Advanced Manufacturing of High Performance Superconductor Wires for Next Generation Electric Machines

DE-EE0007869

University of Houston, SuperPower, E2P Solutions, TECO-Westinghouse

Budget Period 1

Venkat Selvamanickam
University of Houston

U.S. DOE Advanced Manufacturing Office Program Review Meeting
Washington, D.C.
July 17-19, 2018

Overview

Timeline

- Project started May 2017
- Project ends April 2020
- Project 33% complete

Barrier to be overcome

•High Temperature Superconductor (HTS) wire is manufactured in piece lengths of 100 – 500 m with 400X the current carrying capacity of Cu wire

•But at $340/kA-m, it is **10X** price of copper wire

Budget Period	DOE Funding	Cost Share
1	$1,521,011	$380,419
2	$1,529,216	$387,519
3	$1,449,773	$379,609

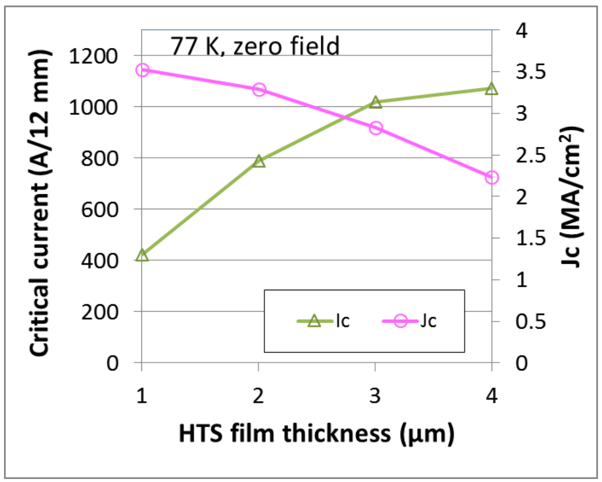
Team Member	Project Role
University of Houston	• Project Lead • Develop Enhanced Superconductor Wire and lower-cost manufacturing • Scale up to 50 m lengths
SuperPower	• Develop and produce improved buffer layer • Transition to commercial wire manufacturing
E2P Solutions	• Construct and test coil made with Enhanced Wire
TECO-Westinghouse	• Design superconductor motor with Enhanced Wire • OEM to transition superconductor motor technology

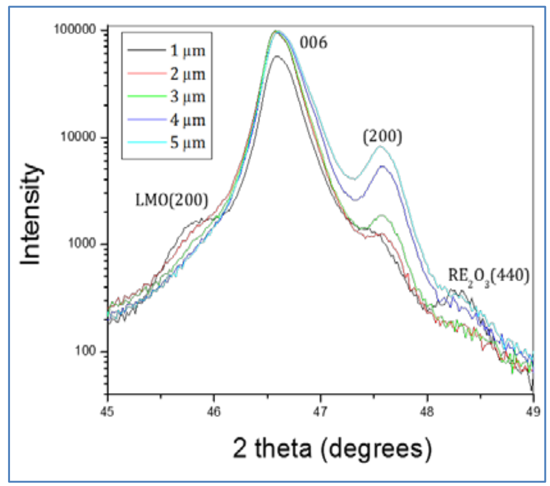
Project Objective

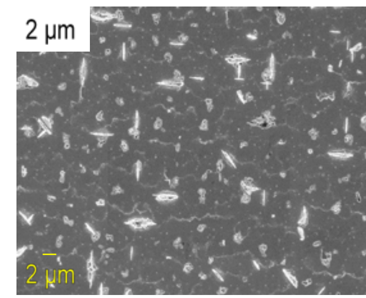
- Project directly supports AMO's Next Generation Electric Machines (NGEM) mission to develop a new generation of energy efficient, high power density, high speed, integrated drive systems for a wide variety of critical energy applications.
- Potential energy savings in using Enhanced Superconductor wire in next-gen industrial motors: > 6250 GWh (0.19% of total US electricity)
- Specific project objectives:
  - Reduce wire price by **10X** to $33/kA-m based on performance at 65 K, 1.5 T to enable commercial use of superconductors wires in NGEM
    - Improve the critical current (I_c) at 65 K, 1.5 T by > **4X** to 1440 A/cm as well as reduce the wire cost by ~50%.
  - Demonstrate advanced manufacturing process for low-cost production of superconductor wires with enhanced performance.
    - Scale up advanced high I_c, low-cost wire to 50 m lengths.
  - Demonstrate the viability of the enhanced superconductor wire for use in motors operating at 65 K
    - Design, construct and test a rotor coil for a 500 HP motor.

