IEA Technology Collaboration Program on High-Temperature Superconductivity (IEA HTS TCP)

US Updates
ExCo Meeting

4 July 2017

Kawasaki, Japan

Outline

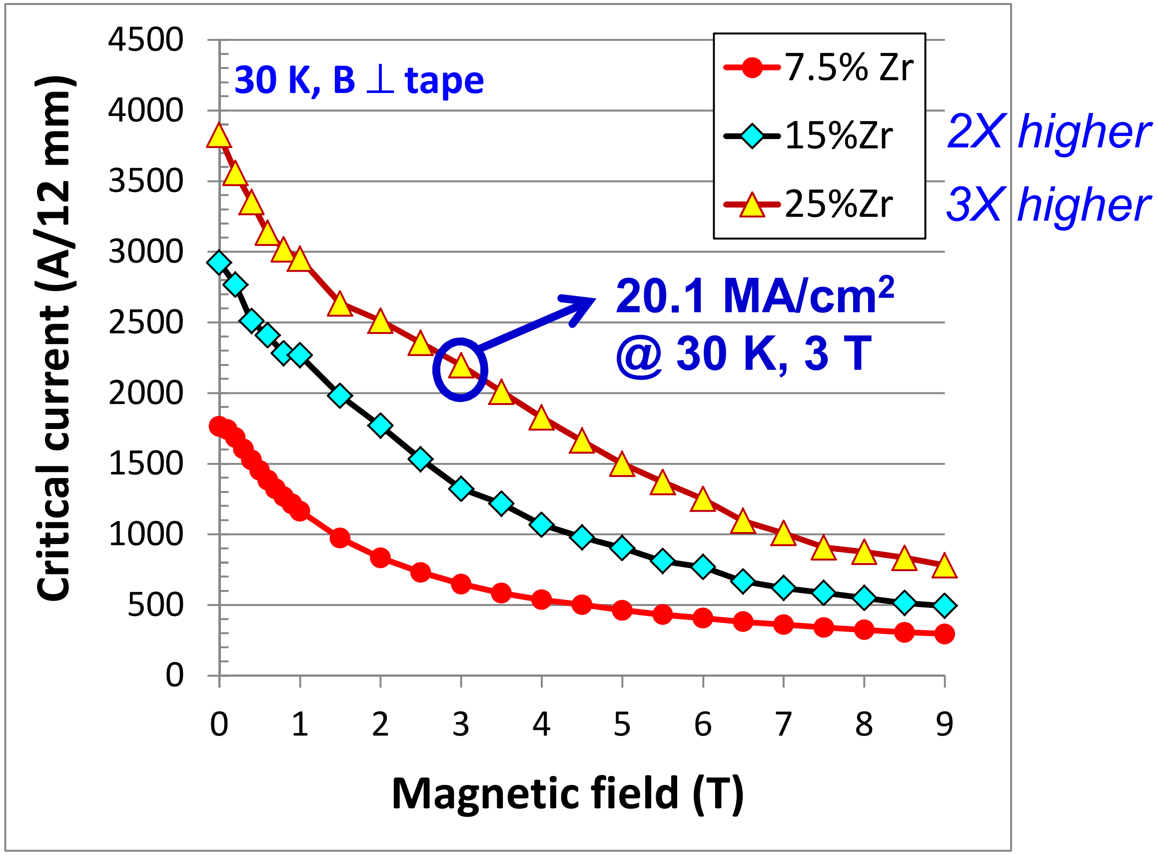
- University of Houston coated conductor activities
- U.S. Department of Energy Advanced Manufacturing Awards
- Advanced Superconductor Manufacturing Institute
- AMSC's Resilient Electric Grid

University of Houston's Coated Conductor Activities

- Improving performance of HTS tapes in high magnetic fields
- Higher performance with thicker REBCO films
- Evaluation of uniformity of low-temperature in-field performance of long tapes based on 77 K measurements
- Multfilamentary tapes

Improving performance of HTS tapes in high magnetic fields

3X improvement in in-field performance with increasing Zr content

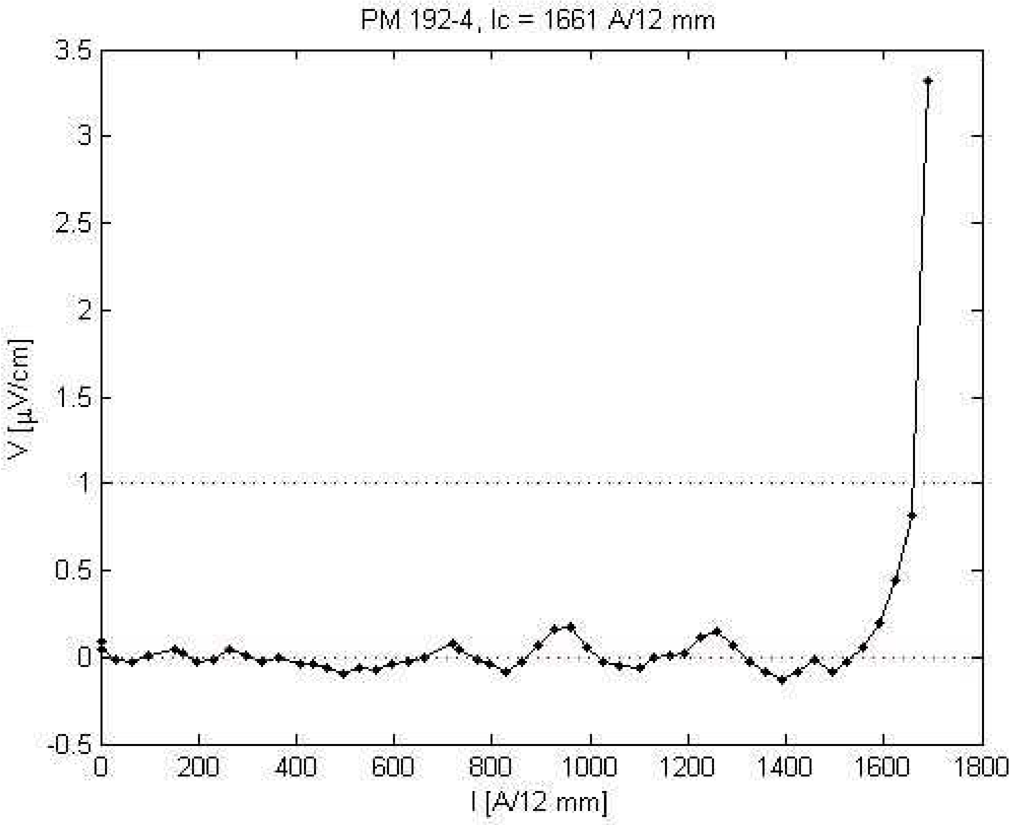


- *Critical current of 25% Zr-added tape at 30 K, 3 T, B||c*
  ~ 2172 A/12 mm
  J_c = 20.1 MA/cm², Pinning force = 603 GN/m³
- *Lift factor at 30K, 3 T, B||c* ***~ 6.4 (200% improvement!)***

- Enabled by engineering a high density of nanoscale defects while maintaining high crystalline quality of the superconductor films

Higher performance with thicker REBCO films

Critical currents over 1600 A/12 mm achieved in thick films made by Advanced MOCVD



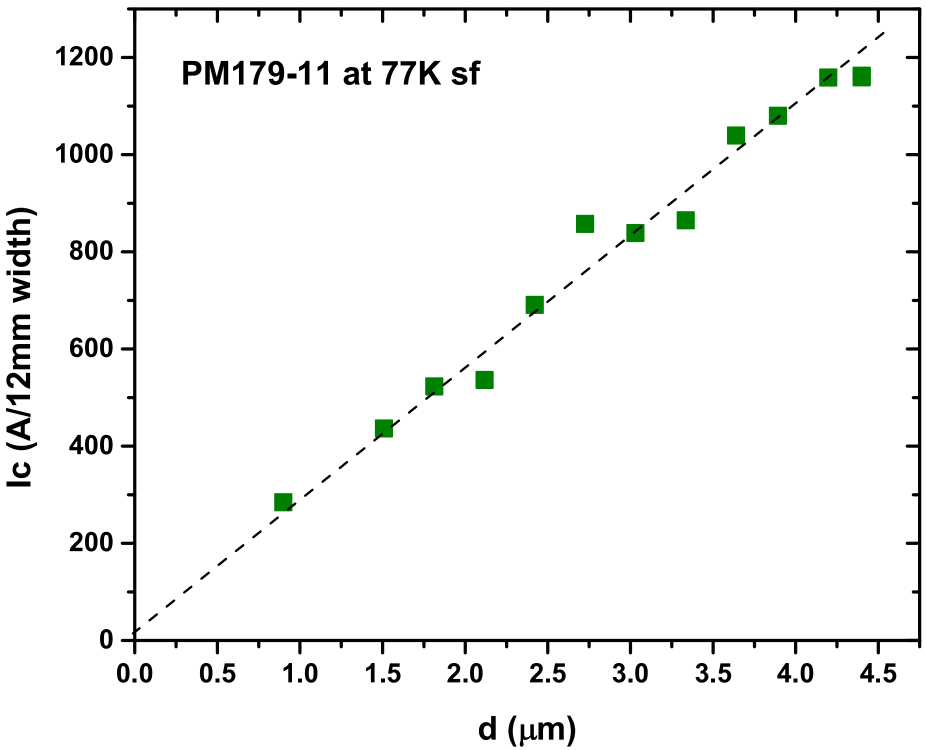
(Gd,Y) $Ba_2Cu_3O_x$ (undoped)

I_c^{sf} (77K) = 1611 A/12 mm (record high current in single time deposition in a MOCVD process)

J_c^{sf} (77K) = 2.92 MA/cm^2

UNIVERSITY of HOUSTON

Linear thickness dependence of critical current of thick film made by Advanced MOCVD

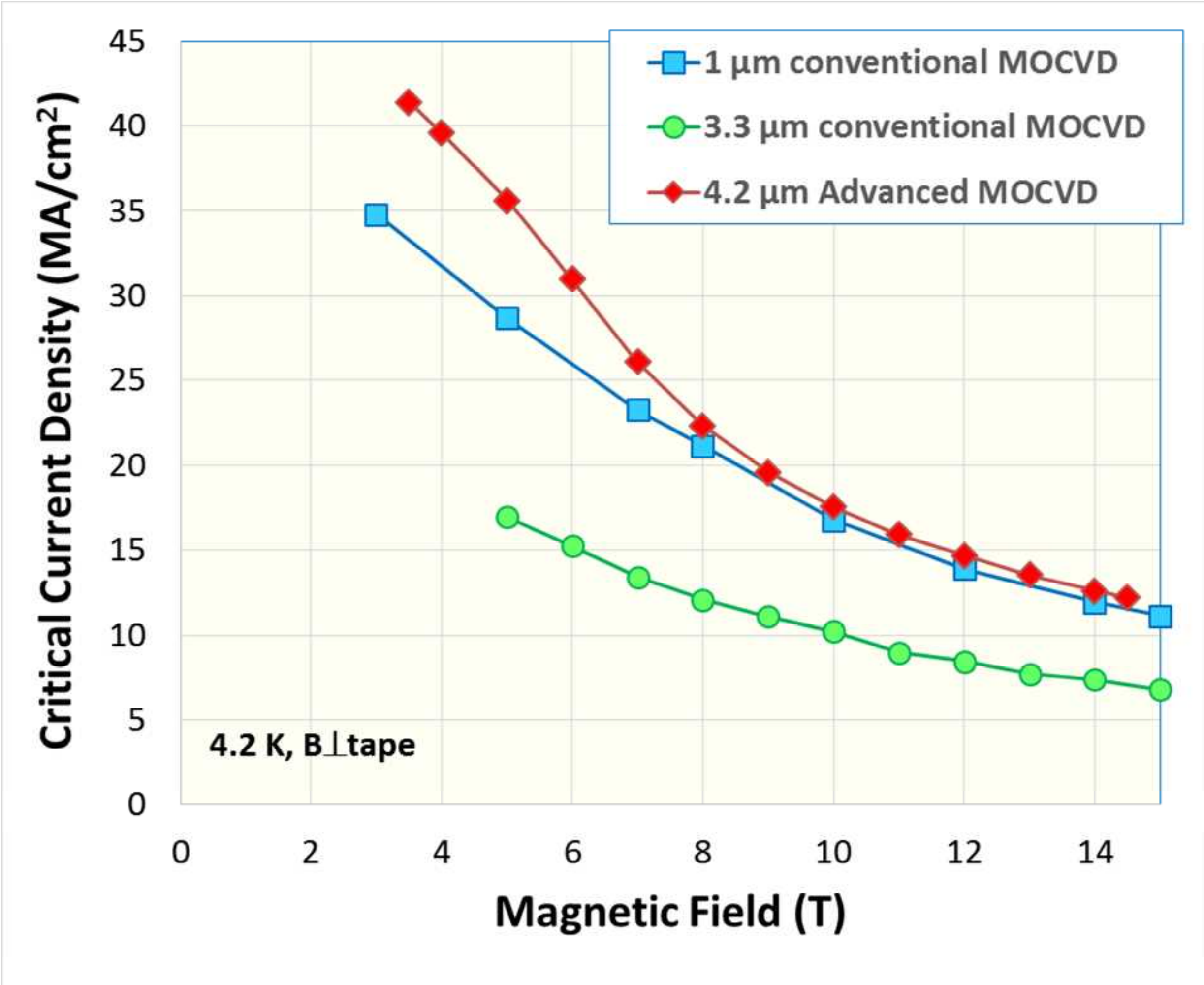


Approx. 300 A/μm-thickness and Jc is almost constant with thickness

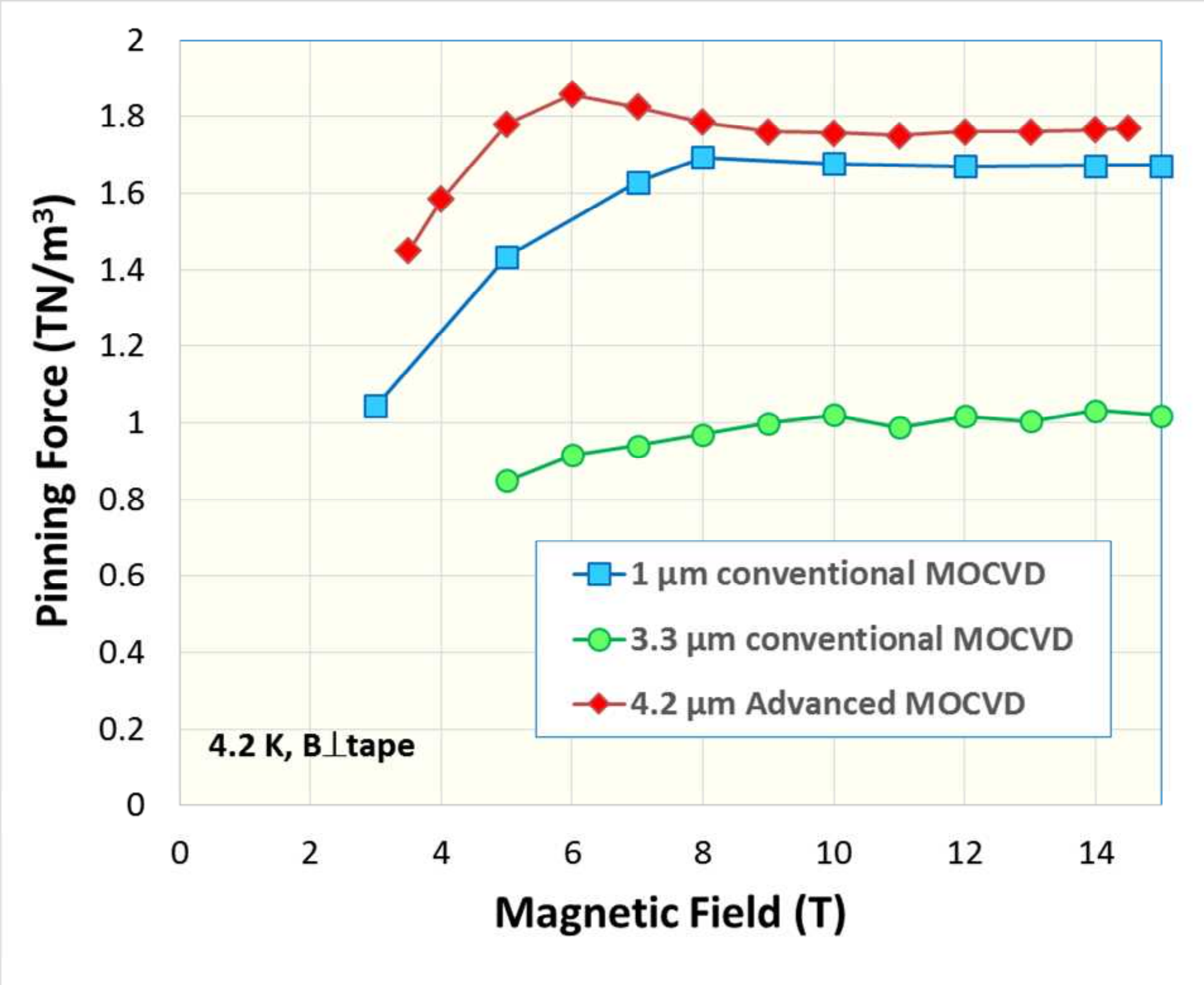
- Excellent tape temperature control by direct heating and use of laminar flow in a confined volume provides Advanced MOCVD the ability to produce very high performance thick film tapes.

