Processes for 2G HTS Wire Manufacturing

DE-EE0007871
STI/M.I.T./TECO
(3) Year Program

SUPERCONDUCTOR TECHNOLOGIES INC.

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Washington, D.C.
June 13-14, 2017

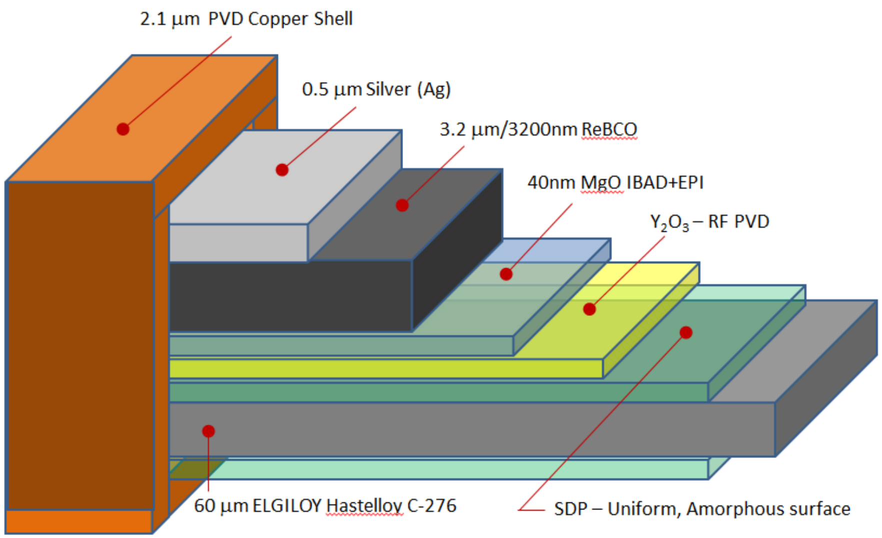
TECO Westinghouse
Massachusetts Institute of Technology
UNIVERSITY OF NORTH TEXAS

Project Objective

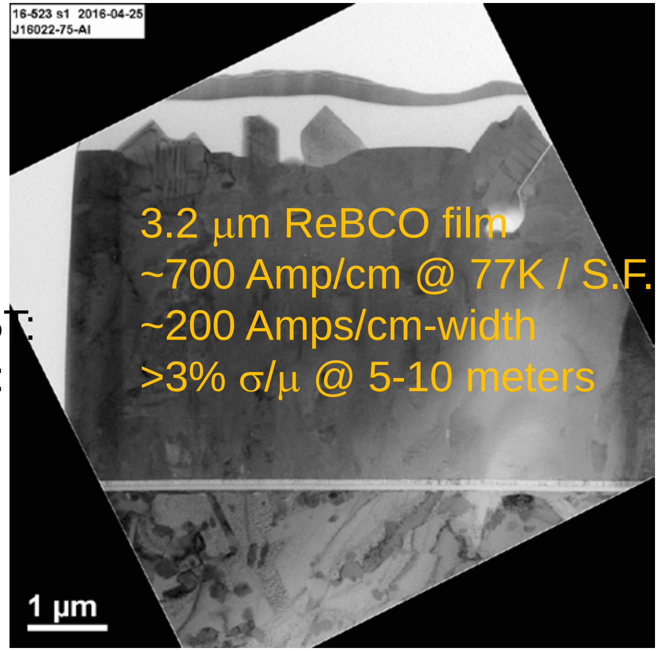
- What are you trying to do?
  - Enable 2G HTS commercial applications, specifically 1 to 2T motors.
    - Increase electrical efficiency of large rotating electric machines
  - Improve 2G HTS Ic >1440 A/cm-width @ 65K in 1.5T B-field, all angles
  - Lower 2G HTS costs by increasing performance & manufacturing yield
- What is the problem?
  - Film growth dynamics and run-to-run control/repeatability
  - Effects of 'pinning' dopants –or- buffer layers on our process
  - Non-linear effects of B-Field & angle on various 'pinning' approaches
- Why is it difficult?
  - (2) types of pinning; a/b-axis (in-plane) c-axis (perp)
  - Both shift composition from pure $Re_1Ba_2Cu_3O_{7-d}$
  - FIND and HOLD these enhanced deposition conditions.
  - Cryogenic measurements in B-field @ high currents challenging

Technical Innovation

- How is it done today, and what are the limits of current practice?



