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

DE-EE0007869

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

Budget Period 2

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Overview

Timeline

- Project started May 2017
- Project ends April 2020
- Project 66% complete

Barrier to be overcome

- RE-Ba-Cu-O (REBCO, RE=rare-earth) 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 Cu

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

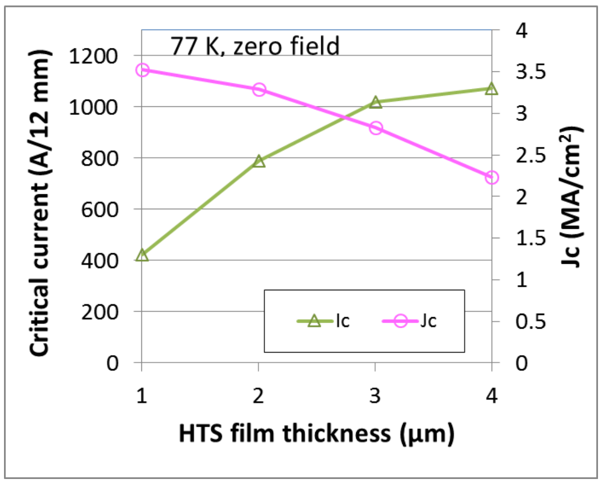
Team Member	Project Role
University of Houston	• Project Lead • Develop Enhanced Superconductor Wire and lower-cost manufacturing • Scale up to 50 m lengths
SuperPower	• Develop and produce improved buffer layer • Transition to commercial wire manufacturing
E2P Solutions	• Construct and test coil made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

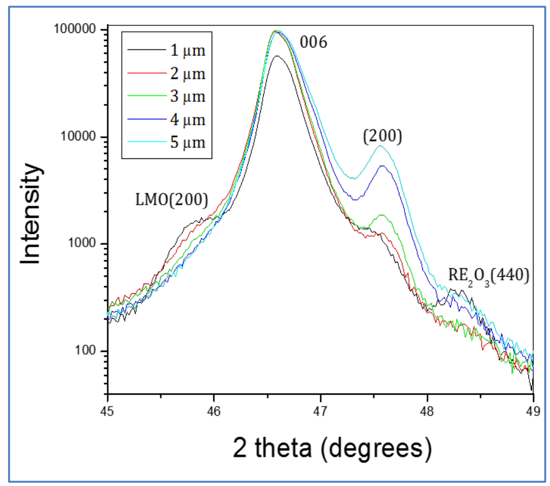
Project Objective

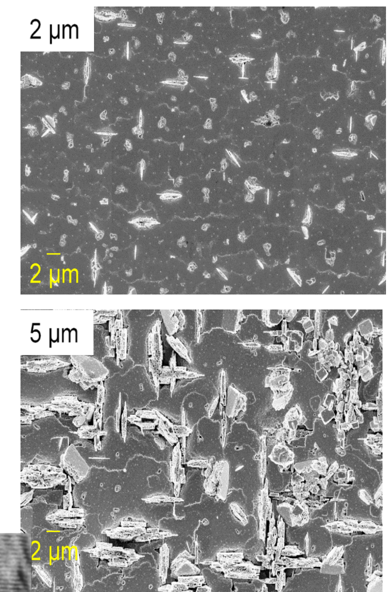
- Project directly supports AMO's Next Generation Electric Machines (NGEM) mission to develop a new generation of energy efficient, high power density, high speed, integrated drive systems for a wide variety of critical energy applications.
- Potential energy savings in using Enhanced Superconductor 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.

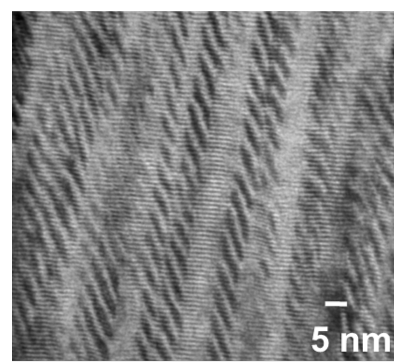
Technical Innovation: Opportunities and Challenges

- 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%)

