Filtered arc plasma assisted PVD coatings for SOFC metallic interconnects

Vladimir Gorokhovsky
Arcomac Surface Engineering, LLC
Bozeman, MT

This Program is Supported by DoE/SECA Contract No. DE-FC26-04NT42225

Technical Issues

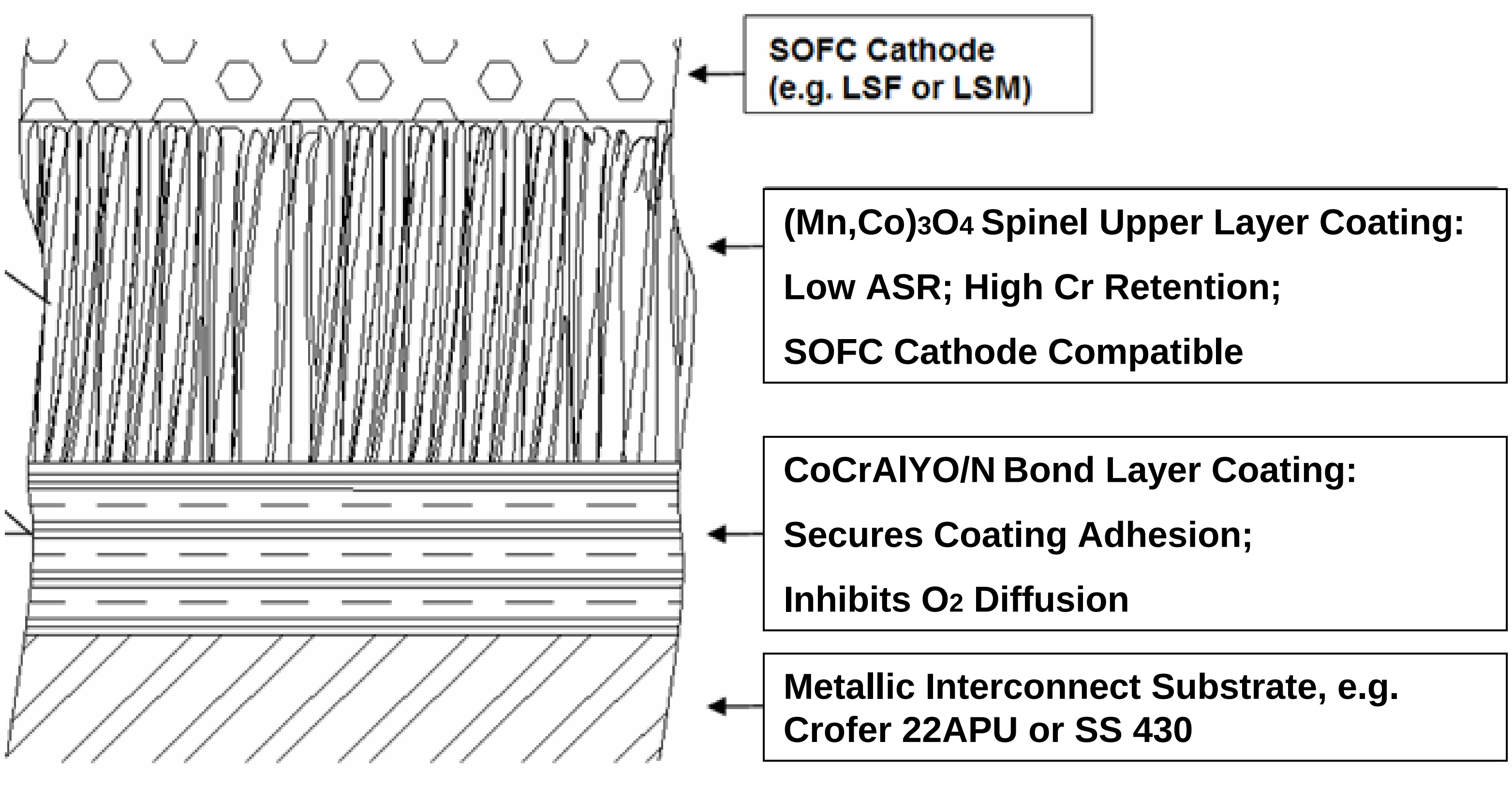
- Can coatings enable inexpensive metallic alloys as interconnects in intermediate temperature (~600-800°C) planar SOFCs?
- What coating compositions and architectures are preferred?
- Can Arcomac's advanced filtered arc plasma assisted hybrid PVD technologies be used to deposit coatings to meet SECA performance and cost goals?