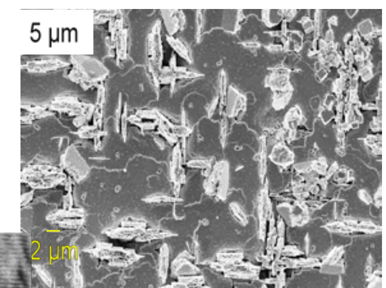
Technical Innovation: Opportunities and Challenges

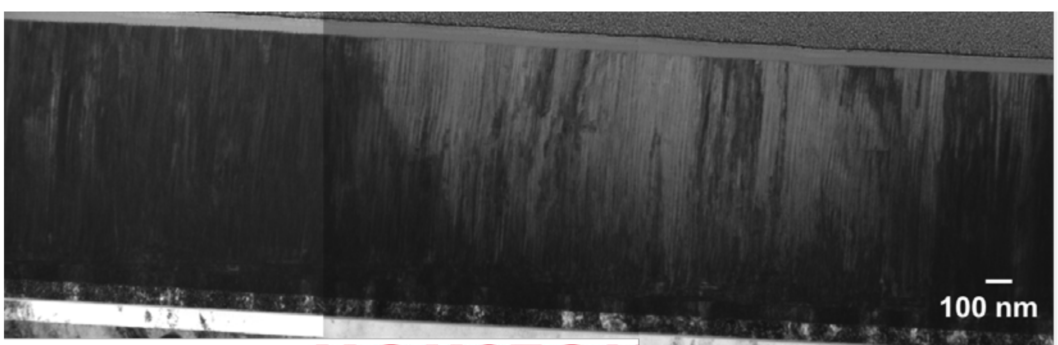
- Increase critical current (I_c) by increasing film thickness from 1.5 µm to 4 µm.
- Increase I_c with a higher density of nanoscale defects (e.g.) $BaZrO_3$ (BZO)
- Reduce cost by improving precursor-to-film conversion efficiency (precursor is highest cost component and efficiency now is only 15%)