UNIVERSITY of HOUSTON

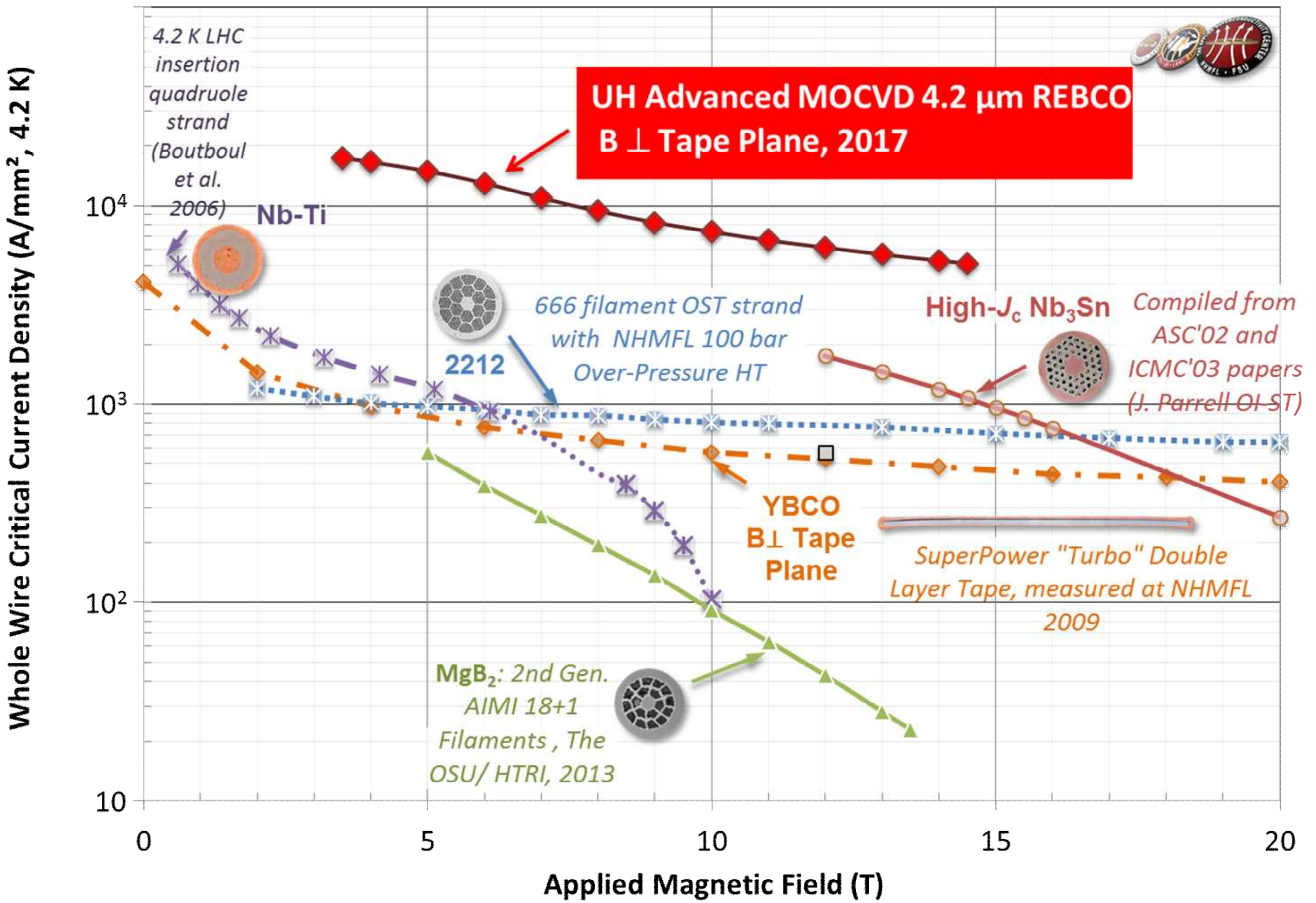
J_c of 4.2 µm thick film by Advanced MOCVD comparable to 1 µm thick films



Pinning Force of 4.2 μm thick film by Advanced MOCVD better than record values



REBCO tape by Advanced MOCVD in a league by itself at 4.2K



J_e of 2017 REBCO 4.5X Nb_3Sn @ 14 T

J_e of 2017 REBCO 7X Bi-2212 @ 14 T

Data maintained by Peter Lee, NHMFL, http://fs.magnet.fsu.edu/~lee/plot/plot.htm
UH data on 15%Zr tapes from *APL Materials* **2,** 046111 (2014)

Program Funded by U.S. DOE's Advanced Manufacturing Office (AMO)

- In Nov 2016, AMO announced $25 M for 13 projects aimed at advancing technologies for energy efficiency motors through applied R&D
- DOE's next generation electric machines projects will address the limitation of traditional materials and designs used in electric motor components by cost effectively enhancing their efficiency, improving their performance, and reducing weight
- This effort will support innovative approaches that will significantly improve the technology in industrial electric motors
- $14.5 M awarded to four HTS projects
  - AMSC, STI, University of Houston: $4.5 M each
  - Florida State University: ~$1 M

http://energy.gov/eere/amo/next-generation-electric-machines-project-descriptions

University of Houston

Dr. Venkat Selvamanickam

- Achieve I_c = 1440 A/12 mm at 65 K, 1.5 T through combination of thick films and high lift factor in Advanced MOCVD tool
- Increase precursor to film conversion efficiency by 3X in Advanced MOCVD tool → to reduce cost to $20–30/m ($35–50/kA-m at 65 K, 1.5 T)
- Scale up process to demonstrate 50 m long tape with I_c = 1440 A/12 mm at 65 K, 1.5 T
- Design and fabricate and test sub-scale rotor coil at 65 K with high performance wire made by lower-cost, high throughput process
- Team Partners:

UNIVERSITY of HOUSTON

SuperPower Inc. A Furukawa Company

e2P

TECO Westinghouse

UH Milestones & Budget

	Year 1	Year 2	Year 3
Performance Metric Critical current at 65 K, 1.5 T	800 A/cm	1440 A/cm	1440 A/cm in 50 m long wires
Cost Metric Precursor-to-film conversion efficiency	3X improvement	4X improvement	4X improvement in 50 m long wires
Application Verification		Selection of design topology for a 500 HP motor	Construction and testing of one coil at 65 K, made with Advanced wire for 500 HP motor

Total Project Budget	
DOE Investment	$4,500,000
Cost Share	$ 1,147,547
Project Total	$5,647,547

Project Metrics

	Prod. Wire now	AMO NGEM2 Target wire
Ic @ 65 K, 1.5 T (A/cm)	340	1440
Wire quantity for 5.5 MW motor* (km)	5.9	1.3
Wire cost for 5.5 MW motor† ($(,000))	236	26
% of motor cost**	67%	8%

- Increased cost of superconducting motor††: $61,000
- Cost savings/year with superconducting motor# ~ $ 40,000
- **ROI ~ 1.5 years**
- **450 metric tons reduction of CO_2 emissions annually per motor**

* 4 mm wide wire

† Wire cost of $40/m for production wire now, $20/m ($35/kA-m) for AMO NGEM2 target wire

** Using a conventional 6000 HP synchronous motor cost ~ $350 k

†† assuming additional $35k cost for cryocooler and other technologies

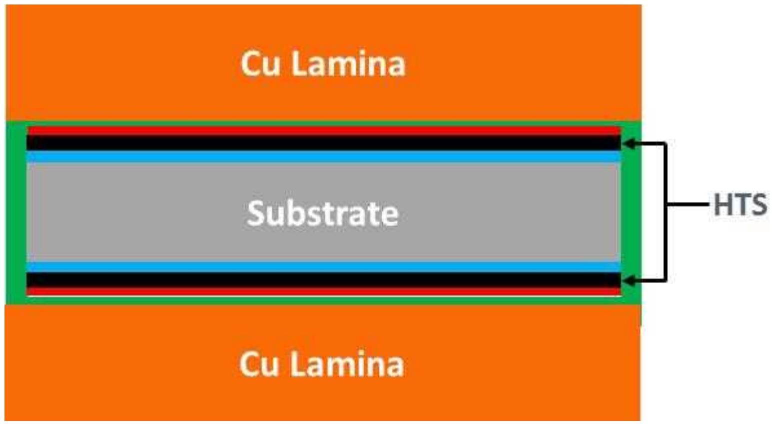
\# 2% improved efficiency, 18 hour operation, 90% up time, $ 0.06/kW-h

AMSC

Dr. Martin Rupich

Technology Summary

This project focuses on development of an innovative wire architecture that contains 2 HTS layers in one thin wire package. Each individual HTS layer, up to 1.5 μm thick, is ion irradiated to enhance the pinning performance at the targeted operating temperatures and fields for electric motors applications. This novel 2G wire architecture will be capable of carrying a critical current of nearly 1500 A/cm-w at 65K, 1.5T (perpendicular to the tape surface) and over 4000 A/cm-w critical current density at 30K, 1.5T (perpendicular to the tape surface). This innovative wire will be produced using low-cost, high-rate roll-to-roll manufacturing processes and is projected to significantly reduce the cost of state-of-the-art 2G HTS wire in terms of $/kA-m at operating conditions.



Key Personnel

Martin Rupich and Srivatsan Sathyamurthy, AMSC
Qiang Li, Brookhaven National Laboratory
Vyacheslav Solovyov, Brookhaven Technology Group
Amit Goyal, University of Buffalo

Program Summary

Period of performance:
36 months

EERE funds:	$ 4.5 M
Cost-share:	$ 1.125 M
Total budget:	$ 5.625 M

	Key Milestones & Deliverables
Year 1	• Development of double layer architecture • Optimization of ion irradiation for 65K, 1.5T • Development of thicker MOD-based YBCO
Year 2	• Process integration • Produce wire with I_c ~1500 A/cm-w at 65K,1.5T
Year 3	• Manufacture production length wire • Demonstrate performance in 500 HP coil

Technology Impact

The innovative 2G wire architecture will result in the first practical, production length 2G wires that meet the demanding performance and cost requirements for broad-scale use in commercial electric machines.

A New Generation of High Performance 2G HTS Wire

U.S. DEPARTMENT OF ENERGY

Superconductor Technologies Inc. (STI)

Ken Pfeiffer

Project Partners: TECO-Westinghouse Motor Company, Massachusetts Institute of Technology, University of North Texas

Proposed project goals:
1) Improve the current-carrying performance of 2G HTS wires to 1440A/cm-width at operating conditions of 65 Kelvin, & 1.5T
2) Reduce the manufacturing costs of 2G HTS wire by improving in-process yield

Technology Summary : STI’s superconducting wire manufacturing approach utilizes simplified, layered wire, architecture designed to scale with high yield and commercial volumes. STI’s wire architecture consists of two key manufacturing processes. First, the prepared substrate proceeds through an Ion Beam Assisted Deposition (IBAD) process in order to produce a template with the proper surface conditions. Then, the HTS materials are deposited onto the template using proprietary Reactive Co-evaporation Cyclic Deposition and Reaction (RCE-CDR) process. The technology in this project will focus on using RCE-CDR for; Increased Film Thickness, Intrinsic Pinning, Dopant Pinning, Superlattice growth and incorporate Precision Automatic Feedback compositional controls.
Completing this technology development will allow us to meet targets identified by DOE EERE.

Technology Impact: STI will transition from R&D to full scale production in the project scope of 3 years. In doing so, this will allow for the enabling technology to be rapidly introduced into Next Generation Electrical Machines utilizing high performance/low cost HTS wire.

Total Project: EERE funds $4.5M plus cost share $1.125M for a total of $5.625M over 3 years.

STI SUPERCONDUCTOR TECHNOLOGIES INC. TECO Westinghouse Massachusetts Institute of Technology UNT UNIVERSITY OF NORTH TEXAS

Advanced Conductor Technologies LLC
www.advancedconductor.com

SuperPower Inc.
A Furukawa Company

Cost-effective Conductor, Cable, and Coils for High Field Rotating Electric Machines

Contract Number DE-EE0007872

Florida State University, Advanced Conductor Technologies, and SuperPower Inc.

June 2017 – June 2020

Professor Sastry Pamidi

Center for Advanced Power System, Florida State University &
FAMU-FSU College of Engineering, Tallahassee, Florida

Partners:

Prof. David Larbalestier	–	Florida State University
Prof. Lance Cooley	–	Florida State University
Dr. Danko van der Laan	–	Advanced Conductor Technologies, LLC.
Dr. Drew Hazelton	–	SuperPower Inc.

