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SOFC Protection Based on a Cost-Effective Aluminization Process

15th Annual SECA Workshop

July 23rd 2014

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Scope Of Presentation

1. Introduction and Motivation
2. Dual MCO/Al coated Interconnect Product Development
   - Reduction Firing Process Window
   - Single-cell Stack Testing
3. Refinement of Aluminide Coating Process
   - Microstructural Characterization
   - Compositional Modifications
4. Manufacturing Development: Process Simplification and Cost Reduction
5. Conclusions

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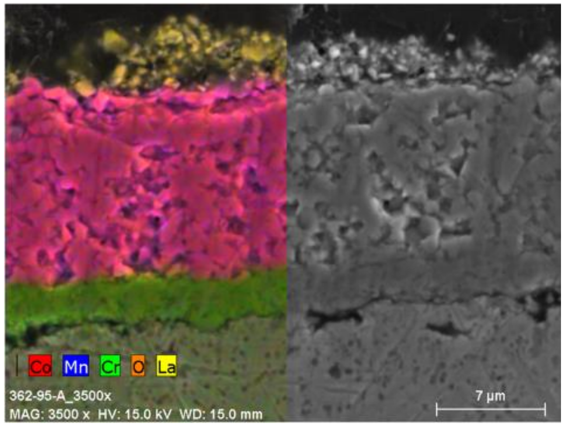
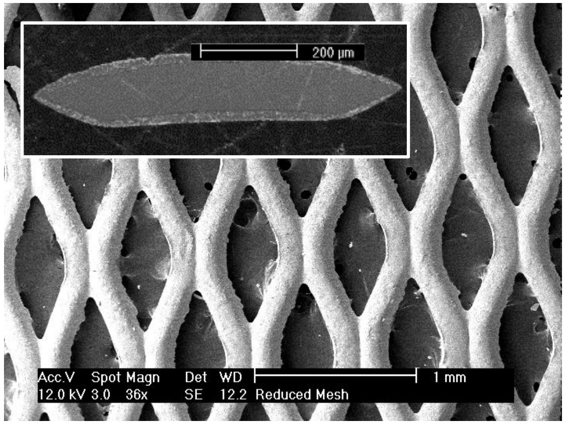
SOFC Coating Development at NexTech

NexTech has developed a range of coatings to extend the materials lifetime of components used in SOFC systems

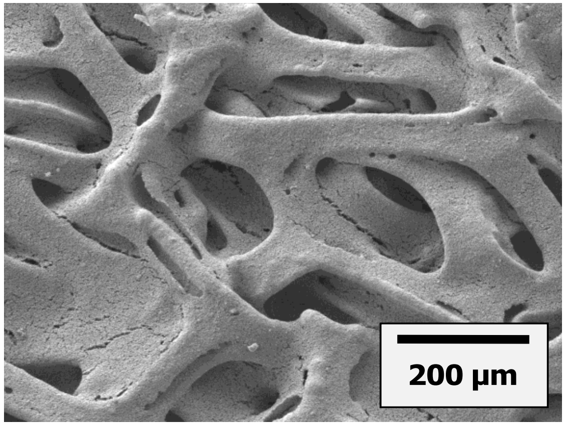
MCO coated IC

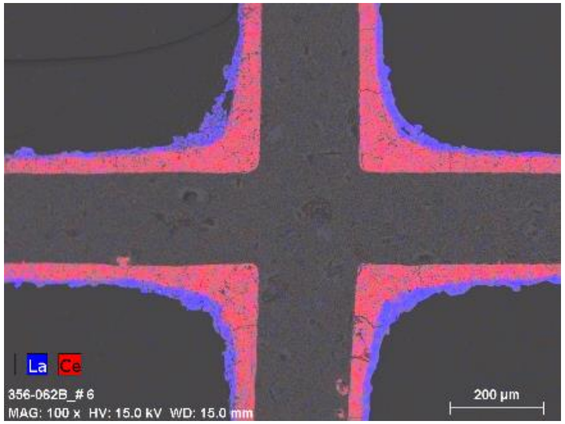




MCO coated current collector mesh

Catalyst coated mesh





Catalyst coated monolith

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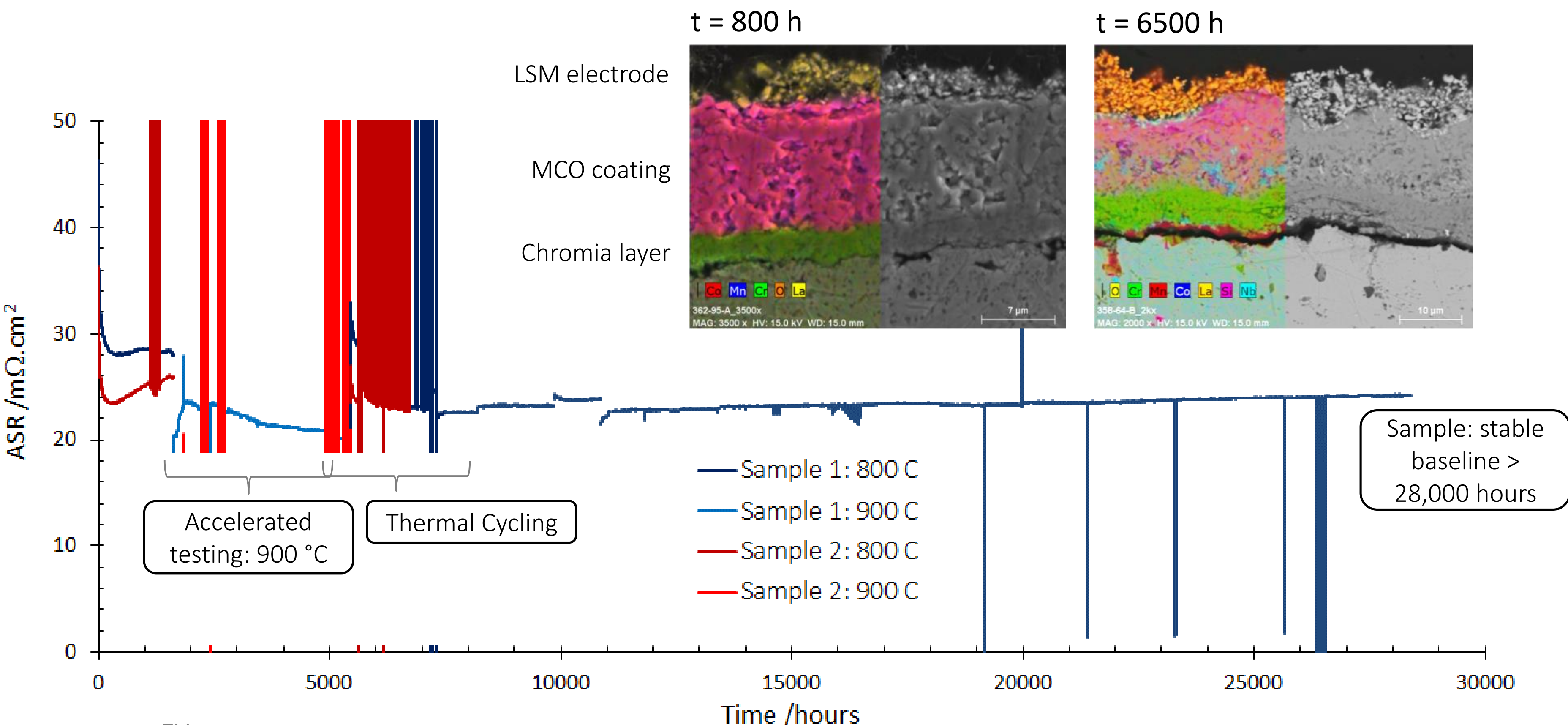
MCO Active Area Interconnect Coating

Manganese cobaltite (MCO) coating has been successfully commercialized at NexTech



AL 441HP™ with symmetric 10 μm MCO coating

800 °C and 900 °C in umidified air with applied current density 0.5 A/cm²

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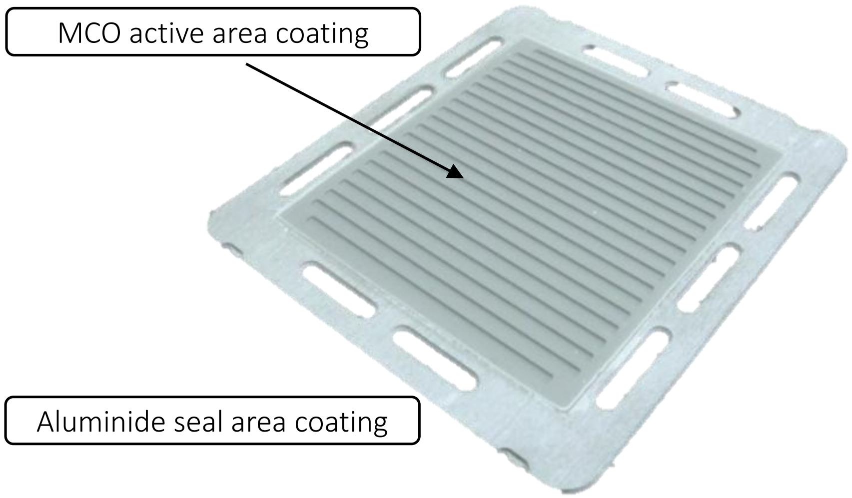
Aluminide Protection Coating

