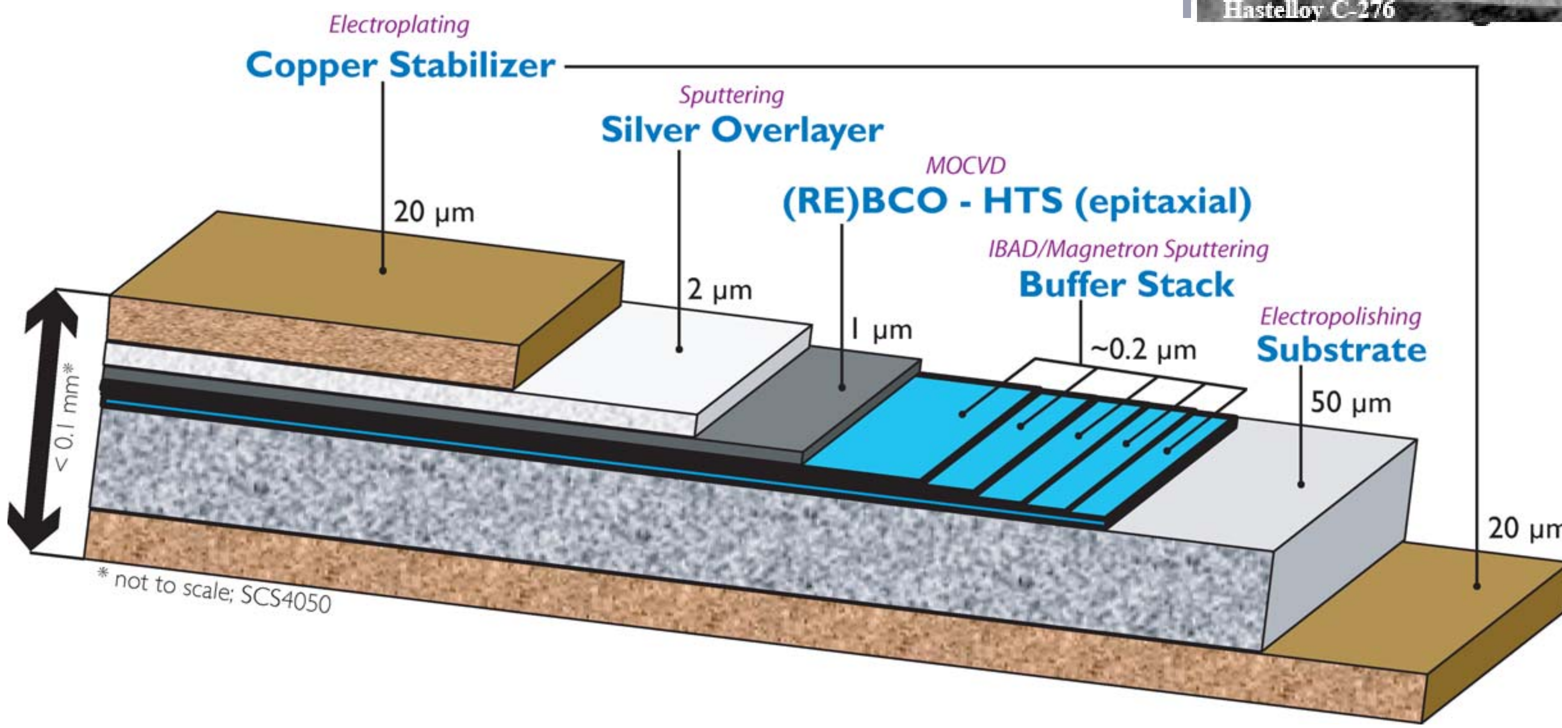
Recent Developments in 2G HTS Coil Technology

Drew W. Hazelton, Francois Roy, Paul Brownsey
SuperPower, Inc.

