Development of high performance thick 2G-HTS tapes using Advanced MOCVD

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OUTLINE

- Introduction

- Development of thick Coated Conductors (5 % Zr addition) with record high $I_c^{sf}$ at 77 K, in a single pass deposition by MOCVD

- Development of thick Coated Conductors (20 % Zr addition) with record high lift factor at 30 K, 2.5 T in a single pass deposition

- Summary
INTRODUCTION
Deficiencies in existing MOCVD systems

- Low precursor conversion efficiency due to flow patterns which increases the cost of producing HTS tapes.
- Temperature is monitored inside susceptor not directly on the tape.
- Temperature variations on the tape surface goes unnoticed as it gets absorbed by large thermal mass of susceptor without any temperature change.

Conventional MOCVD design is not suitable for developing thick films without a-grains in single pass deposition and exhibits low precursor conversion efficiency.
Issues with existing MOCVD systems

Thick Film Growth

Existing MOCVD has achieved record high Ic performance at 30K, 2.5 and 3T via heavy Zr doping and thick films.

But growth of films thicker than ~1 μm necessitates two-pass deposition in existing MOCVD.

This complicates the process and increases cost.
Advanced MOCVD System

GOALS:
- Enable growth of thick films in single pass via improved temperature control, uniformity and monitoring.
- Improve precursor to film conversion efficiency to reduce wire cost.

APPROACH:
- Direct Ohmic Heating of Tape
- Non-contact temperature monitoring
- Low volume, laminar cross-flow design for flow/temp. uniformity
Advanced MOCVD System:

- Radical departure from conventional design to address the targeted goals

LEFT: 3D Schematic of the system

RIGHT: The system was successfully designed and built under ARPA-E funded Program
A-MOCVD FILM QUALITY

Conventional MOCVD:

1 µm thick film

Advanced - MOCVD:

The features on the film are limited to the surface layer only (end of run conditions)

3.9 µm thick film

The ability to grow very thick films with no a-axis grain formation opens the pathway to growing very high performance coated conductors.
Development of high performance thick Coated Conductors
(5 % Zr addition)
4.3 µm thick film deposited in a single pass with purely c-axis oriented REBCO

$(\text{Gd,Y}) \text{Ba}_2\text{Cu}_3\text{O}_x$ (5 mol.% Zr addition)

$I_{c}^{sf}(77K) = 1322 \, A/12 \, mm$ (record high current in single time deposition in a MOCVD process)

$J_{c}^{sf}(77K) = 2.56 \, MA/cm^2$
4.4 μm thick film deposited in a single pass with purely c-axis oriented REBCO

\((\text{Gd,Y}) \, \text{Ba}_2\text{Cu}_3\text{O}_x\) (5 mol.% Zr addition)

\(I_{c}^{sf} (77K) = 1248 \, \text{A/12 mm}

\(J_{c}^{sf} (77K) = 2.38 \, \text{MA/cm}^2\)
Linear thickness dependence per micron of thick film

- Approx. 300 A/µm-thickness and Jc is almost constant with thickness
- Tc onset = over 91.5 K
- Excellent tape temperature control by direct heating and use of laminar flow in a confined volume provides A-MOCVD the ability to produce very high performance thick film tapes.

A great potential for achieving much higher performance in the future by fine tuning composition and process conditions.
Development of high performance thick Coated Conductors (20 % Zr addition)
In-field performance of a 2µm, 20% Zr REBCO film grown in A-MOCVD in single pass.

\[ I_c \sim 3346 \text{ A/12 mm at 30 K, 2.5 T, } B \parallel c \]

Lift factor \( \sim 9 \) (new record – higher than the value of 7(best) observed in tapes made by conventional MOCVD)
TEM plane-view of a 20% Zr REBCO sample processed by A-MOCVD:

$Ic \sim 3346 \, A/12 \, mm \, @ \, 30 \, K, \, 2.5 \, T, \, B||c$

$Lift \, factor \sim 9$

*Average BZO size: 4-5 nm*

*Average BZO spacing: 12-13 nm*
TEM plane-view of a 20% Zr REBCO sample processed by A-MOCVD:

Better process control enables controlled growth of small diameter nanorod, enhancing the BZO nanorod density in the tapes.

$Ic \sim 3417 \, A/12 \, mm \, @ \, 30 \, K, \, 2.5 \, T, \, B||c$

Lift factor $\sim 8.5$

Average BZO size: 3-4 nm

Average BZO spacing: 12-13 nm
Single pass A-MOCVD matches the performance of two-pass conventional MOCVD

Further improvement via tuning the ration between Ic at self field and LF
SUMMARY

- New Advanced MOCVD with better temperature control, better process control and laminar flow has been used to develop thick coated conductors of above 4 µm with only c-grains.

- Very high performance of 4.29 µm thick coated conductors (5% Zr added) deposited in a single deposition at 77 K, 0T.
  - $I_c^{sf}(77K) = 1322\ A/12\ mm$ (record high current in single time deposition by MOCVD)
  - $J_c^{sf}(77K) = 2.56\ MA/cm^2$
  - $T_c = 92.3\ K$
  - No dead layer, Linear thickness dependence – 300 A/µm

- Very high performance of 2 µm thick coated conductors (20% Zr addition) deposited in a single deposition at 30 K, 2.5T
  - $I_c = 3346\ A/12\ mm$
  - Lift factor ~ 9 (record high value)
  - Average BZO size: 4-5 nm
  - Average BZO spacing: 12-13 nm
THANK YOU