FARADAY TECHNOLOGY, INC.

Electrodeposited Mn-Co Alloy Coating for SOFC Interconnects

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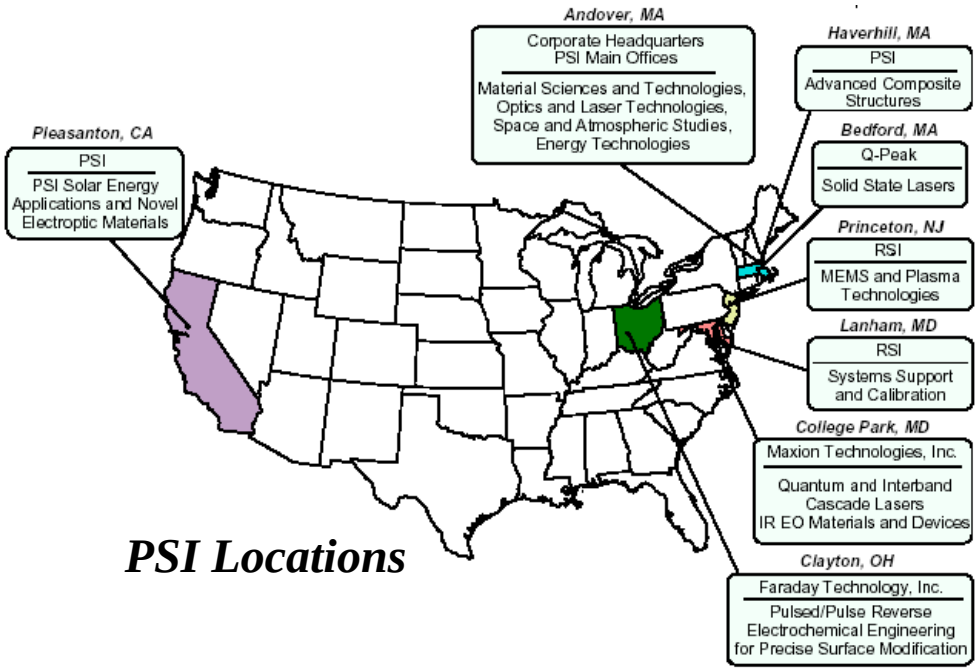
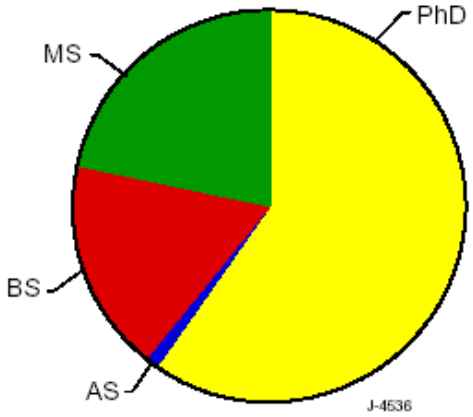
Faraday Technology, Inc.

- Faraday Technology specializes in electrochemical engineering
  - www.faradaytechnology.com
- Faraday is a wholly-owned subsidiary of Physical Sciences, Inc. (Boston, MA)
  - www.psicorp.com
  - Collectively, the company staffs ~185 employees - ~100 with PhDs
  - Annual revenue of ~ $50M



PSI Locations



PSI Employees by Education

Faraday Technology, Inc.

Platform Technology: Pulse/Pulse Reverse Processing

Total Manufacturing Solution

Core Competency: Design and Engineer of Novel Electrochemical Hardware

Either may be applied independently to improve current industrial practices or may be combined for a total manufacturing solution

- Electronics
- Edge and Surface Finishing
- Engineered Coatings
- Battery and Fuel Cell Power
- Environmental Systems
- Corrosion and Monitoring Services

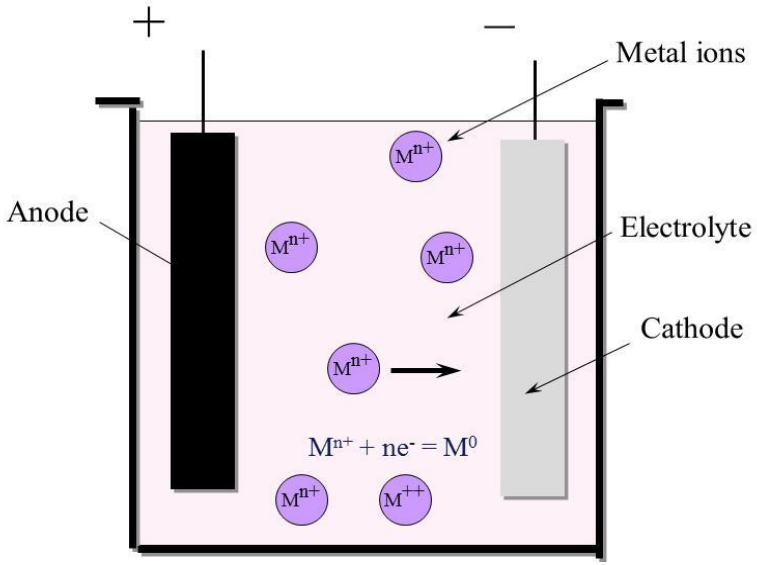
- Enables uniform processing
- Applicable for additive or subtractive electrochemical processes
- Uniform processing is achieved over entire substrate, improving end product reliability

Achievements

- Completed 2000 hour thermal soak evaluation
- Initiated long-term on-cell performance evaluation using 4 cm ϕ 441 stainless steel button cell
- Demonstrated capability to increase relative Mn content in alloy coating
- Began coating industrial scale interconnects

FARADAYIC® Processing

Conventional (DC) Electrodeposition



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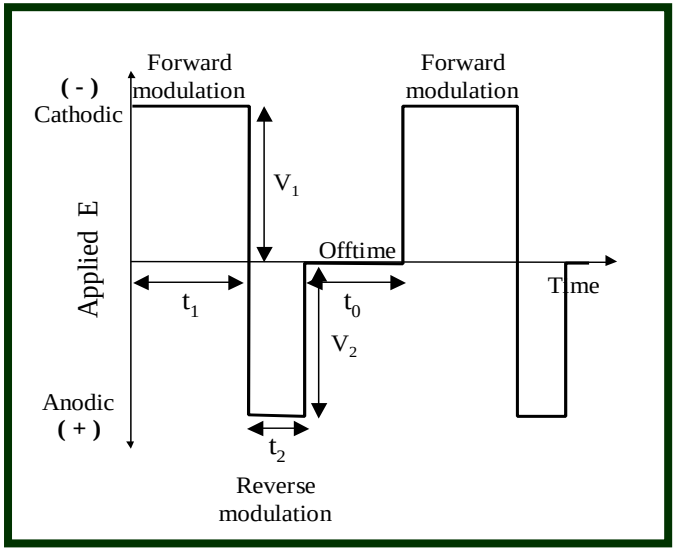
FARADAYIC® Process