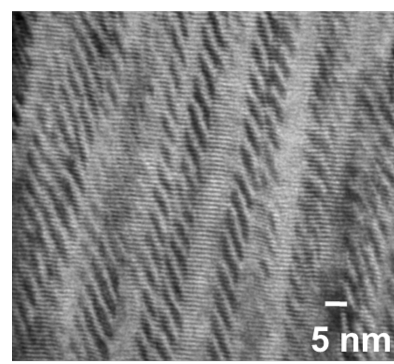




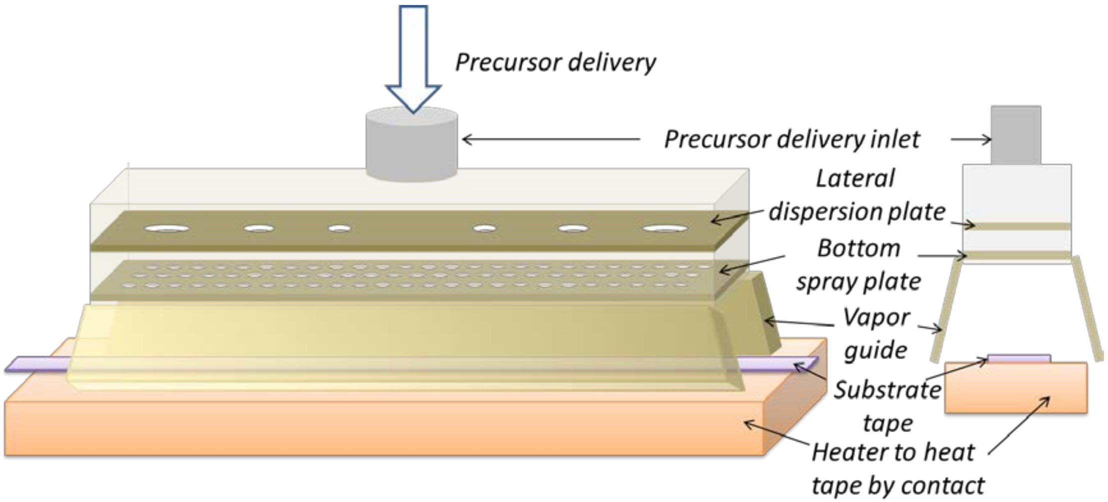


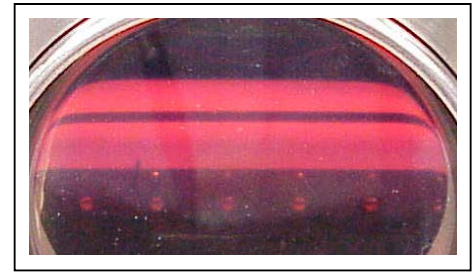




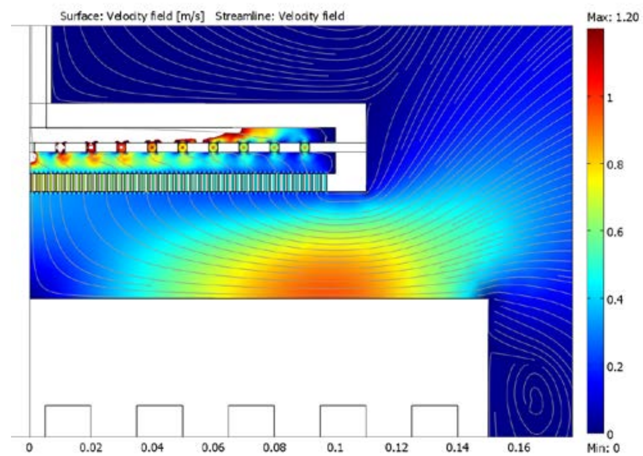


Challenge: Deficiencies of conventional manufacturing





Contact heating in conventional Metal Organic Chemical Vapor Deposition (MOCVD)