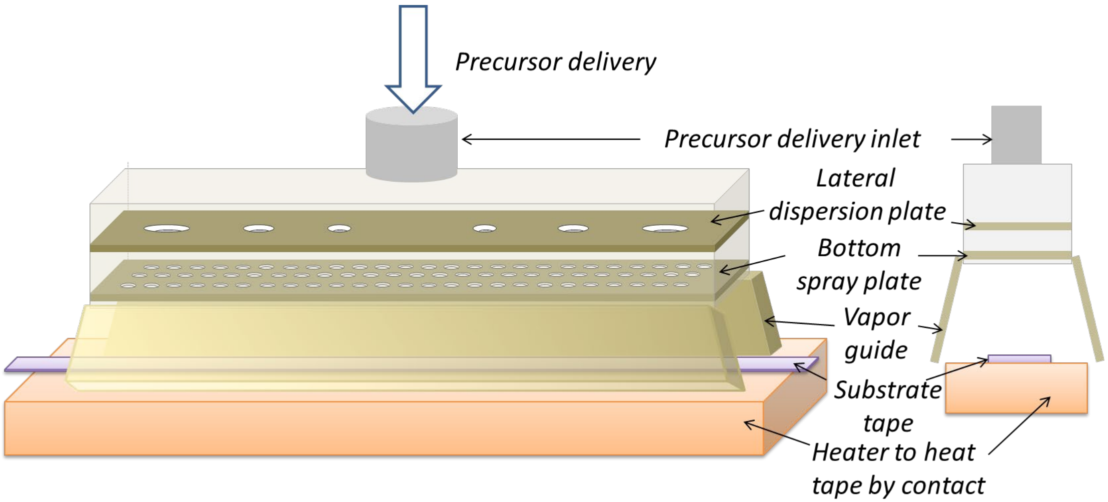


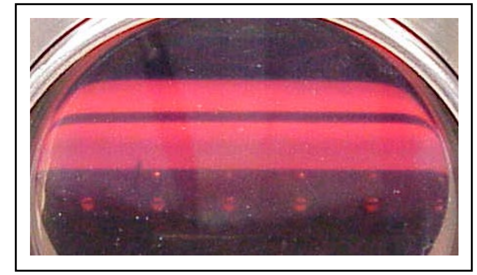




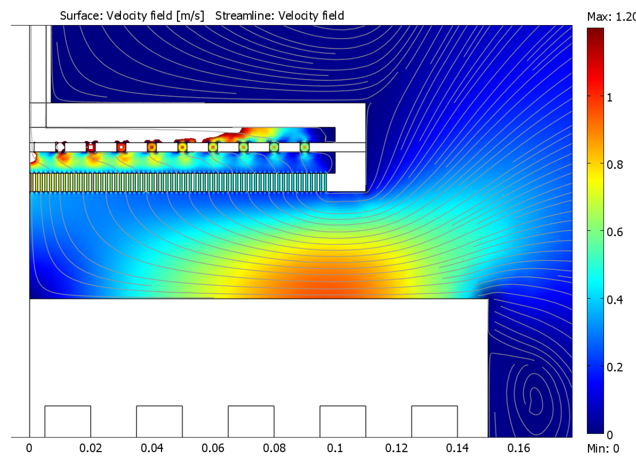


Challenge: Deficiencies of conventional manufacturing





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

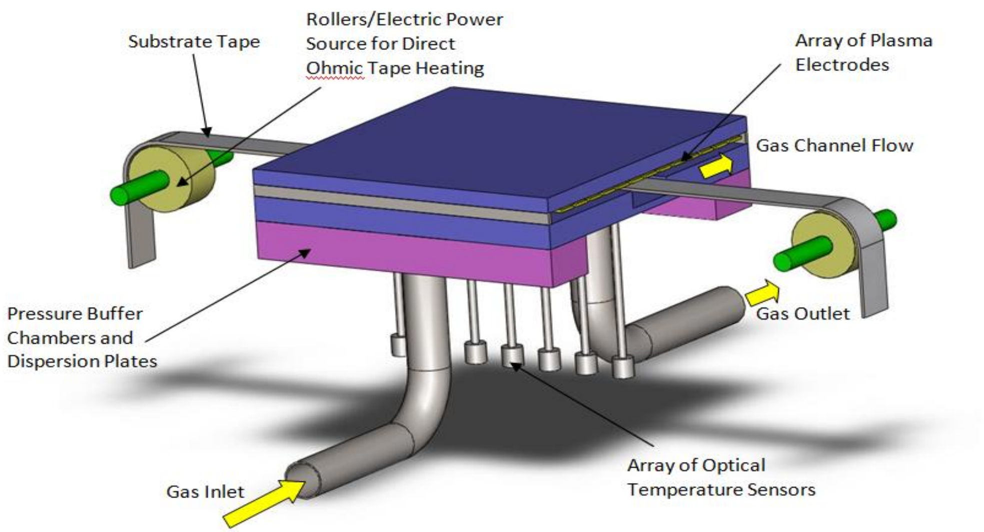


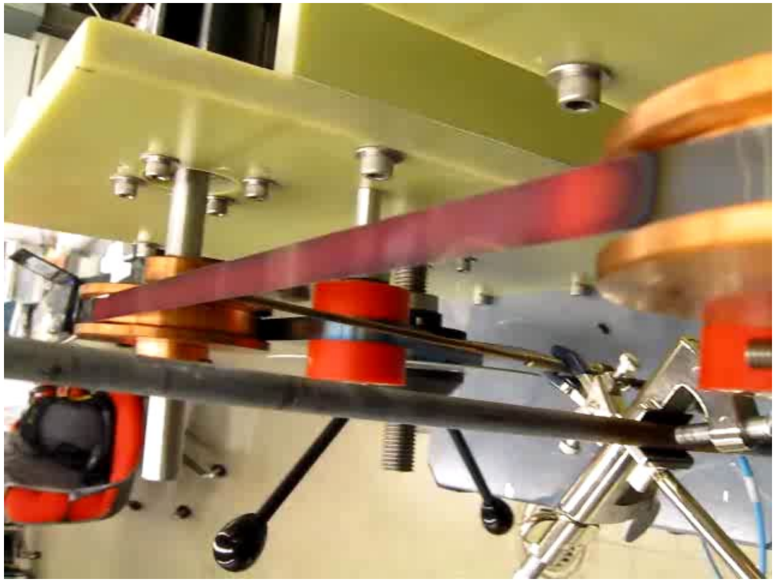
- Poor temperature control and precursor flow non uniformity in conventional R2R MOCVD wire manufacturing → reduction in J_c of thick films, inconsistent growth of nanoscale defects and low manufacturing yield of high I_c wires
