Advanced Manufacturing of High Performance Superconductor Wires

DE-EE0007869

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

Budget Period 1

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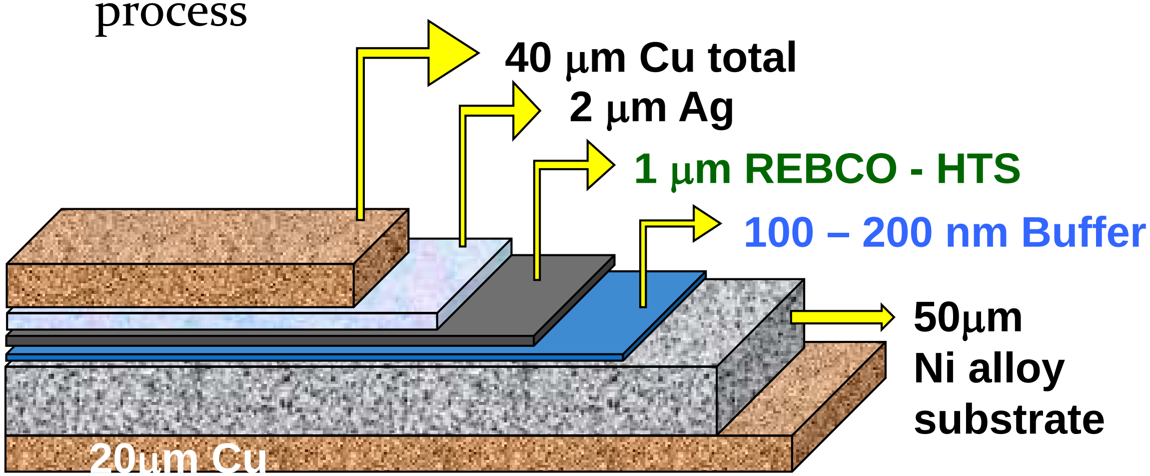
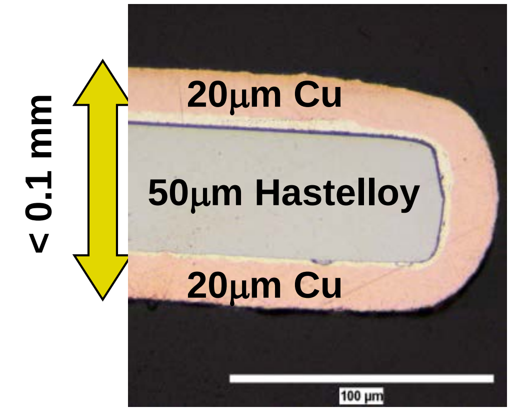
Background: HTS Wires

- HTS wire is produced by thin film vacuum deposition on a flexible nickel alloy substrate in a continuous reel-to-reel (R2R) process.
  - Only 1% of wire is the superconductor
  - ~ 97% is inexpensive nickel alloy and copper
  - Automated, reel-to-reel continuous manufacturing process





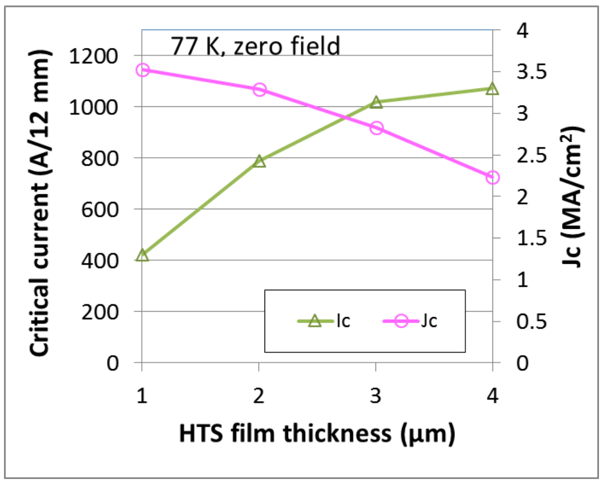
- HTS wire is manufactured in piece lengths of 100 – 500 m with 400X the current carrying capacity of copper wire
- But at $340/kA-m (based on 65 K, 1.5 T performance), it is **10X** price of copper wire