Project Objectives

- To address the unacceptably **high cost** of Second Generation High Temperature Superconductors (2G HTS) for commercial applications and to enhance the **reliability** of HTS magnet coil based motors and other devices

- Currently, coils are wound using single strand conductor. Insulated single strand conductors cannot current share around defects in conductors, often leading to local burning and coil failure

- This project will **demonstrate that use of Conductor on Round Core (CORC) cables** instead of single strand conductors will eliminate the risk of damage to the coils due to the many localized defects still present in coated conductors

- This project hopes to show that low cost, run-of-the-mill conductors, which contain defects, can be used to **make reliable coils for industrial motors by winding the coils using CORC cables that facilitate sharing of current**

Technical Innovation

- Manufactured 2G HTS conductor is run through quality controls to identify and isolate sellable sections. The yield is reduced and the cost of long piece lengths is high
- Typical self field quality controls miss some defects that will manifest only in operating conditions of high currents and magnetic fields
- We will characterize the manufactured conductors using a specialized tool “YateStar” to **map the density and distribution of defects in field at 65 K**
- We will fabricate and test CORC cables with the thoroughly characterized conductor to **compare the performance of cables made with the best conductor with the cables made from run-of-the-mill conductor**
- Establishing the **relationship between the defect density and distribution and the performance of CORC cables** allows appropriate design of the cables for reliable operation of HTS machines
- The goal is to show that properly designed CORC cables allow significant current sharing that can tolerate use of manufactured conductor with defects that would otherwise be cut out **thus increasing the yield, lowering the cost, and increasing the reliability of HTS machines**

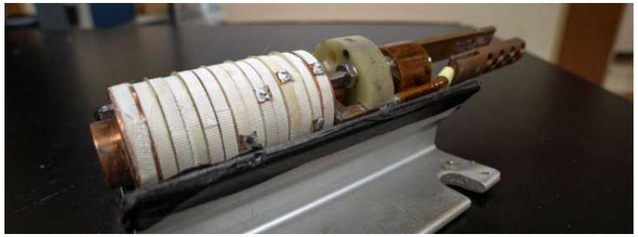
Technical Approach

- Collaborative approach
  - SuperPower - HTS conductor manufacturer
  - Advanced Conductor Technologies - CORC Cable manufacturer
  - Florida State University – Advanced HTS characterization, coil and cable characterization capabilities at variable temperatures and magnetic fields

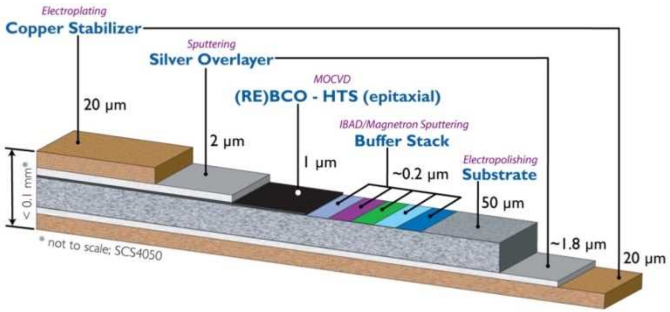
1. SuperPower will provide HTS conductor batches in long lengths
2. Florida State University will characterize the conductor using “YateStar” to map the density and distribution of defects in field at 65 K
3. Advanced Conductor Technologies will fabricate CORC cables with varying cable designs and winding parameters
4. Florida State University will test the cables and ultimately test coils with CORC cables at 65 K

- Iterations of the process will lead to knowledge of
  - Correlations between defect density and distribution and the performance of CORC cables
  - Relative performance of CORC cables with run-of-the-mill conductor and CORC cables with best available conductor
  - Cable design and winding parameters that produce best CORC cables for motor applications

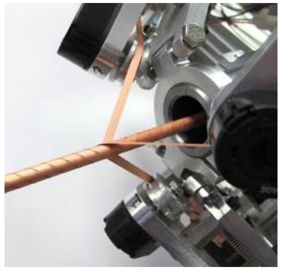
Technical Strengths of Project Partners



- Florida State has generated the highest field (42.5 T, 11.5 T REBCO in 31 T resistive) test magnets and is presently commissioning the first >30 T all superconducting magnet (15 T LTS + 17 T REBCO)



- SuperPower provided the coated conductor for both the magnets above



- ACT has contracts for coated conductor cable from 5 customers and has provided the only macroscopically isotropic REBCO conductor made to date, with the highest current density of any HTS cable (344 A/mm² at 4.2 K and 20 T)

Project Management & Budget

- Duration of the Project: 3 years
- Expected start in July 2017

Total Project Budget	
DOE Investment	$1,000,000
Cost Share	$250,000
Project Total	$1,250,000

Results and Accomplishments

- The project has not started
  - The Statement of Work has been agreed upon
  - AMO is conducting the final review
  - We expect the project to start in July 2017

Advanced Superconductor Manufacturing Institute

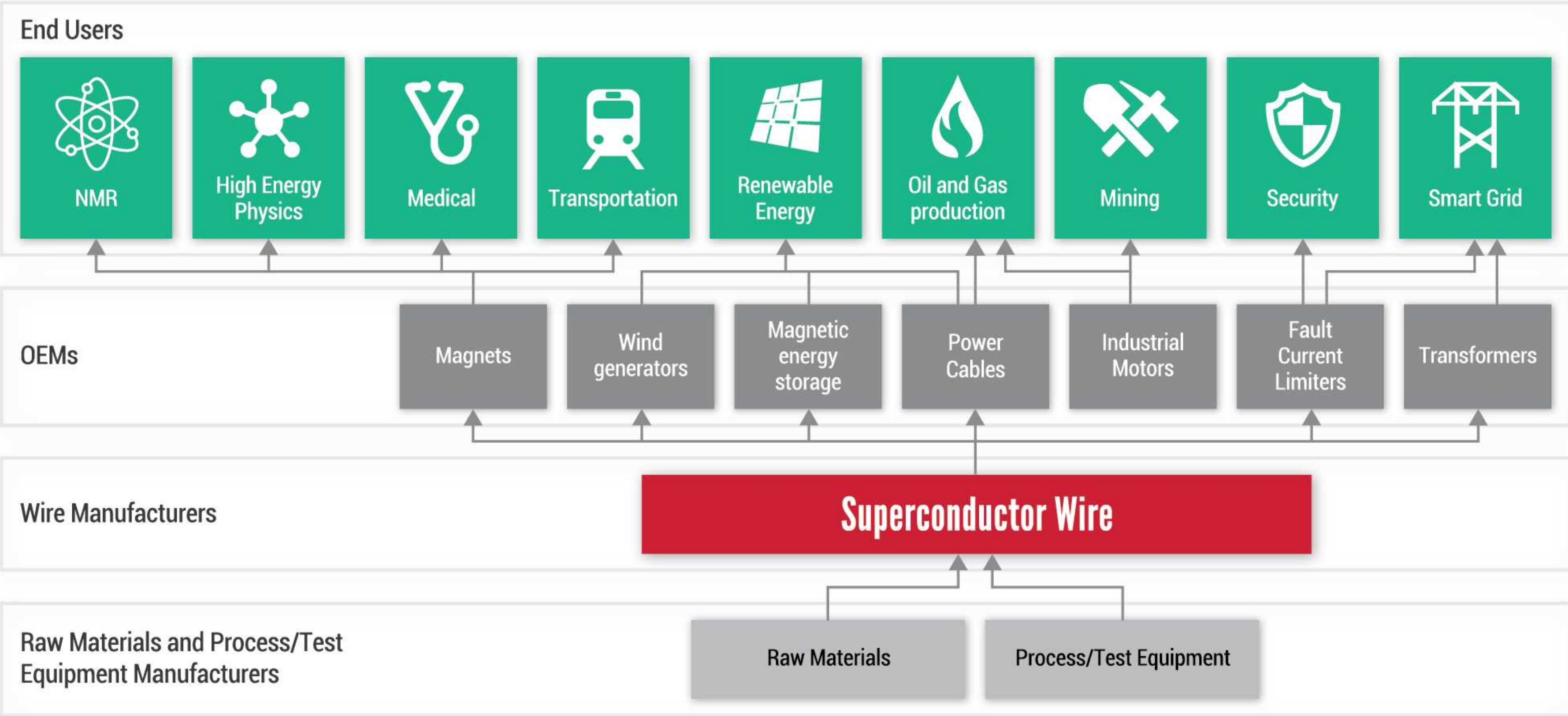
The Opportunity

Revolutionize HTS manufacturing through a collaboration of industry, academia and government, securing U.S. competitiveness

- Break impasse!
- Industry-driven projects
- Share knowhow
- Develop workforce
- Engage small businesses
- Involve entire value chain

ASMI Advanced Superconductor Manufacturing Institute

Entire Value Chain Involved in ASMI



Objectives of ASMI

- Address the "**missing middle**" in advanced superconductor manufacturing innovation to bridge the gap between manufacturing of superconductor prototypes to commercialization.
- Establish an '**industry commons**' to test concepts close to maturity and to be a test-bed for comprehensive testing of homogeneity and reliability of superconductor wires and power devices.
- **Workforce development and training** in superconductor manufacturing at all education levels.
- Engage and assist **small and medium enterprises** to address manufacturing impediments to commercialization and reduce the associated manufacturability risk during adoption of this technology.

ASMI Actively Working with Superconductor Industry for 3+ Years

- ASMI established as a 501c(3)
- First workshop held in 2013
- Industry steering committee established and holding monthly meetings since Jan. 2014
- NIST-funded AMTech program since June 2015

Advanced Manufacturing Technology Consortia (AMTech) Program

- 2nd Workshop held in Nov. 2015
  - 60+ attendees; mainly industry
  - Industry-driven projects identified

ASMI Advanced Superconductor Manufacturing Institute

Nine projects identified by industry for ASMI to pursue

Wire Manufacturing

- Reduced capital costs and increased throughput for HTS through manufacturing equipment/process innovations
- In-line QC tools for manufacturing
- Low AC loss conductor
- Extend the piece lengths by developing enhanced joint technology

Component Manufacturing

- Improvement and cost reduction for cryogenic components
- Manufacturing techniques to enhance coil reliability and cost effectiveness; develop methods for quench detection and protection

Integration

- Prototype testing, accelerated life testing and modeling and validation
- Develop devices that connect with standard utility interfaces
- Develop standards for applications, cryogenics, wire

ASMI Advanced Superconductor Manufacturing Institute

Goals Targeted to Overcome Barriers

1. Achieve a **10-fold increase in manufacturing throughput** with negligible increase in capital costs → ***overcomes Wire availability barrier***
2. Develop **in-line quality control and process control tools** for real-time detection of yield-limiting problems to improve yield of kilometer-long wires from **quality single digits to over 90%.** → ***overcomes cost barrier***
3. Develop innovative manufacturing equipment and process technologies for production of **fine multifilamentary superconductor wires in lengths of 1000 meters to achieve 10 to 50-fold reduction** in AC losses → ***overcomes performance barrier***
4. Develop **cryogenic technologies for long-life/low maintenance, low cost** → ***overcomes reliability barrier***
5. Conduct **reliability testing and standards development** to accelerate new superconductor products for industry, promote **interoperability** and incentivize entry into the market→ ***overcomes reliability barrier***

ASMI Advanced Superconductor Manufacturing Institute

Achieving these goals will enable US industry to capture the significant commercial opportunities

Extensive Participation

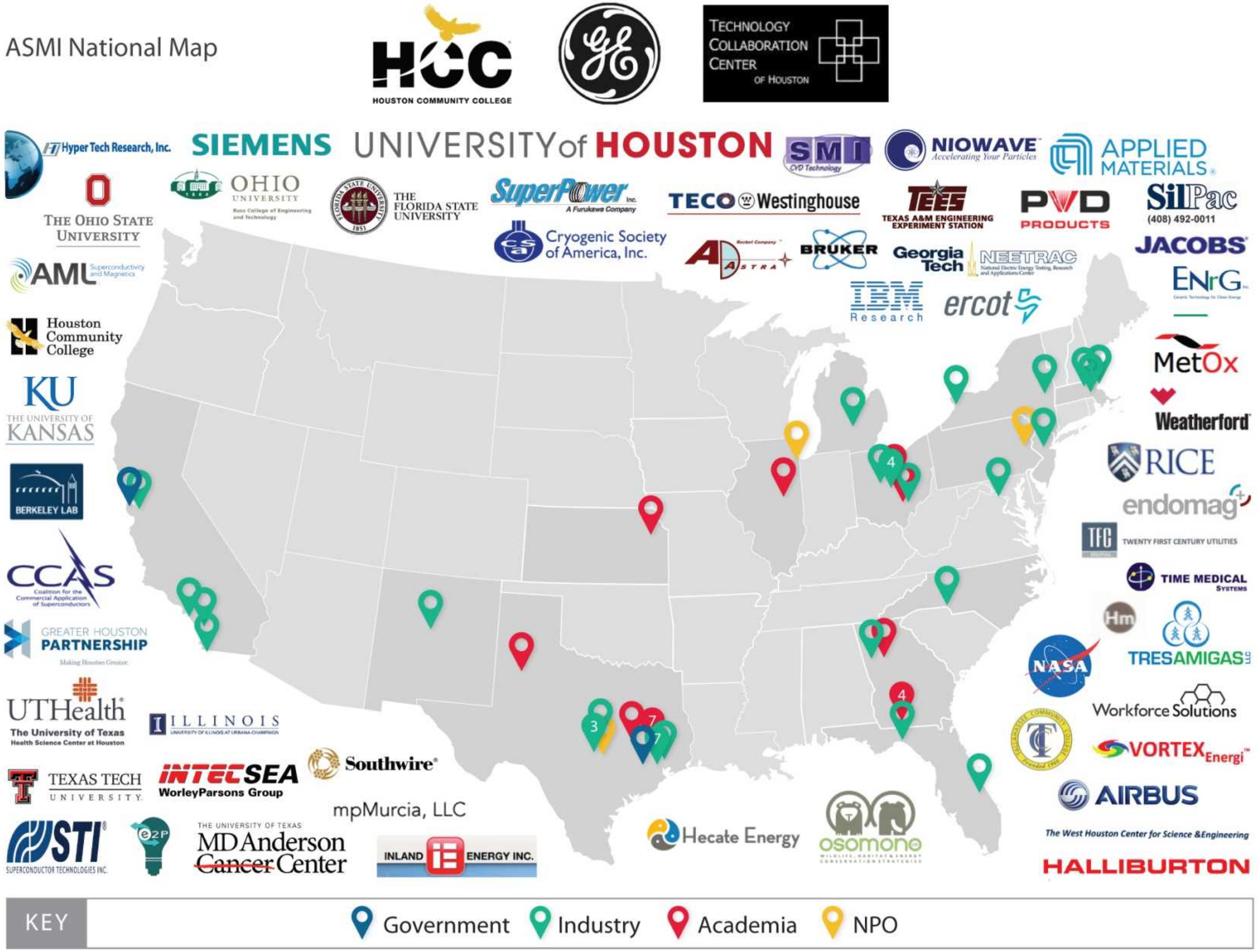


Figure 1.1. ASMI draws broad support from partners across the nation in industry, academia, and government.

ASMI Status

- Did not secure FY2016 funding from NIST; proposal "deferred"
- If appropriations are available in FY2017, then ASMI stands a good chance of being funded
- Workshop held in Washington, DC on March 7-8, 2017
  - Discussed principles of the institute's operation
  - Discussed how to handle intellectual property
  - Refined scope, goals, milestones, and risk mitigation plans for OEM driven projects
  - Developed a roadmap

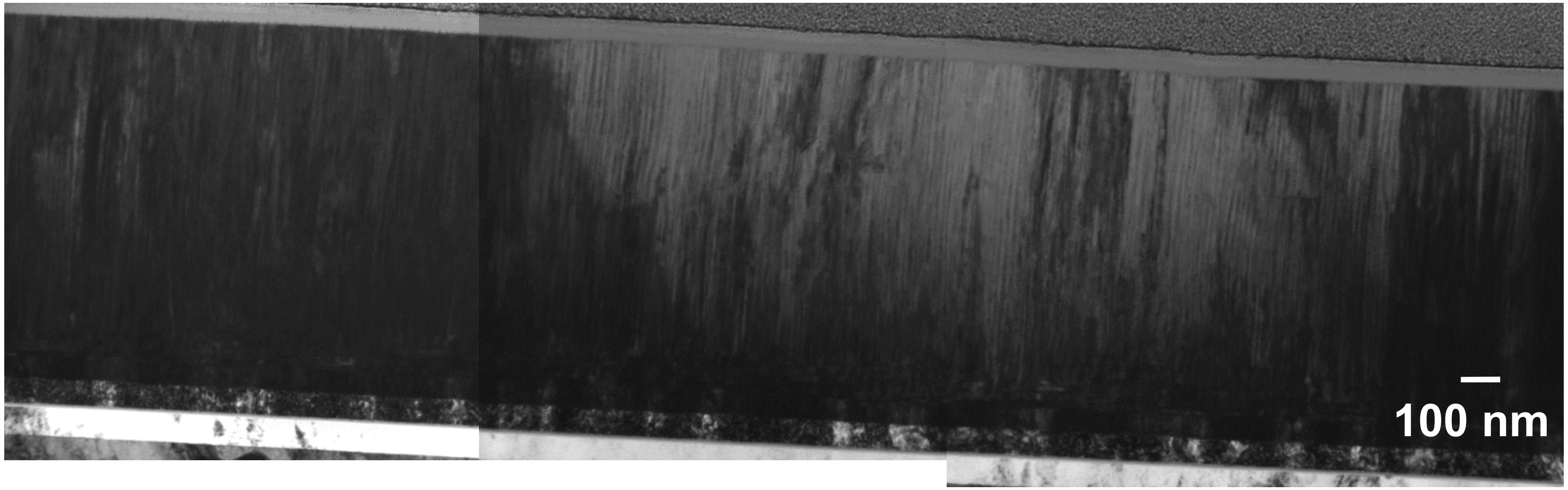
ASMI Advanced Superconductor Manufacturing Institute