2011 EUCAS (European Conference on Applied Superconductivity)
Den Haag, The Netherlands – September 19, 2011   1-LB-07

SuperPower 2G HTS architecture





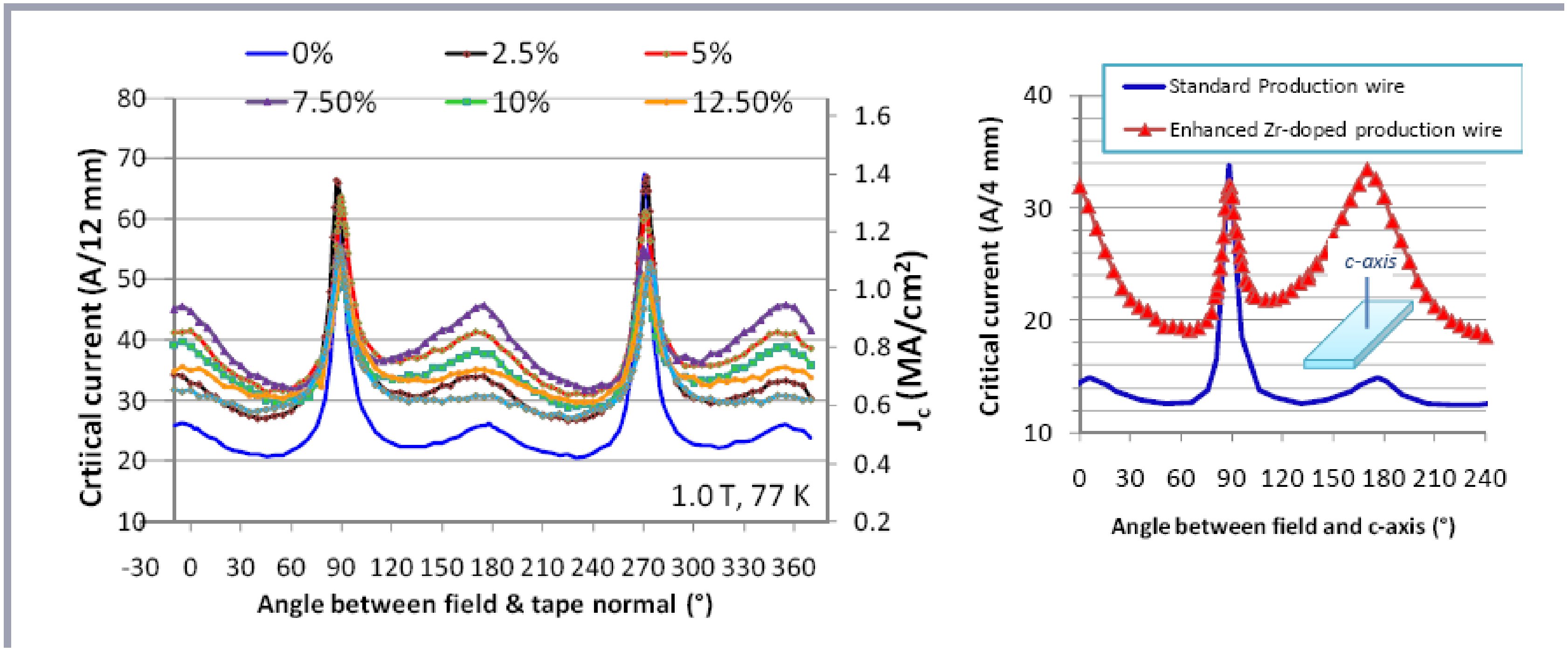
Demands on conductor for coil applications

- High current density
- High strength
- Long lengths
- High operating currents (particularly for HEP applications)
- Low ac losses (to enable fast charge/discharge, ac applications)
- Persistent current switches / joints (NMR applications)