Thick Limits: 3.2 µm ReBCO film
Ic: ~700 Amp/cm @ 77K / S.F.
Ic @ 65K/1.5T: ~200 Amps/cm-width
Ic Uniformity: >3% σ/µ @ 5-10 meters



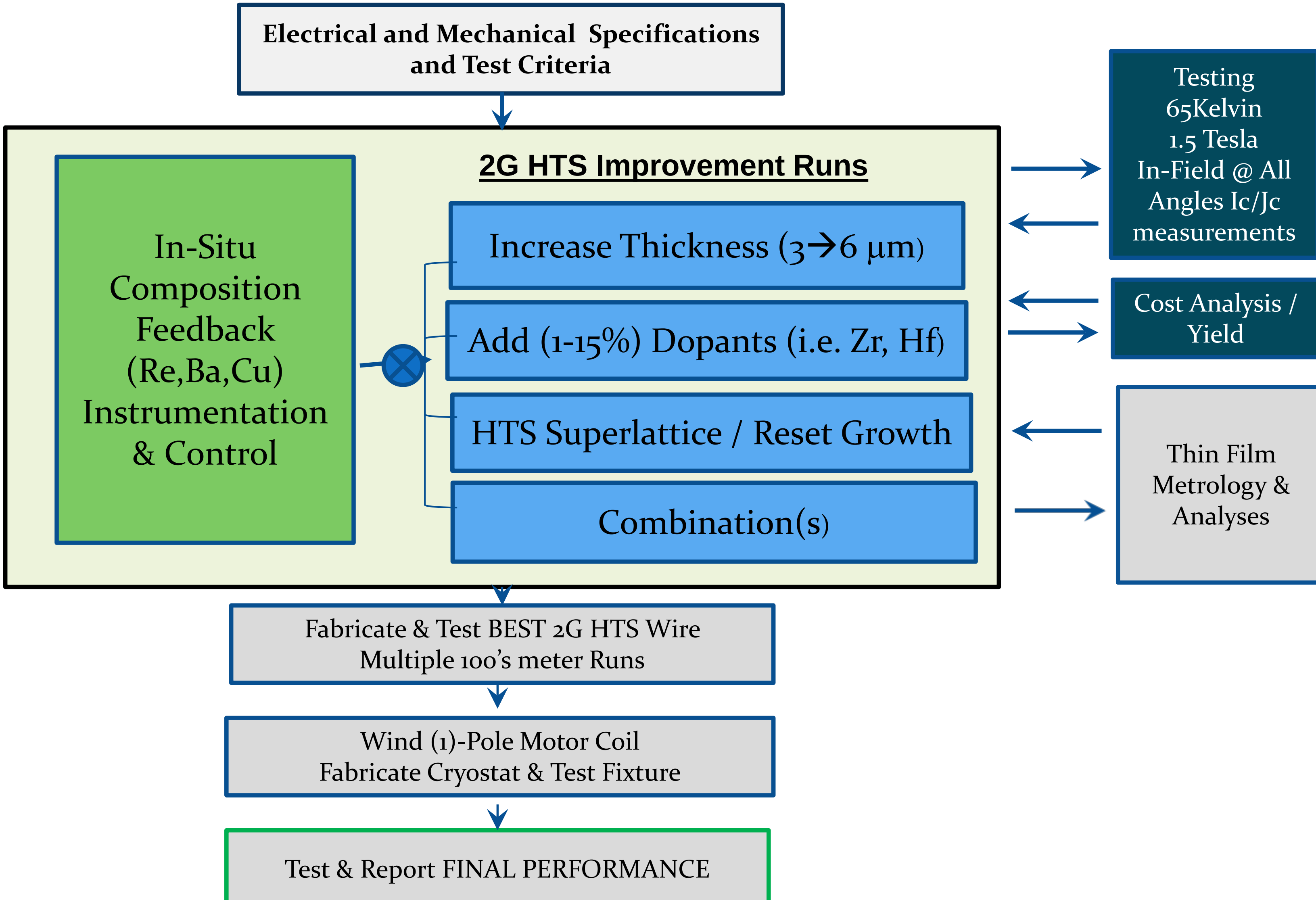
100mm	100mm	12mm	Buffer	MgO-Cubic	$Re_1Ba_2Cu_3O_{7-d}$	Ic Metrology	Encapsulant
Foil Supply	SDP	Slit & Clean	RF PVD	IBAD & EPI	RCE-CDR	TapeStar	Copper PVD
Polycrystalline Metal	Amorphous Ceramic		Amorphous Ceramic	Aligned Crystalline	CeO_2 – Heat-Up ReBCO - @ Temp Silver -Cooldown		

Vendor Process | STI In-House Process | DOE Award Focus

Program Overview

65K,1.5T,1440 A/cm

Improve 2G HTS In-Field Performance for Electric Machines and Reduce cost



Technical Innovation

- What's new in your approach, and why do you think it will be successful?