- Highly turbulent precursor flow → very inefficient conversion of expensive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

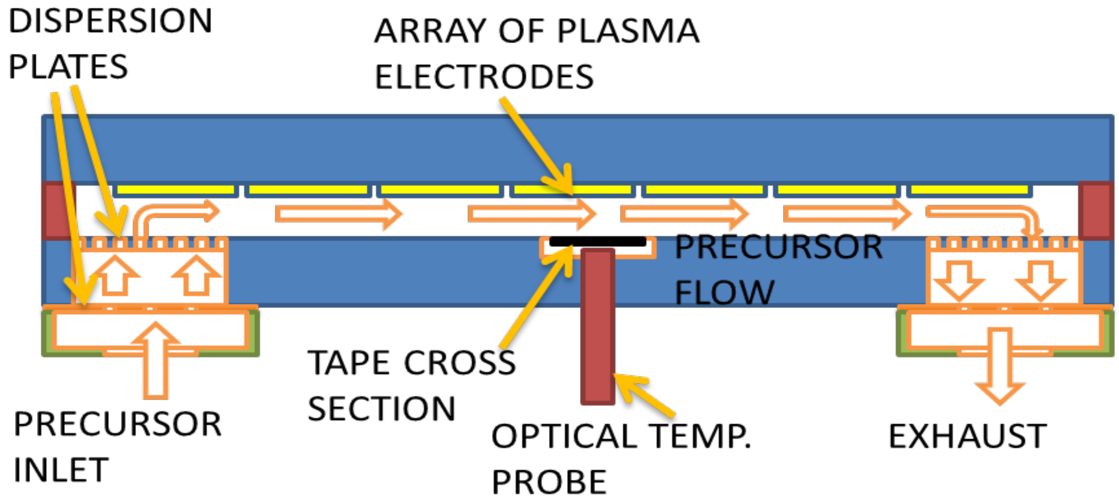
- New reactor to address all deficiencies of current production tools designs
  - Derived from modeling
  - Low volume, laminar flow design for uniform temperature, flow, higher conversion efficiency of precursor to film
  - Direct tape heating, direct tape temperature monitoring
  - Stable precursor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