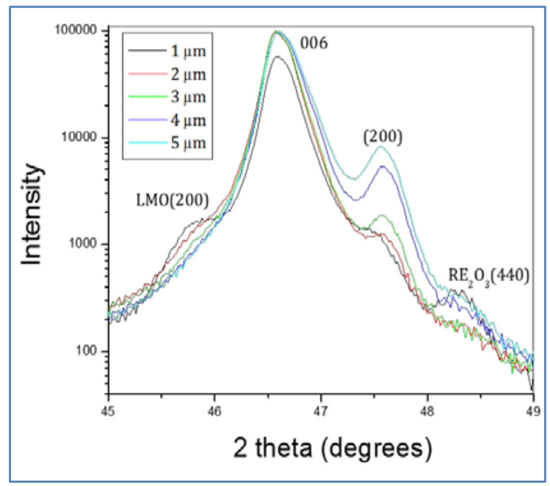
Project Objective

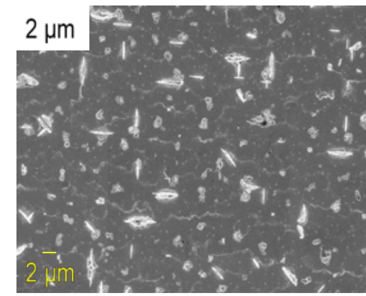
- Enable commercial use of RE-Ba-Cu-O (REBCO) superconductor wires in next-generation electric machines
  - Reduce wire price by **10X** to $33/kA-m based on performance at 65 K, 1.5 T.
    - Improve the critical current (I_c) at 65 K, 1.5 T by > **4X** to 1440 A/cm as well as reduce the wire cost by ~50%.
  - Demonstrate advanced manufacturing process for low-cost production of REBCO wires with superior performance.
    - Scale up advanced high I_c, low-cost wire to 50 m lengths.
  - Demonstrate the viability of the advanced REBCO wire for use in motors operating at 65 K
    - Design, construct and test a rotor coil for a 500 HP motor.

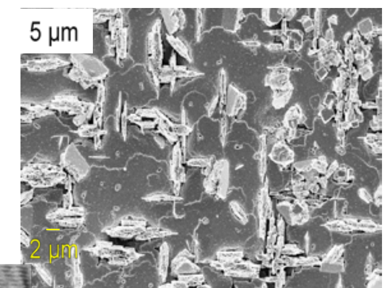
Technical Innovation: Opportunities and Challenges

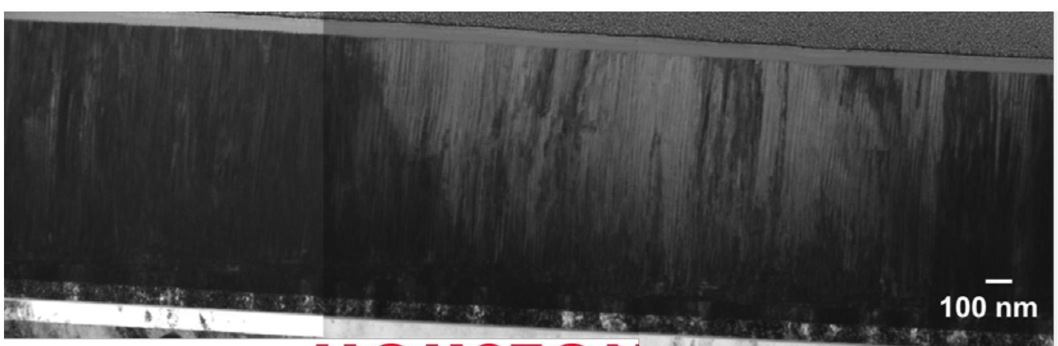
- Increase critical current (I_c) by increasing film thickness from 1.5 µm to 4 µm.
- Increase I_c with a high density of nanoscale defects (e.g.) $BaZrO_3$ (BZO)
- Reduce cost by improving precursor-to-film conversion efficiency (precursor is highest cost component)