NexTech is developing an aluminide protective coating to improve high temperature oxidation/corrosion and chromium volatility resistance of metallic components used in SOFC systems

Dual MCO/Aluminide Coated Metallic Interconnect

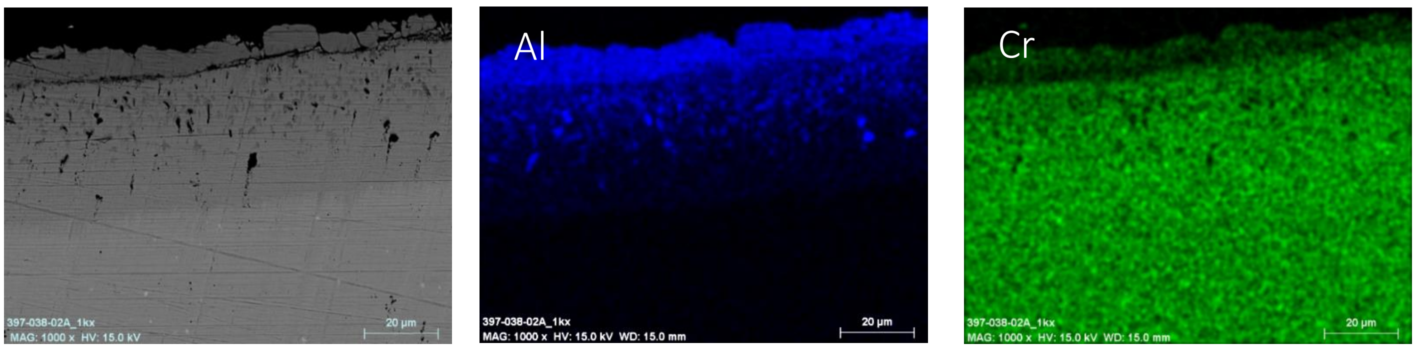


Coated Balance of Plant Components

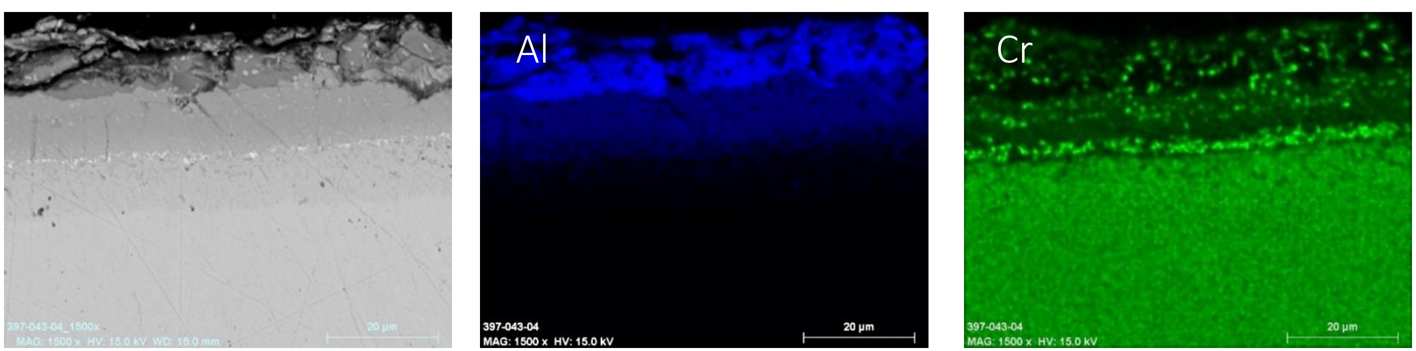
Motivation

NexTech's coating process successfully reproduces the diffusion based surface microstructure produced by more conventional aluminization processes

Vapor Phase Aluminization (VPA) Coating Microstructure on SS316



NexTech's Aluminide Coating Microstructure on SS316



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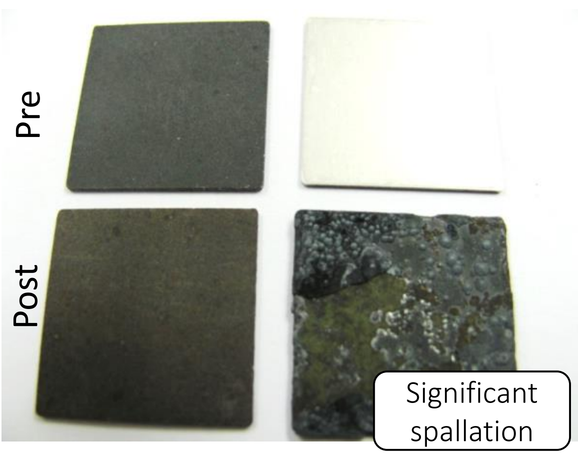
Preliminary Results

Utility of aluminide coating demonstrated through enhanced oxidation, chromium volatilization, and coking resistance on commercially important IC and BoP alloys

Oxidation Resistance SS304

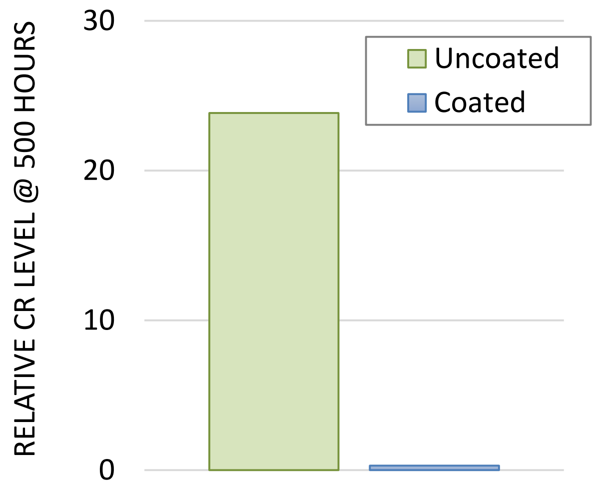
Coated Uncoated



SS304 with and w/o aluminide coating
500 hours in humidified air at 900 °C

10X improvement oxidation resistance

Cr Volatilization Resistance SS304

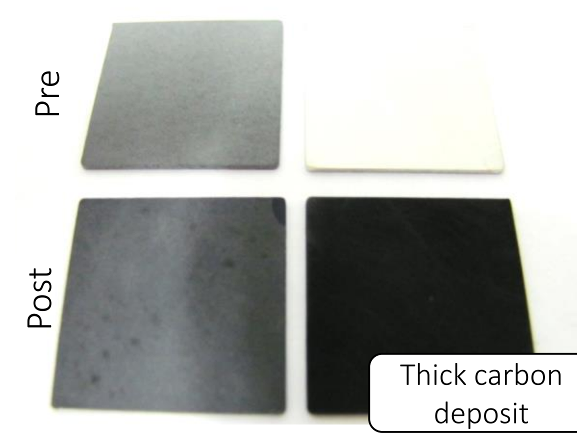


SS304 with and w/o aluminide coating
500 hours in air at 900 °C
EDS of Cr capturing material

15X reduction chromium volatilization

Coking Resistance SS304

Coated Uncoated



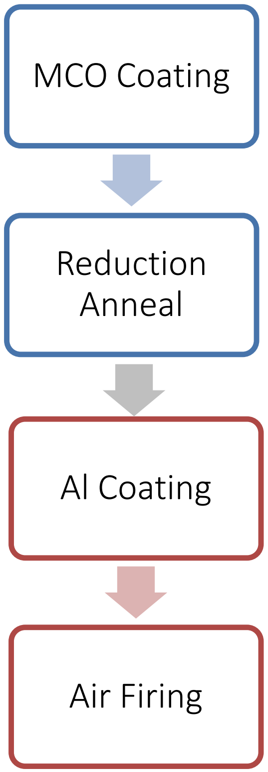
SS304 with and w/o aluminide coating
24 hours at 600 °C
18 % CH_4, 45 % CO, 37 % CO_2

Excellent coking resistance

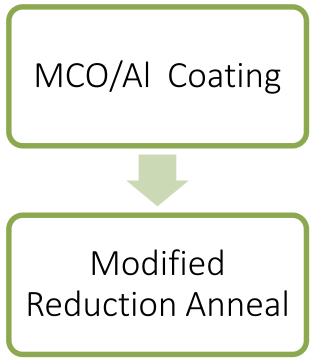
Dual MCO/Aluminide Coating Process Flow

Demonstrated the feasibility of modified reduction co-anneal strategy to apply dual MCO/aluminide coatings