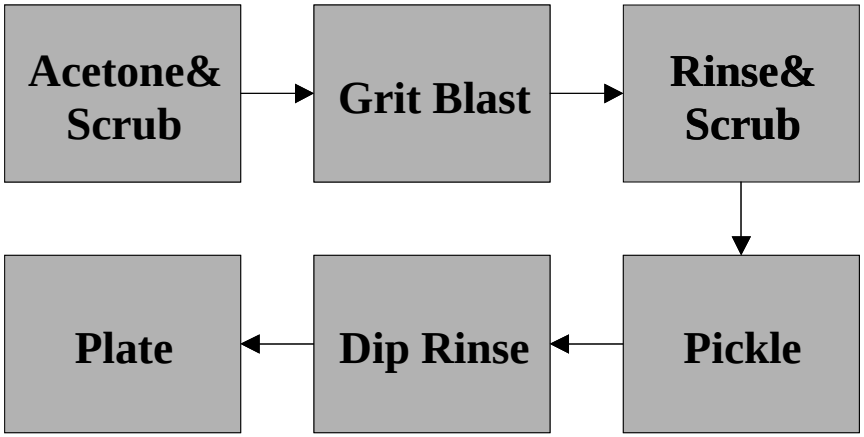


- Fast deposition rates
- Simple deposition equipment
- Non-line-of-sight deposition
- Industrially scalable

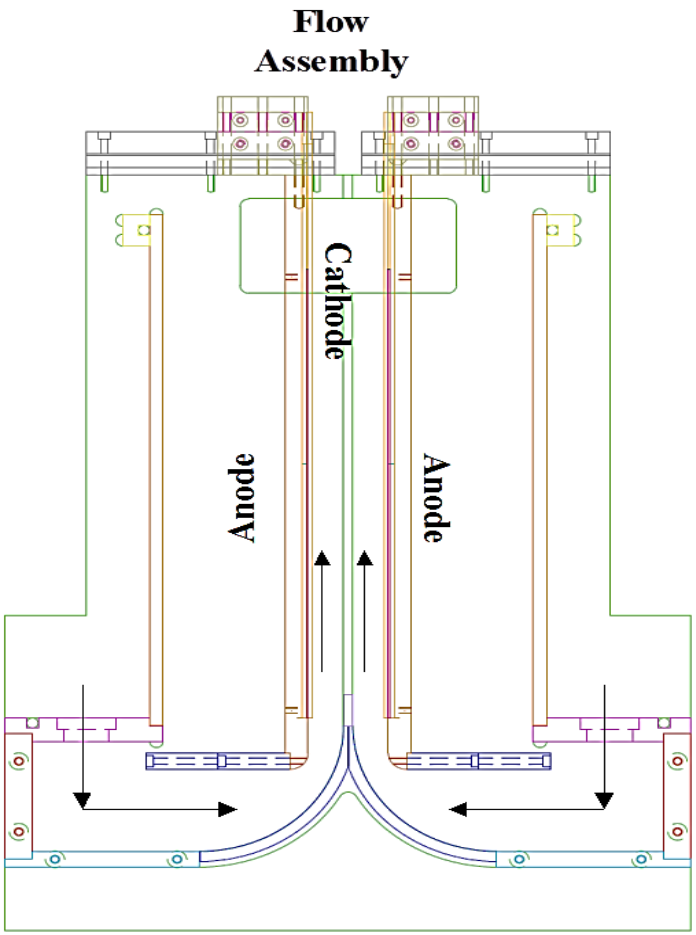
- Improved electric field control
  - Enhanced control of coating thickness uniformity
  - Enhanced control of alloy composition
- Improved coating of “hidden surfaces”

Coating Process

- Surface pretreatment to remove oxide and enhance coating adhesion
- Electrodeposition to coat interconnects with Mn-Co alloy
  - Pulse and pulse reverse electric fields to control deposit properties
- Elevated thermal treatment to convert alloy to spinel