Technical Accomplishments

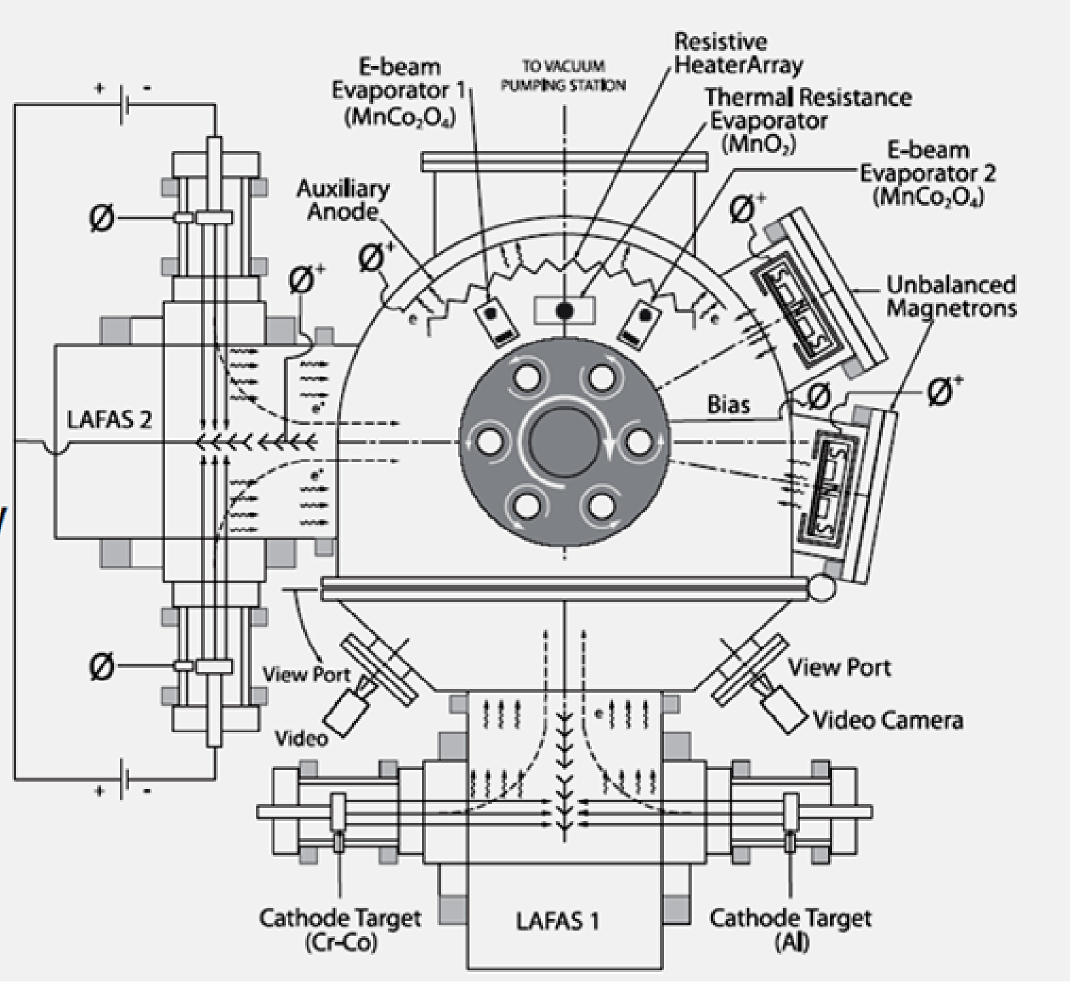
- Developed and tested novel, filtered arc plasma assisted hybrid coating process combing EBPVD, thermal evaporation and filtered arc deposition (FAD) technologies to deposit dense and highly adherent $(Mn,Co)_3O_4$ coatings in economically-favorable process.
- Developed dense and highly adherent Cr-Al-Y-O diffusion barrier bond coating layer, stable at 800°C
- Significantly reduced oxidation rates vs. uncoated steels
- Significantly reduced Cr volatility
- Achieved low and stable ASR values

Technical Approach:

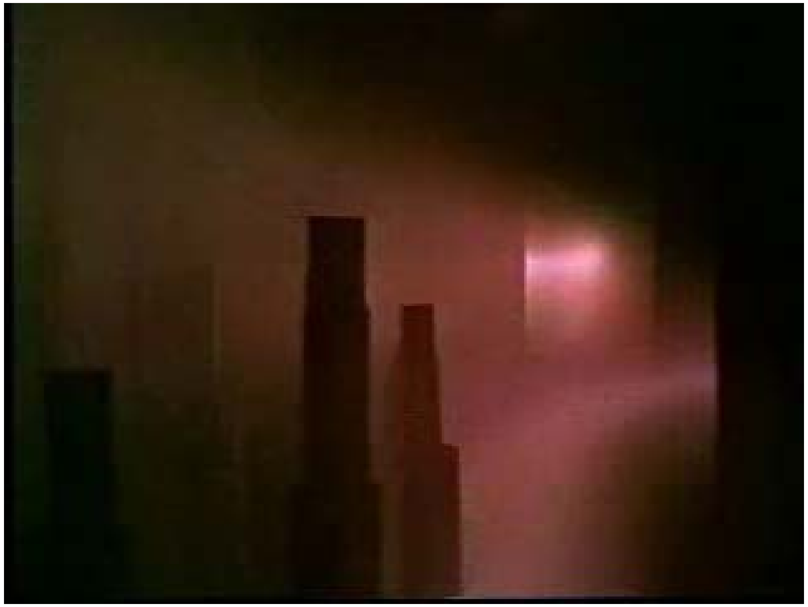
Dual Segment Hybrid Coating Architecture and Composition