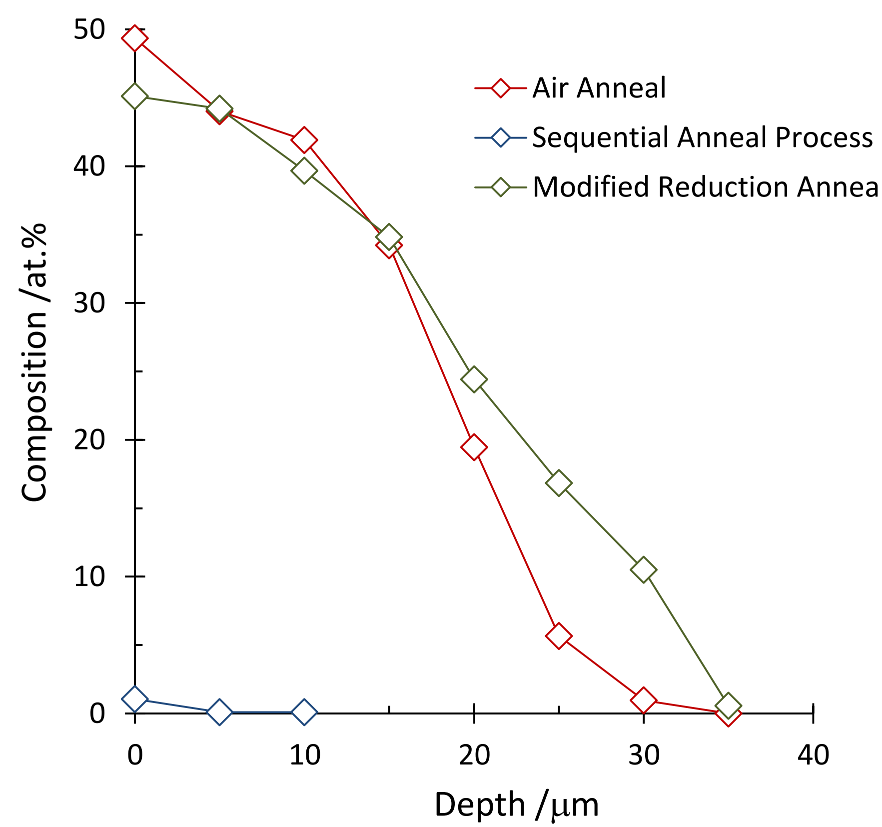
I: Sequential MCO and Al coatings



II: Combined MCO and Al coating with co-firing

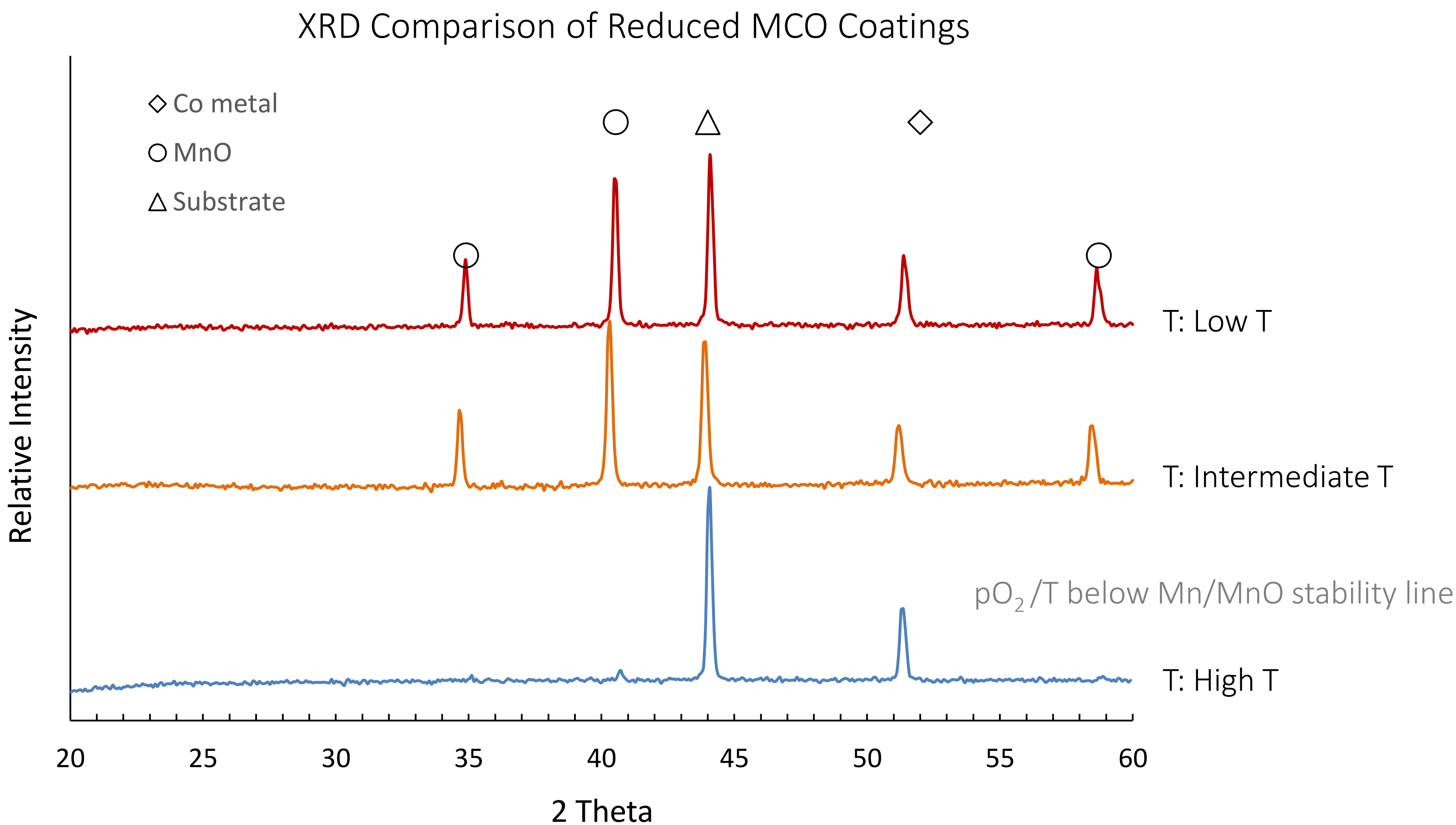


Aluminum Diffusion Profile



Co-Anneal Temperature Process Window

Process window defined to achieve controlled reduction of the MCO coating to form MnO + Co cermet and required aluminum diffusion profile to form desired aluminide coating



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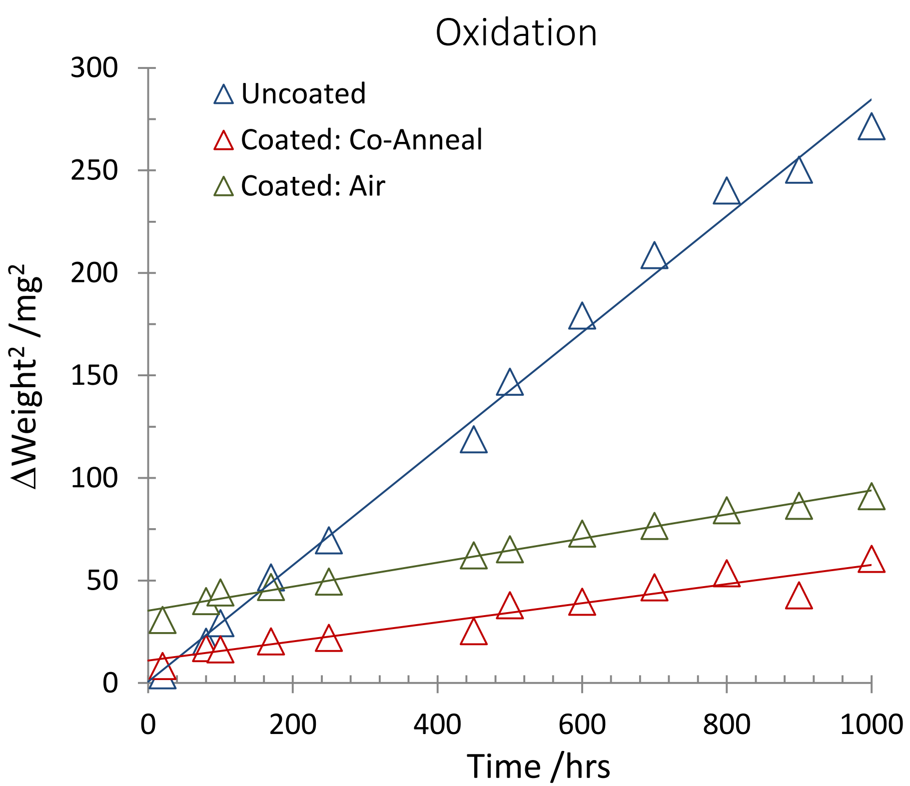
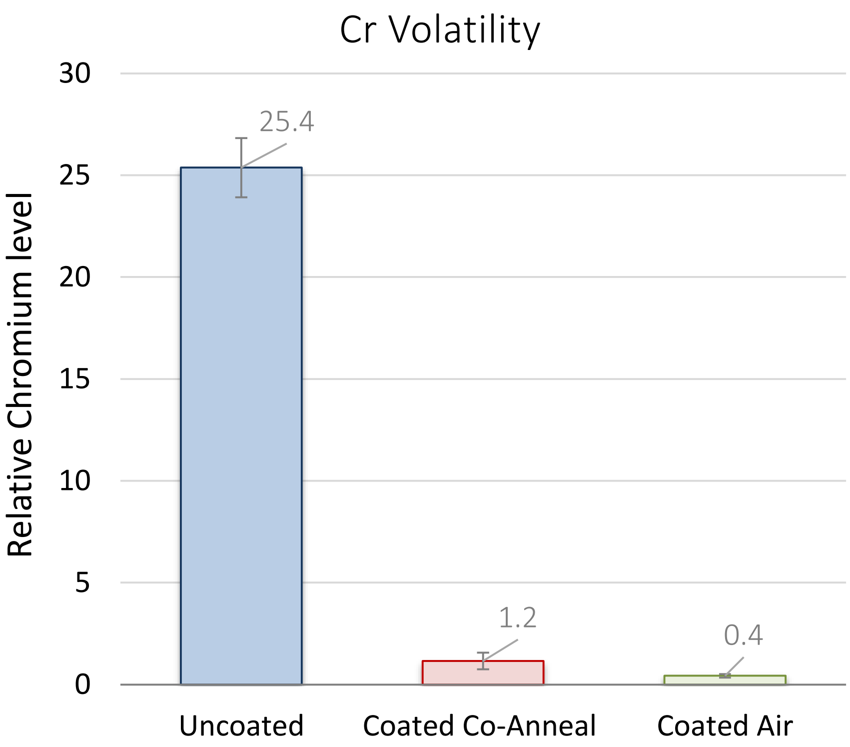
Oxidation/Chromium Volatility Analysis