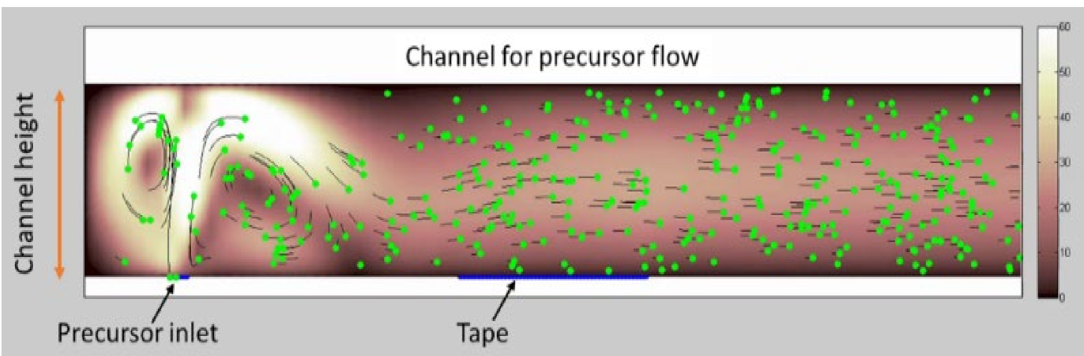


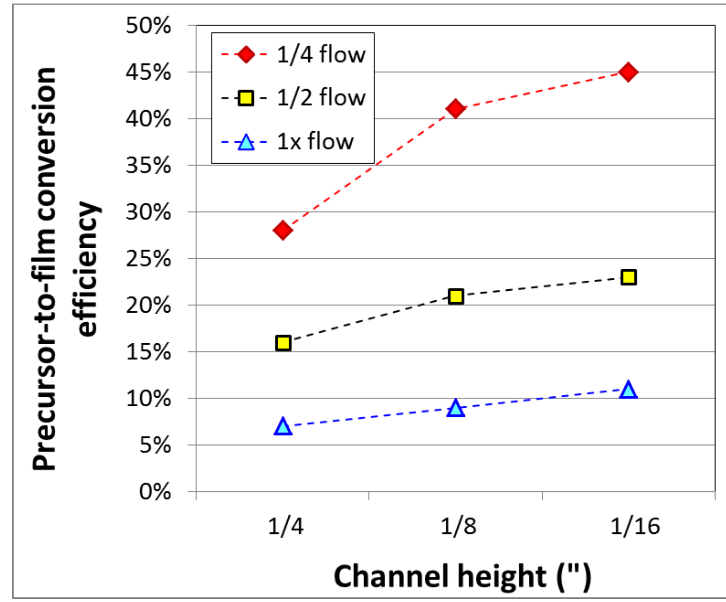


Several new innovative designs implemented in new MOCVD reactor

Technical Approach: Advanced MOCVD



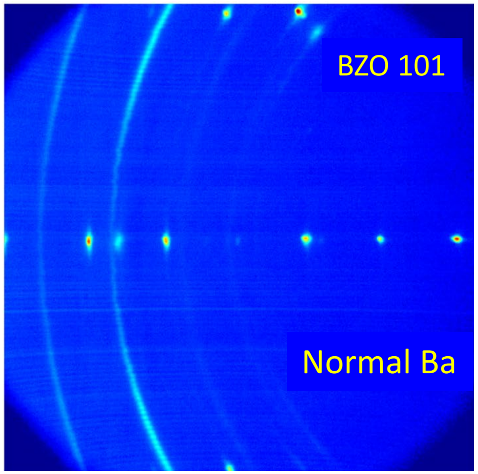


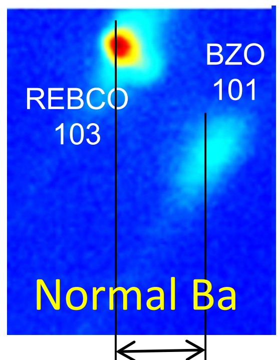


Modeling of flow dynamics in Advanced MOCVD reactor shows 45% (3X) precursor to film conversion efficiency can be attained

Technical Approach: In-line 2D XRD

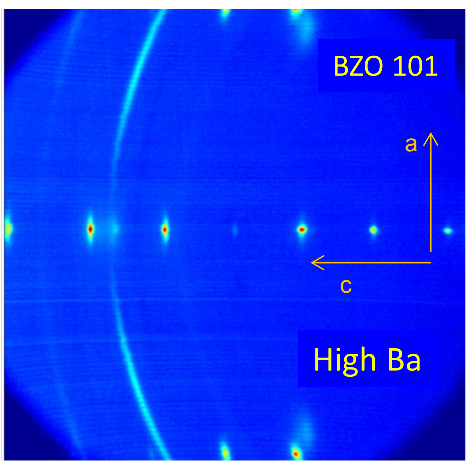
Low Ba wire: Normal BZO nanoscale defects