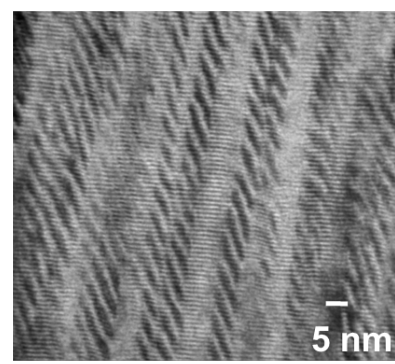




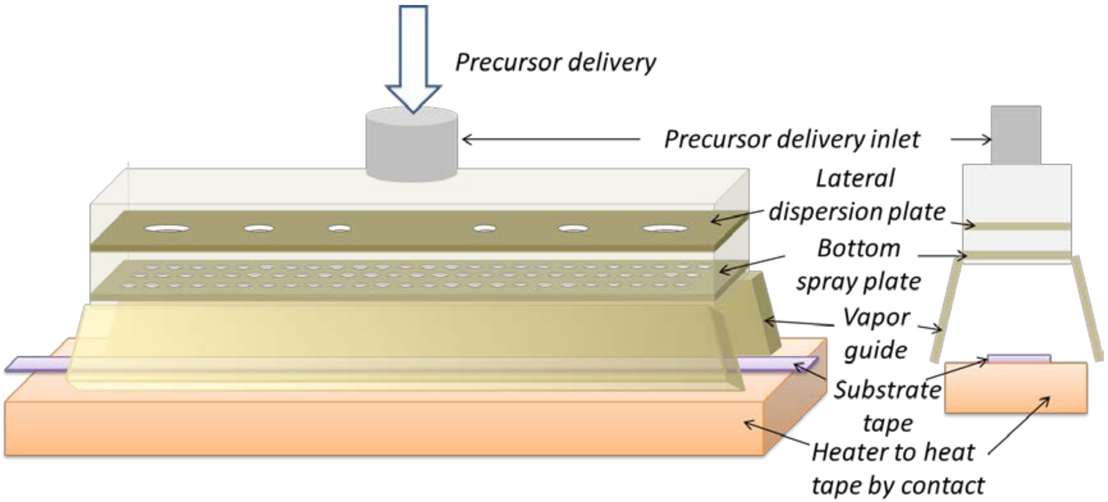


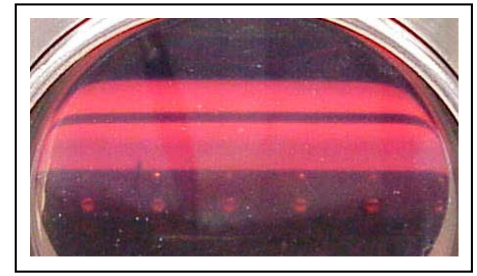




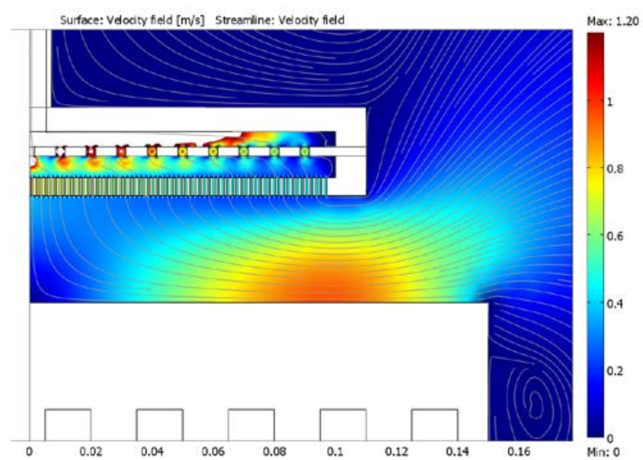


Challenge: Deficiencies of conventional manufacturing





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

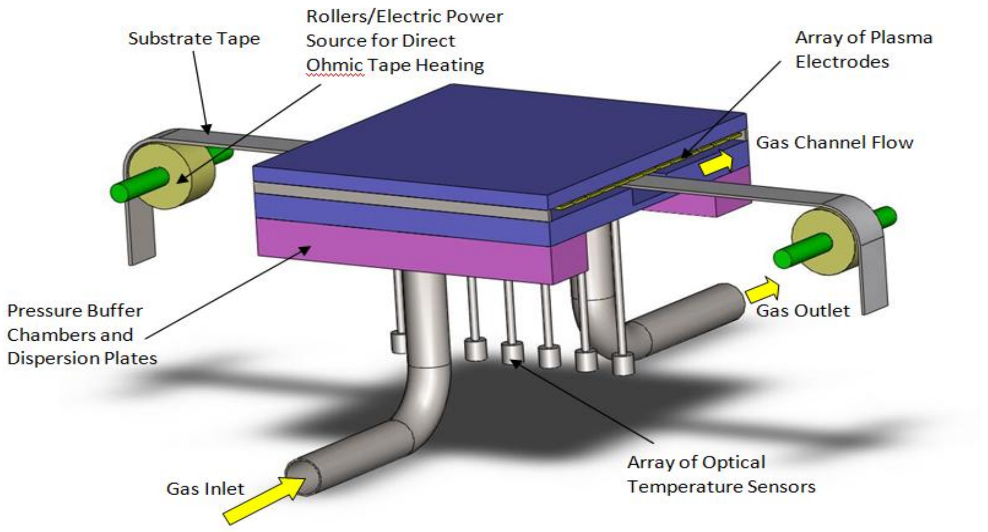


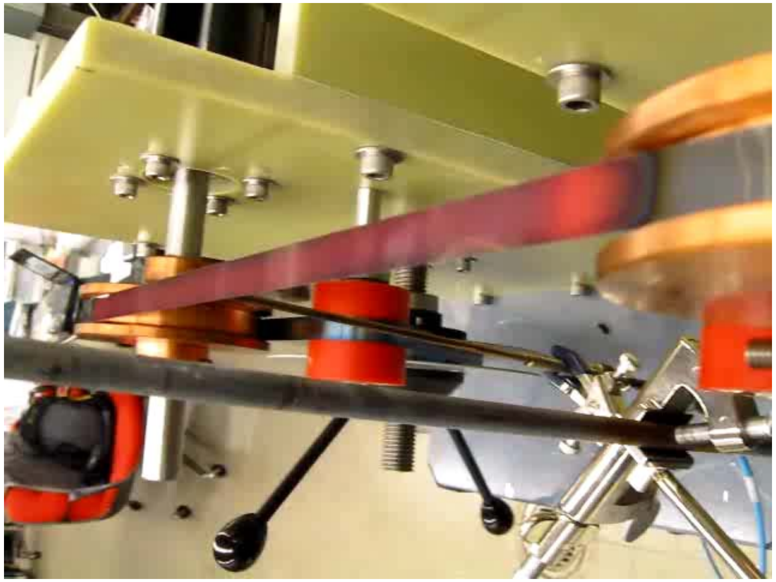
- Poor temperature control and precursor flow non uniformity in conventional R2R MOCVD wire manufacturing → reduction in J_c of thick films, inconsistent growth of nanoscale defects and low manufacturing yield of high I_c wires
- Highly turbulent precursor flow → very inefficient conversion of expensive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