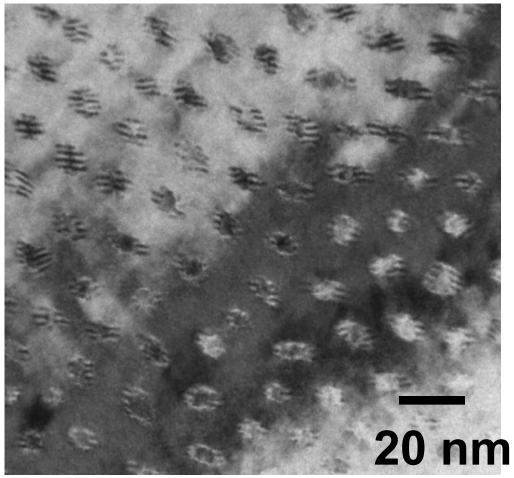
AMSC’s Resilient Electric Grid (REG)

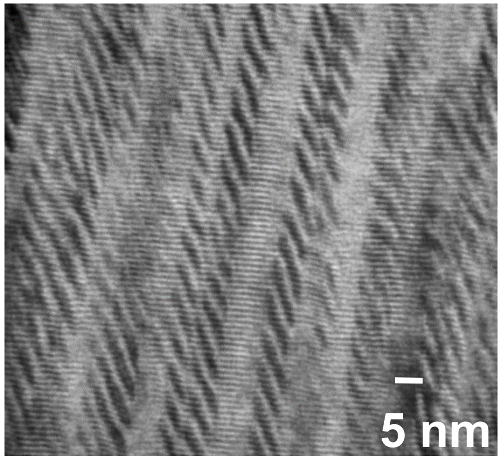
- AMSC is conducting resilient electric grid deployment studies
- Focus on evaluating REG as a solution for a distribution utility
- Seattle City Light is 5^{th} US electric utility to enter a REG study with AMSC
- ComEd in Chicago, Eversource in Bostin, Pacific Gas and Electric in northern and central California, PEPCO in Washington, DC
- Work with ComEd is furthest along
  - Working on site and scope
- AMSC is expanding marketing to Australia and the UK

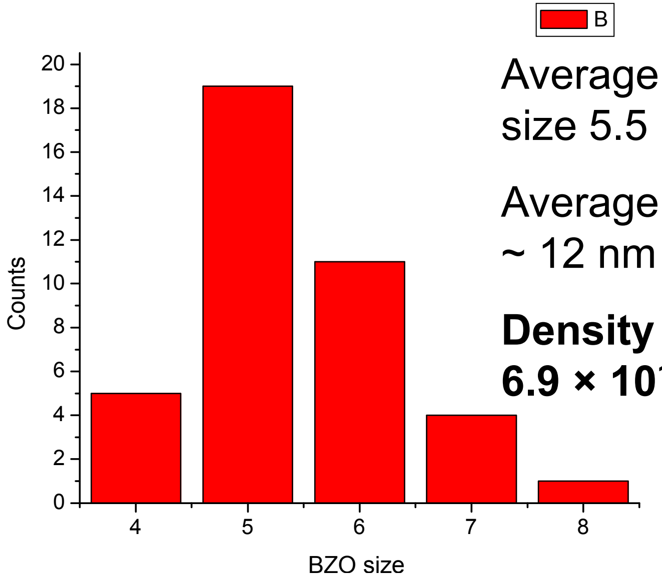
Supplemental Slides

High density of extended $BaZrO_3$ (BZO) nanoscale defects in Zr-added tapes







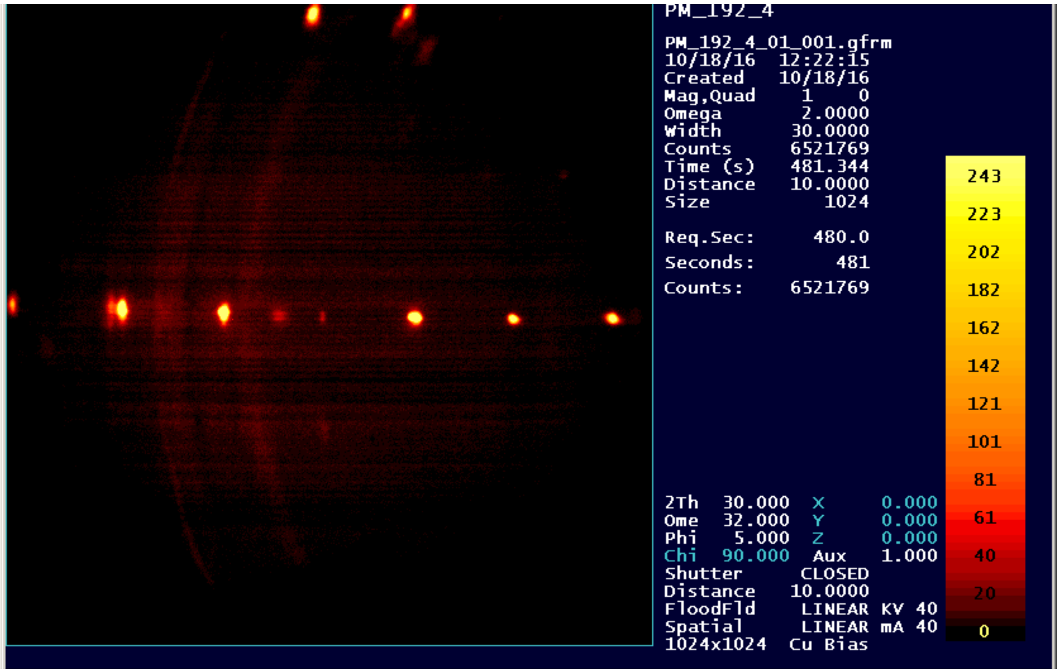


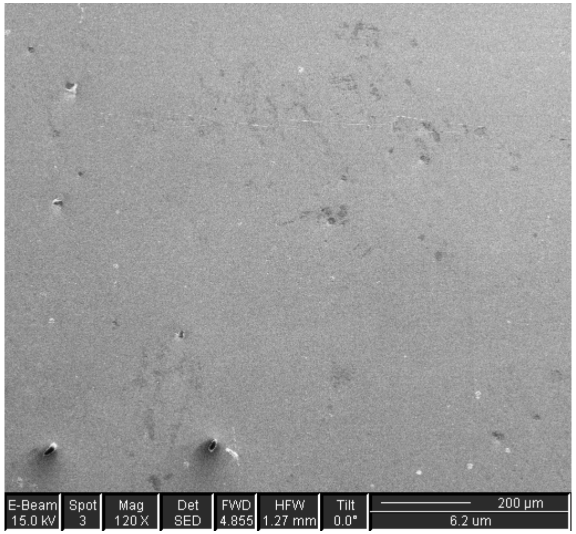
Average BZO size 5.5 nm

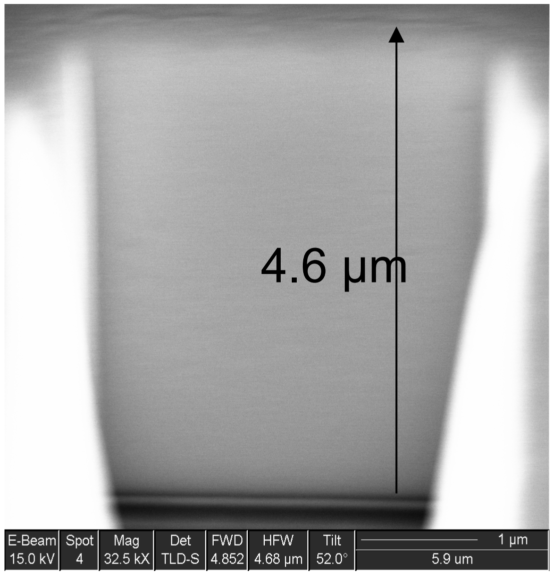
Average spacing ~ 12 nm

Density = 6.9×10^{11} cm^{-2}!

4.6 μm thick film deposited in a single pass with purely c-axis oriented REBCO

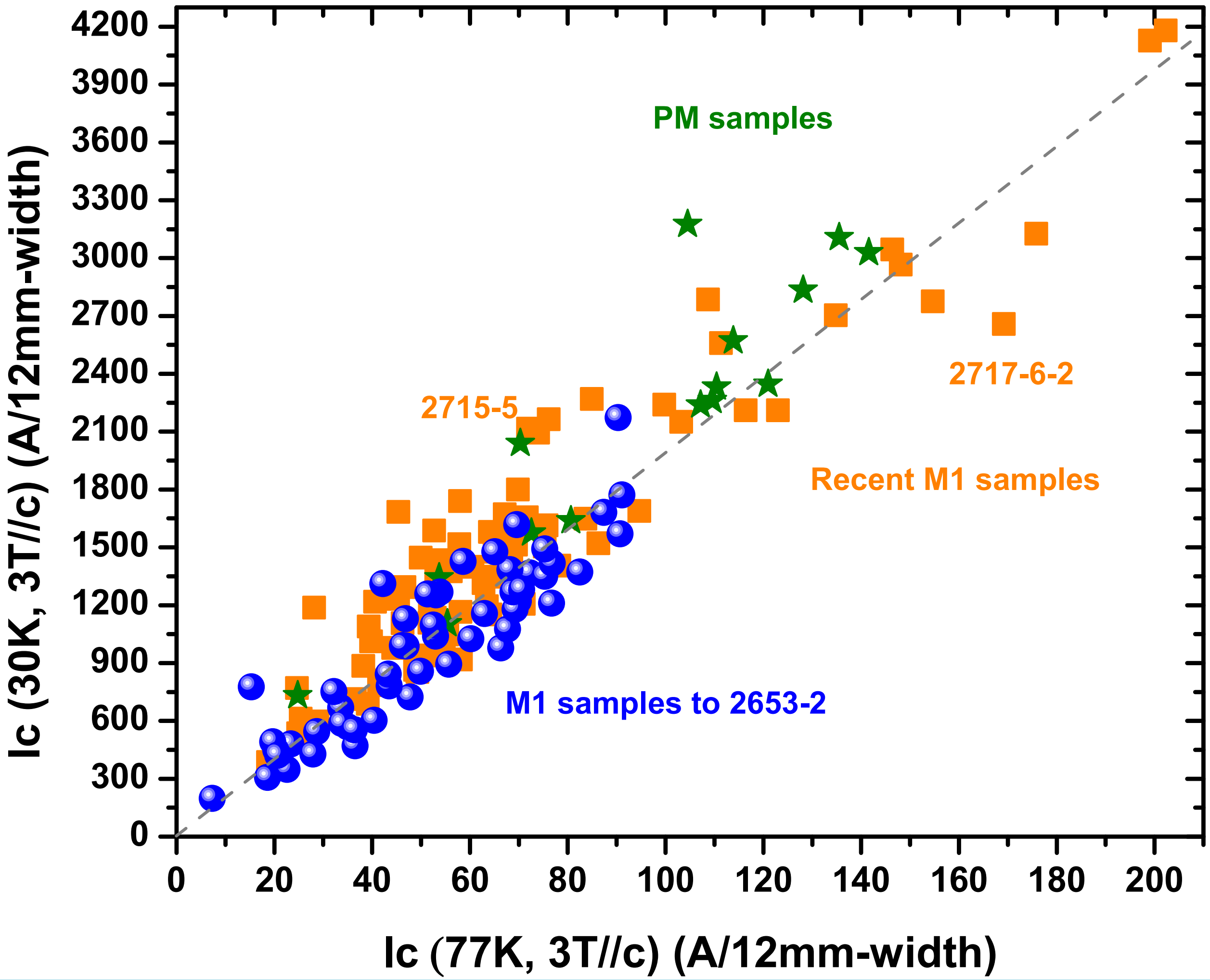






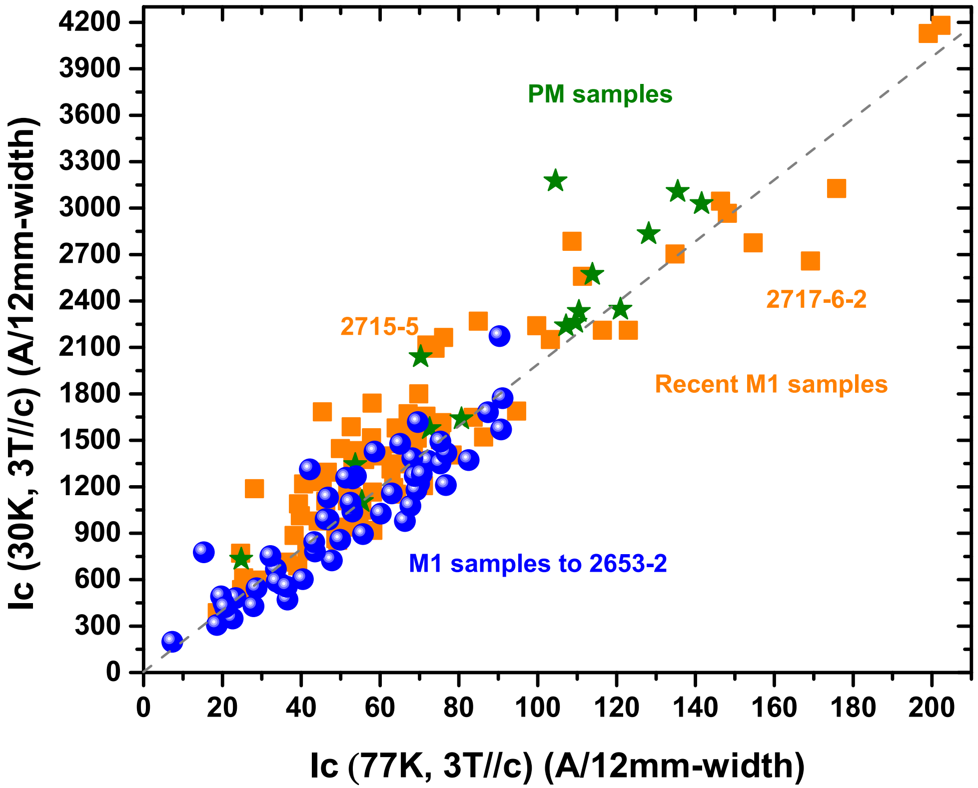
Evaluation of uniformity of low-temperature in-field performance of long tapes based on 77 K measurements

Good correlation between I_c at 77 K, 3 T at in-field I_c at 30 K, 3 T



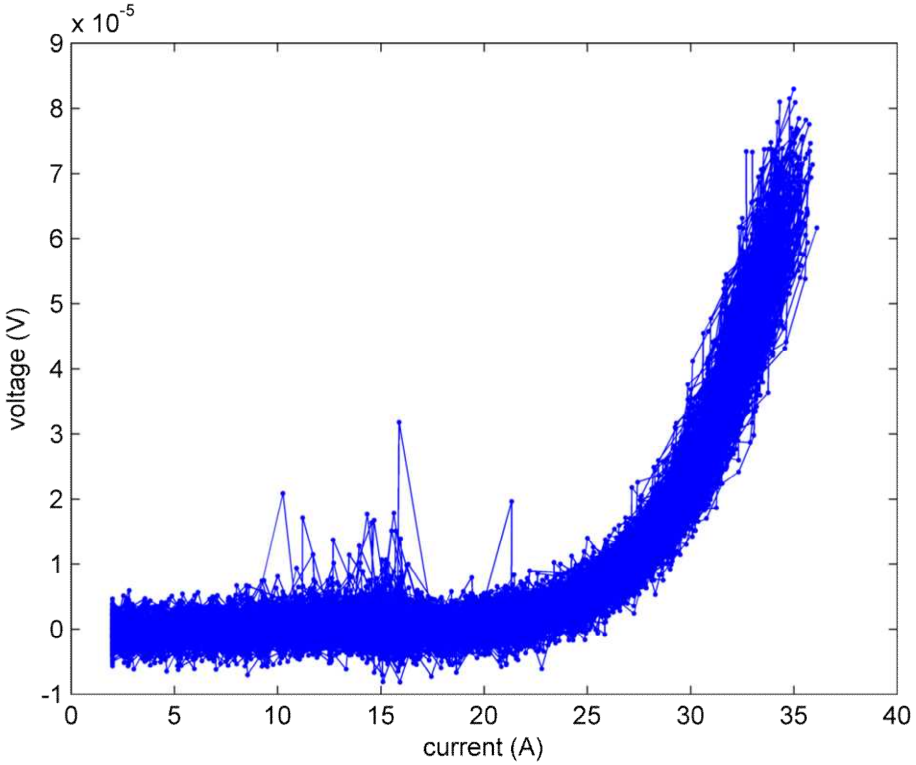
I_c at 77 K, 3 T at B||c is good predictor of I_c at 30 K, 3 T at B||c