SuperPower 2G HTS current density enables compact coils

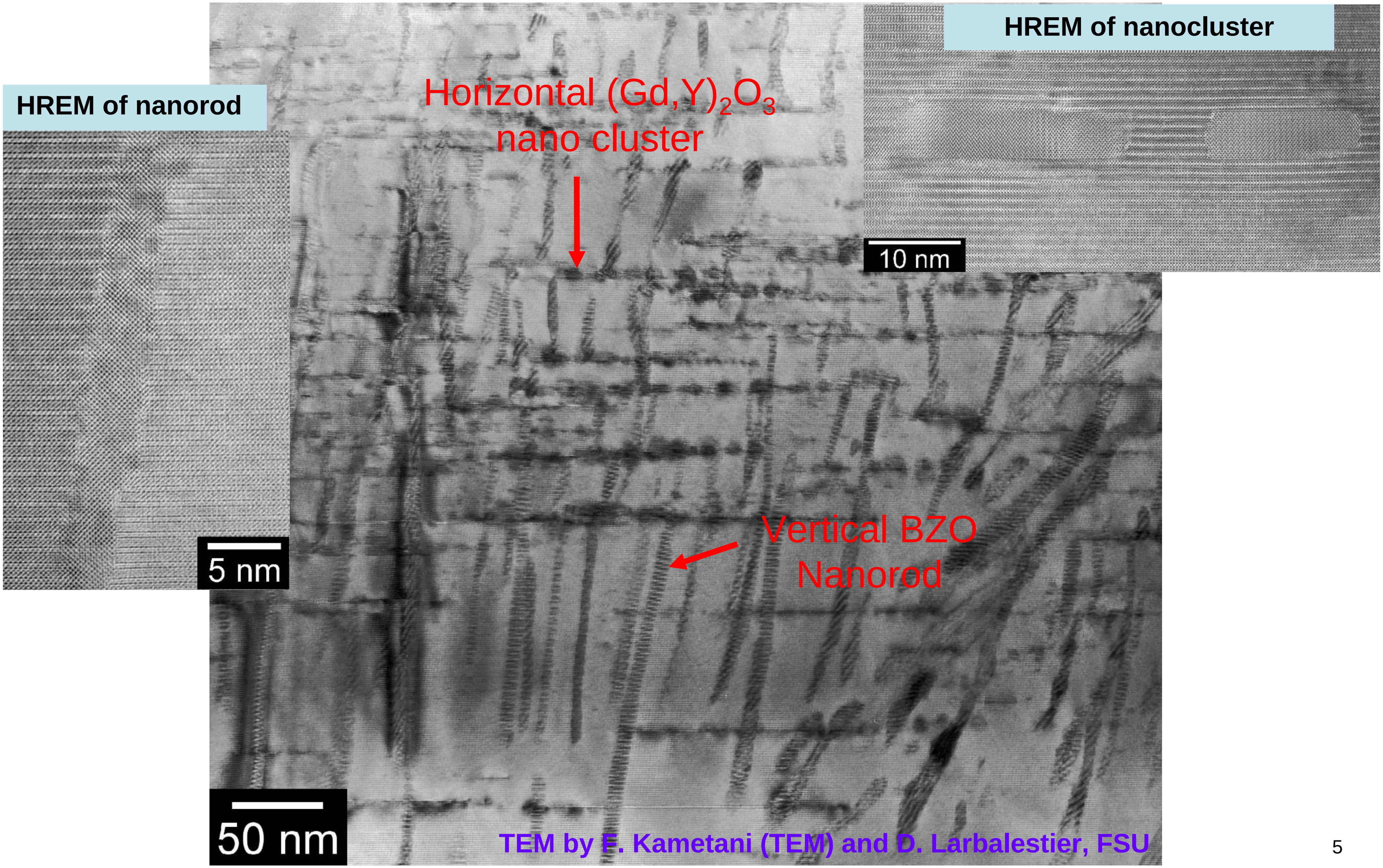
- Thin cross-section translates into high engineering current density needed for compact coils
- Improvements in (RE)BCO thickness and advanced pinning drive current density enhancements
- Hastelloy C276 substrate provides high strength required for high field inserts
- No additional reinforcement needed in many designs, enhancing current density