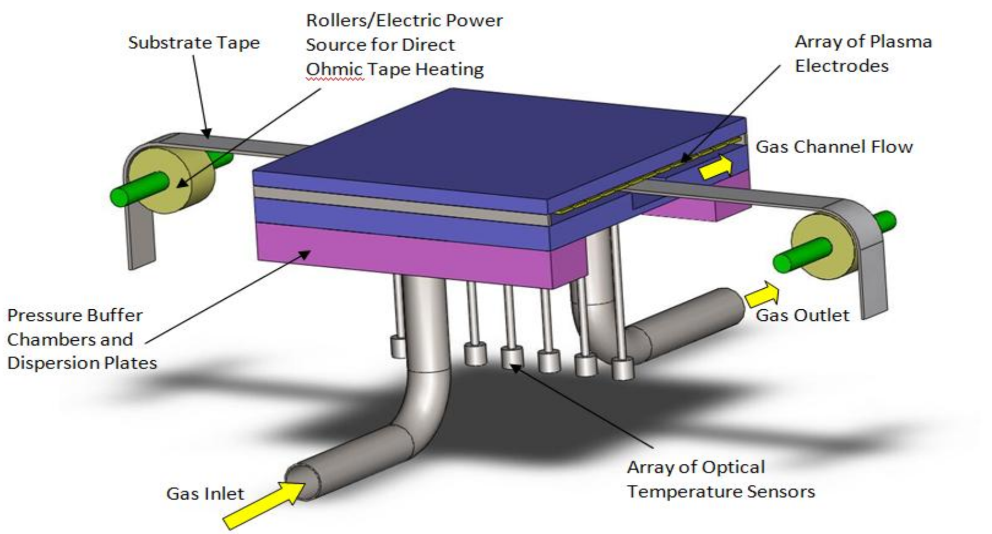


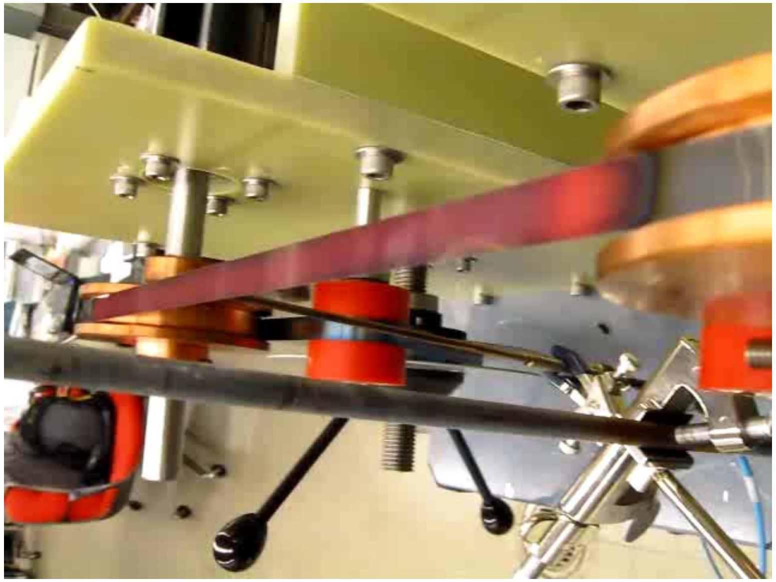
- Poor temperature control and precursor flow non uniformity in conventional R2R MOCVD wire manufacturing → reduction in J_c of thick films, inconsistent growth of nanoscale defects and low manufacturing yield of high I_c wires
- Highly turbulent precursor flow → very inefficient conversion of expensive precursor to film (~ 15%)

Existing MOCVD reactor design is not suitable for level of process control needed for high and consistent performance and for cost effective material use

Technical Approach: Advanced MOCVD

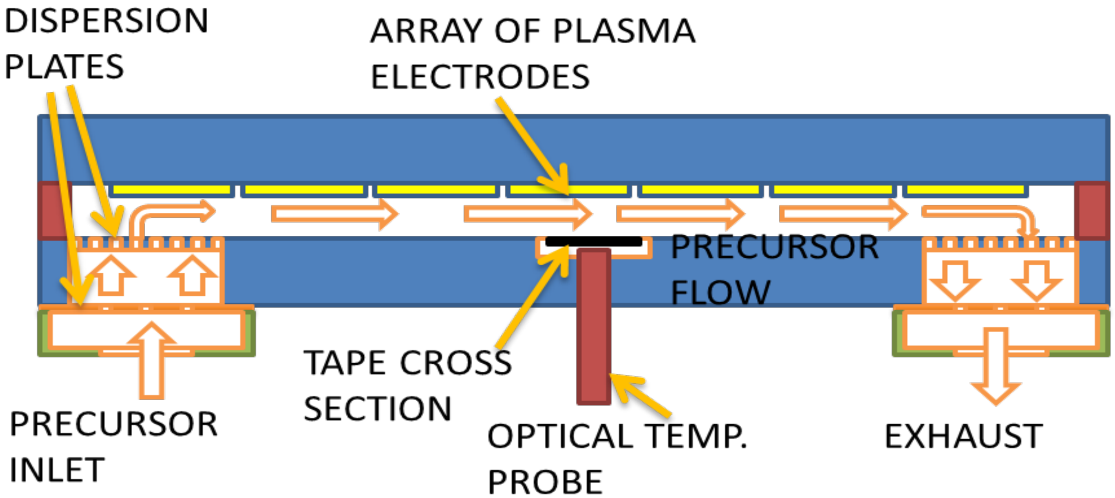
- New reactor to address all deficiencies of current production tools designs
  - Derived from modeling
  - Low volume, laminar flow design for uniform temperature, flow, higher conversion efficiency of precursor to film
  - Direct tape heating, direct tape temperature monitoring
  - Stable precursor delivery system
  - Plasma enhancement for enhanced reaction kinetics