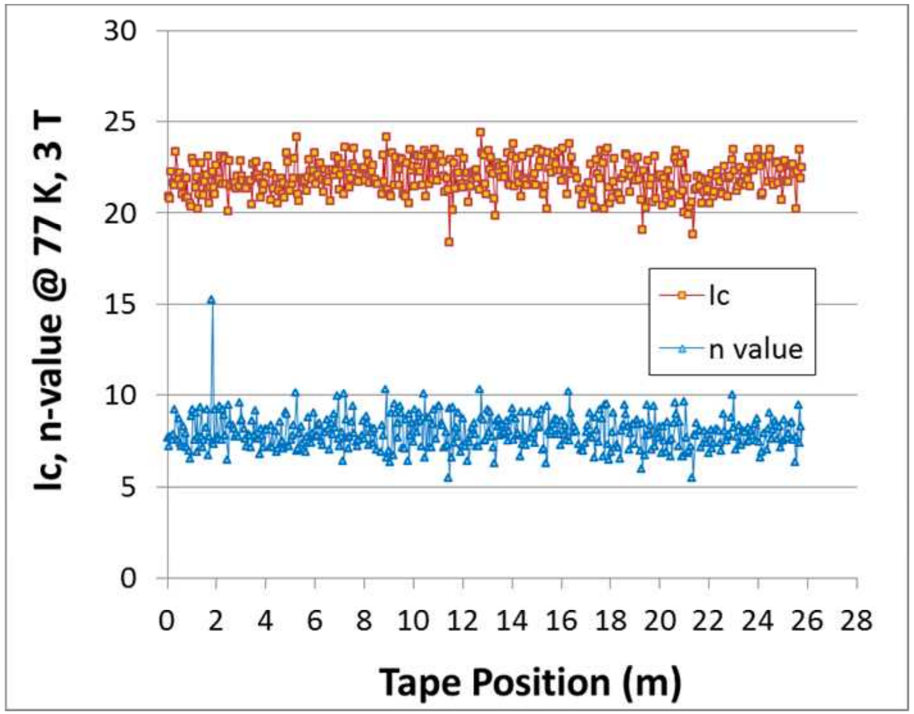
Reel-to-reel testing system to rapidly qualify consistency and uniformity of I_c in a magnetic field of 3 T



R2R in-field I_c measurement system enables verification of consistency and uniformity in in-field performance of long tapes at 4.2 K using 77, 3 T measurements

Reel-to-reel testing system as a tool to qualify consistency and uniformity of in-field performance of HTS tapes



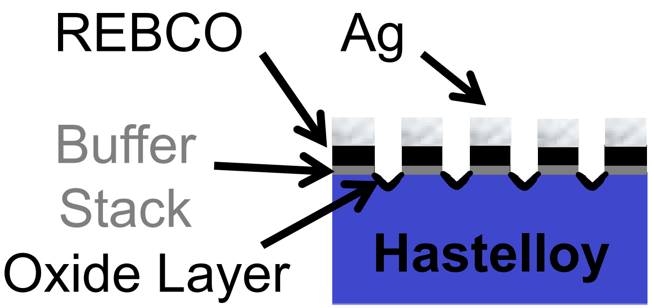


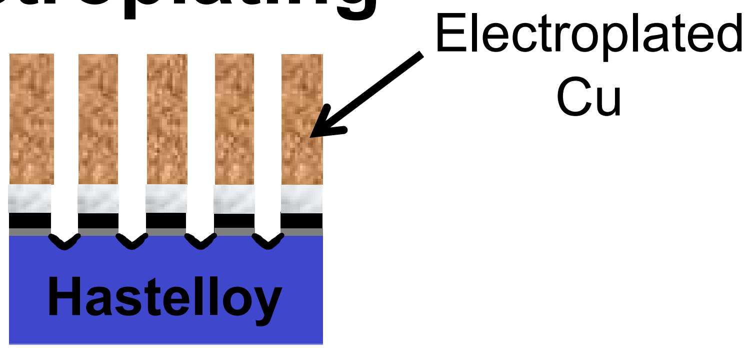
426 I-V curves at 77 K, 3 T every 5.7 cm of 26 m long tape

Standard deviation in I_c at 77 K, 3 T ~ 4%
Standard deviation in n value at 77 K, 3 T ~ 9%

Multfilamentary tapes

Fully-filamentized conductor by Laser Striation and Selective Electroplating





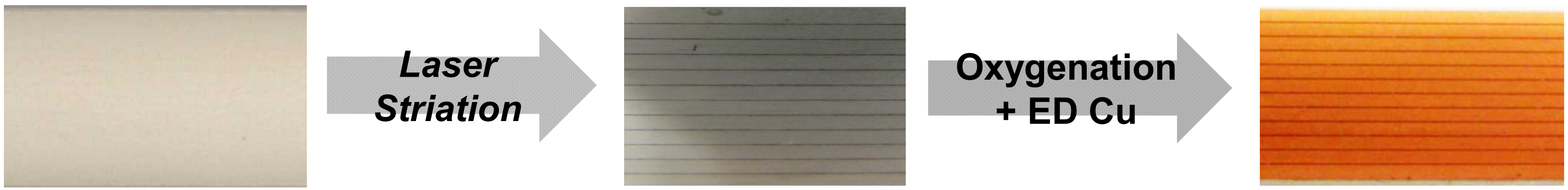
Laser Striation + oxygenation

Selective Cu Electroplating

Non-striated
12 mm wide Ag sputtered tape

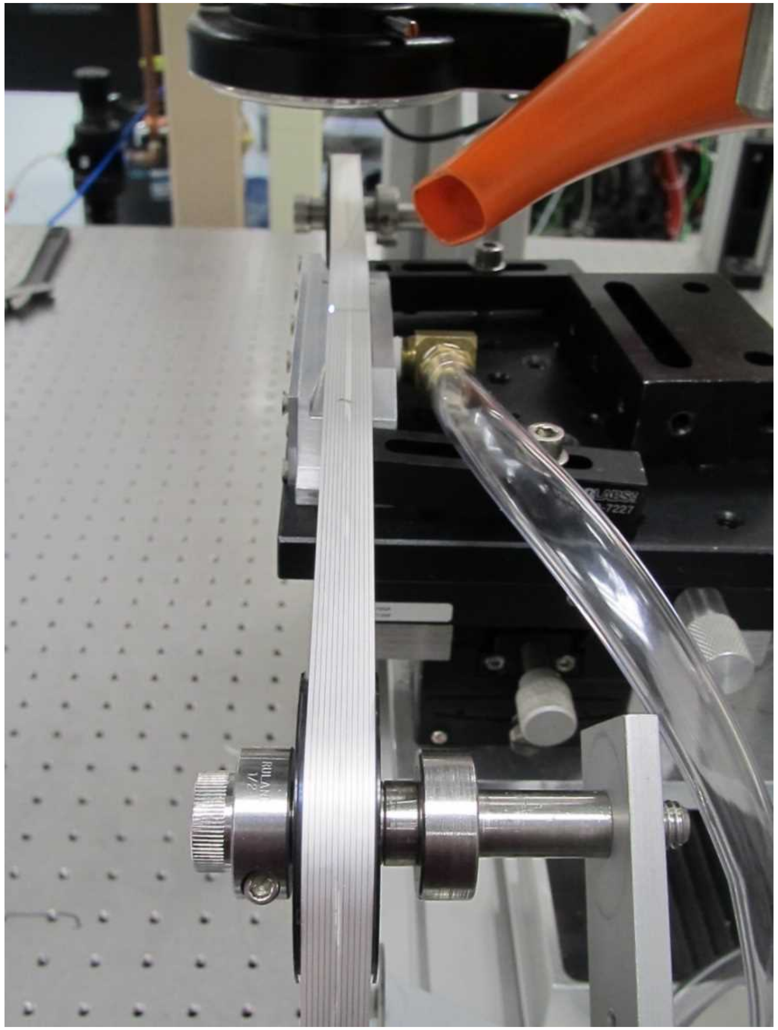
12-filament , 12 mm wide tape

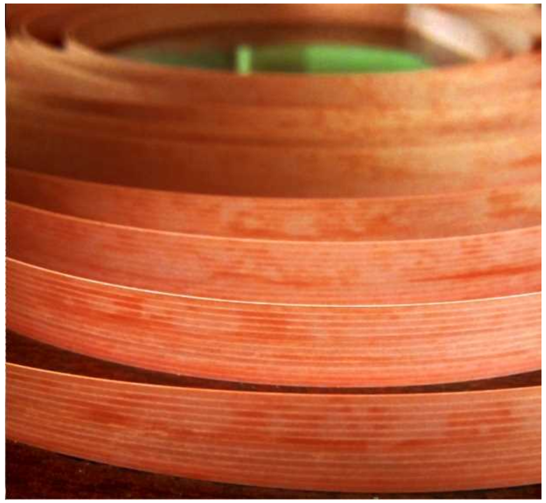
12-filament tape with electroplated Cu



I. Kesgin, G. Majkic, and V. Selvamanickam, “A simple, cost effective top-down method to achieve fully filamentized low AC loss 2G HTS coated conductors” , *Physica C.* **486,** 43–50 (2013)

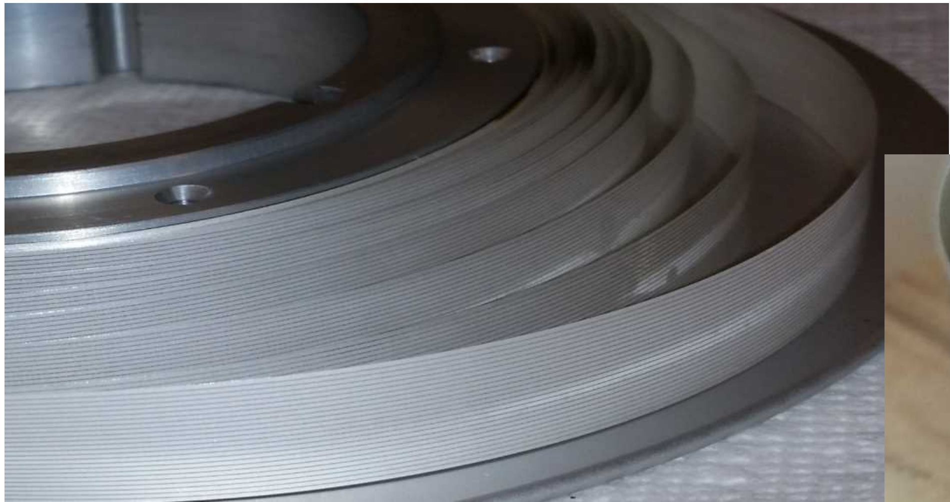
Long-length fabrication of multifilamentary coated conductors