Improved pinning by Zr doping of MOCVD (RE)BCO layer

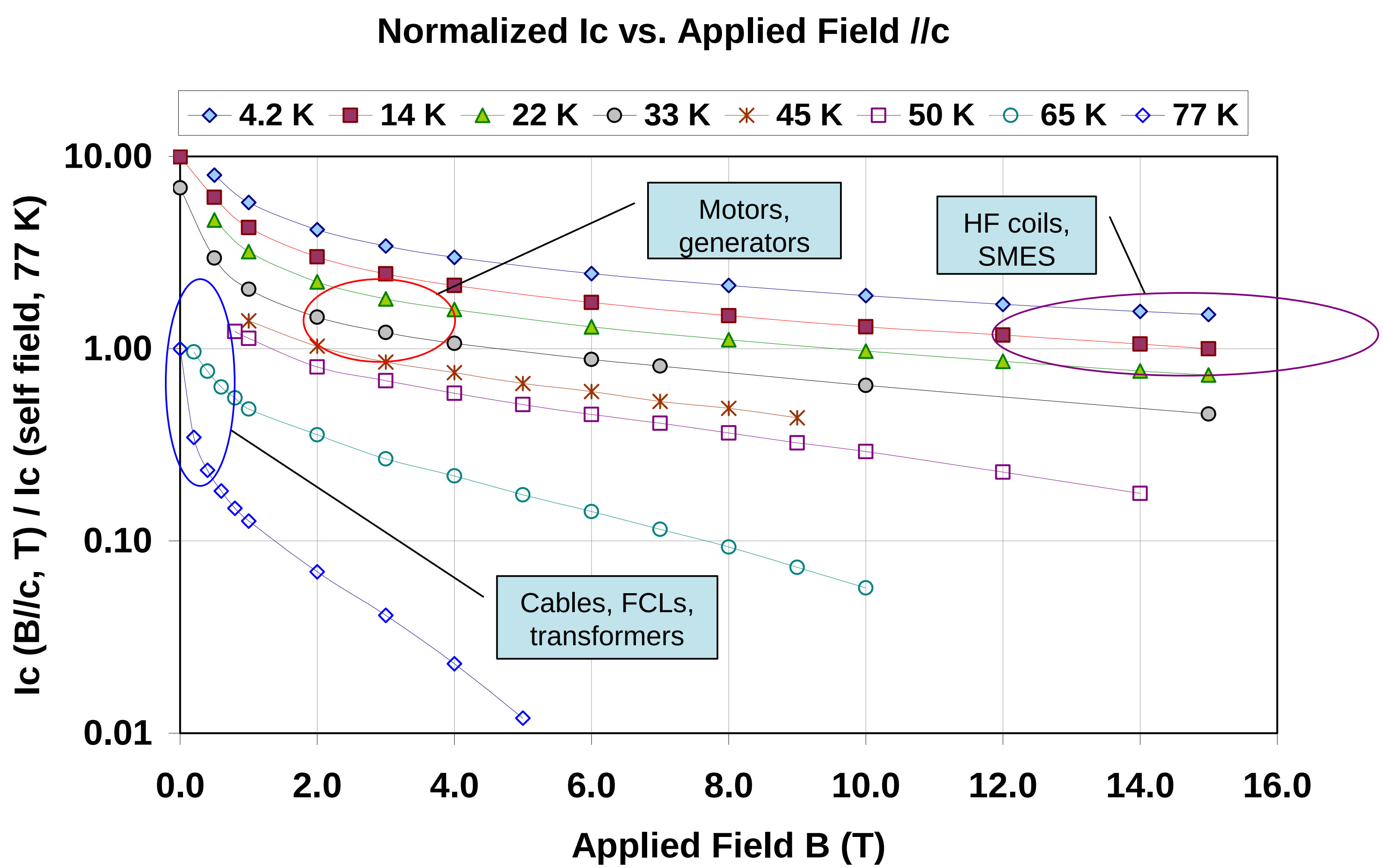


- Systematic study of improved pinning by Zr addition in MOCVD films at UH
- Process "know how" transitioned to SuperPower manufacturing

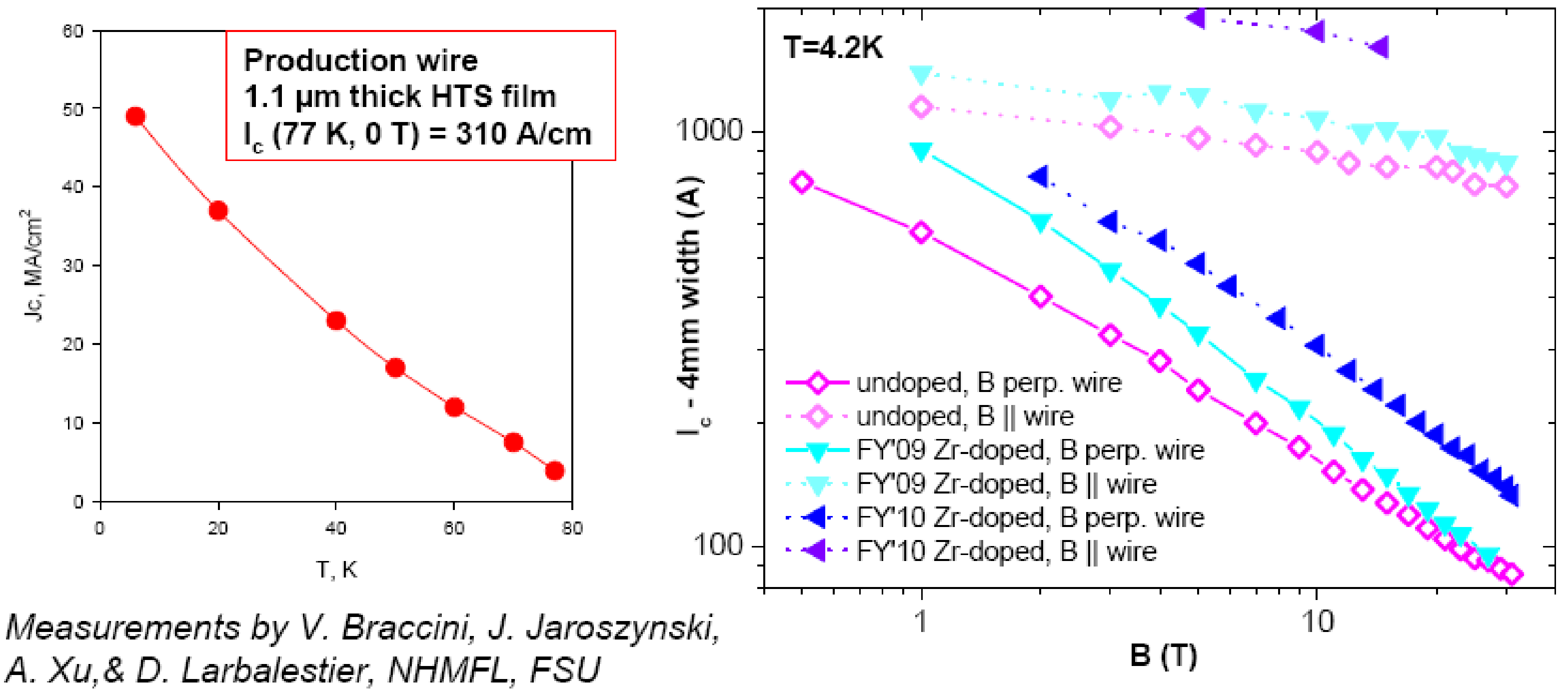
Development of nano-defect pinning sources