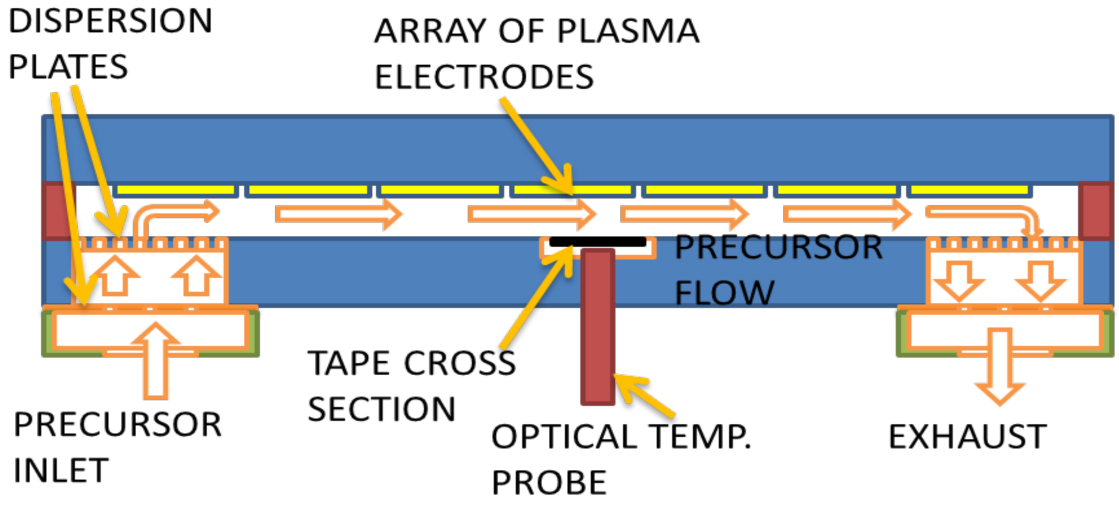
- New reactor to address all deficiencies of current production tools designs
  - Derived from modeling
  - Low volume, laminar flow design for uniform temperature, flow, higher conversion efficiency of precursor to film
  - Direct tape heating, direct tape temperature monitoring
  - Stable precursor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