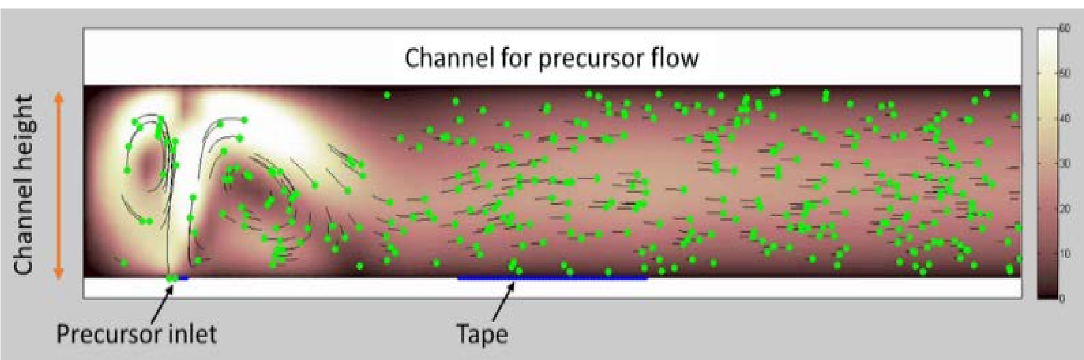


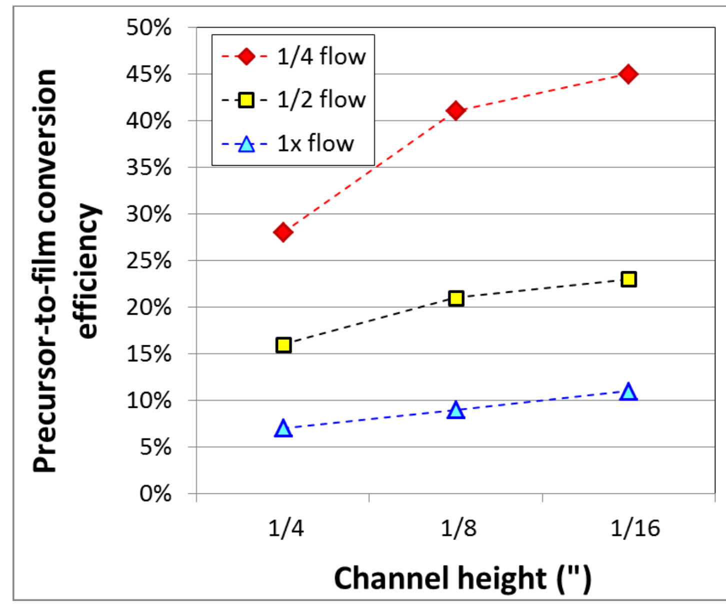


Several new innovative designs implemented in new MOCVD reactor

Technical Approach: Advanced MOCVD



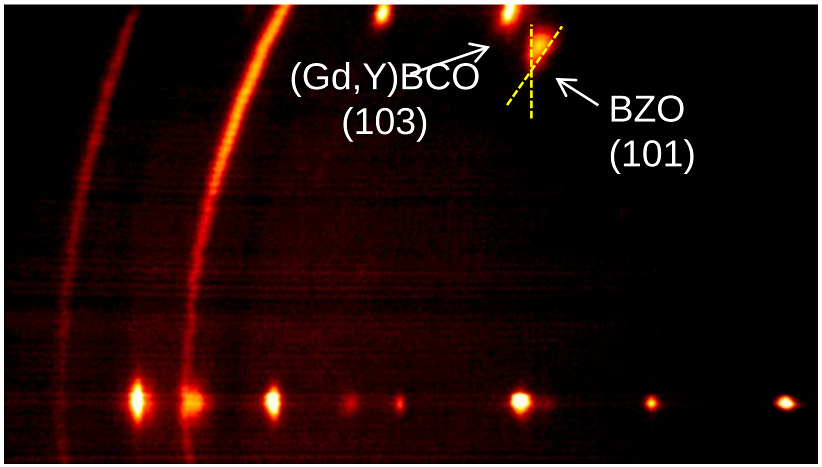




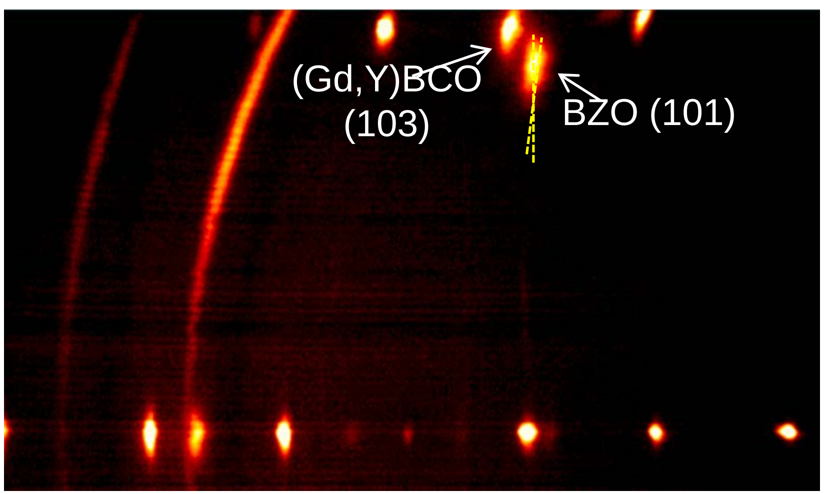
Modeling of flow dynamics in Advanced MOCVD reactor shows 45% (3X) precursor to film conversion efficiency can be attained