2G HTS offers excellent performance for all coil device operating ranges



Ic improvement by pinning extends to higher fields



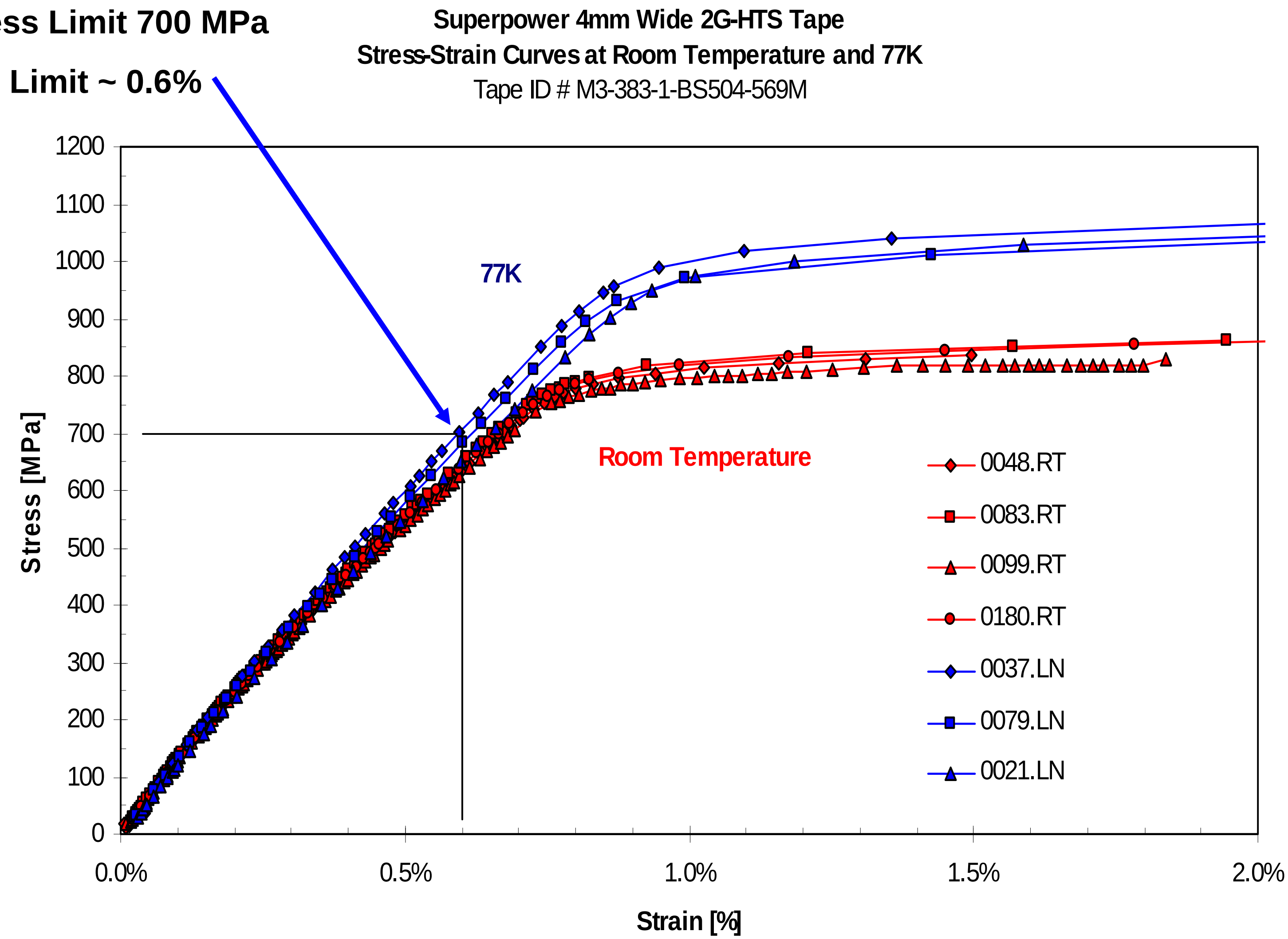
Measurements by V. Braccini, J. Jaroszynski, A. Xu,& D. Larbalestier, NHMFL, FSU