  1] Thickness – <(5)μm on wafer scale & limited flex substrate

  2] Intrinsic & Extrinsic Pinning – reported by others as very successful, untried @ STI. Required additional source evaporant & controls.

    - We have used Intrinsic Pinning sucessfully; off-stoichometry & ReOx

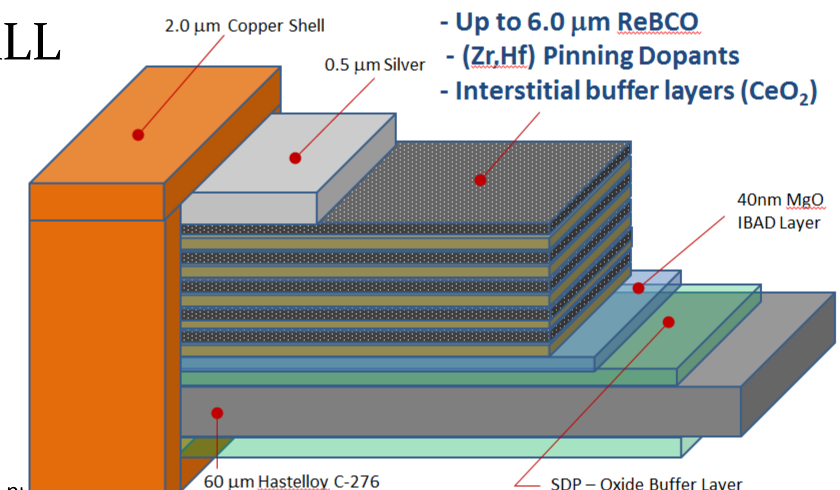
  3] Reset-Buffers /Alternating Superlattics– we've proven 'reset' film growth @ wafer scale is possible

    - c-axis screw dislocations @ > 1 μm tend to 'heal', reset their growth.

  - COMBINE ALL to find 'BEST' B-field performance @ all angles AND Mfg. Yield.
  - Cost increases; (minimal, <10-15% COGS increase)
    - RE/Ba/Cu Raw materials ~2X Thickness, 2X material cost
    - Pinning Dopants 5-15% stoichometery, extra sources
    - Personnel; Run preparation + 2 Hrs runtime batch
  - Yield cannot go down even with added deposition complexity

Fundamental Knowledge to be Gained

- What are the key unknowns to be answered?
  - What is the ReBCO Film thickness limit which maintains a increasing Ic vs. ReBCO thickness?
    - 230 Amps @ 0.7 micron // 800+ Amps @ 3.2 micron ReBCO
    - Substrate/buffer/ReBCO film stress optimization vs. thickness?
  - What is the optimum pinning dopant concentration and ReBCO stoichometry which enhances Ic and maintains high production yields?
  - What are the B-field performance effects of a multi-layer film stack of ReBCO with unique properties in each layer?
  - YIELD of ALL

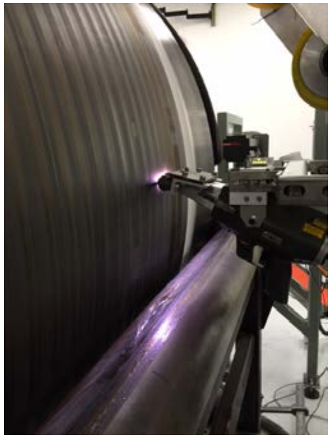


Technical Approach

- Address scientific/technological approach
  - Test/Evaluate 3+ wire enhancement options (thick/intrinsic/extrinsic/superlattice/combinatorial)
  - Assess mechanical, magnetic, electrical performance + Mfg. Yield
  - Choose 'best-in-class' to scale-up 100's meters length
  - Build demonstration Mwatt coil → (1) motor pole
- Address participant roles and responsibilities
  - M.I.T. – Dr. Leslie Bromberg, HTS Applications
    - In-Field measurements , HTS performance validation
    - Design / fabrication coil & testing apparatus
  - University of North Texas – Dr. Marcus Young, materials
    - SEM, TEM, Metrology
  - TECO/Westinghouse – H. Kamaker/E. Chen
    - Design 1.5T motor coil Mech., Magnetic, & Elect. coil engineering
    - Wire specifications for 'in-motor' coil performance