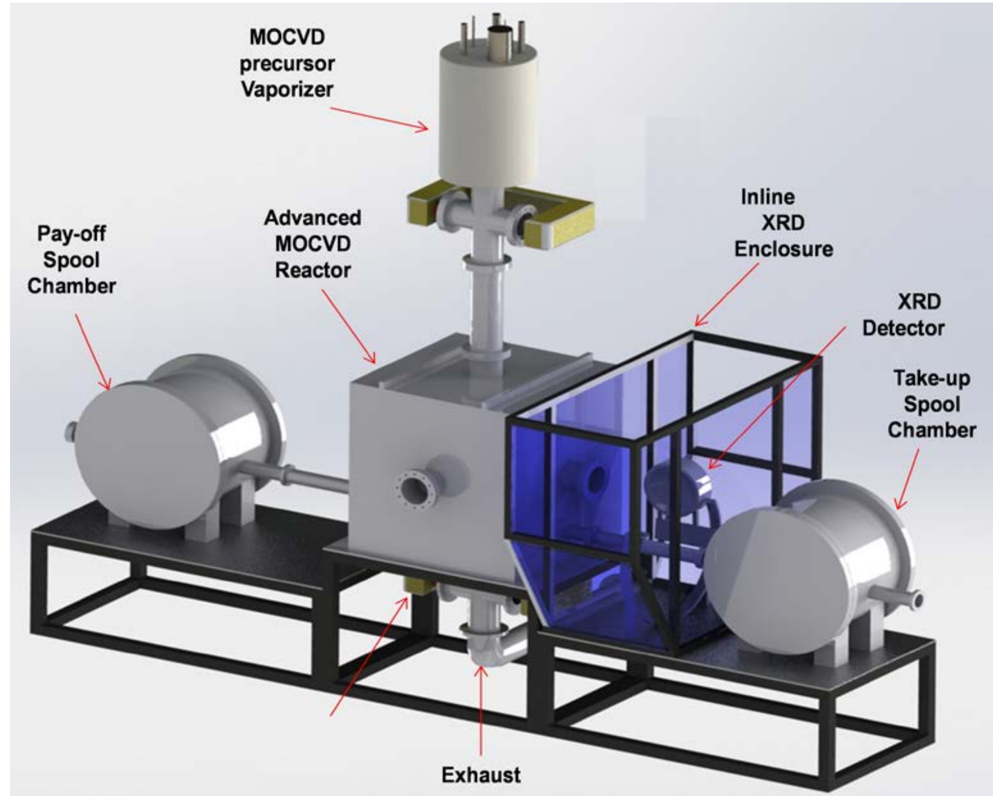
Technical Approach: In-line 2D XRD

Low I_c wire: Normal BZO nanoscale defects



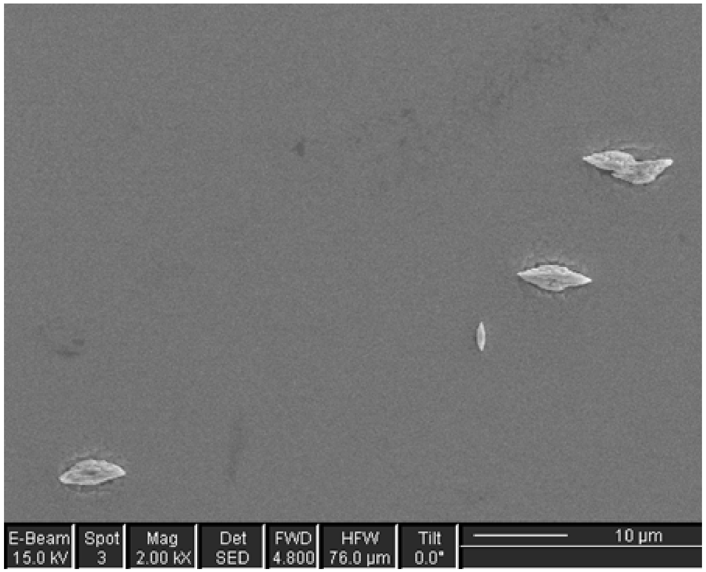
High I_c wire: Small BZO nanoscale defects



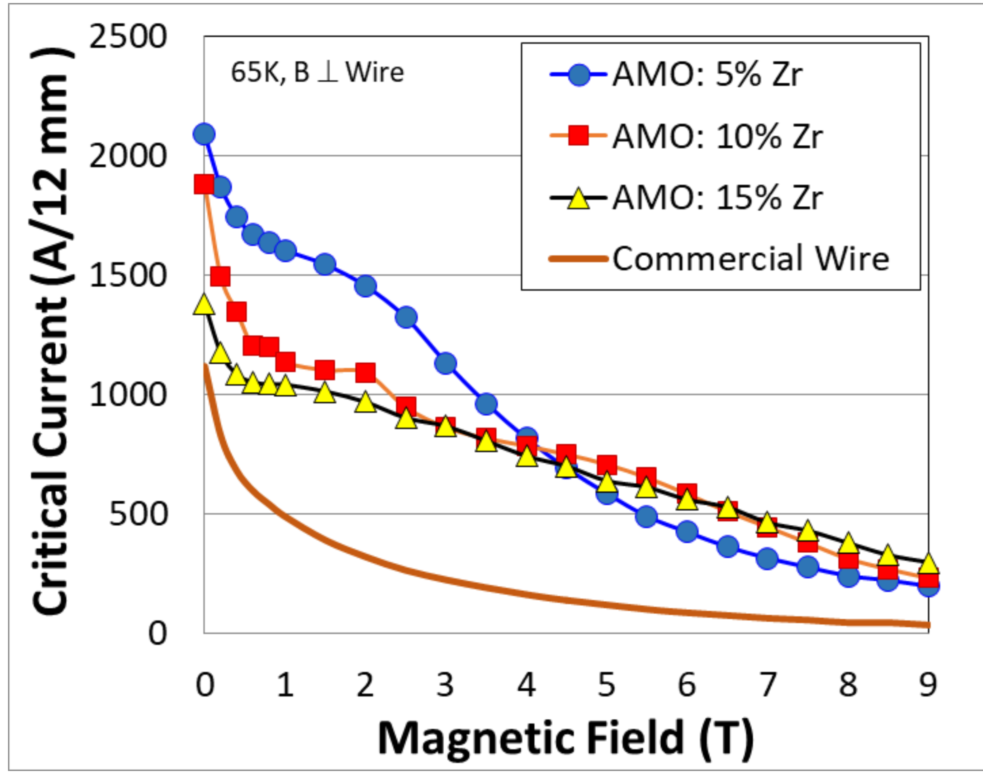


In-line 2D X-ray Diffraction system in MOCVD manufacturing tool for real-time verification of nanoscale defect growth in HTS film for high-yield manufacturing of high-performance wires

Results and Accomplishments



4 µm thick films made by Advanced MOCVD with less than 3% a-axis grains



- *Optimized Zr content in 4 µm films for best performance at 65 K, 1.5 T*
- *Critical current at 65 K, 1.5 T = 1285 A/cm*