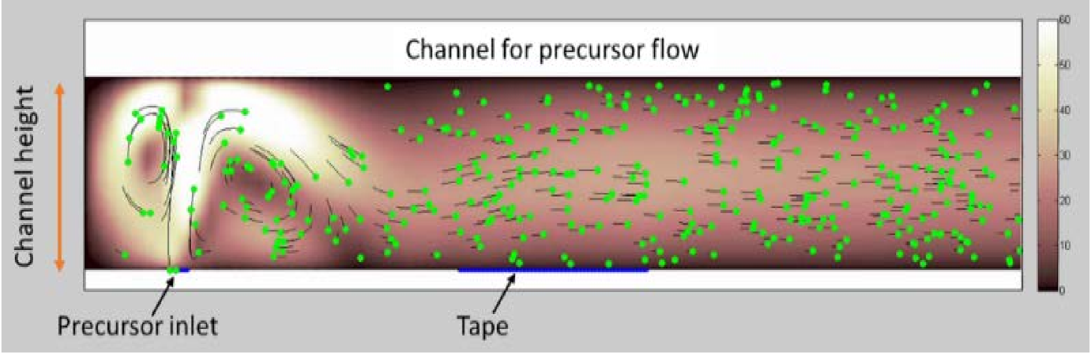


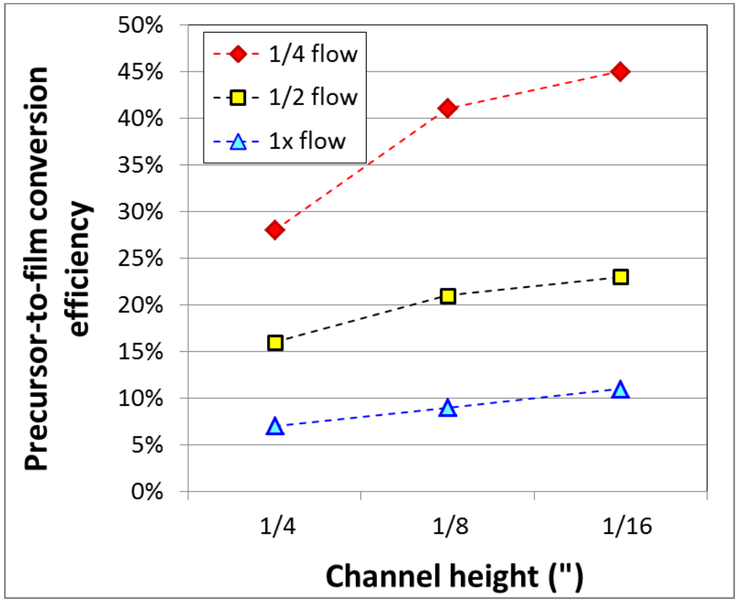


Several new innovative designs implemented in new MOCVD reactor

Technical Approach: Advanced MOCVD

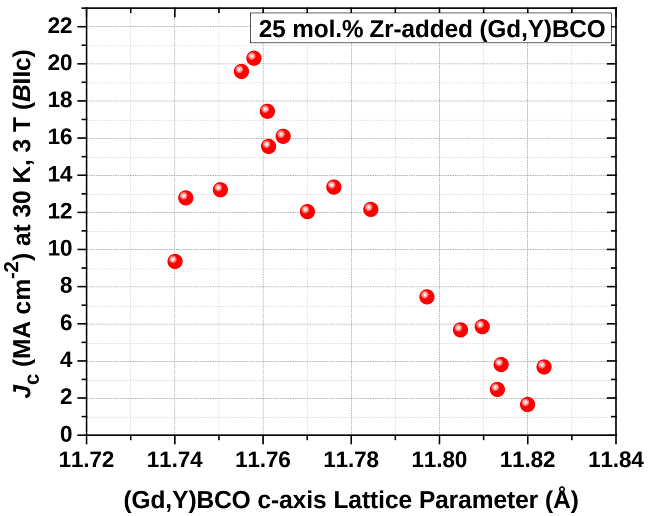


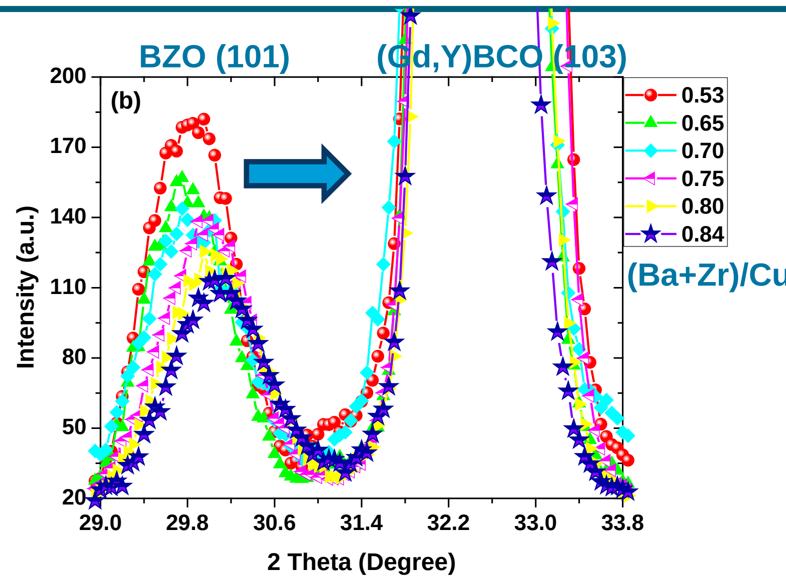


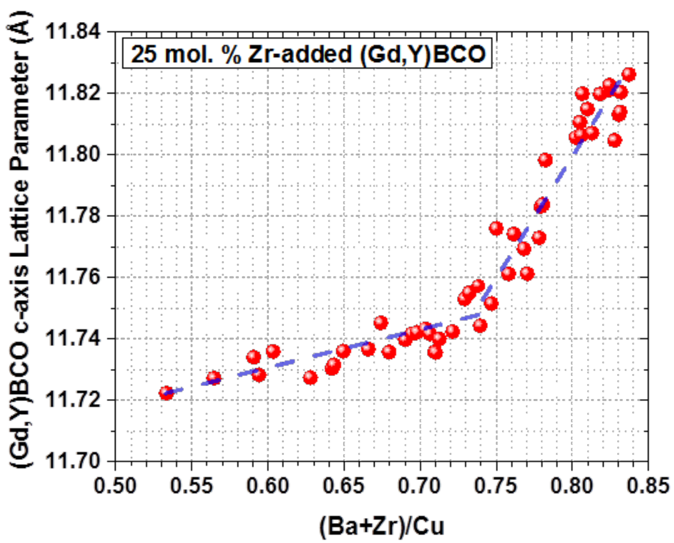


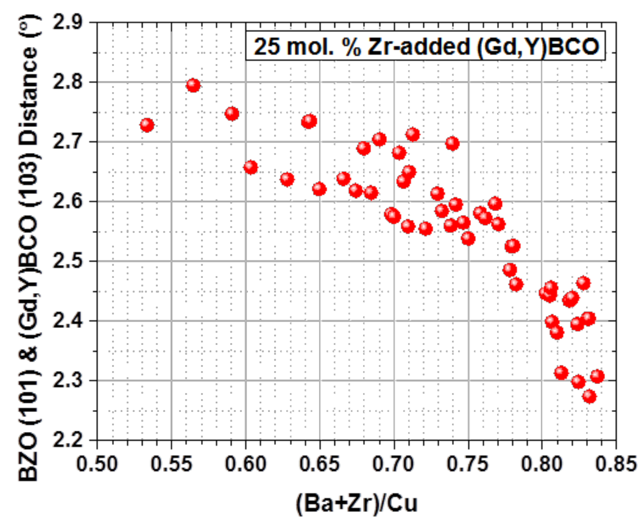