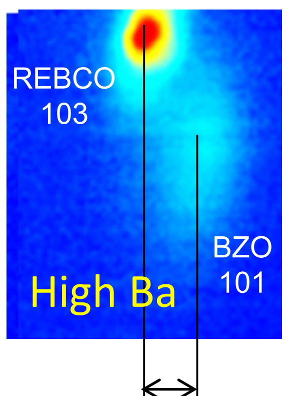




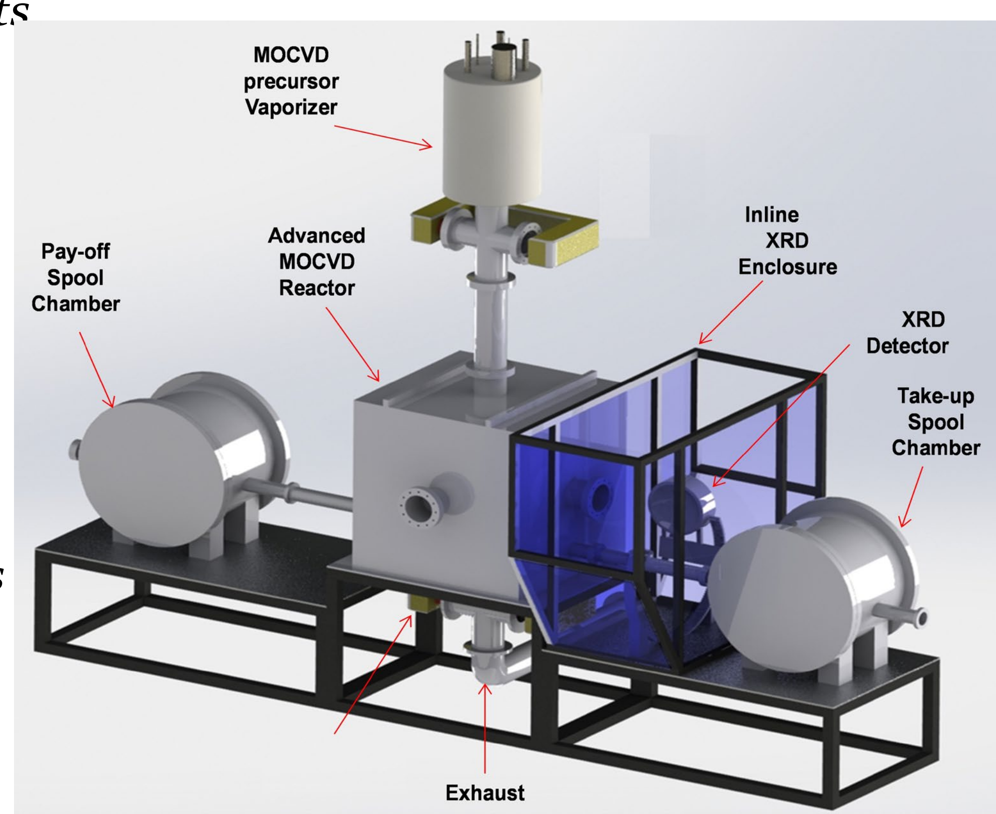
C axis mismatch

High Ba wire: Small BZO nanoscale defects



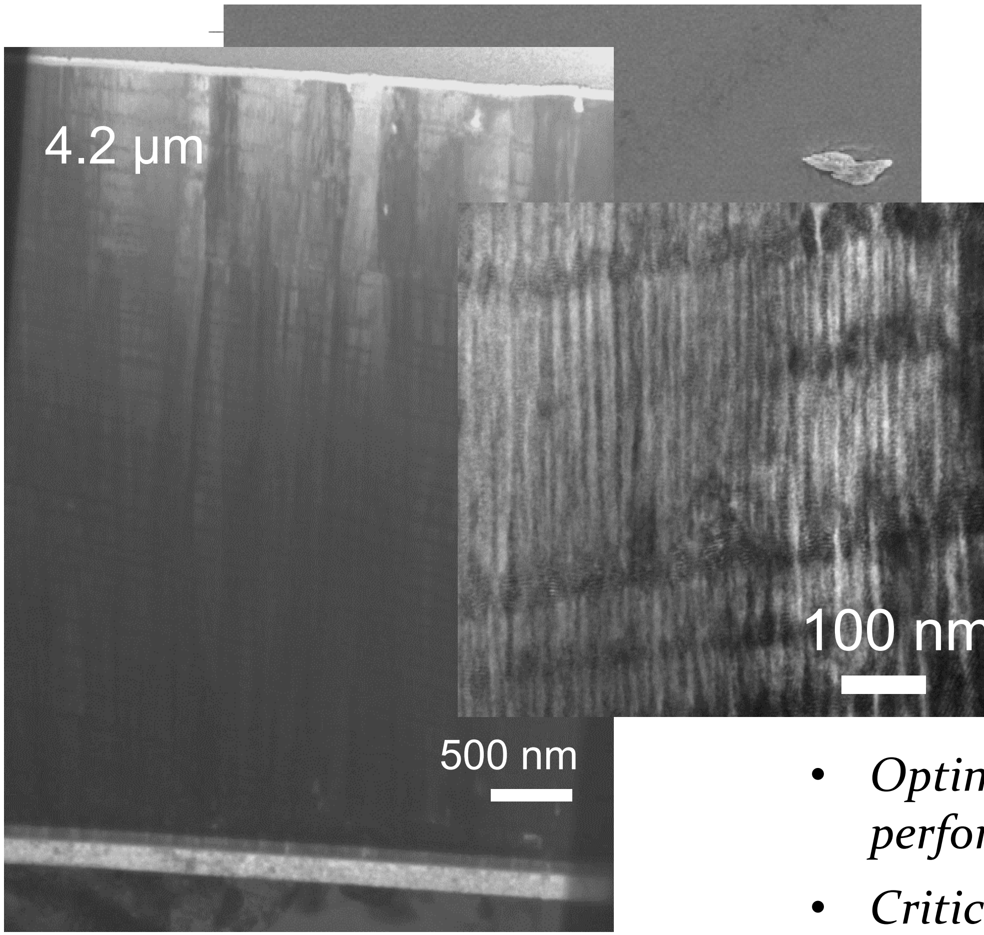


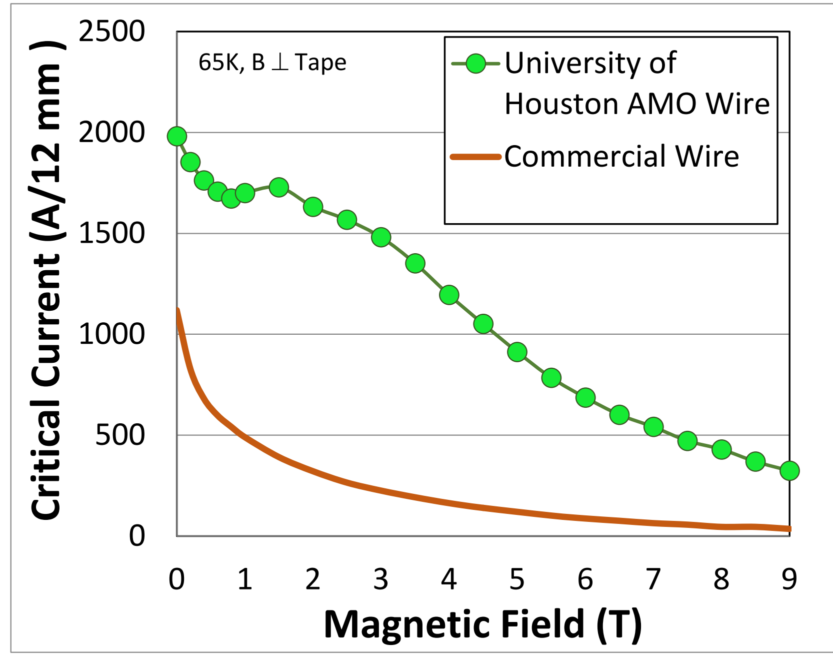
C axis mismatch



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

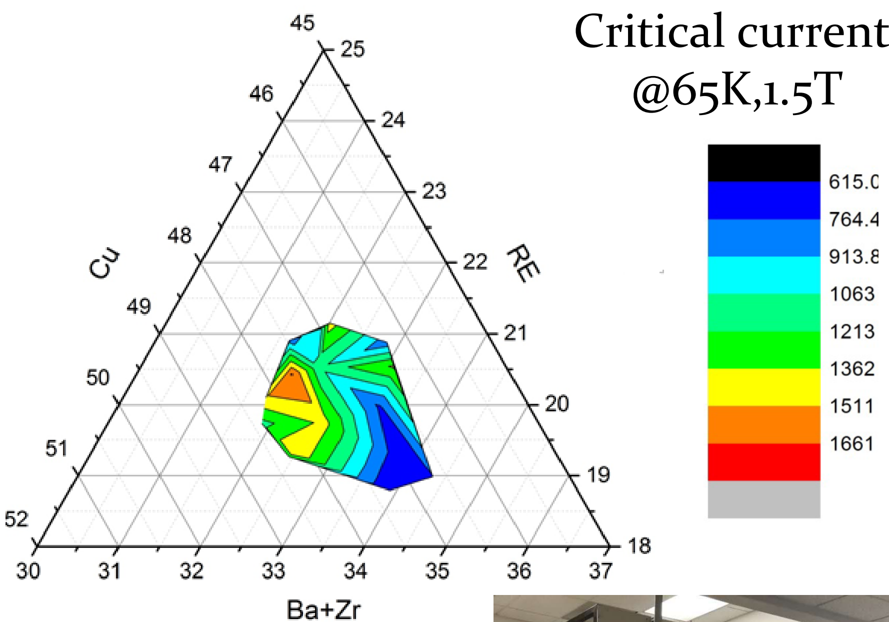