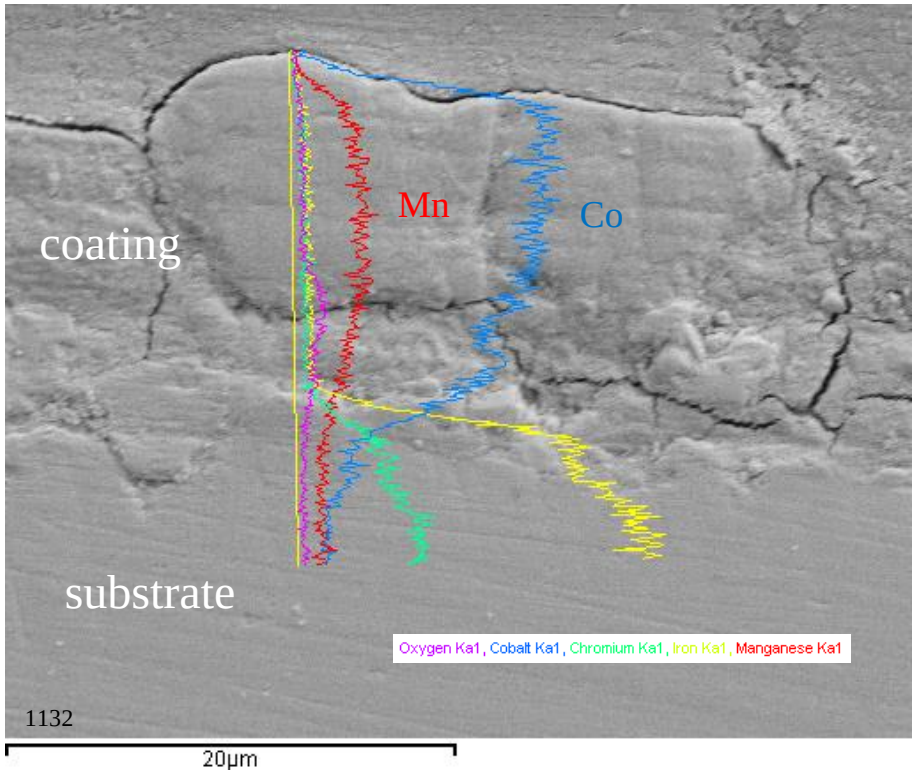
Pilot Scale Electrodeposition Equipment



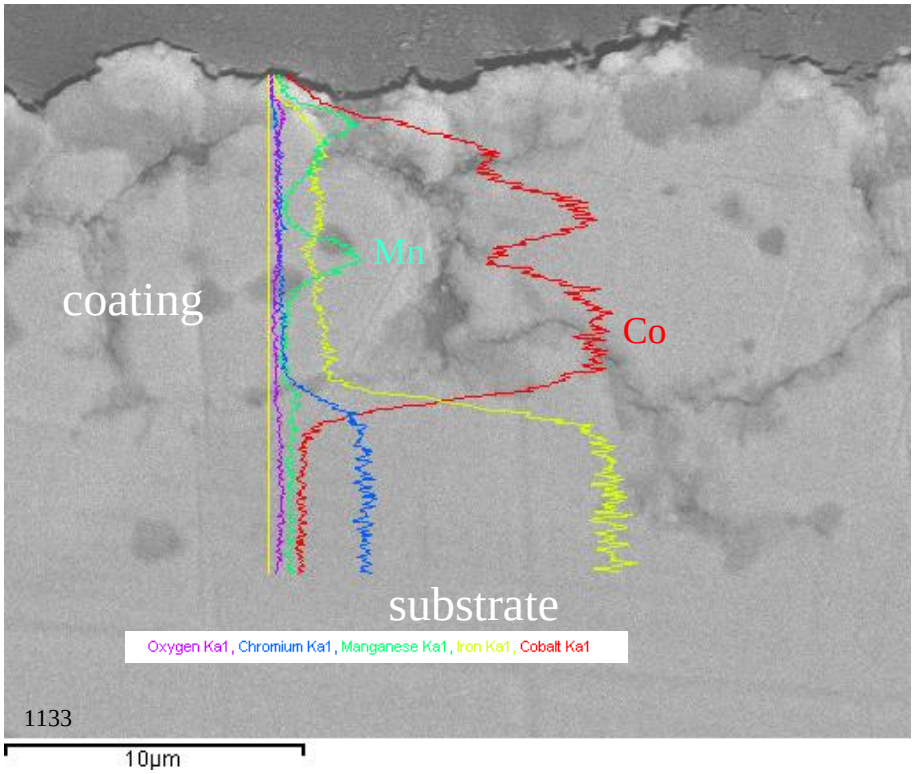
Based upon Faraday's electrochemical cell design that facilitates uniform flow across the surface of a flat substrate (US patent #7,553,401)

2000 Hour Thermal Soak at 800 ℃

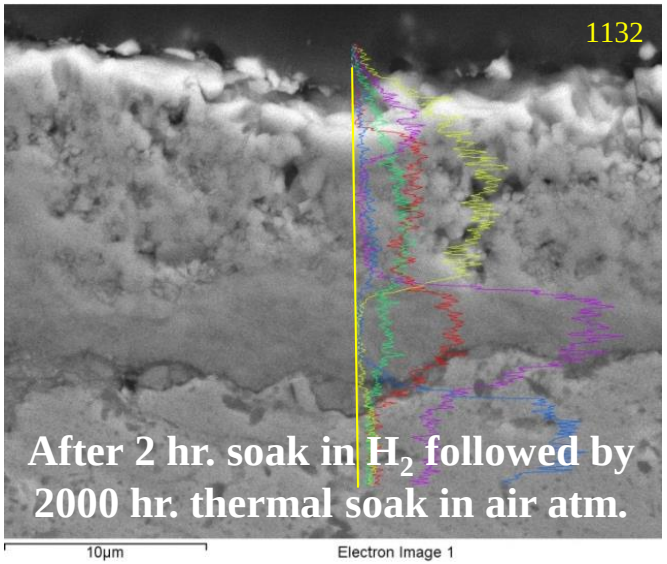
As deposited

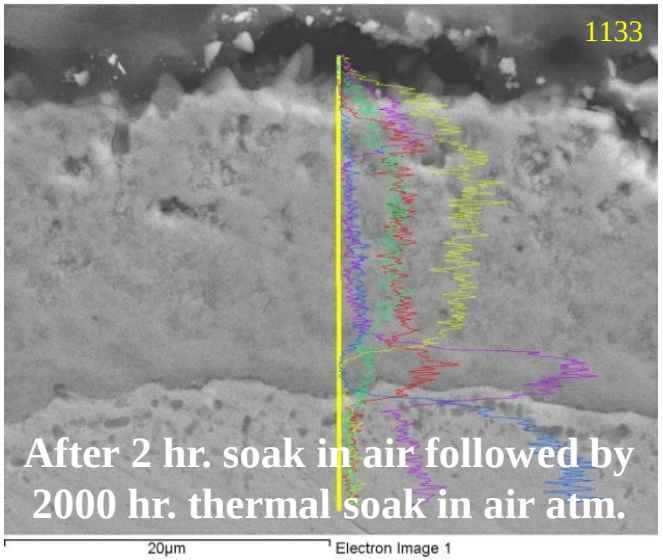


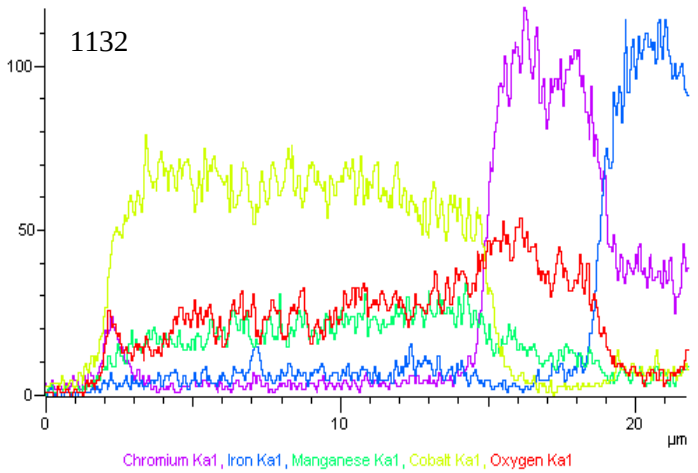
2 hr. thermal treatment in H_2 atm prior to thermal soak