Co-anneal process does not reduce enhanced oxidation resistance and chromium volatilization resistance of coating



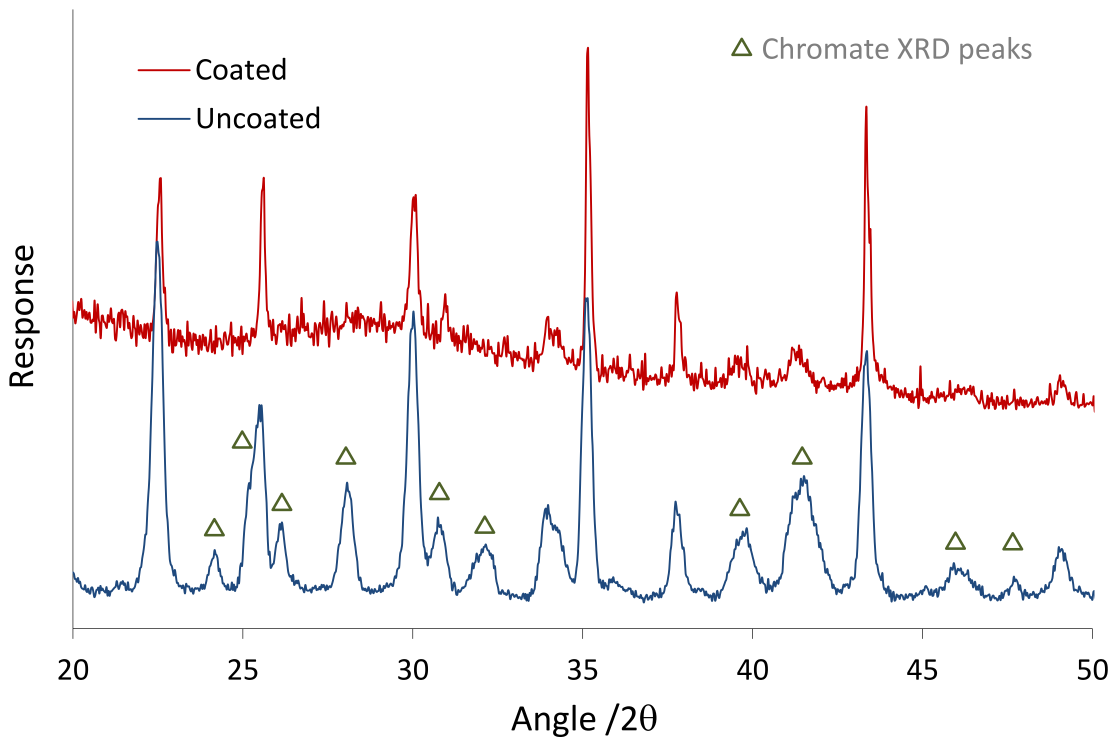


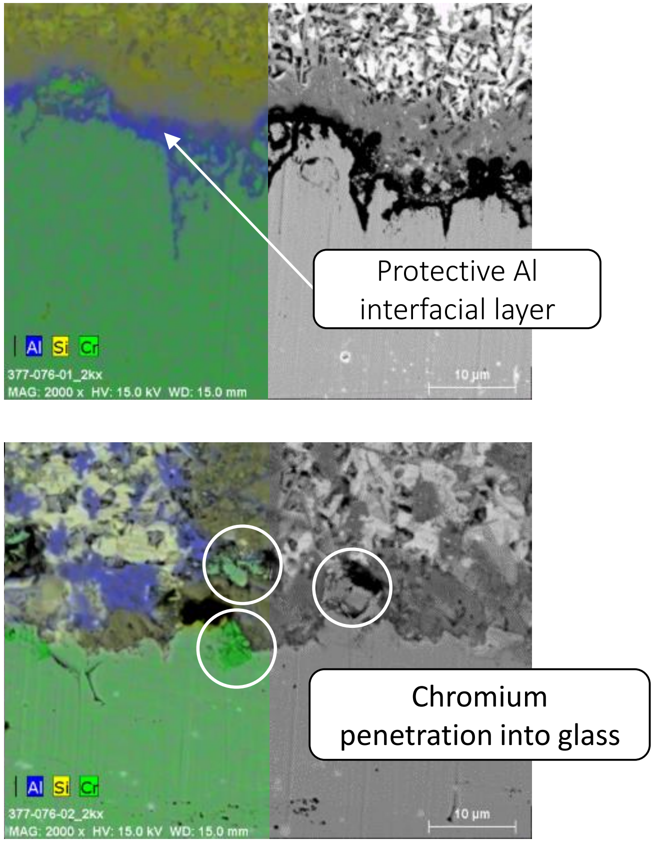
AL 441HP™ with and w/o aluminide coating
1000 hours in air at 900 °C

Seal/IC Interactions

Aluminide Coating is effective at reducing detrimental glass-seal interactions

XRD spectra of glass-seal/IC





Ferritic SS - AL 441HP with and w/o aluminide coating
Composite glass seal (80 % alumina, 20 % PNNL G18 glass)
Ageing: 4 hours at 850 °C in air

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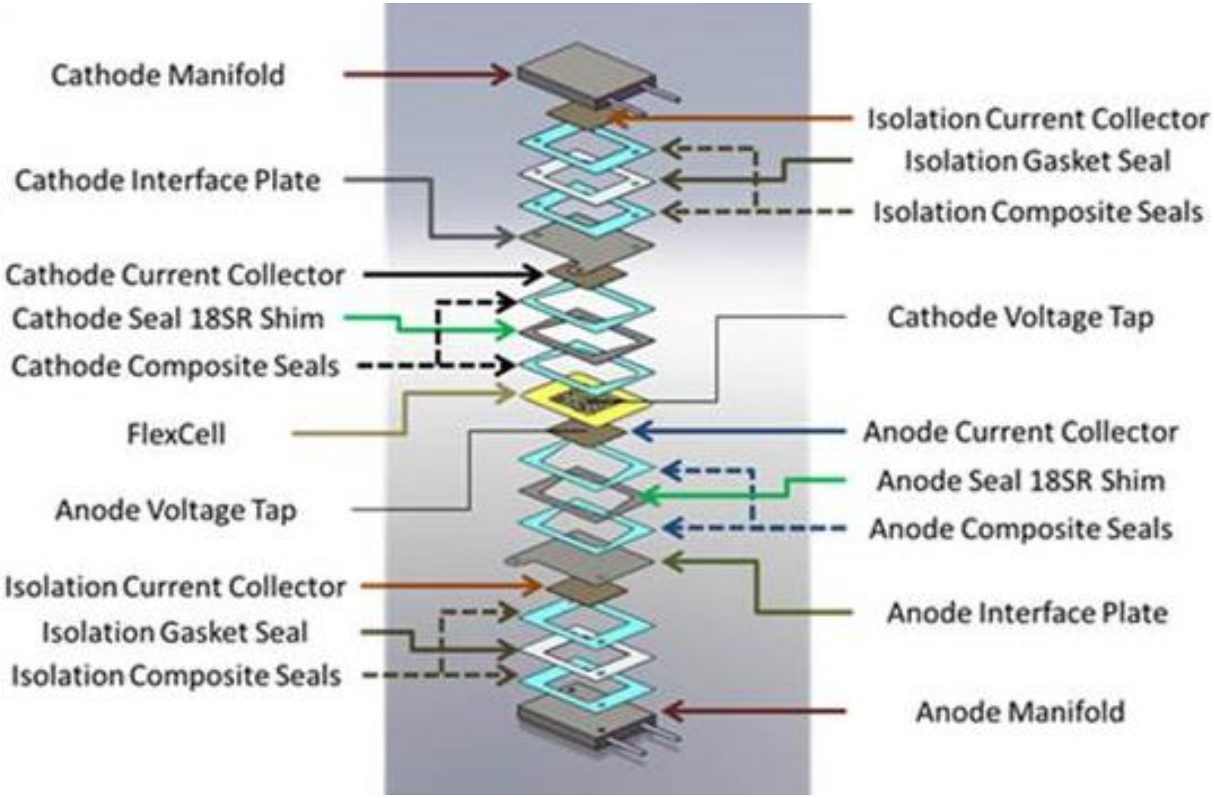
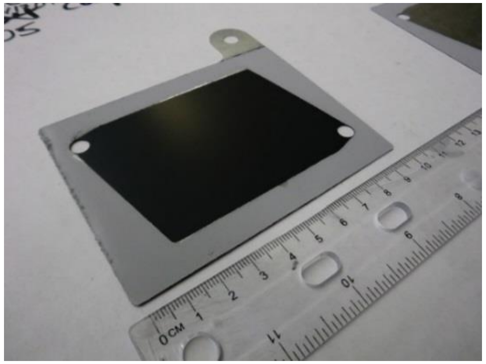
Single-Cell Stack Test