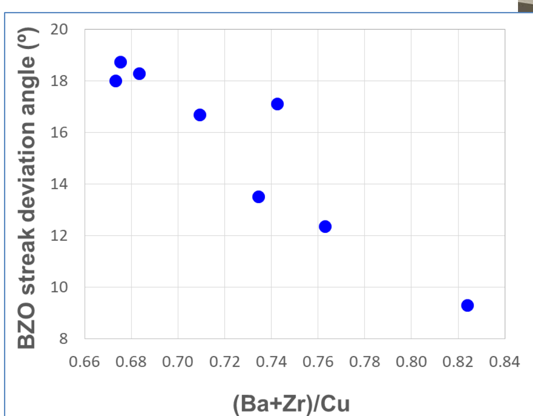
4 μm thick films made by Advanced MOCVD with less than 3% a-axis grains and continuous BZO nanocolumns

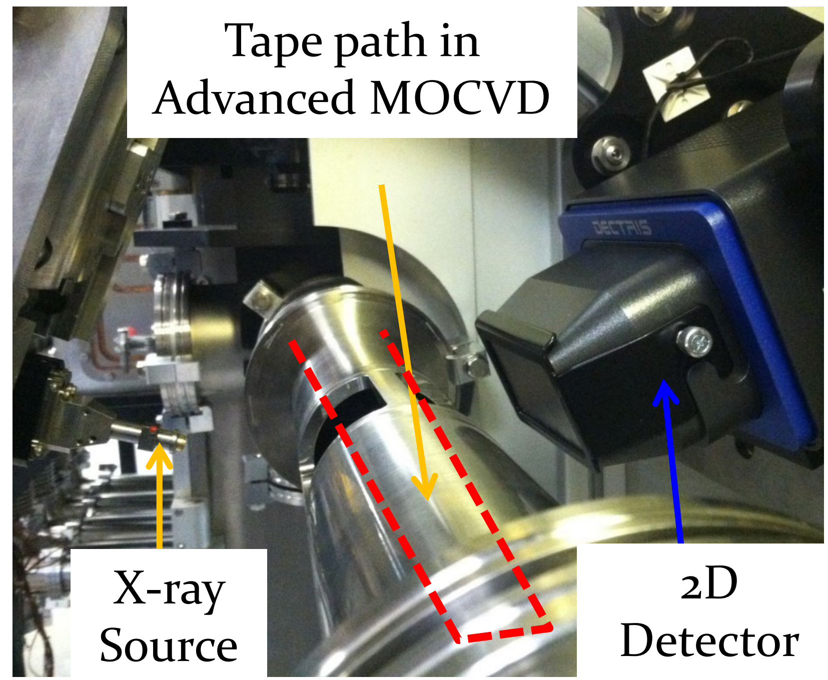
- *Optimized Zr content in 4 μm films for best performance at 65 K, 1.5 T*
- *Critical current at 65 K, 1.5 T = 1440 A/cm*