Advances with Zr-doping locked into production

SuperPower 2G HTS has excellent mechanical strength

77K Stress Limit 700 MPa

Strain at Limit ~ 0.6%



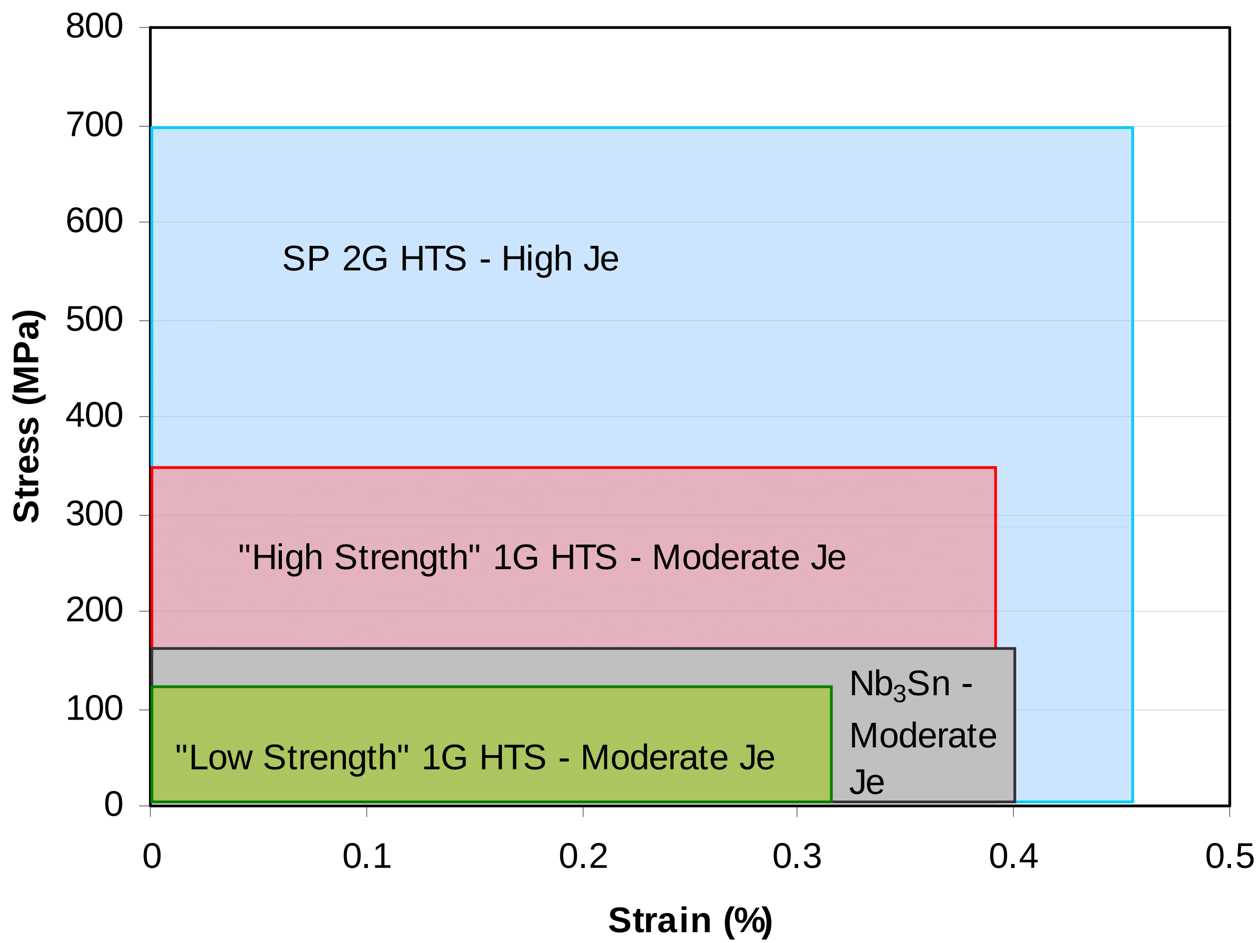
Data from R. Holtz, NRL

Summary of mechanical properties

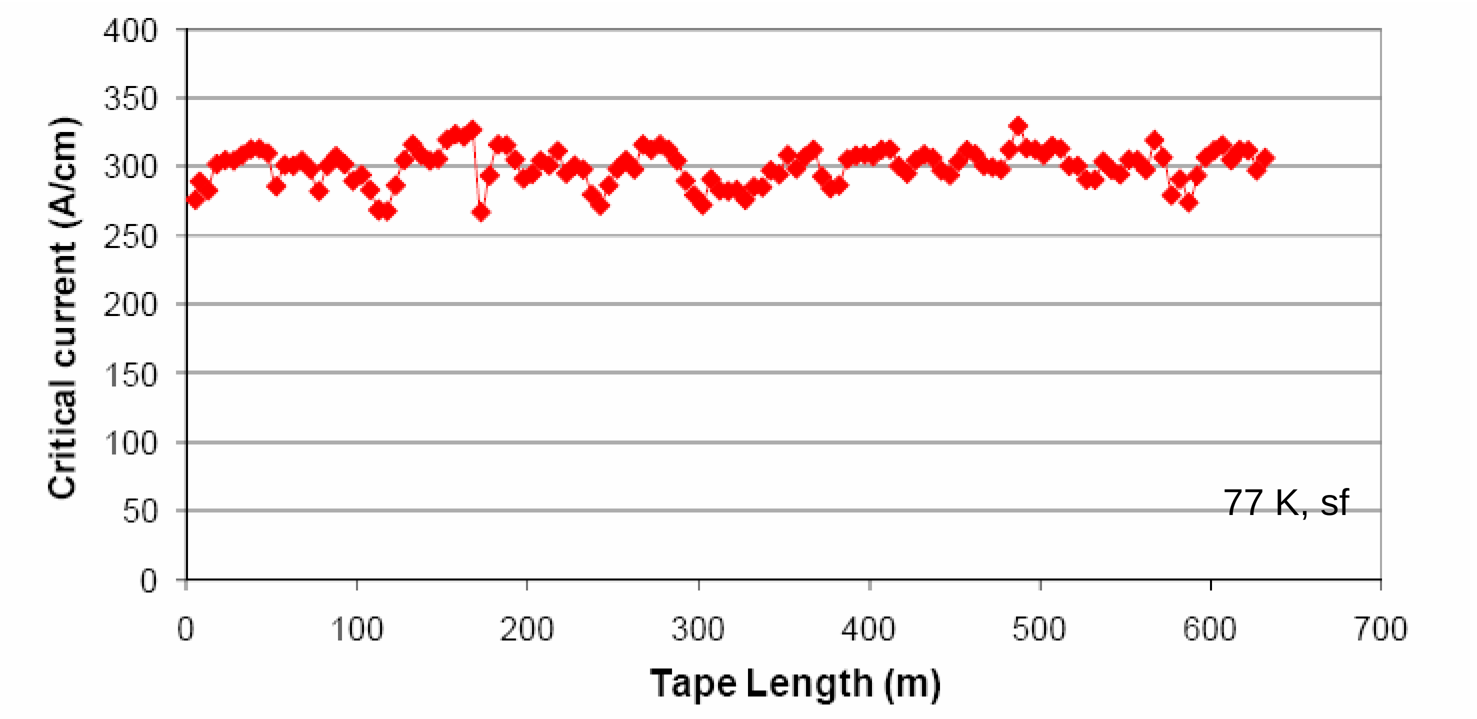
Yield Stress (77K)	970 MPa (140.7 ksi) @ 0.92 % strain
Stress Limit (77K) 98% Ic reversibility 90% Ic(zero strain) at limit (slide 3)	700 MPa (101.5 ksi) @ 0.6 % strain
Modulus Initial (77K, before Cu limit) Final (77K, after Cu limit)	 122.5 GPa 116.7 GPa
Fatigue Limit (77K)	> 100,000 cycles, <680 MPa tensile

SCS4050 with 40 microns copper

“React/Wind” SP 2G HTS conductor has large operating stress-strain window compared to other conductors

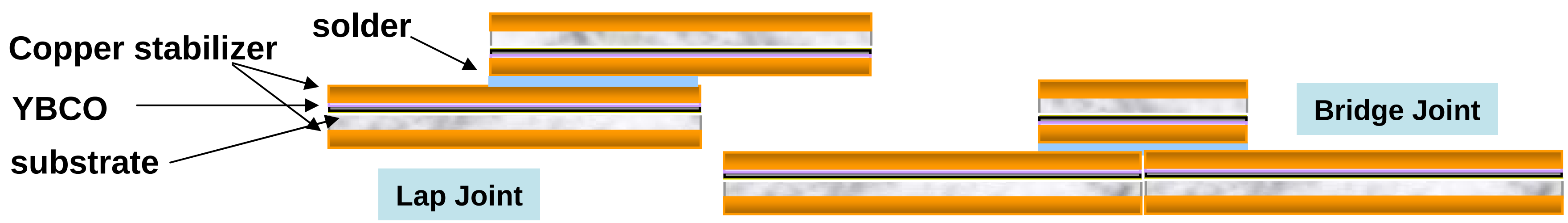


Routine manufacturing of Zr-doped tapes in long length initiated



Long tapes with Zr-doping exhibit critical currents of >250 A/cm in tapes run through the manufacturing facility

Low resistance joints/splices readily made



- No degradation in Ic (1 μV/cm) over the joint or splice
- Splice resistance typically ~ 10 nΩ (4 mm x 100 mm)
- No degradation in Ic and resistance when splice is bent over 25 mm diameter and thermal cycled three times.
- Variety of solders can be used (InAg, SnSb, PbSn)

Coil applications: world record performance achieved in HF insert coils with SP 2G HTS wire

2009:	27.4 Tesla at 4.2K in 19.9 Tesla background field (SP)
2008:	33.8 Tesla at 4.2K in 31 Tesla background field (NHMFL)
2007:	26.8 Tesla at 4.2K in 19 Tesla background field (SP)
2006:	2.4 Tesla at 64K in self field (SP)