Modeling of flow dynamics in Advanced MOCVD reactor shows 45% (3X) precursor to film conversion efficiency can be attained

Technical Approach: X-ray Diffraction for QC





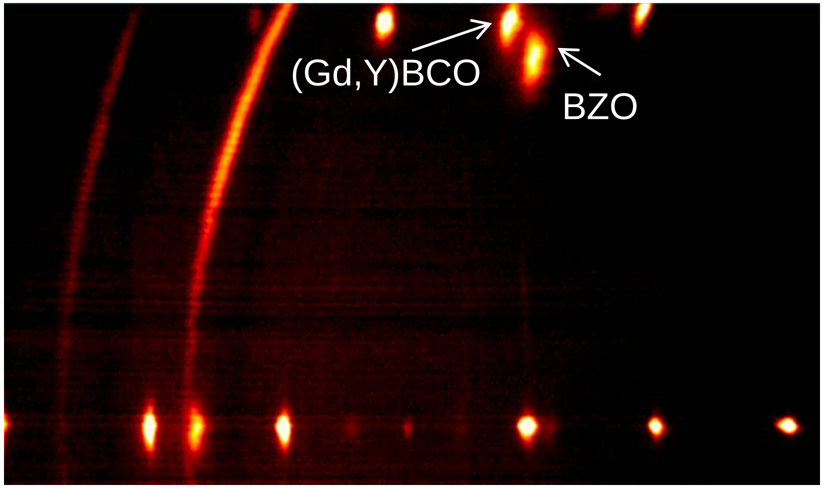




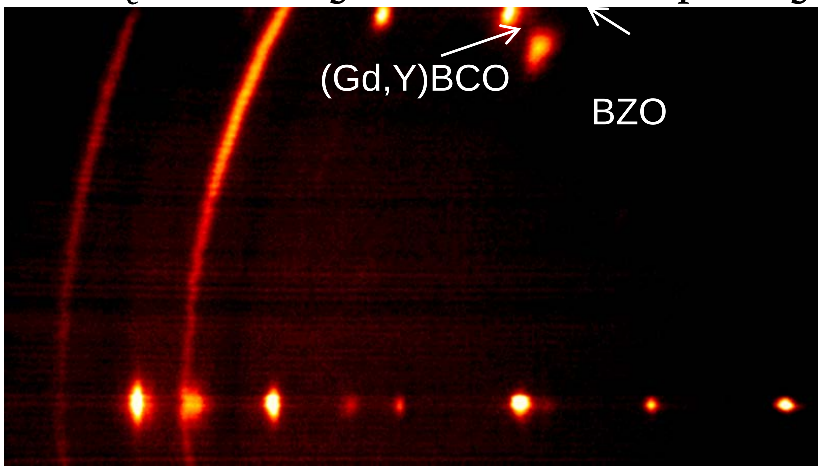
XRD peak spacing of BZO and REBCO is an excellent metric for in-line QC