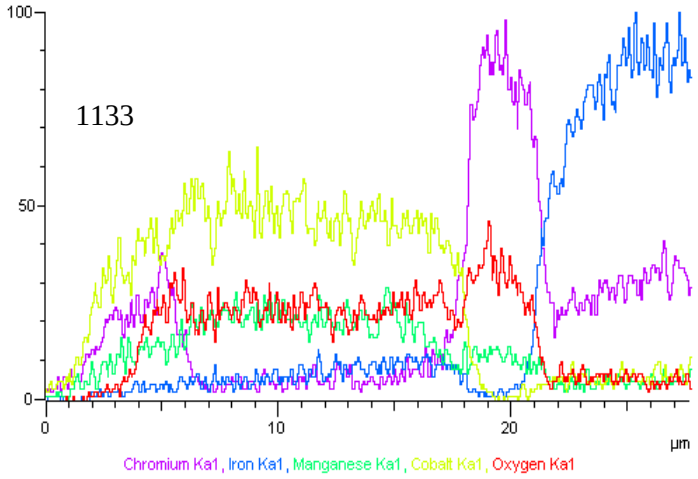


2000 Hour Thermal Soak at 800 ℃









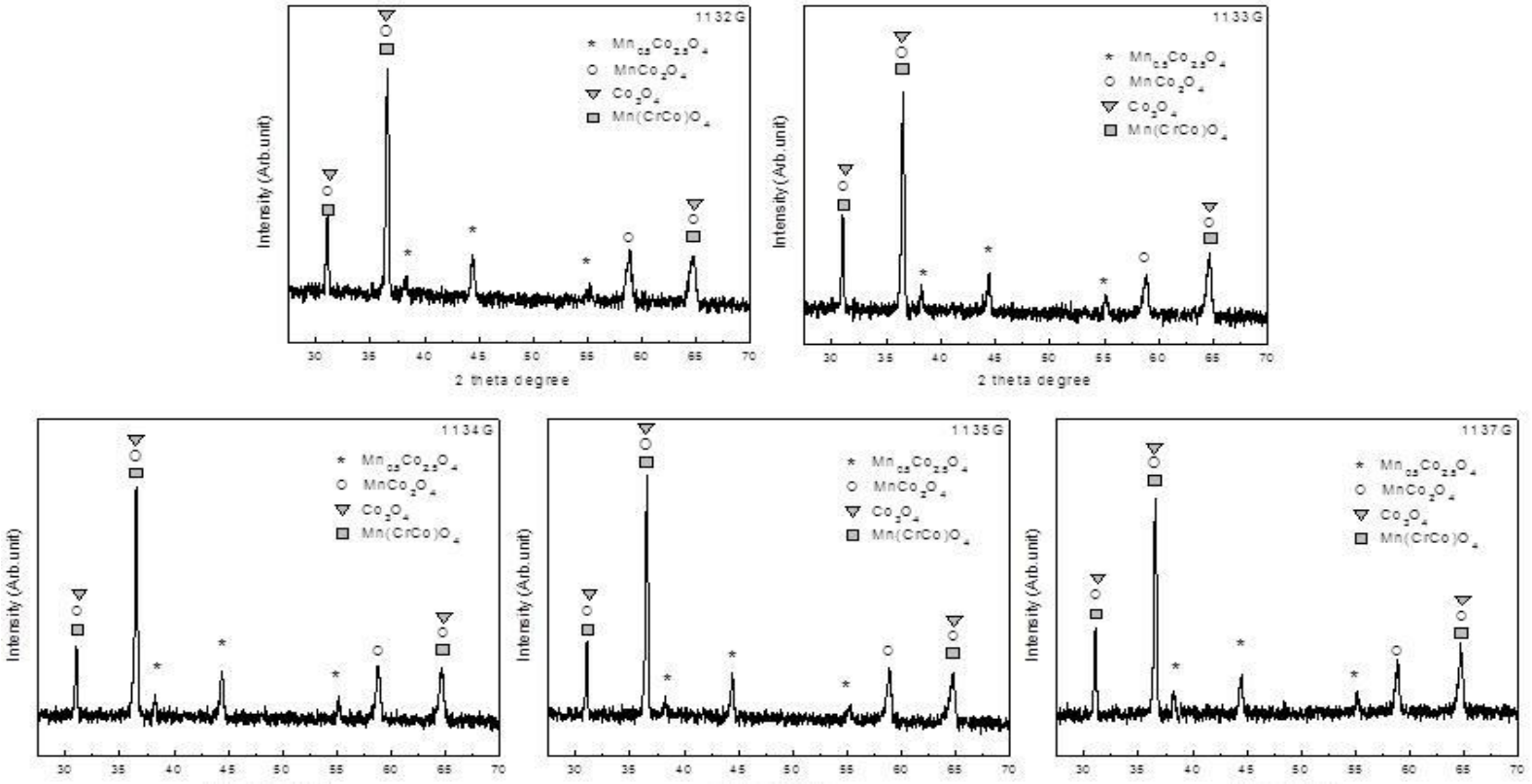
Co
Mn
O
Cr
Fe

2000 Hour Thermal Soak at 800 ℃

The ASR is ≤ 30 mΩ cm^2 after 2000 hrs. at 800°C

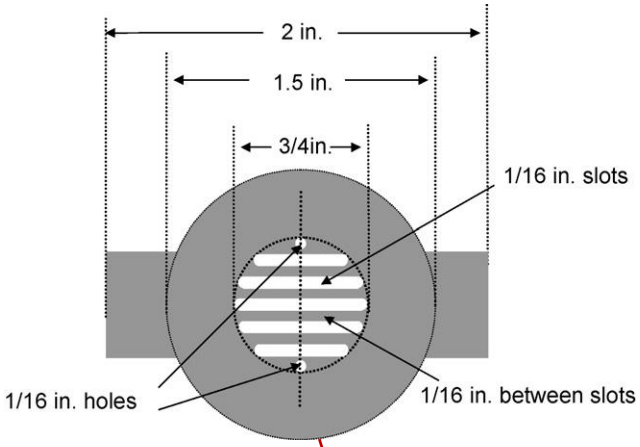
	Sample No.	Thickness Co-Mn/Chromia (µm)	Relative Atomic%		ASR (mΩ·cm^2)
			Co	Mn	
H_2 atm exposure for 2 hours followed by thermal soak for 2000 h	1132	12/5	89	11	27.6
	1136	17/4	92	8	21.6
Air atm exposure for 2 hours followed by thermal soak for 2000 h	1133	14/5	85	15	29.1
	1135	16/6	85	15	30.6
	1137	15/5	85	15	26.0