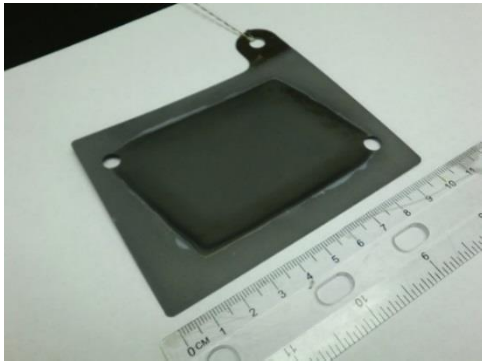
Performance of dual MCO/aluminide coated interconnects evaluated in concert with all other components of an actual stack under application relevant conditions



Dual MCO/Al coated IC: *Green*

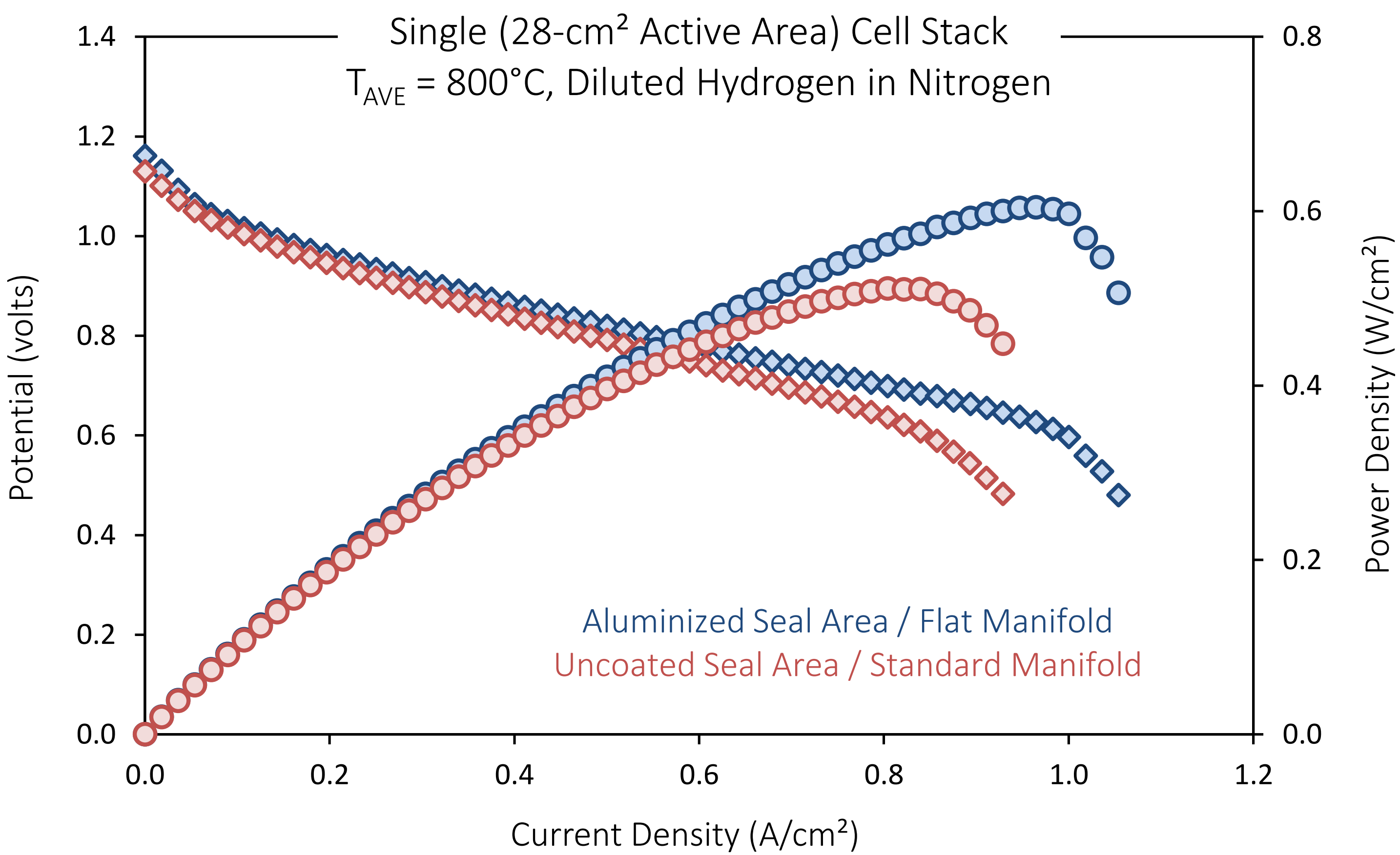


Dual MCO/Al coated IC: *Reduced*



Single Cell Stack Test Stand Results

MCO/Al dual-coated interconnects demonstrate enhanced stack performance (improved powder density and fuel utilization) vs. no seal area coating



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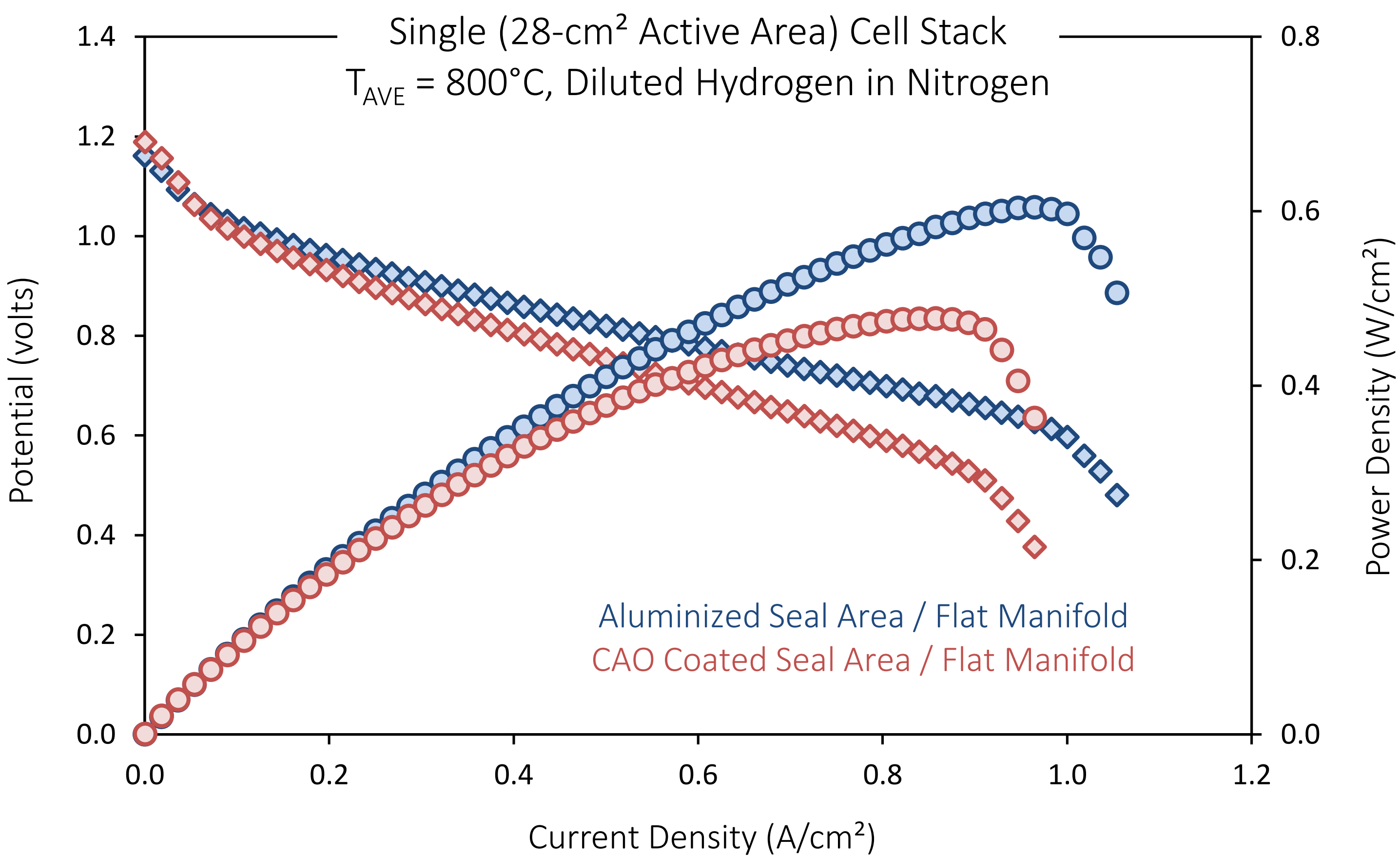
Single Cell Stack Test Stand Results

Performance improvement is also demonstrated compared to existing seal area coating (CAO)