Technical Approach

- What is the technical approach for the project?
  - Address potential project risks and unknowns; and methods and timeline for mitigation.
    - Risks: Obtaining <1440Amps/cm @ 65K, 1.5T
    - Repeatability of Process conditions
      - In-Situ Process Controls → LIBS –or- LA-ICP-MS
    - Long-Length Measurements in Field @ all angles
      - Need a new metrology machine designed.
      - Wire quality for Coil Fabrication & Application
      - TECO will lead specification development
      - STI will test on existing test fixtures

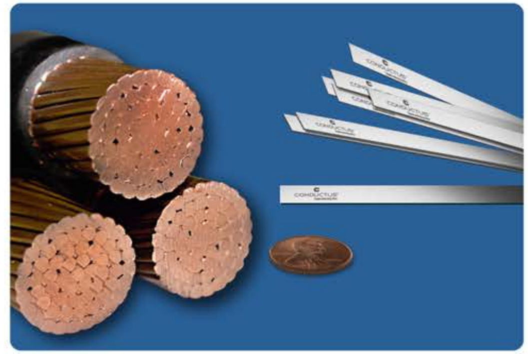


Laser Cleaning

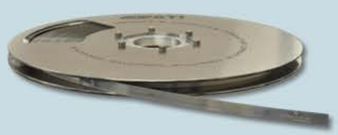
  - Address unique execution attributes (e.g., market leadership position, commercialization experience, etc.)
    - We are the only 2G HTS company which can do THIS process.
    - Proven commercial track record of HTS products - over 6,000 HTS products deployed in Tier 1 wireless operator networks
    - Today, 100% focused on commercializing 2G HTS wire

Validation of the Gained Knowledge

	CONDUCTUS® Superconducting Wire	Conventional Copper
Capacity	100X Greater	Low
Efficiency	Extremely High	Poor - Significant Heat Loss
Size, Weight	Compact, Light Weight	Large and Heavy
Economics	Improving	Static, Limited
Design	Enabling New Devices	Limited



CONDUCTUS®
Superconducting Wire



Next Generation Machines
Enabling Technology
2G HTS Superconducting
Wire vs Conventional Copper

- Heavy Industry: highly efficient motors and generators
- Energy: New high efficiency large scale wind turbines, New energy storage
- Defense: High power density systems, electric aircraft
- Transportation: Ship propulsion, MagLev
- Medical: Ultra sensitive Imaging Techniques
- Science: 3X the performance of current superconducting magnets, fusion

Industry stake holders: Advanced Superconducting Manufacturing Institute (ASMI) participation – Large Addressable Market

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

Transition (beyond DOE assistance)

- Engineering effort under EERE program will be implemented on commercial scale production system
- Production capacity ; 750km (assumes 4mm)
- New high performance low cost wire for NG machines developed under EERE will be ready to be scaled up after year 3
- State of the art factory, expandable by 5X to meet demand.
- Manufacturing scales with modular design

Measure of Success

Next Generation Electrical Machines; Enabling Technologies

- ✓ **300X the power density over conventional copper wire**

Advance Superconductor Manufacturing Institute (ASMI) estimates market opportunity is $40B by 2030

Goal: Eliminating Resistance with 2G HTS wire in new electrical devices

- ✓ Massive gains in efficiency from infrastructure to enterprise.
- ✓ Existing copper infrastructure suffers from up to 18% power loss due to electrical resistance

Program success determined by the integration of NEW 2G HTS wire in innovative Next Generation Electrical Machines for commercial deployment.

Project Management & Budget

- Project plan is 3 Years
- Project task and key milestone schedule
- Year 1 – Improve Ic and reduce cost of 2G HTS wire
- Year 2 – Optimize Ic – fabricate 'best-in-class' wire in quantity
  - 1440A @ 65K in field of 1.5T
- Year 3 – Build and validate a 1250 HP Coil in cryo test fixture
  - Meet target cost objective of $50kA-m

Total Project Budget	
DOE Investment	$4,497,115
Cost Share	$1,124,279
Project Total	$5,621,394