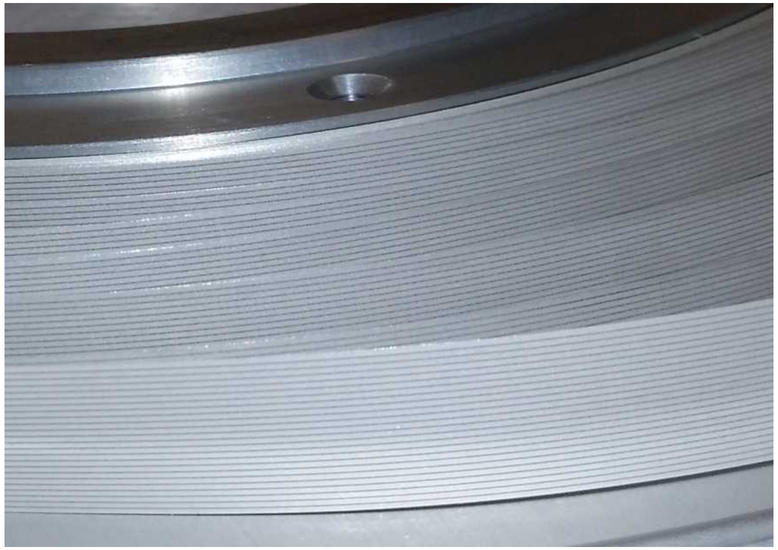




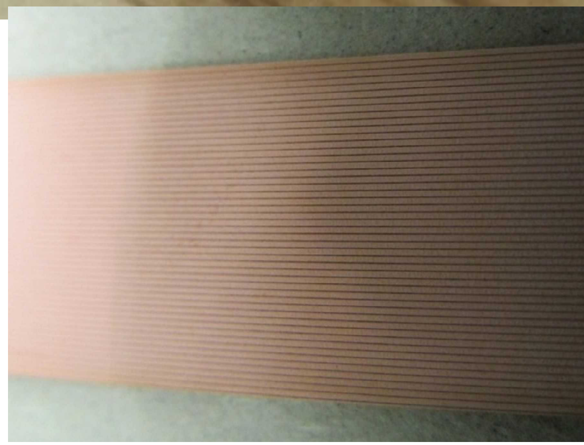
Higher filament count coated conductors

24-filament conductor

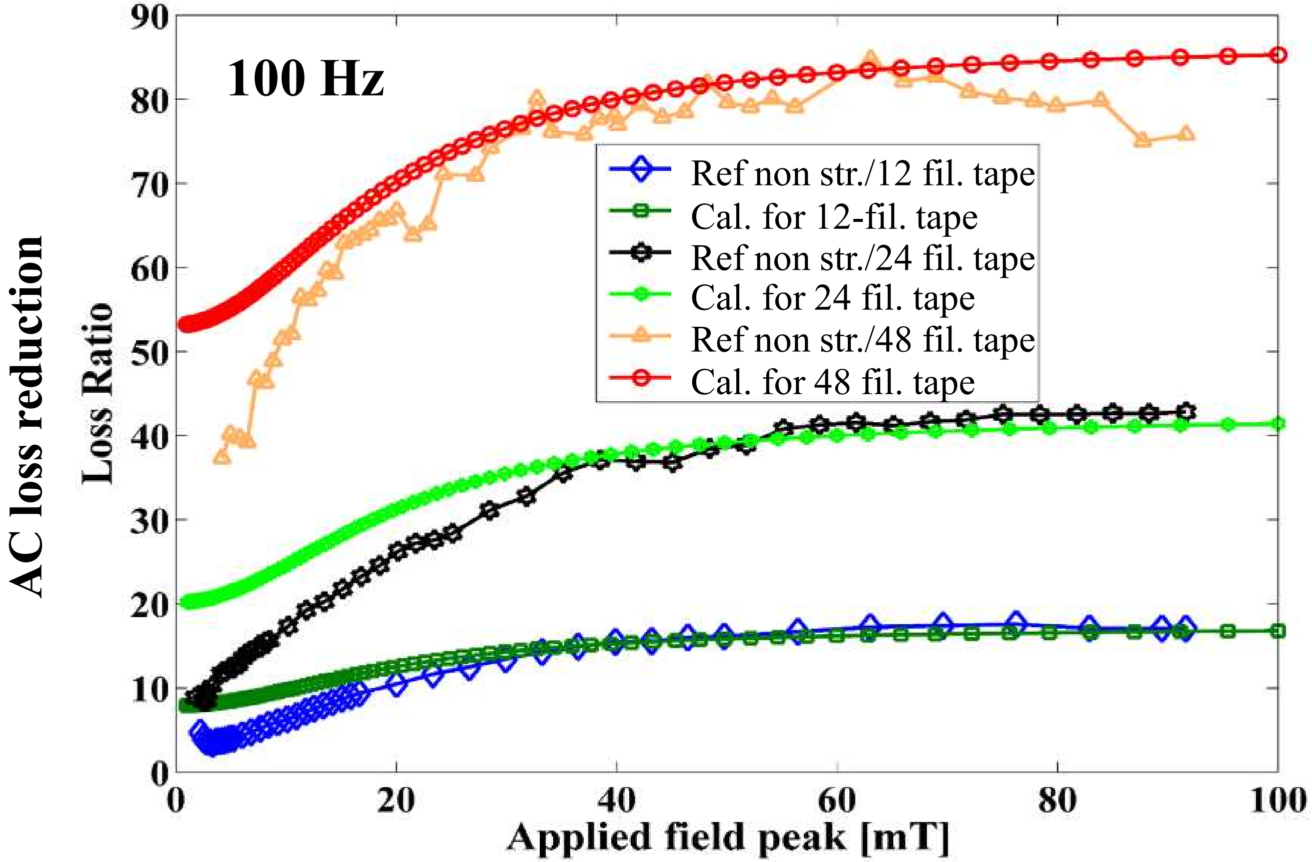




48-filament conductor



Significant ac loss reduction with multifilamentary coated conductors



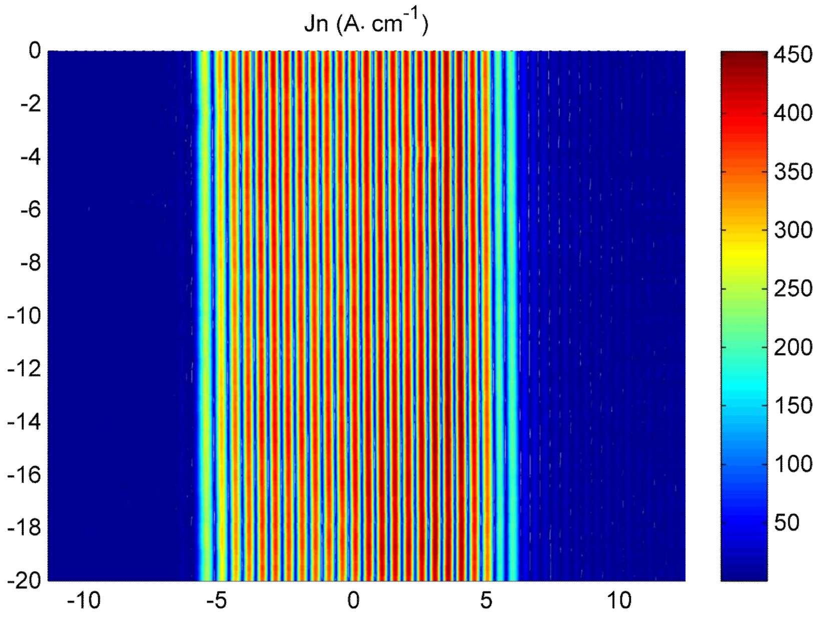
I. Kesgin, G. Levin, T. Haugan and V. Selvamanickam, “Multifilament, copper-stabilized superconductor tapes with low alternating current loss” *Appl. Phys. Lett.* **103,** 252603 (2013)

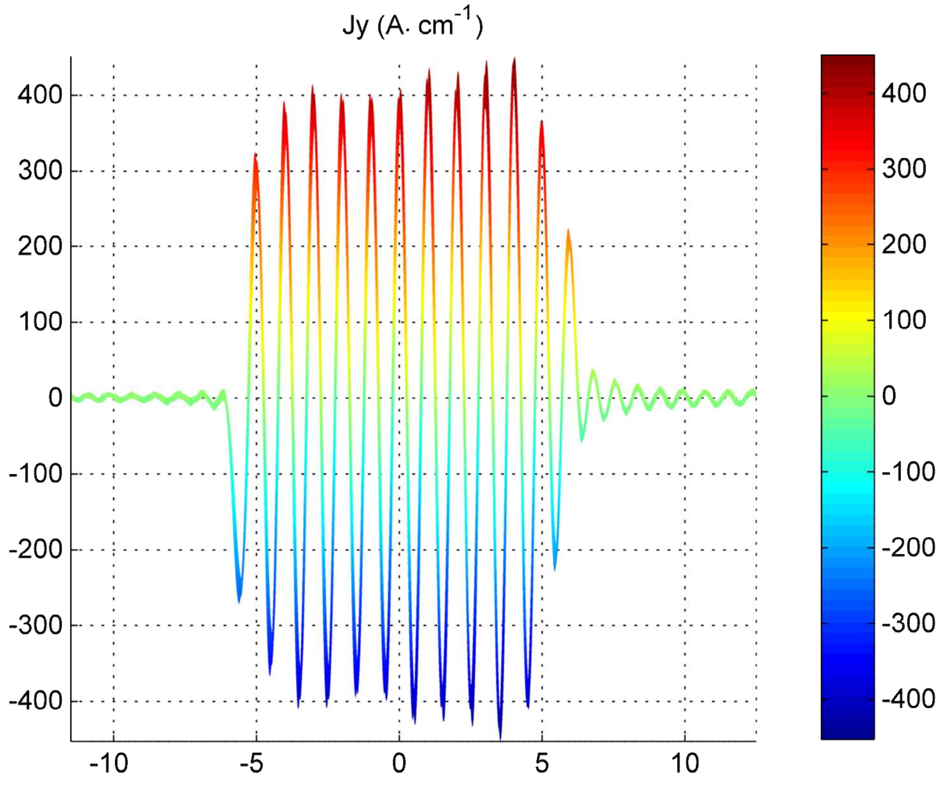
These are the highest reported values of AC loss reduction in coated conductors fabricated with a thick copper stabilizer.

Scanning Hall Probe Microscope to qualify filament homogeneity

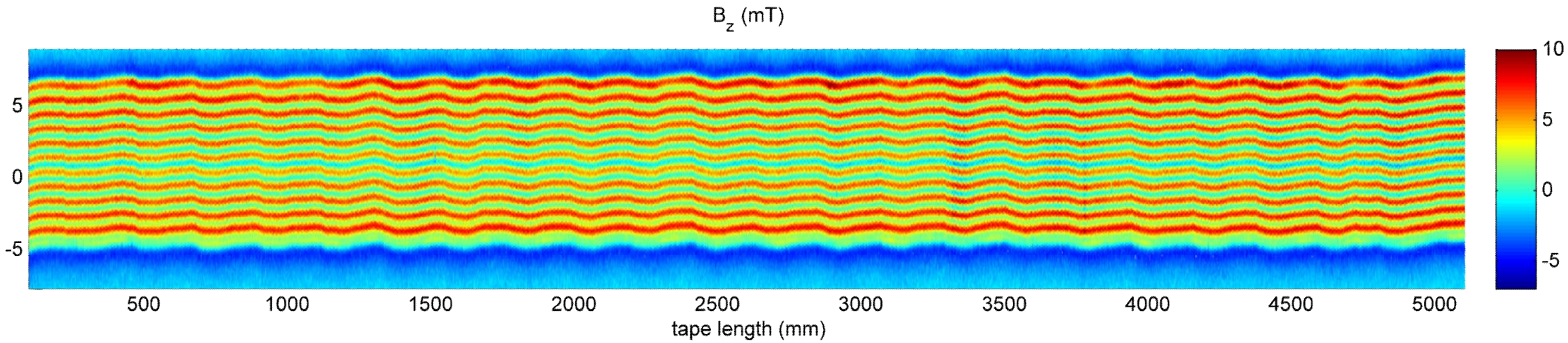
Reel-to-reel, Scanning Hall Probe Microscopy system:

- To visualize critical current uniformity on a sub-millimeter scale to identify defects that cause critical current drop outs.
  - Valuable for high yield manufacturing & for multifilamentary wires

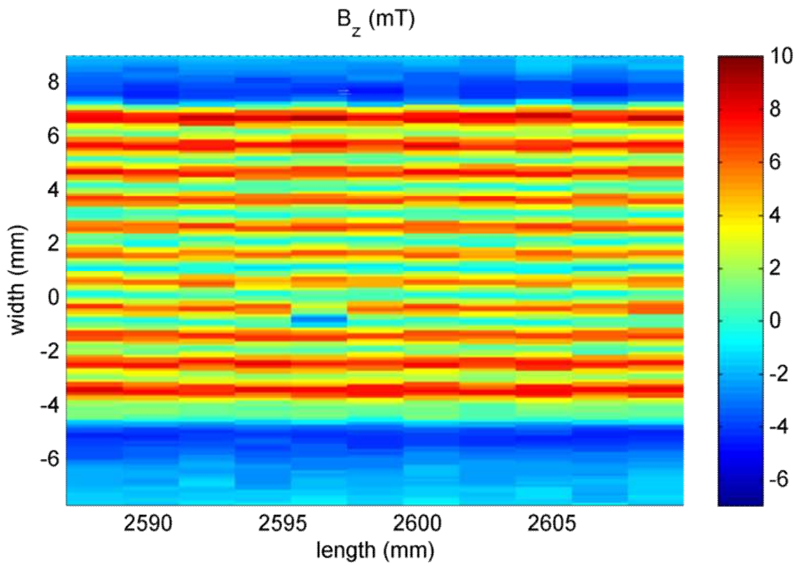


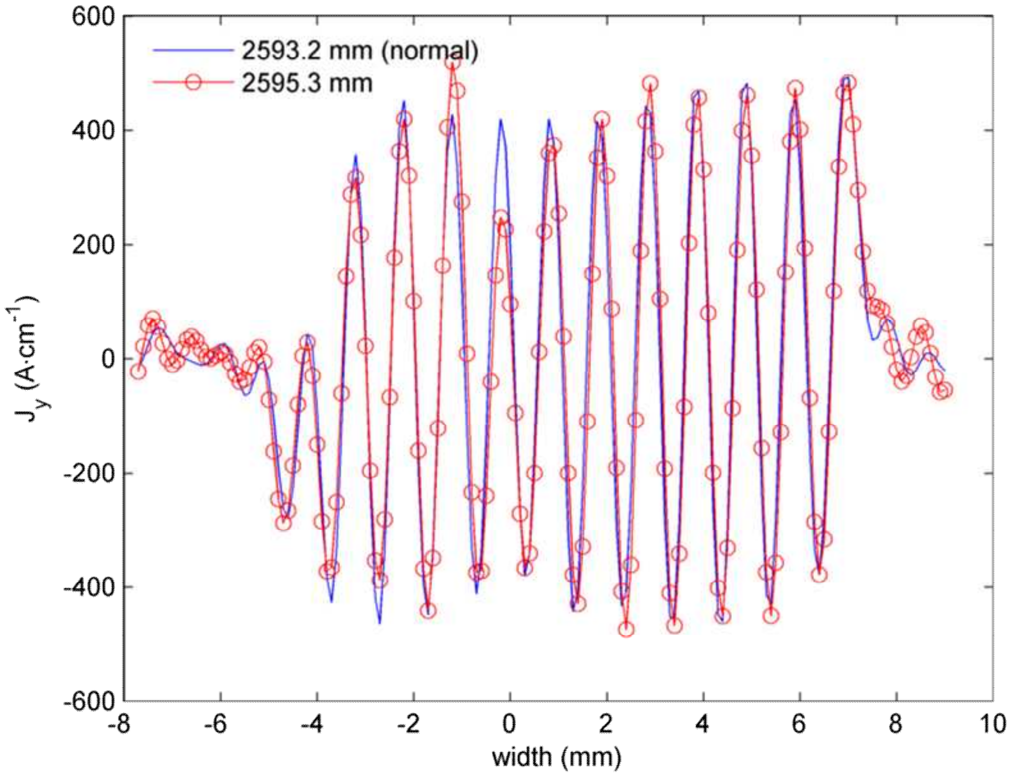


Reel-to-reel SHPM used to map current flow through long multifilament tapes



Defects identified in current flow map by reel-to-reel SHPM of long multifilament tapes





Transition and Deployment (outside the scope of the DOE funded effort)

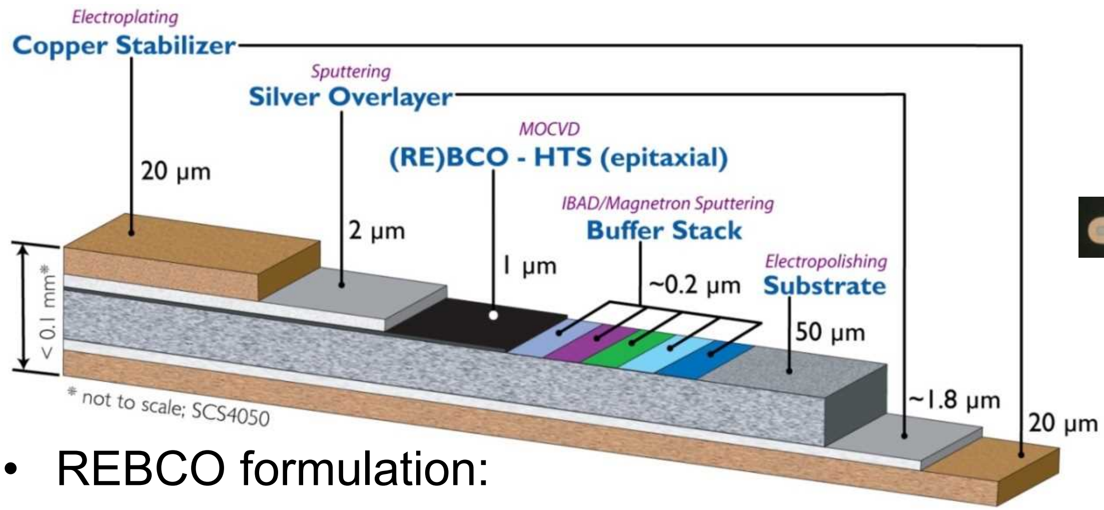
- Original Equipment Manufacturers are waiting for inexpensive HTS conductor and reliable motor designs
- Success in this project will pave the way to low cost HTS cables suitable for industrial motor applications
- Successful demonstration of CORC cables for motor applications will lead to commercial transition of the technology
  - The HTS conductor and cable manufacturers have strong partnership
  - both companies have strong collaborations and joint projects with the University partner
  - CORC cable technology is rapidly developing with the support from DOE High Energy Physics, DOE Fusion Sciences, and US Navy

Measure of Success

- Successful demonstration of CORC cables fabricated with "unsorted" conductor will lower the cost and increase reliability of HTS machines
- This project will be a success if we demonstrate the current sharing in CORC cables that will enhance the reliability of HTS motors and other coil based applications
- Success will be measured by the reduction in cost of HTS conductors obtained through higher yield
- HTS adoption in industrial motors will significantly increase the energy efficiency of industrial motors – Positive economic and environmental impact

2G HTS wire production at SuperPower

IBAD-MOCVD based REBCO wire on Hastelloy substrate



Cross-sectional image of a Cu-plated wire

- REBCO formulation:
  - **AP** (Advanced Pinning) – with enhanced in-field performance for B//c, targeting at coil applications such as high-field magnets, SMES, motors/generators
  - **CF** (Cable Formulation) – for cables, transformers, FCL
- I_c(77K, s.f.)/12mm = 400-600A, piece length = up to 500m.
- Variations in width (2-12mm), substrate thickness (30, 50 or 100µm) Ag thickness (1-5µm), Cu thickness (10-115µm), and insulation
- Bonding conductors : 2x2mm, 2x4mm, 2x12mm (face to face / back to back)