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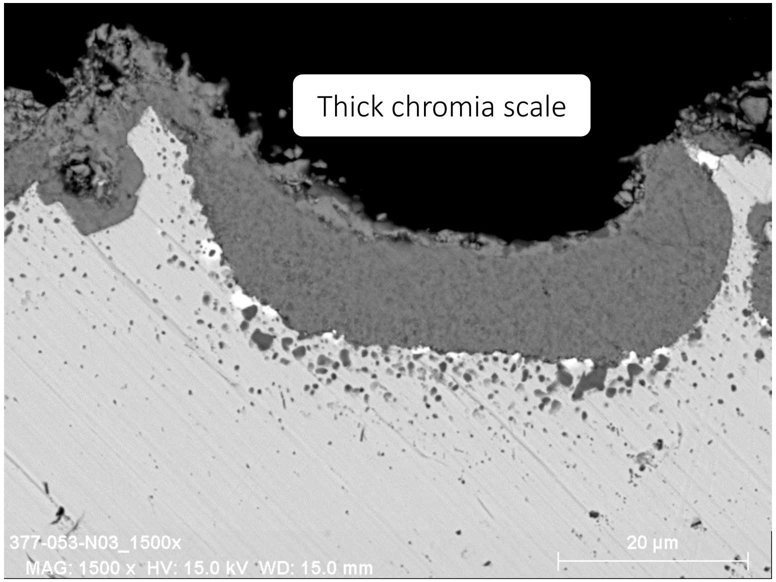
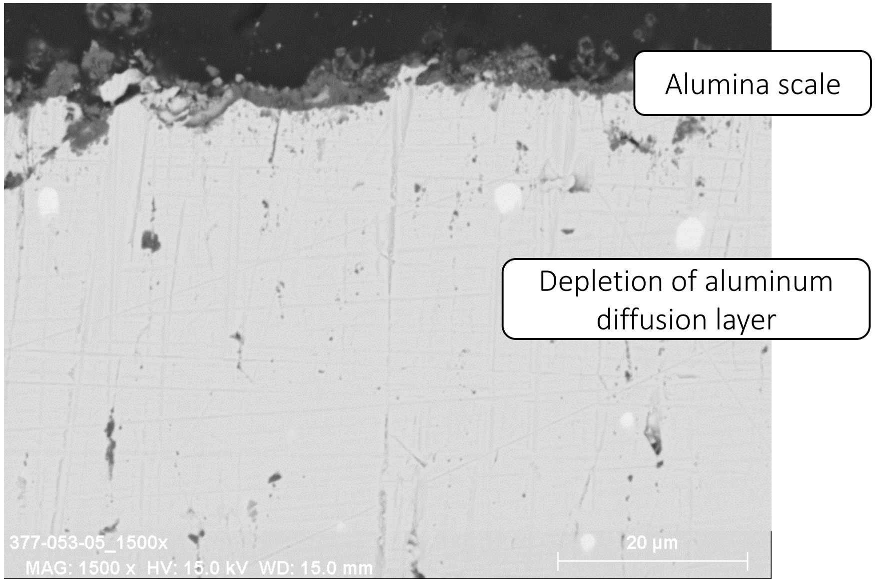
Post-Test Analysis: Ferritic SS441

Enhancement of the high temperature performance of coated 441 is based on the formation of a thin alumina surface oxide instead of a thick chromia scale

Uncoated



Coated (Standard Processing)



Ferritic stainless steel - AL 441HP with and w/o aluminide coating
1000 hours in air at 900 °C

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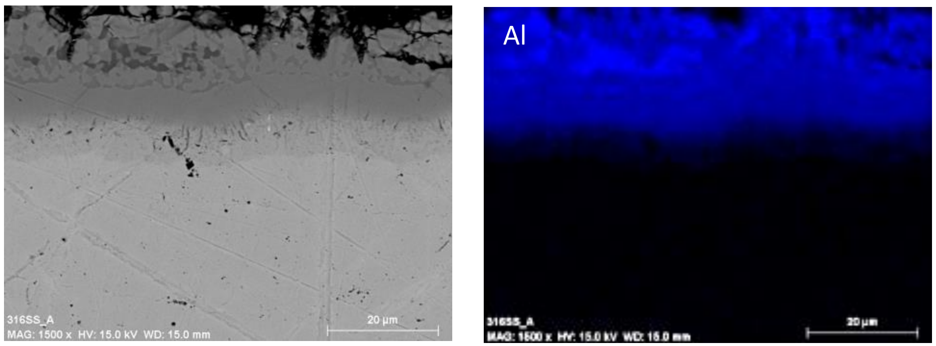
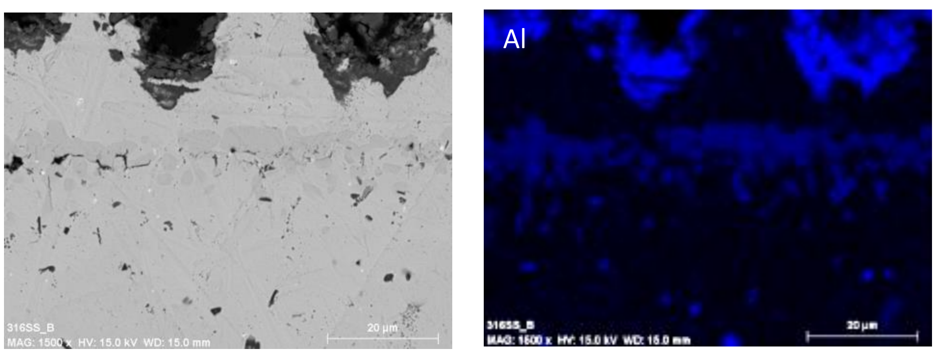
Post-Test Analysis: SS316