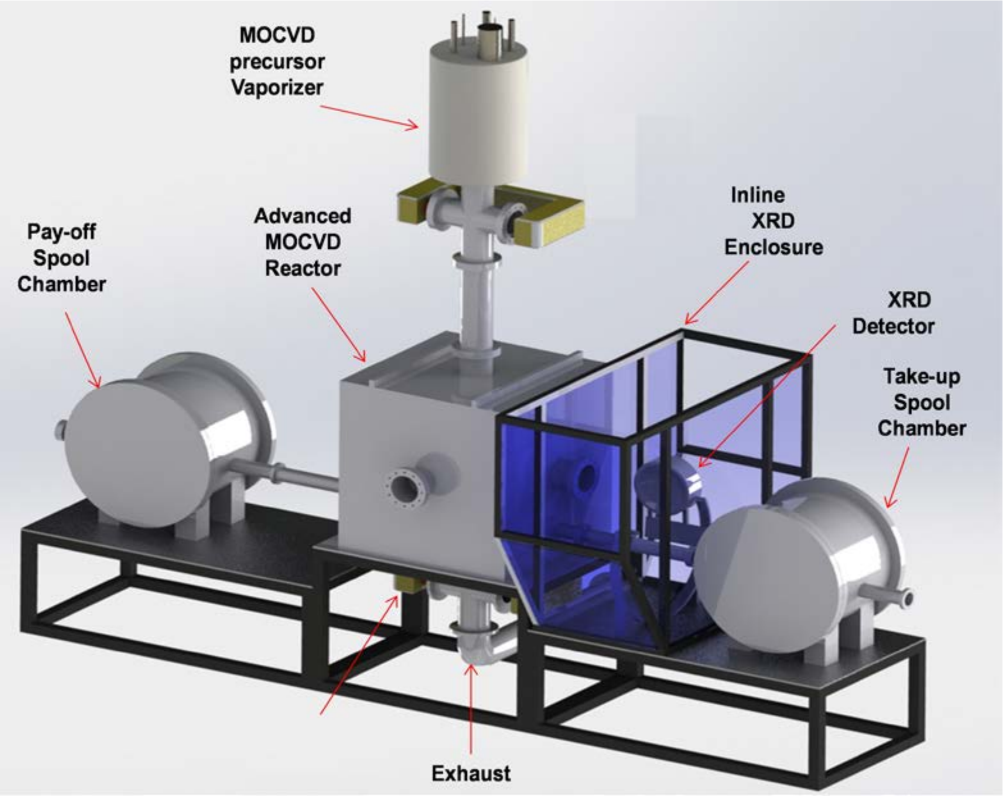
Technical Approach: In-line XRD

High I_c wire: Small BZO-REBCO spacing



Low I_c wire: Large BZO-REBCO spacing





In-line 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

Transition (beyond DOE assistance)

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

- Lower wire cost → Competitive capital cost → Short term for ROI
- Higher operating temperature (65 K) → Simpler cryogenics → Reliability
- Consistency in performance →Predictability
- Higher throughput → High volume production → Availability

Transition (beyond DOE assistance)

End Users

Electric Aircraft | All-Electric Ship | Power Generation | Renewable Energy | Oil and Gas production | Mining

OEMs

Airborne Generators | Propulsion Motors | Utility generators | Wind generators | Industrial Motors

Wire Manufacturers

High Performance, Low Cost NGEM2 Superconductor Wire

Measure of Success

	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

Fundamental knowledge to be gained

- Influence of internal strain between dopants and superconductor film on the size and orientation of nanocolumnar defects
- Epitaxial superconductor film growth and quality of thick films (4 – 5 μm)
- Effectiveness of flux pinning of nanocolumnar defects of different dopants at 65 K
- Reaction kinetics of superconductor film growth in constrained laminar flow geometry in metal organic chemical vapor deposition (MOCVD) reactor
- Influence of substrate and intermediate buffers on biaxial texture quality in films made by ion beam assisted deposition.

Project Management & 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 Status

- Project started May 5, 2017
- Begun Budget Period 1 tasks
  - Task 1.1.a: Demonstrate 4 - 5 μm thick films with Zr-doped REBCO
  - Task 1.1.b: Find optimum Zr content to maximize retention factor in I_c at 65 K, 1.5 T
  - Task 1.1.c: Optimization of buffer stack for improved texture
  - Task 1.1.d: In-line X-ray Diffraction Quality Control tool development in MOCVD
  - Task 1.2: Improve precursor-to-film conversion efficiency in Advanced MOCVD