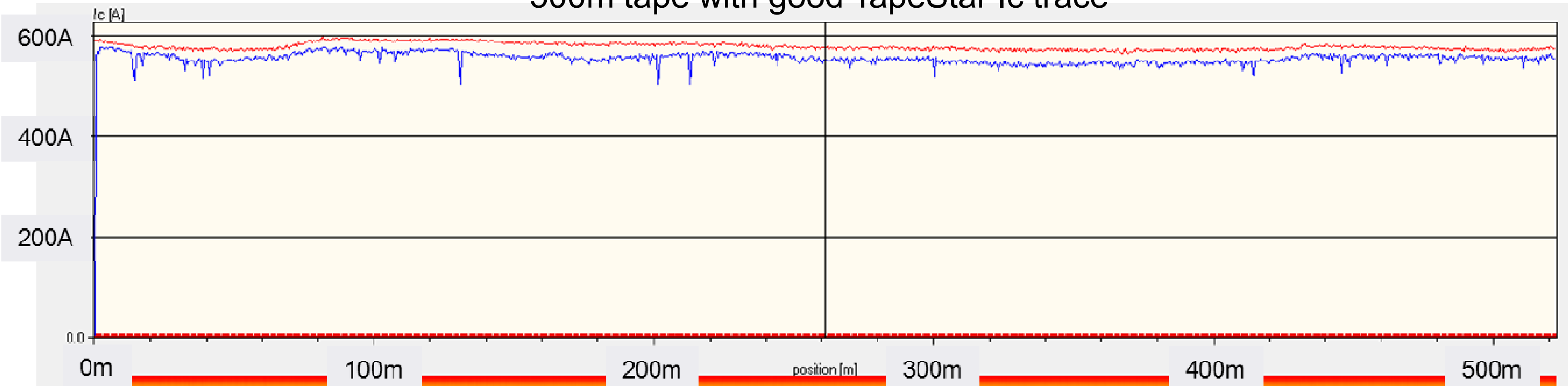
2mm wide tapes on 30 mm substrates focus of this project

2G HTS wire has been produced since 2006
Continuous improvements introduced into processing

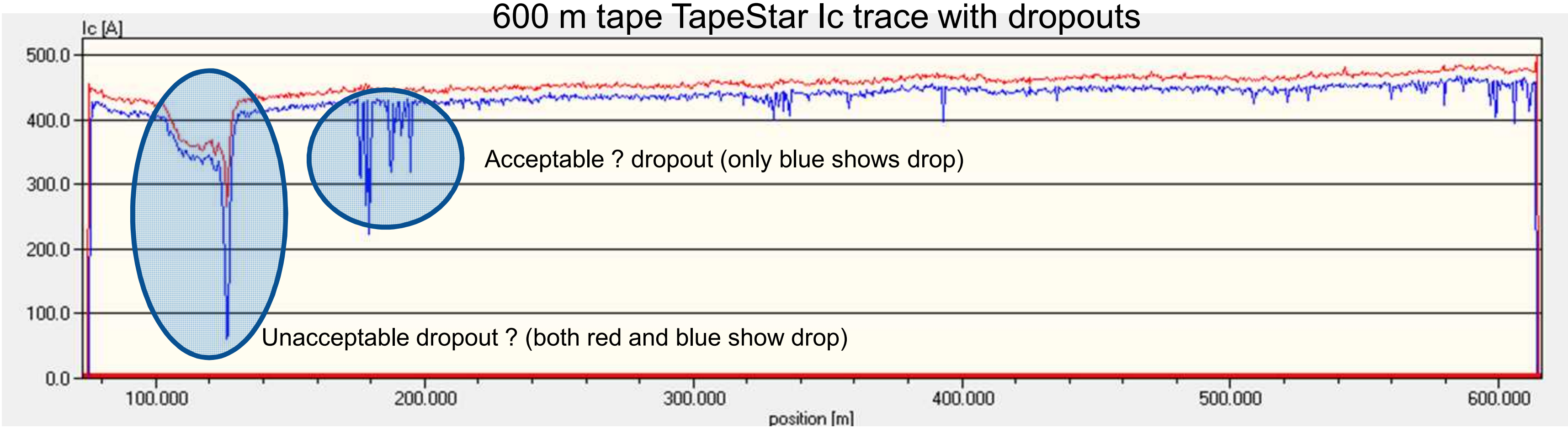
SuperPower Inc.
A Furukawa Company

Ic drop-outs in Manufacturing – Can they be used in CORC cables?

500m tape with good TapeStar Ic trace



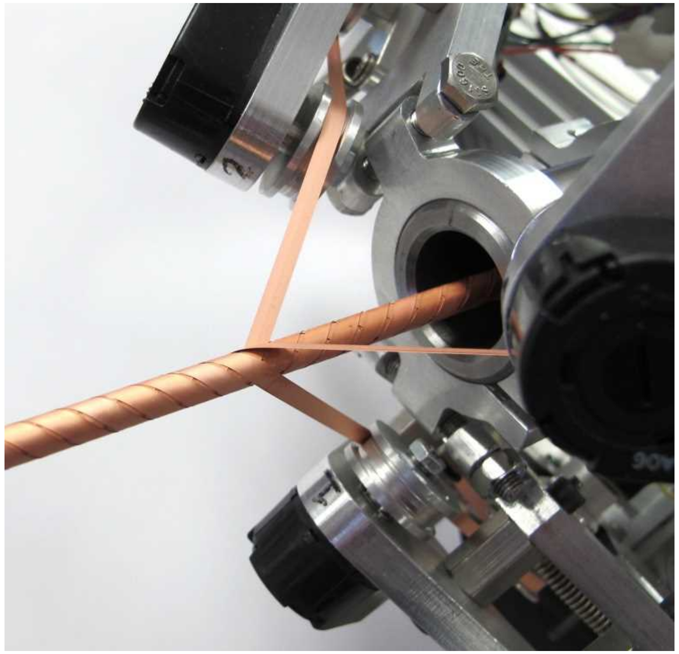
600 m tape TapeStar Ic trace with dropouts



CORC® Wires for Rotating Machines

CORC® wire details

- Wound from 2-3 mm wide tapes with 30 μm substrate
- Typically no more than 30 tapes
- Thickness between 2.5 and 4.5 mm
- Highly flexible with bending to less than 50 mm diameter
- High level of current sharing has the potential to allow for tape dropouts



CORC® wire production

- In-house winding machine
- Capable of winding continuous lengths of up to 50 meters (longer lengths in coming year)
- Performance retention of tapes in CORC® wire between 95 and 100 % after winding

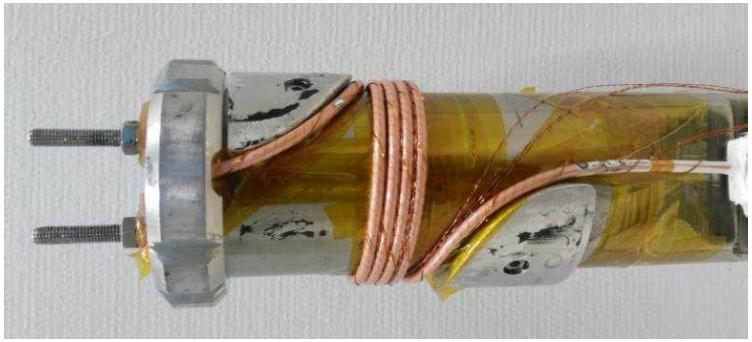
Two CORC® wires of 25 m in length each

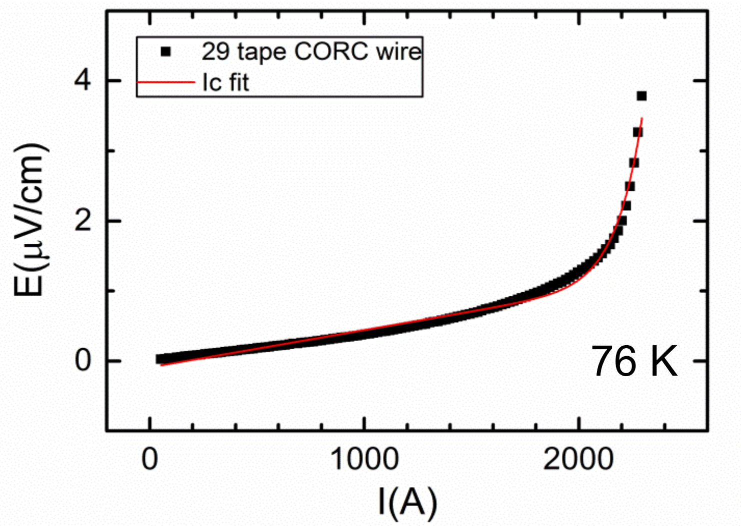
Advanced Conductor Technologies LLC
www.advancedconductor.com

CORC® Wire Performance

CORC® wire layout

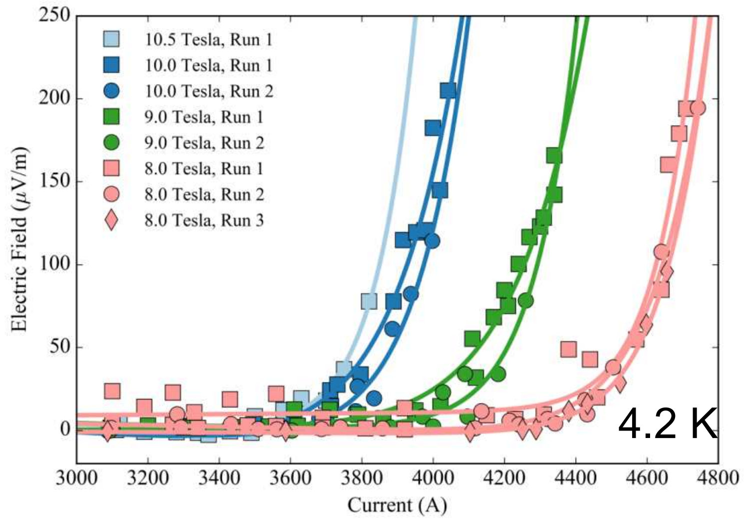
- 29 tapes of 2 mm width
- 3.6 mm diameter wire
- Wound into 60 mm ID coil





Results

- I_c = 2,191 A (76 K, self-field)
- I_c = 3,370 A (4.2 K, 10 T)
- Projected J_e(20 T) = 250 A/mm^2



Current Sharing in CORC® Wires

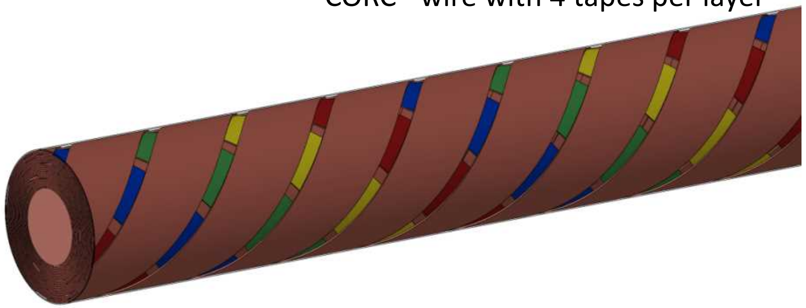
High level of current sharing in CORC® wires

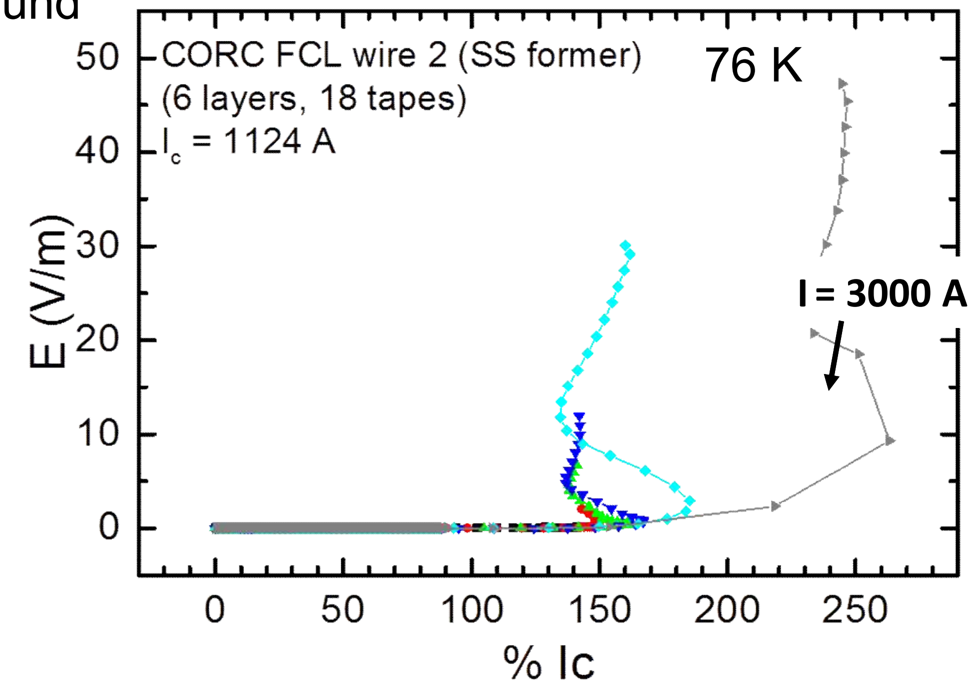
- Short twist pitch of tapes in CORC® wires
- Direct contact between each tape and up to 8 other tapes per twist pitch
- More paths for current sharing around tape defects

Current sharing demonstrated

- Operation in Fault Current Limiting mode
- Pulsing overcurrents up to 2.5x I_c
- No burnout, even after 89 pulses

CORC® wire with 4 tapes per layer



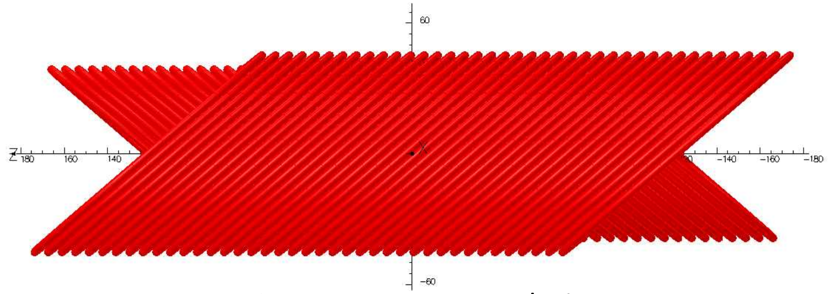


Data points shown at 1 ms time intervals.