2009 Insert Coil

Look for new results from
- NHMFL
- MIT
- BNL

New FCL transformer under development

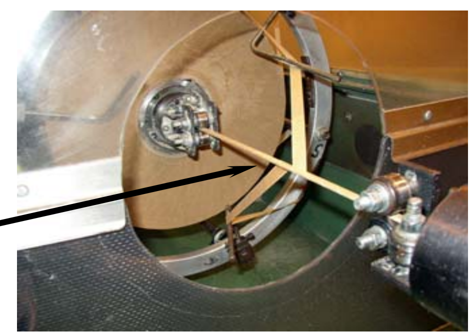
FCL transformer being designed and constructed i

$ 21.2 M Smart Grid program

- Partners:
  - Waukesha Electric Systems,
  - SuperPower,
  - University of Houston,
  - Oak Ridge National Laboratory
- To be installed in Southern California Edison grid by 2014 (MacArthur Substation)
- 28 MVA (69 kV : 13 kV, 40 MVA overload capability)
- Fault current limiting capability ~ 40 to 50%

The 2G HTS windings will be similar to WES's conventional design

- HV– Continuous disc winding; 8-12 turns/disc
- LV– Screw winding; 8-15 conductors in parallel.
  - Roebel cable is another option
- Exact number of disc turns or parallel conductors is determined by unit power ratings and tape I_c
- Windings will contain several individually-tested modules to limit amount of conductor at risk in a test failure
- Conductor transpositions will be at module junctions
- Need laminated or thick plated HTS tape to handle:
  - High speed insulating process
  - High stresses during fault
  - FCL function



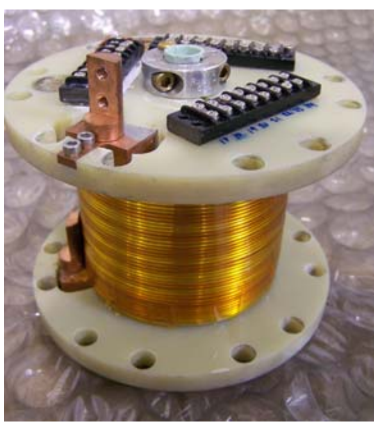
HTS w/ Insulation

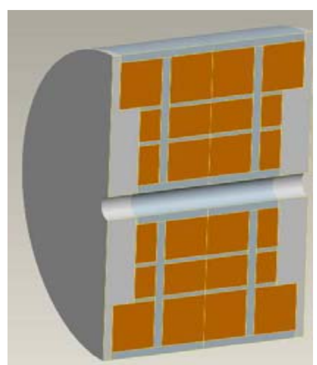
New superconducting magnetic energy storage (SMES) project initiated

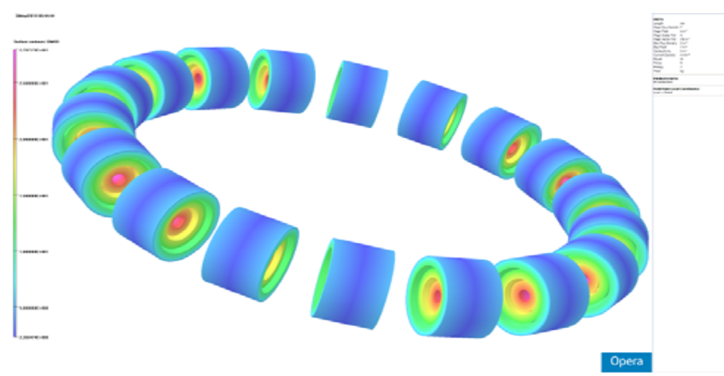
- ARPA-E funded proof of concept project recently awarded ($5.2M/3yr)
- Project Participants
  - ABB (lead – power electronics / system integration)
  - Brookhaven National Laboratory (high field coil design / fabrication)
  - SuperPower (2G HTS / coil design support)
  - Univ. Houston (enhanced 2G HTS fabrication)
- Storage capability in proof of concept coil (~2.5 MJ / 20 kW)
  - 25 Tesla coil
  - Enhanced power electronics
  - >80% round trip efficiency

Why high field HTS SMES?

- Energy stored scales as $B^2 * r^3$, while losses scale as r^2
- 2G HTS enables high field operation for a compact, high energy density system
- Toroidal geometry lessens the external magnetic forces, reducing the size of mechanical support needed.
- Fields in a toroidal SMES are mainly axial (//a,b), maximizing the use of 2G HTS
- Due to the low external magnetic field, toroidal SMES can be located near a utility or customer load.







SuperPower Inc.

Challenges

- High fields equate to high stresses
  - mainly hoop stress << SP 2G HTS can handle up to 700 MPA hoop stress
- High performance conductor required for economics to be competitive with advanced batteries (need to be in the $50/kAm range)
- Persistent current joints / switches highly desirable to reach loss targets
- Long lengths will be required to minimize / eliminate splices / joints (each splice is a loss source)

Questions?

Thank you for your interest!

For further information about SuperPower,
please visit us at: www.superpower-inc.com

or e-mail: info@superpower-inc.com