2000 Hour Thermal Soak Testing

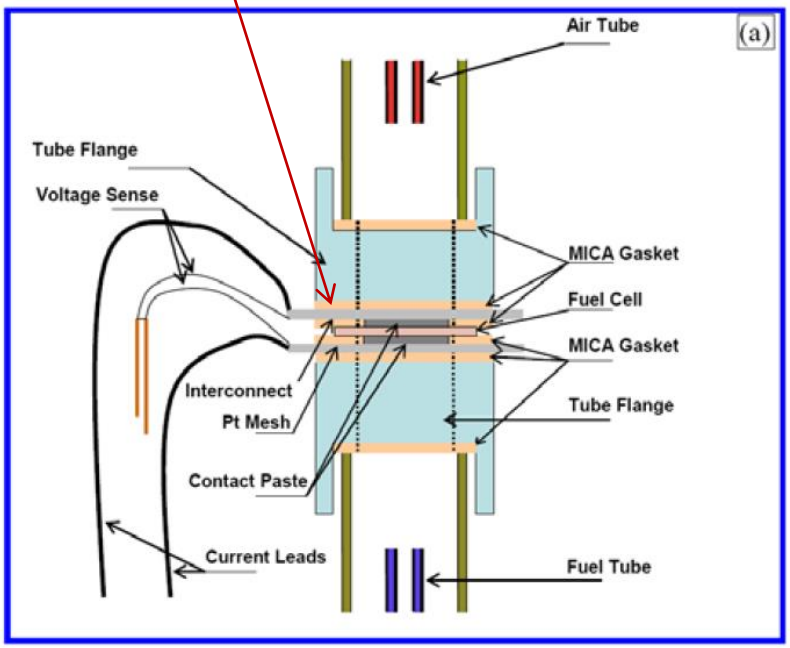


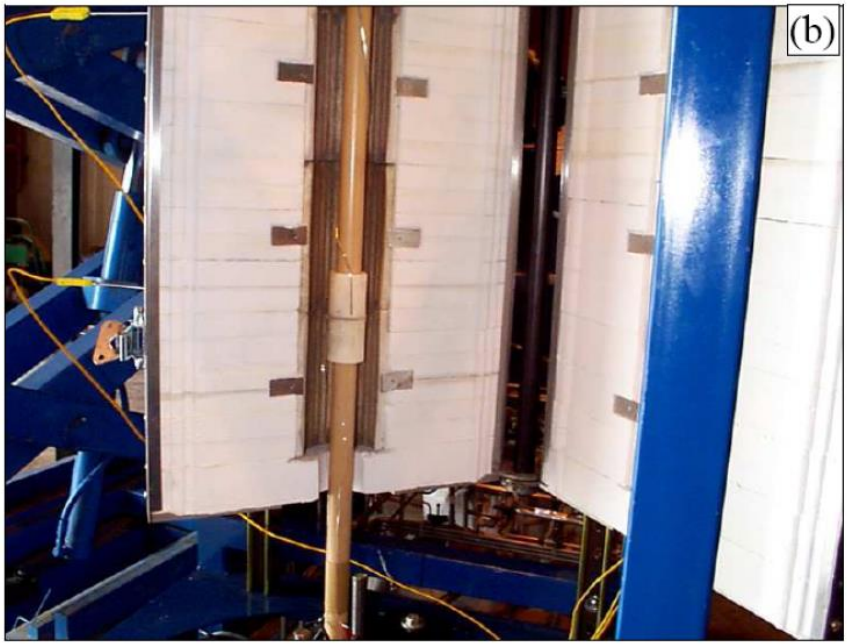
- Mixture of spinel phases
  - $Mn_{0.5}Co_{2.5}O_4$ and $MnCo_2O_4$
  - Co_3O_4
  - $MnCrCoO_4$
    - Believed to form from Cr contamination in furnace due to uncoated areas of samples
- Negligible differences observed between samples