Similar long-term microstructural behavior is observed for coated SS316

Coated SS316: As Processed

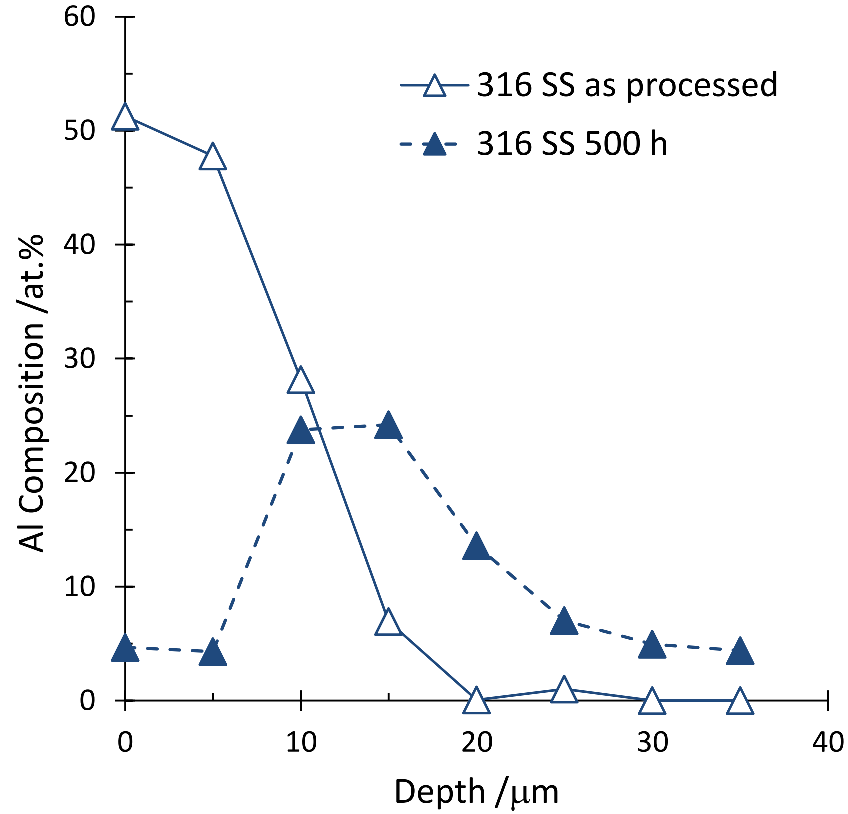


Coated SS316: t = 500 h



SS316 with aluminide coating
500 hours in humidified air at 900 °C

Aluminum Diffusion Profile



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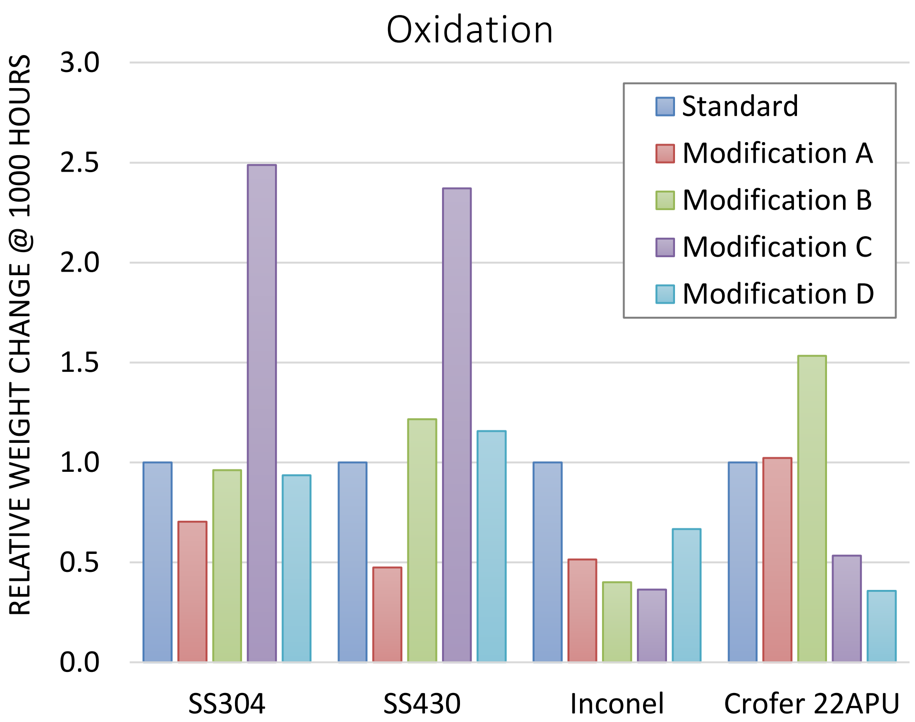
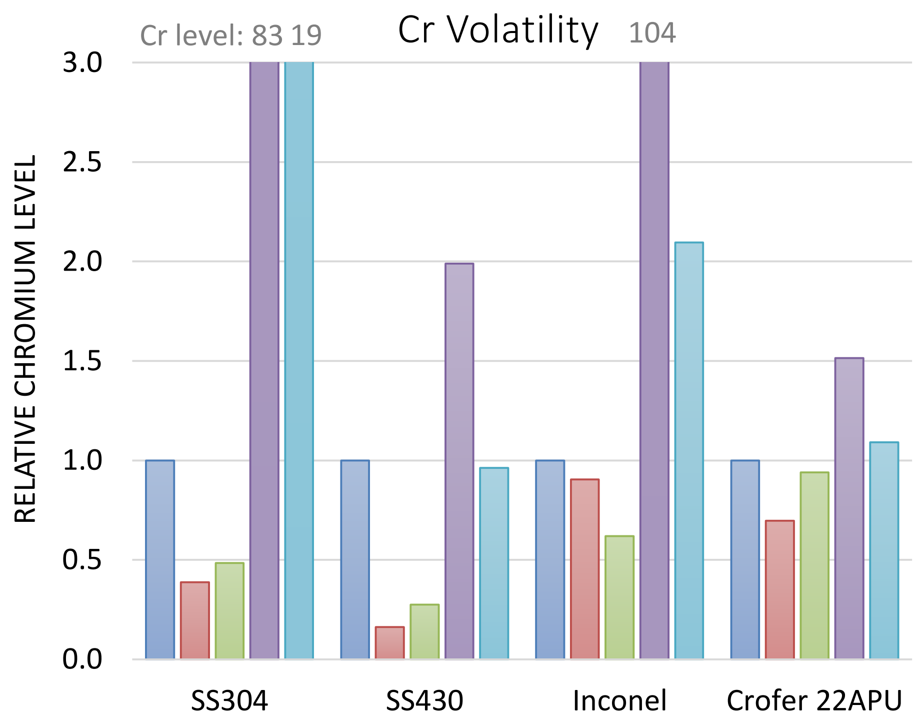
Coating Refinement: Compositional Modifications

Process modifications A and B show promise – improved oxidation and chromium volatilization resistance compared to the standard coating process

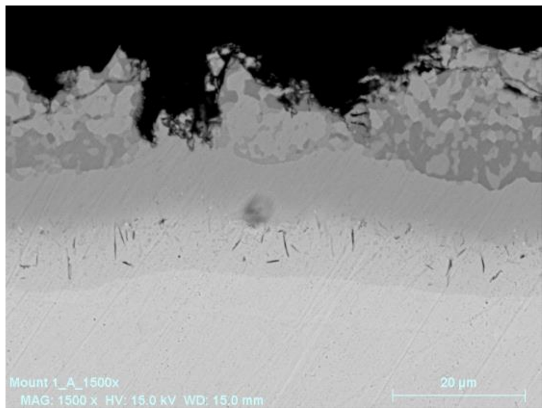
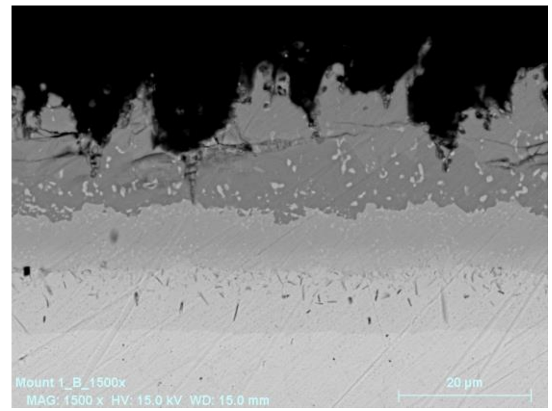
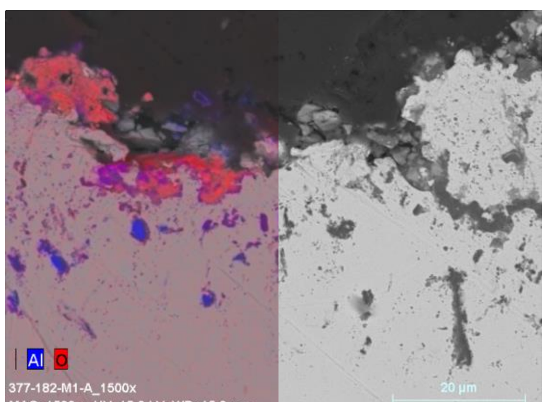
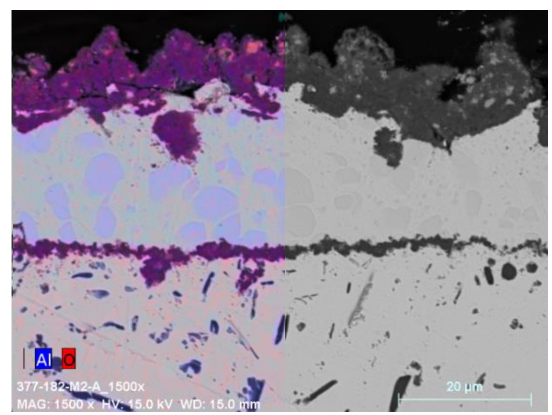




Oxidation and chromium volatility: 1000 hours in humidified air at 900°C

Microstructural Analysis: Modification A

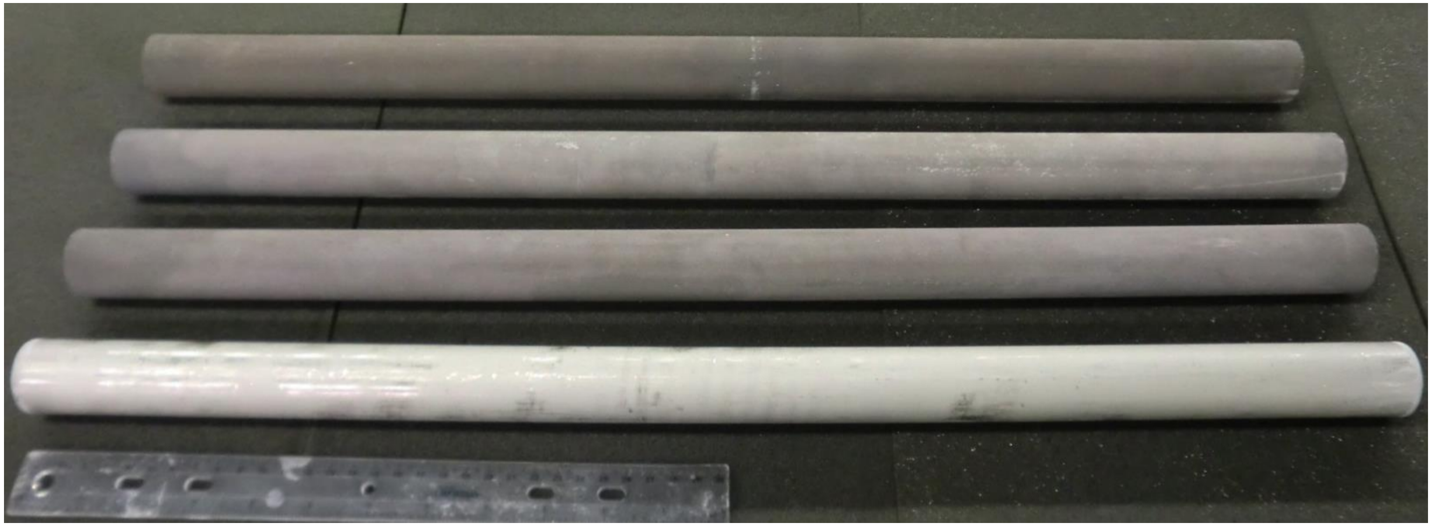
Process modification A improves the coating's high temperature stability by successfully constraining aluminum in an enriched sub-surface layer and preserving a protective alumina scale

	Standard	Process Modification A
As-processed		
Post-Oxidation 1000 hours in humidified air at 900°C		

Balance of Plant: Process Development

Prototype component developed to demonstrate the feasibility of the coating on an application-specific component