CORC® Wires Developed for Magnets

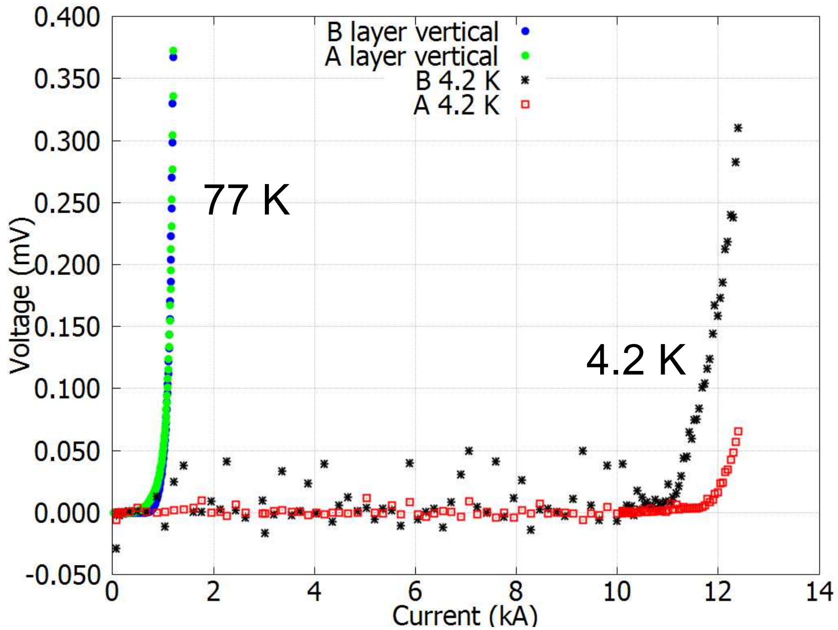
CORC® wires for accelerator magnets

- Canted-Cosine Theta (CCT) accelerator magnet design
- Goal is to reach 20 T at 4.2 K
- High flexibility and current density of CORC® wires make them prime candidate



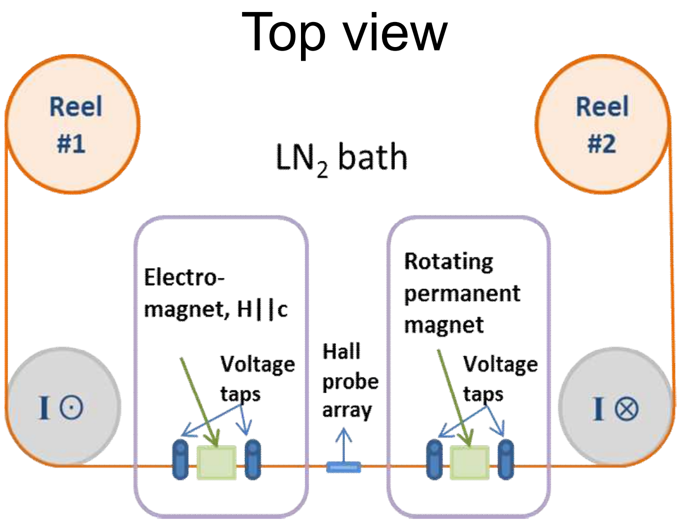
2-Layer CCT magnet design
(Lawrence Berkeley National Laboratory)

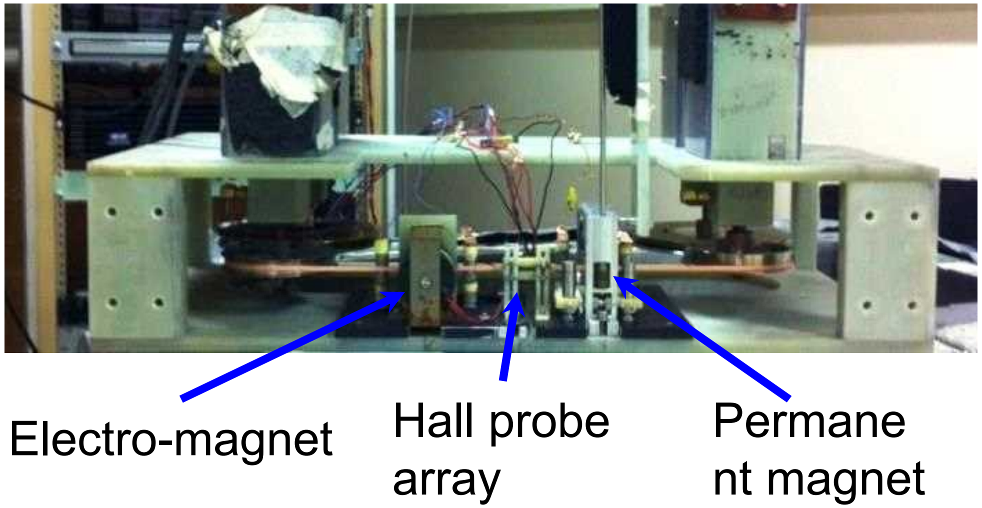
2-layer, 3-turn CCT magnet wound from 29-tape CORC® wire



Advanced Conductor Technologies LLC
www.advancedconductor.com

YateStar– unique instrument for length-wise transport and magnetization measurements with great spatial sensitivity

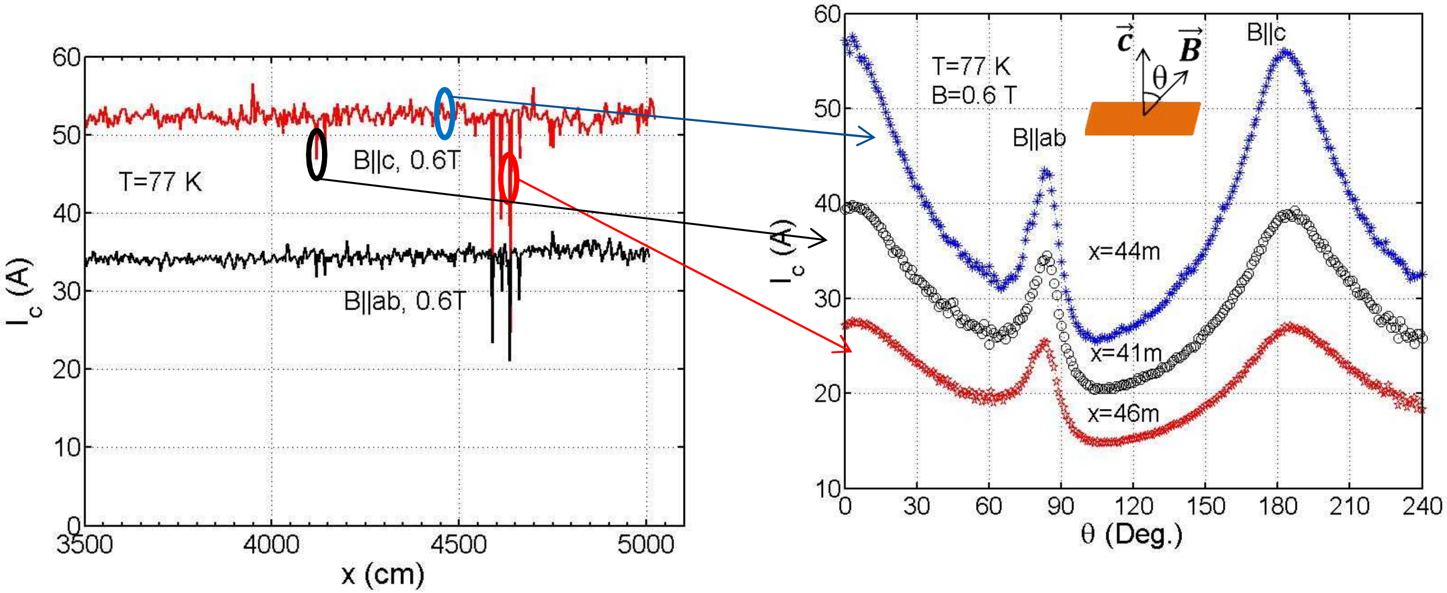




- Designed by Yates Coulter (NHMFL-LANL) and further developed at ASC by improvements to indexing, increase in length capability and addition of remanent field Hall probe array
- Transport measurement: I_c (x, θ, B) [resolution ~2 cm]
  - ✓ Two channels for I_c(x) [normally perpendicular and parallel field]
  - ✓ Any interesting point for I_c(θ)
- Magnetization measurement: higher resolution [~ 1 mm] and speed

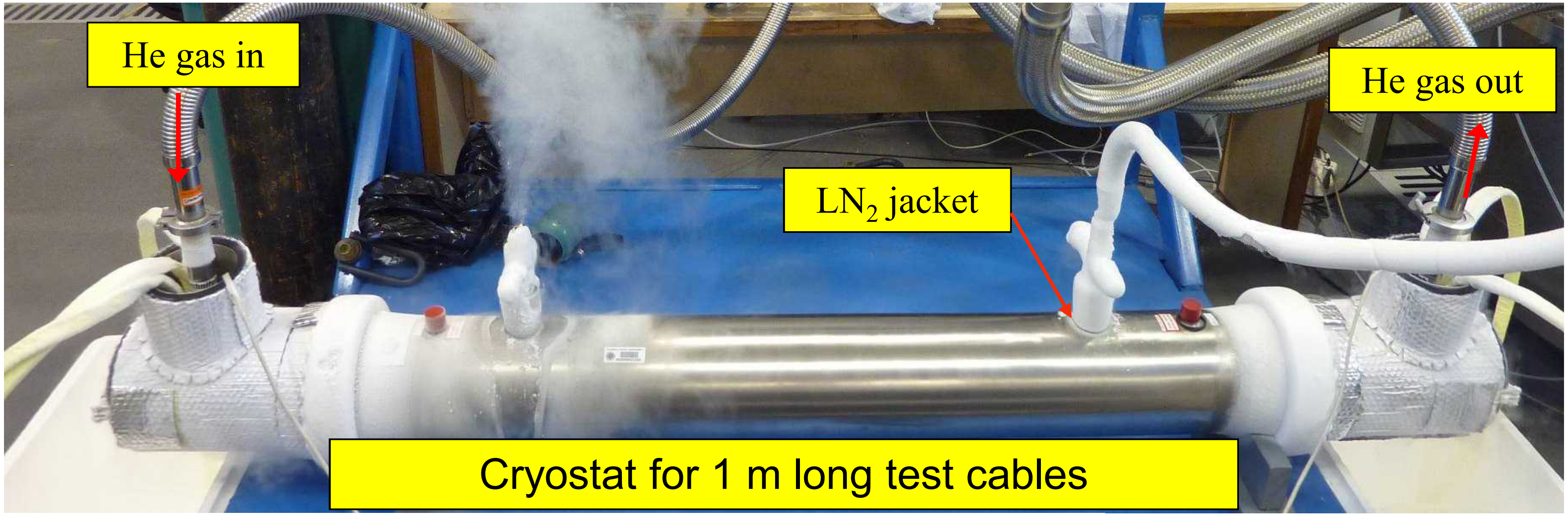
NATIONAL HIGH MAGNETIC FIELD LABORATORY

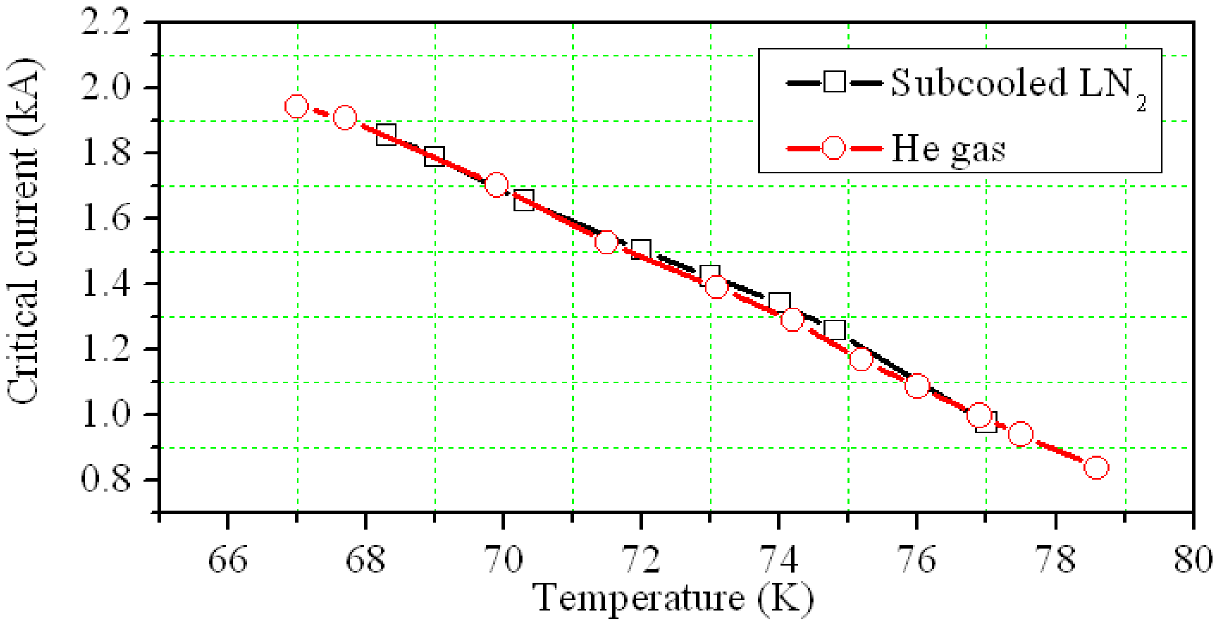
$I_c(x)$ measurement with B‖*ab* and B‖*c*, $I_c(\theta)$ measurement on any region – efficient ways for vortex pinning evaluation



- $I_c(x)$ with field in two orientations.
- Angular I_c at different points. In this case, the *c*-peak degrades more at the defects, compared to the *ab*-peak.

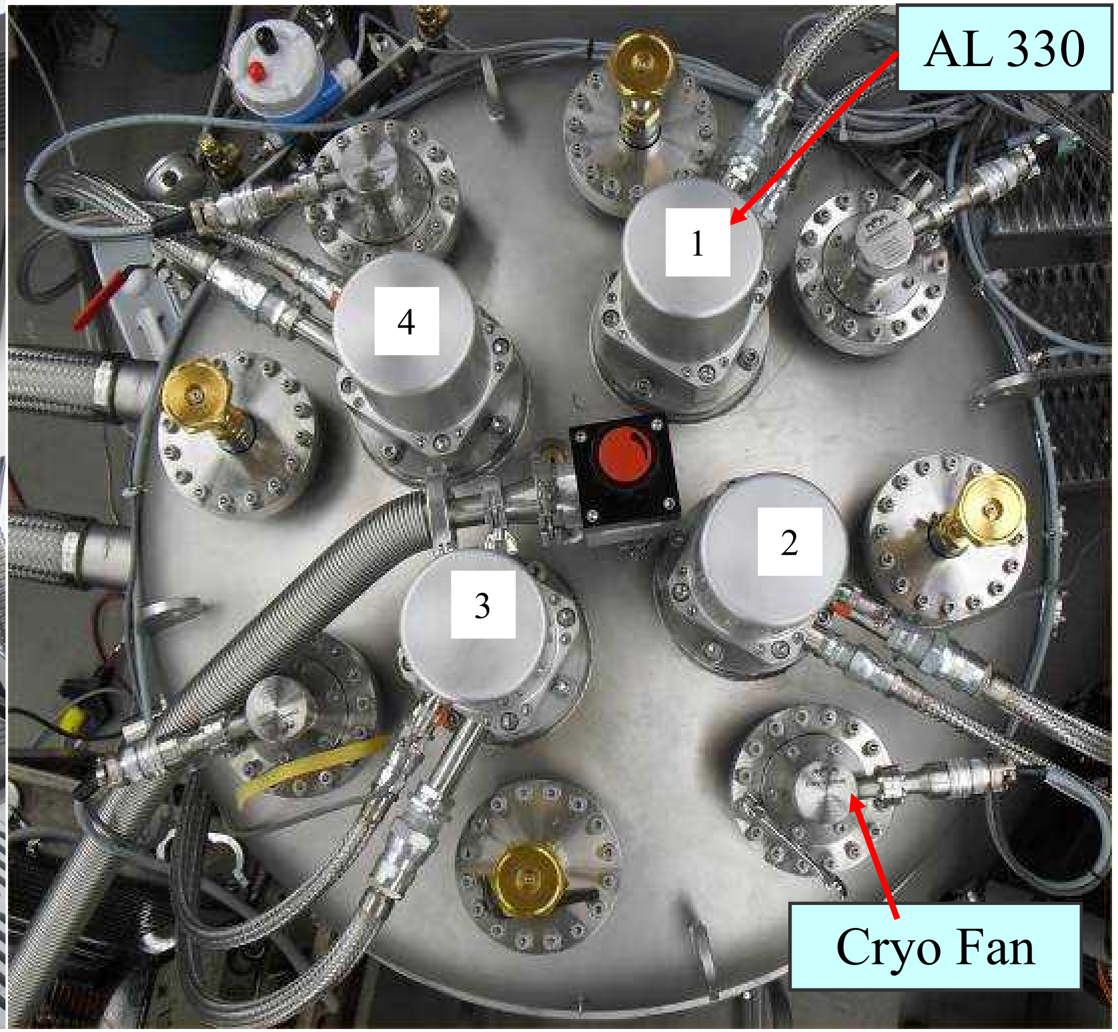
Characterization of HTS cables at variable T





FSU-CAPS been developing novel high power density HTS cables for 50-70 K operation

Cryogenic helium circulation systems for superco cable characterization



HTS cables are characterized at variable temperatures (45 -80 K) at current up to 6 kA for design optimization and validation

Advanced Superconductor Manufacturing Institute (ASMI)

- Did not secure FY2016 funding from the National Institute on Standards and Technology
- If appropriations are available in FY2017, then ASMI stands a good chance of being funded
- Workshop held in Washington, DC on March 7-8, 2017
  - Discussed principles of the institute's operation
  - Discussed how to handle intellectual property
  - Refined scope, goals, milestones, and risk mitigation plans for OEM driven projects
  - Developed a roadmap