Long-term On-cell Performance Evaluation

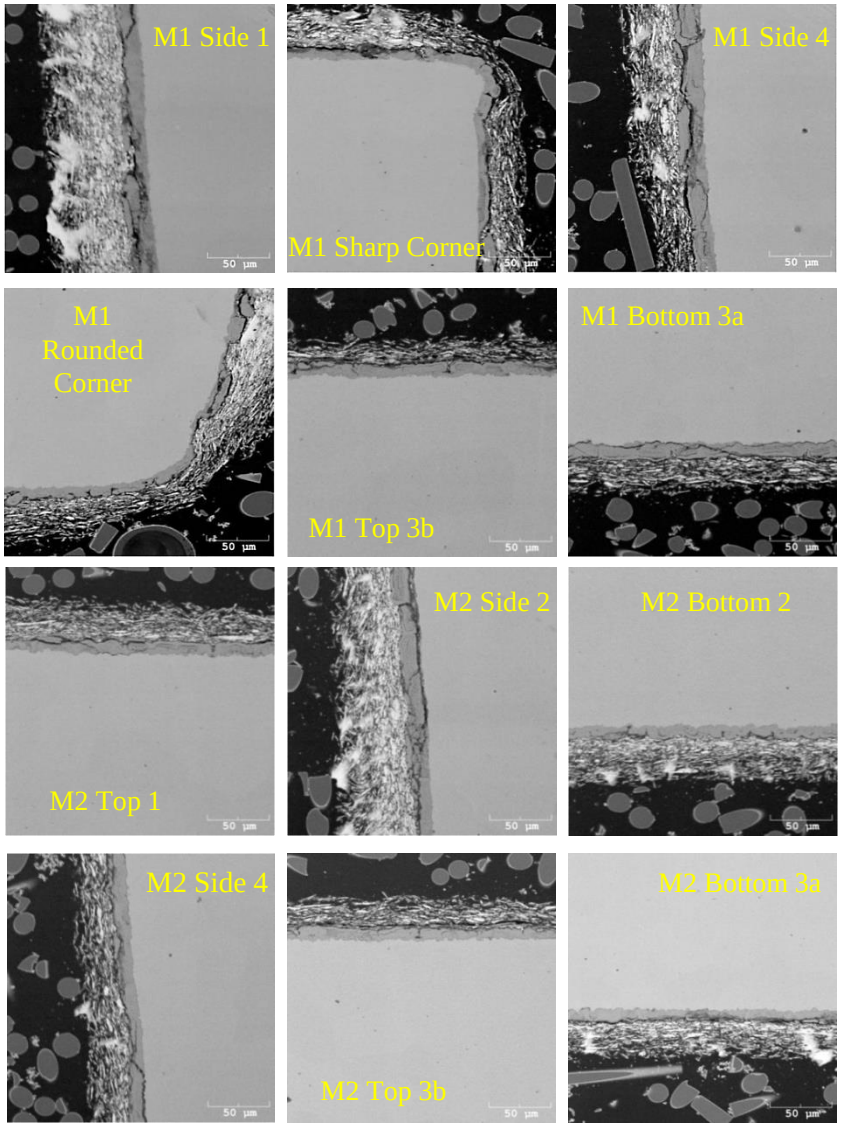


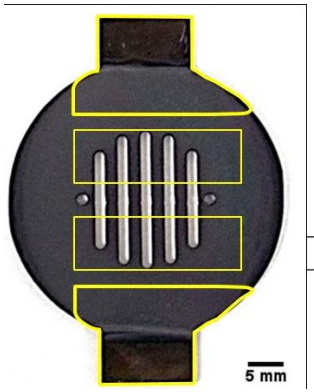
- Faraday deposited Mn-Co coatings onto both sides of button cell
- Samples sent to WVU for long term on-cell testing
- WVU to analyze the coating subsequent to the on-cell tests



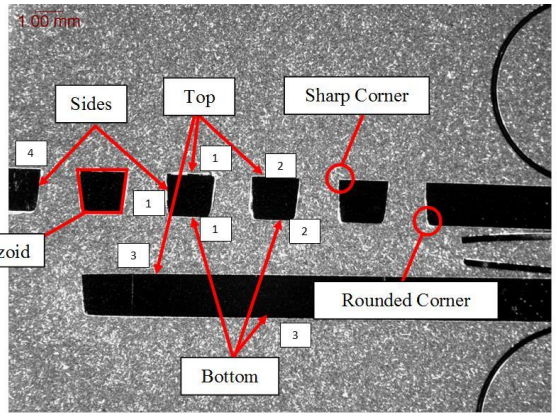


Long-term On-cell Performance Evaluation





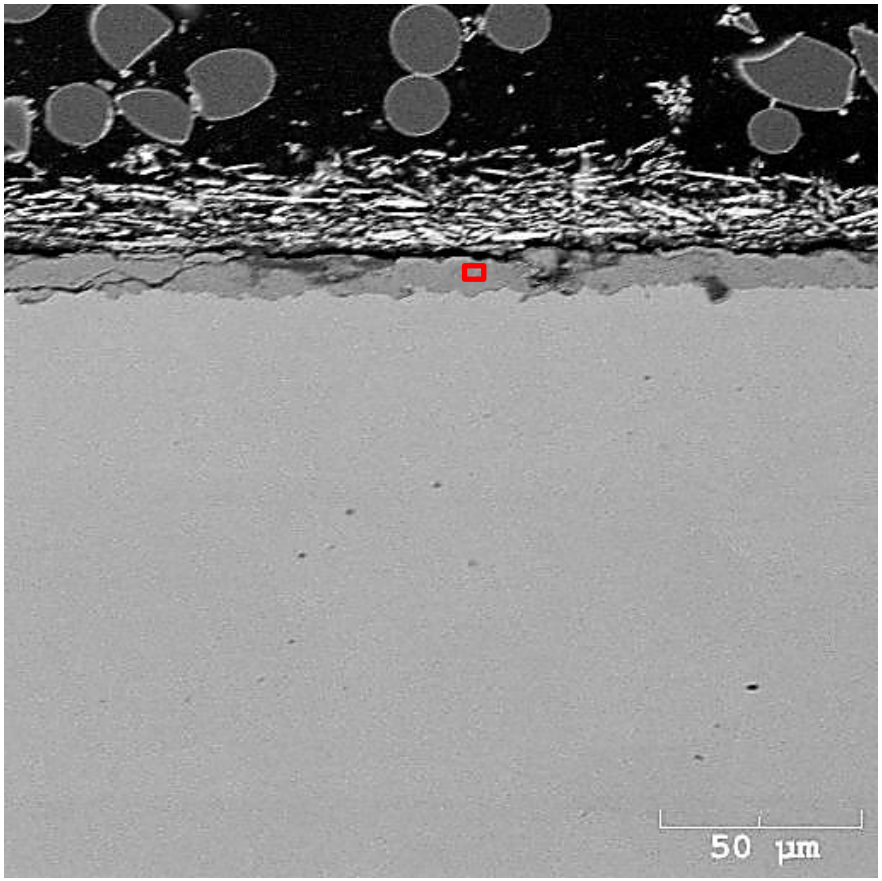
Trapezoid



Analysis Location	Coating Thickness (µm)
M1 Side 1	18.5
M1 Sharp Corner	7.8
M1 Side 4	18.9
M1 Rounded Corner	9.0
M1 Top 3b	10.2
M1 Bottom 3a	10.8
M2 Top 1	10.0
M2 Side 1	17.2
M2 Bottom 2	9.9
M2 Side 4	14.8
M2 Top 3b	9.5
M2 Bottom 3a	11.5