Prototype 2 ft. long 310 SS coated pipe



Dip-coating application

Aerosol spray deposition

Roller coating

Uncoated

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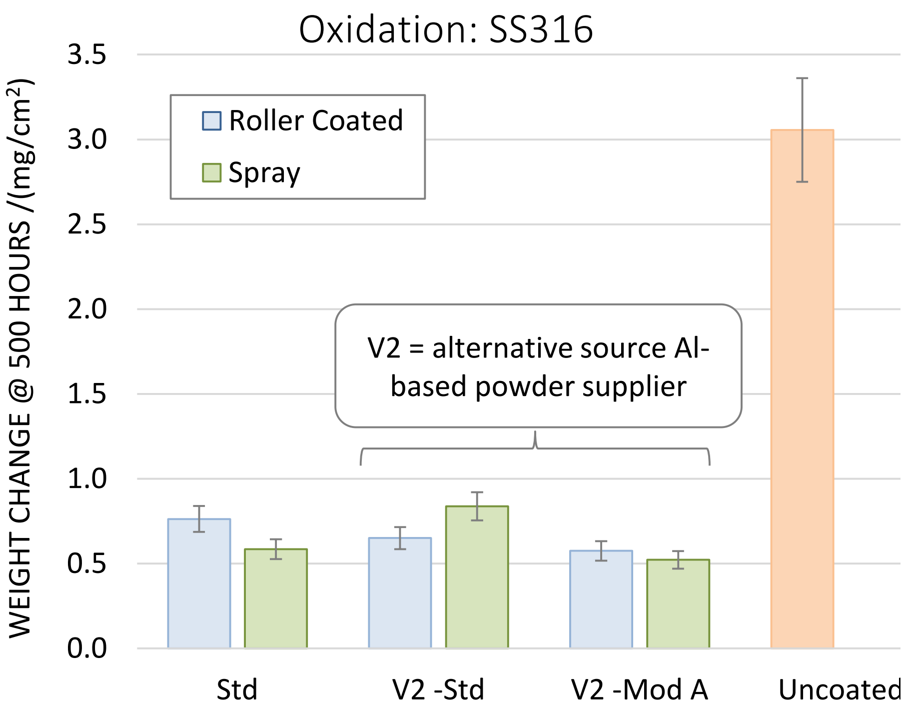
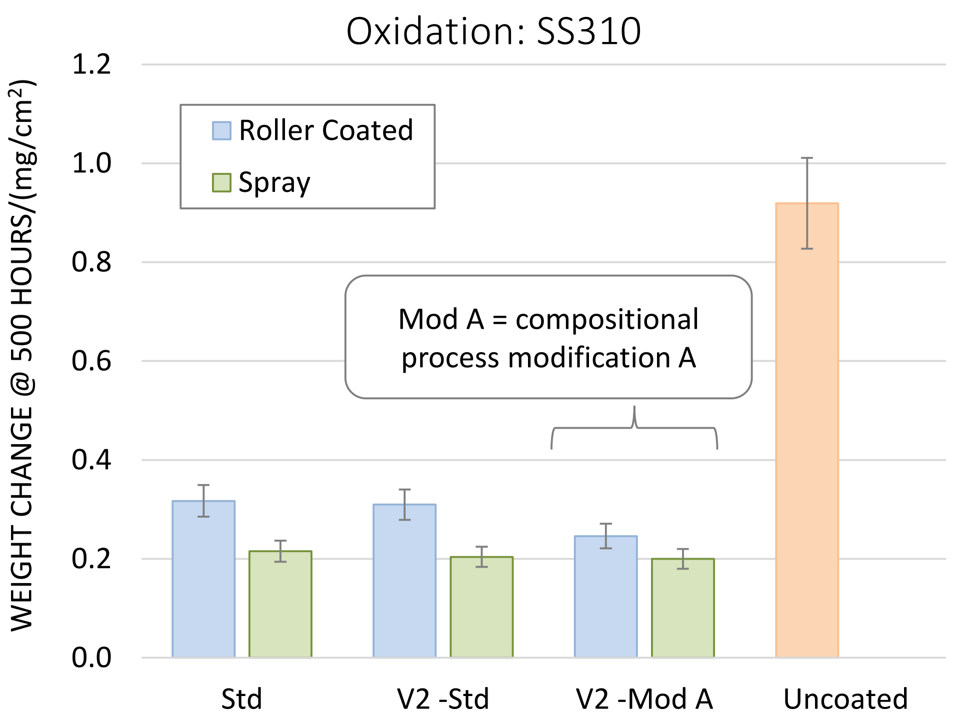
Process Simplification/Cost Reduction

Performance verification and process improvement qualification conducted to develop cost-effective, scalable coating process





Oxidation: 500 hours in humidified air at 900°C

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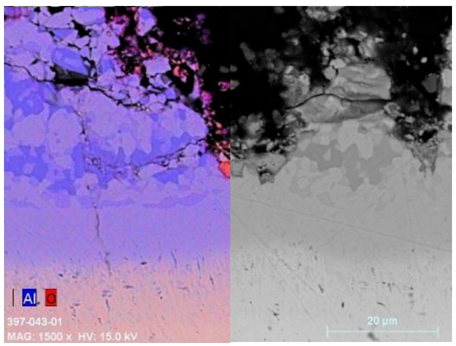
Coating Refinement: Process Simplification

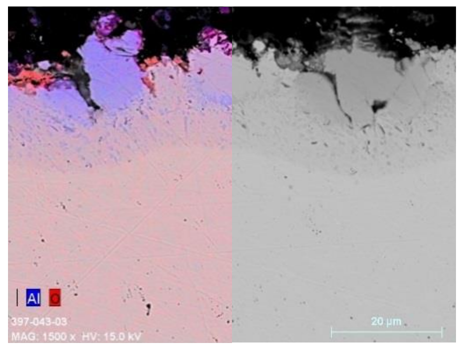
Similar coating microstructures produced via different application processes and the uniformity of aluminide diffusion layer improved with process modification A

As Processed Coating Microstructures with Alternative Powder Vendor (V2): Standard Process

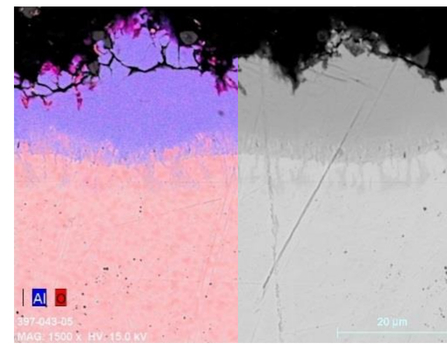
SS316 - Sprayed



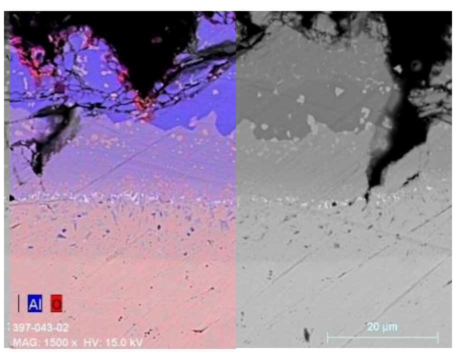
SS316 – Roller Coated

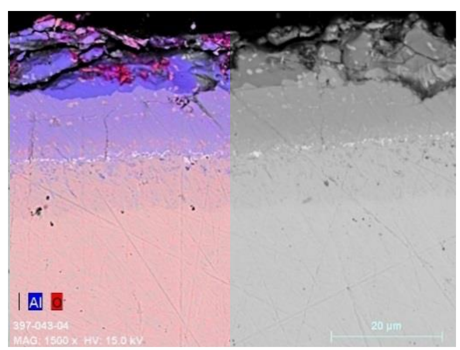


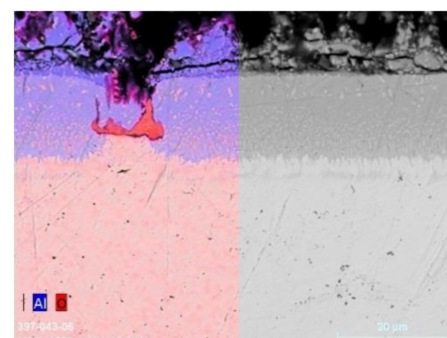
SS310 - Sprayed



As Processed Coating Microstructures with Alternative Powder Vendor (V2): Modification A Process







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Conclusions

- NexTech is developing a cost-effective process for applying protective aluminide coatings to metallic components used in SOFC systems.
- Modified co-anneal operation enables successful co-processing of aluminide coating with commercially available manganese cobalt oxide (MCO) active area coating for dual MCO/aluminide coated interconnects.
- Critical functionality of the aluminide coating demonstrated on a range of commercially important alloys:
  - Enhanced high-temperature oxidation, chromium volatilization, and coking/carburization resistance.
  - Enhanced stack performance (improved powder density and fuel utilization) established for dual MCO/aluminide coated interconnects compared to interconnects with a single MCO active area coating (no seal coating) and NexTech's incumbent CAO seal area coating.
- Compositional process modifications identified to improve long-term, high temperature coating stability.
- Process improvements (process simplification/cost reduction) identified to further enhance value proposition of coating technology.

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Acknowledgements

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  U.S. Department of Energy: Contract Number: DE-SC0008203

  Project Manager: Dr. Seth Lawson