  → *exceeds Budget Period 1 Go/No-Go Milestone of 800 A/cm*

  → *4X critical current of Commercial wire*
- *Next milestones: Increase I_c to 1440 A/cm & scale up to 50 m lengths*

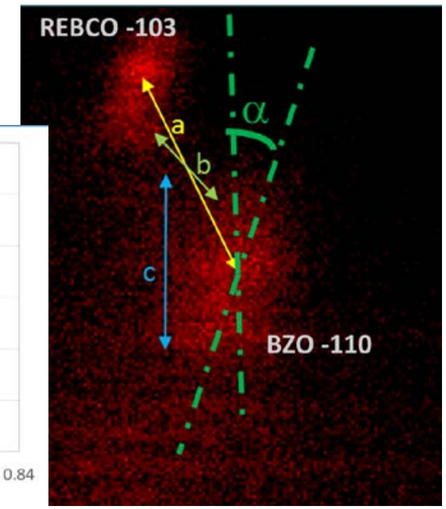
Results and Accomplishments

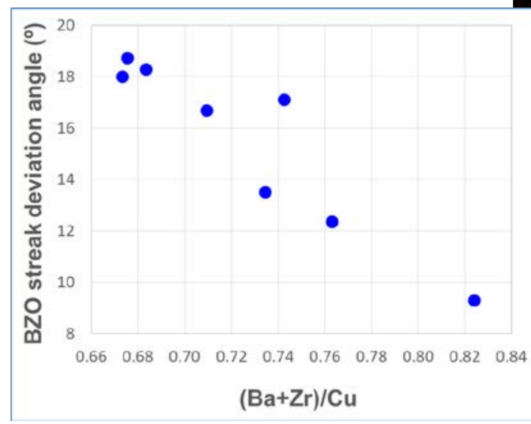
46% (3X) precursor-to-film conversion efficiency achieved through modified Advanced MOCVD reactor design

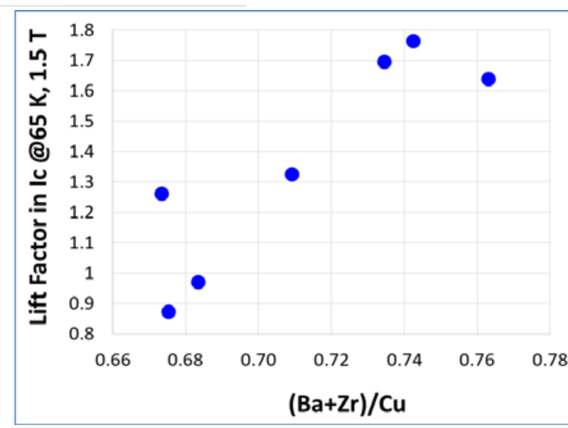
Reactor design	HTS Film Thickness (µm)	Precursor-to-film conversion efficiency
¼" laminar flow channel height, standard precursor flow	3.8	17%
⅛" laminar flow channel height, ½" precursor flow	5.2	46%

- *3X increase in precursor use efficiency → 5 µm film (with much higher performance) can be made at the same unit cost of today's commercial tape (1.7 µm film)*
- *Next – Increase efficiency to 5.4X & scale up to 50 m*

Utilized 2D-XRD for non-destructive prediction of film composition and wire performance







- *Next– in-line 2D XRD in MOCVD for real-time QC*

Transition and Deployment beyond this Program

Advanced Manufacturing of High Performance Superconductor Wires will enable commercialization of Next Generation Electric Machines through:

- Lower wire cost → Competitive capital cost → Short term for ROI (**1.5 years compared to 7 years with today's wire**)
- Higher operating temperature (65 K) → Simpler cryogenics → Higher Reliability
- Consistency in performance →Predictability
- Higher throughput → High volume production → Availability

Enhanced, low-cost wire manufacturing technology will be commercialized by our partner, **SuperPower**

Superconducting motors using enhanced, low-cost wire will be commercialized by our OEM partner, **TECO-Westinghouse**

Additional products that will be targeted with other OEMs using the enhanced, low-cost wire: **Airborne generators for electric aircraft, Propulsion motors, Utility generators and Wind generators**

Questions?