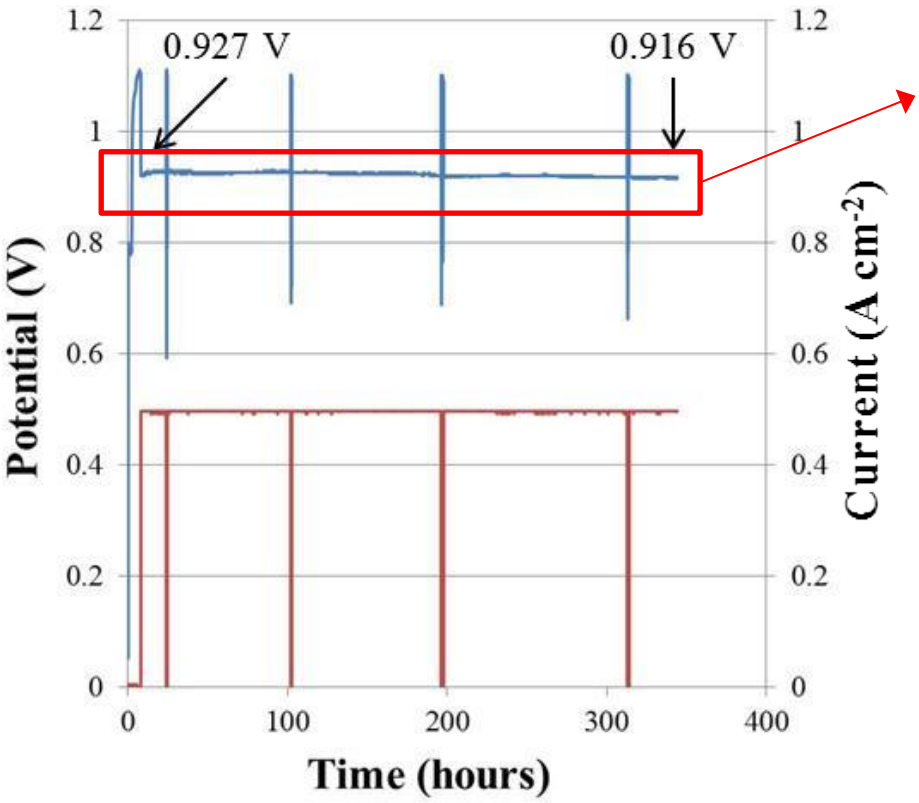
Long-term On-cell Performance Evaluation