  → Met Budget Period 2 Go/No-Go Milestone of 1440 A/cm
  → 4.4X critical current of Commercial wire
- *Next milestone: Scale up to 50 m lengths*

Results and Accomplishments



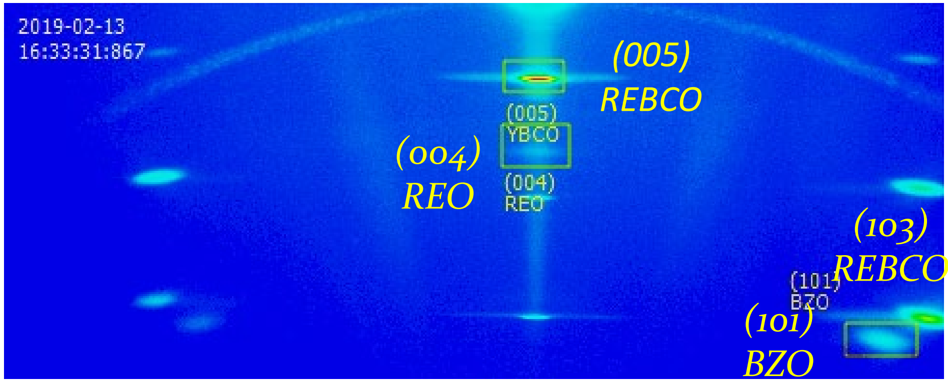
Compositional Mapping of 4 μm thick, Zr-added films made by Advanced MOCVD shows film composition has to be maintained in a narrow range