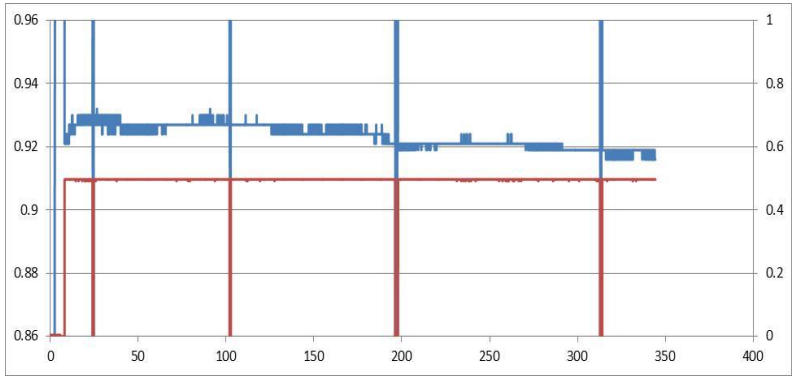
M1 Top 2

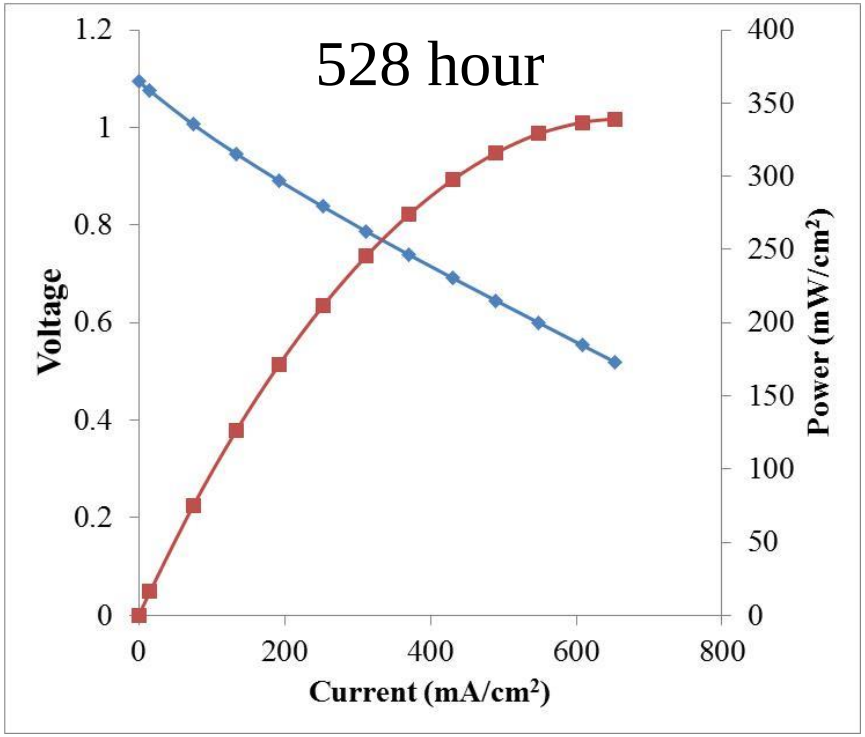


Element	At%
O	35.1%
Al	0.3%
Cr	1.2%
Mn	8.2%
Fe	0.9%
Co	54.2%

Long-term On-cell Performance Evaluation



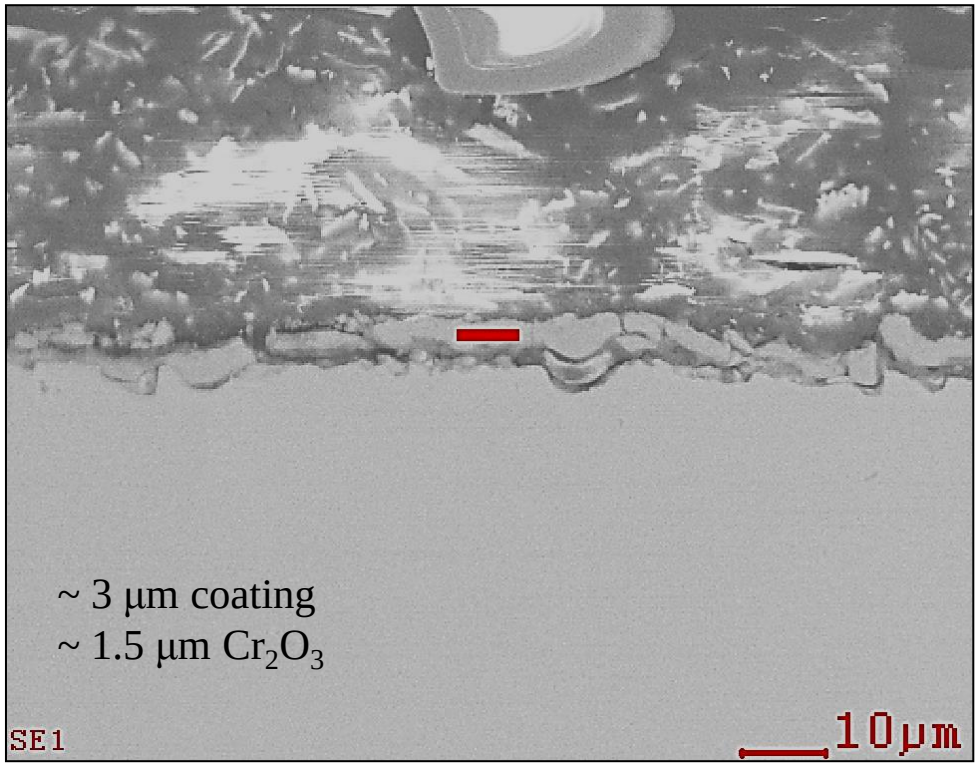




Constant current performance (0.5 A cm^{-2})
1.2 % voltage decay after 344 hr.

Related Program Tasks

Increased free [Mn] in electrolyte plating solution

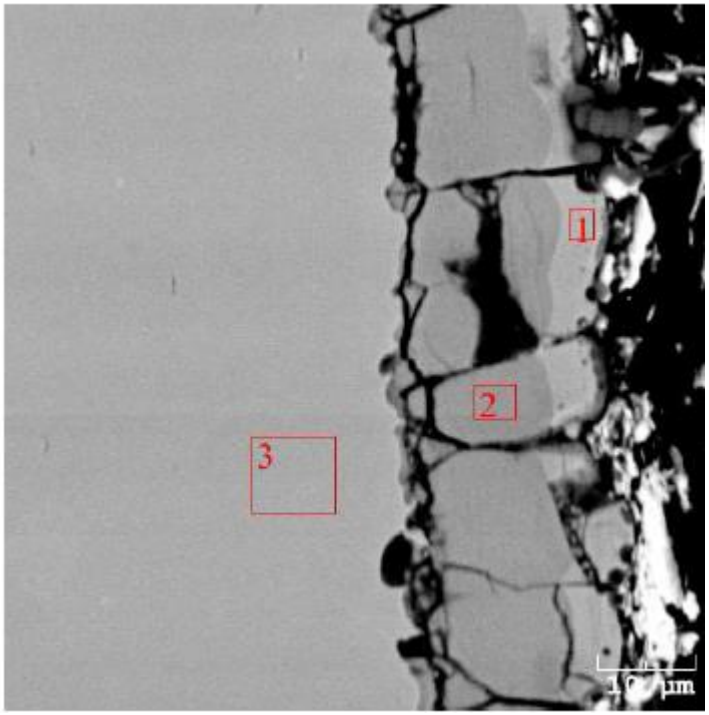


Element	*At%*
OK	64.8
AlK	0.2
CrK	4.0
MnK	11.2
FeK	6.4
CoK	13.3

Related Program Tasks

Sequenced waveform to form Co-Mn layer followed by Co rich layer

Before spinel conversion

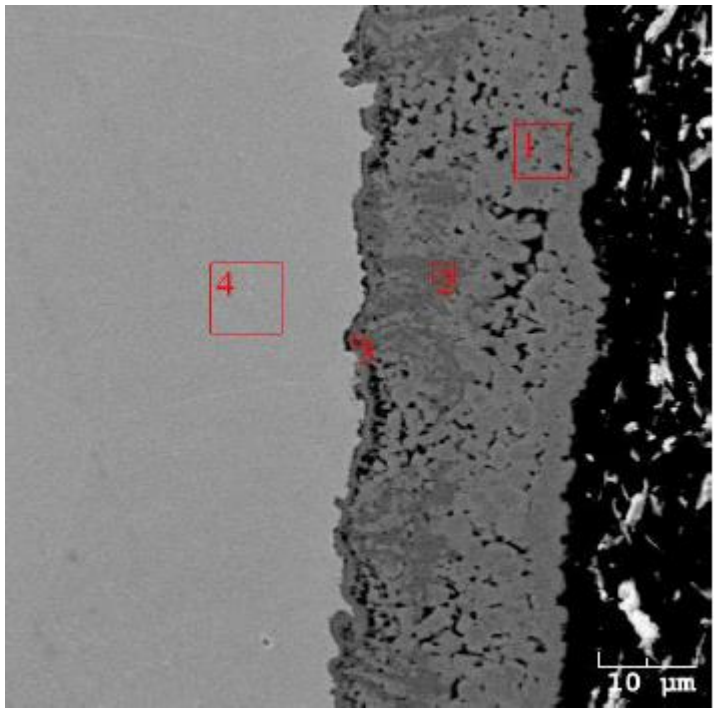


Element	Rel. Atomic %		
	Spot 1	Spot 2	Spot 3
O	5.8	12.8	0.7
Al	0.6	0.9	0.2
Cr	0.3	0.3	17.7
Mn	2.8	10.9	0.4
Fe	0.3	0	80.5
Co	90.3	75.1	0.5
Co:Mn	32:1	7:1	N/A (substrate)

Related Program Tasks

Sequenced waveform to form Co-Mn layer followed by Co rich layer

After spinel conversion



Element	Rel. Atomic %			
	Spot 1	Spot 2	Spot 3	Spot 4
O	23.9	27.2	24.8	1.4
Al	0.5	0.4	0.9	0.6
Cr	1.3	1.5	14.5	17.8
Mn	4.7	15.2	7.7	0
Fe	0.1	0.7	10.7	80.1
Co	69.6	55.1	41.3	0.1
Co:Mn	15:1	4:1	N/A (Cr scale)	N/A (substrate)

Future Work

- Complete long-term on-cell performance evaluation of button cells
- Qualification/Demonstration of interconnect coating by industry under SOFC operating conditions

Acknowledgments

- Briggs White and SECA Program Management

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Thank You!