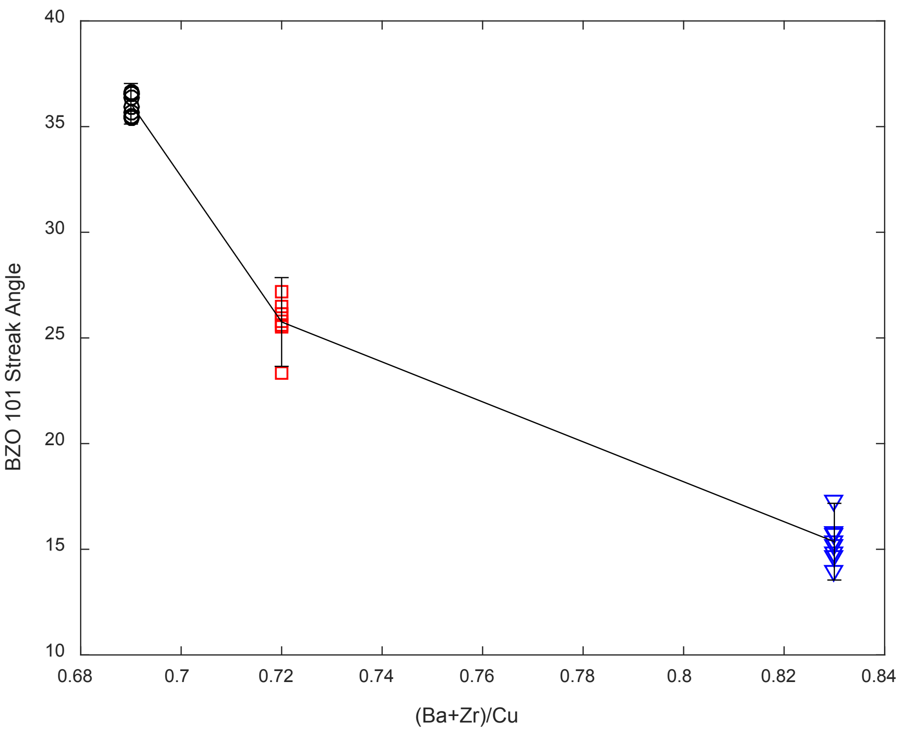


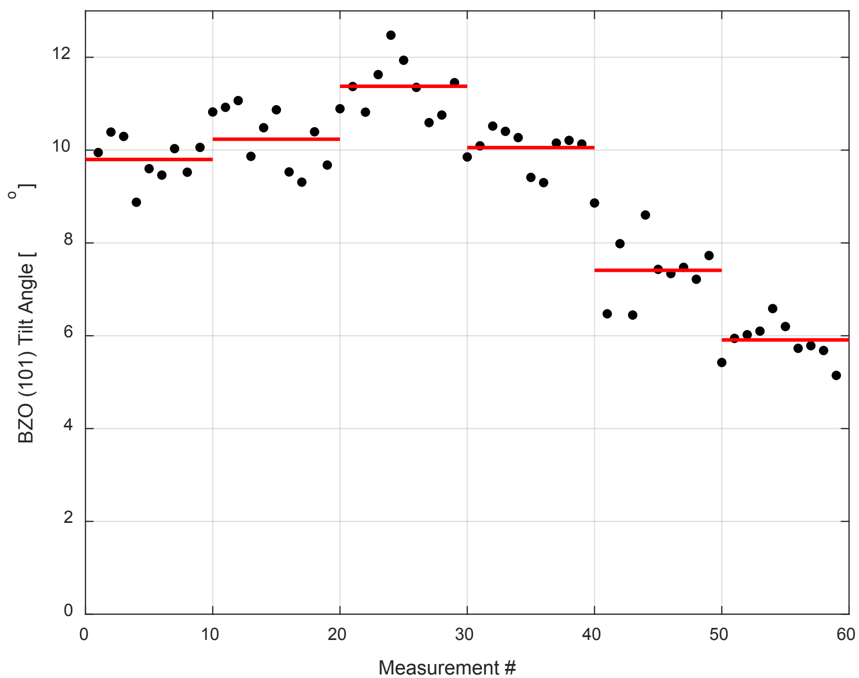
In-line 2D XRD built and installed in pilot MOCVD tool for film monitoring & control

Results and Accomplishments



Key phases (REBCO, BZO, REO) identified in a single snapshot in in-line 2D XRD in pilot MOCVD tool





- *BZO (101) streak angle from in-line XRD predictive of critical film composition*
- *Mapped variation in BZO (101) streak angle along tape length by in-line XRD*

Results and Accomplishments

Pilot-scale Advanced MOCVD built and commissioned for 50 m wire manufacturing

60% (4X) 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%
1/16" laminar flow channel height, ½" precursor flow	3.7	60%

- *4X increase in precursor use efficiency → 4 μm film (with 4.4X performance) made at a lower unit cost than today's commercial wire (1.7 μm film)*
- *Next - scale up to 50 m*

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**