Hybrid PVD Coating Technology: Filtered Arc Plasma Source Ionized Deposition (FAPSID) Surface Engineering Process



Top view



Project Coating Matrix

		Upper Coating Layer - Deposited by FAD-Based PVD Techniques			
FAD-Bond Coating Layer		None	FAD-EBPVD Mn1.5Co1.5O4	FAD CoMn +O2	FAD Co + TRE MnO2
	None		X	TBP	TBP
	Cr/Al + O2/N2	PR	PR	TBP	TBP
	CrAlY/Al + O2/N2	X	X	TBP	TBP
	CoCrAlY/Al + O2/N2	TBP	TBP	TBP	TBP

FAD-EBPVD = Hybrid Filtered Arc-assisted Electron Beam Physical Vapor Deposition

FAD = Filtered Arc Deposition (All Bond Coatings)

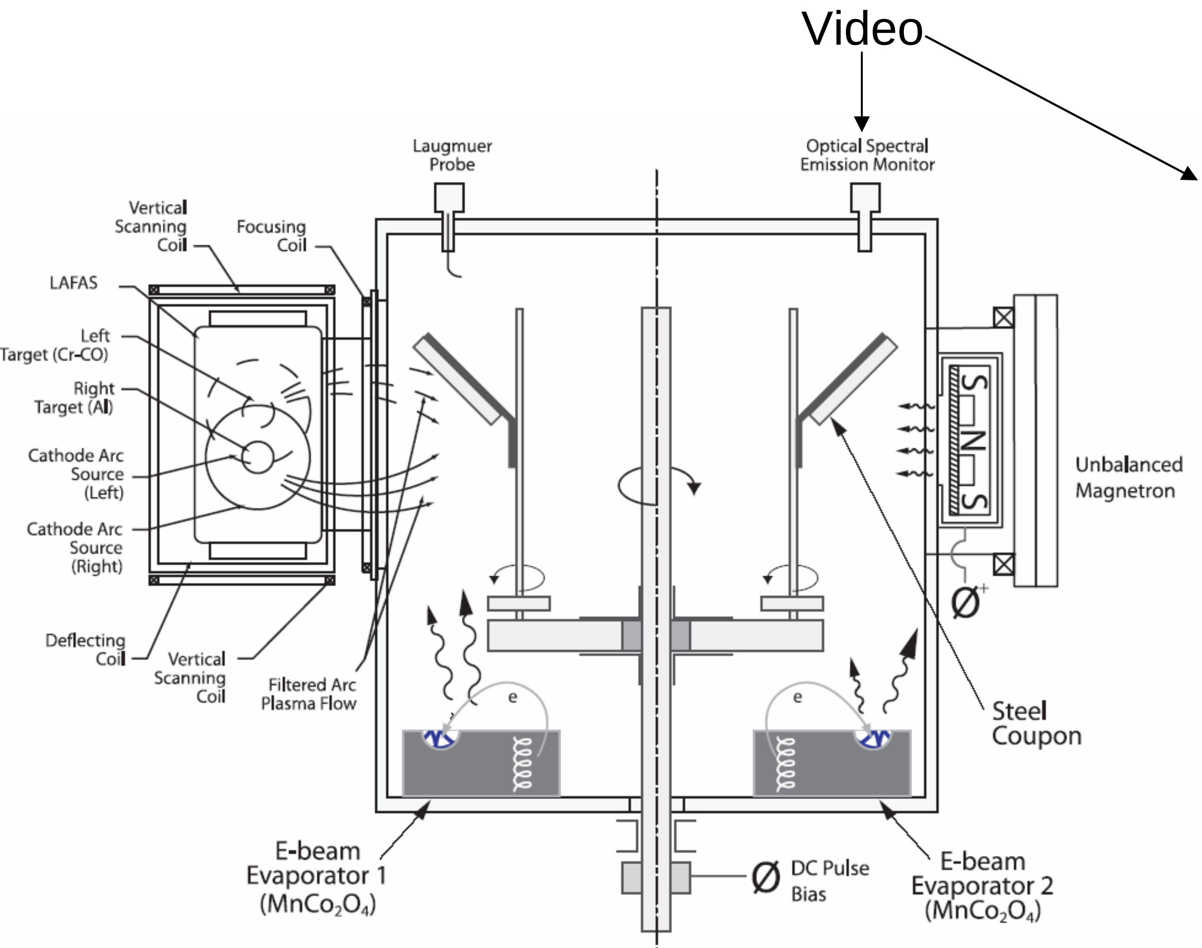
TRE = Thermal Resistance Evaporation

TBP = To Be Prepared

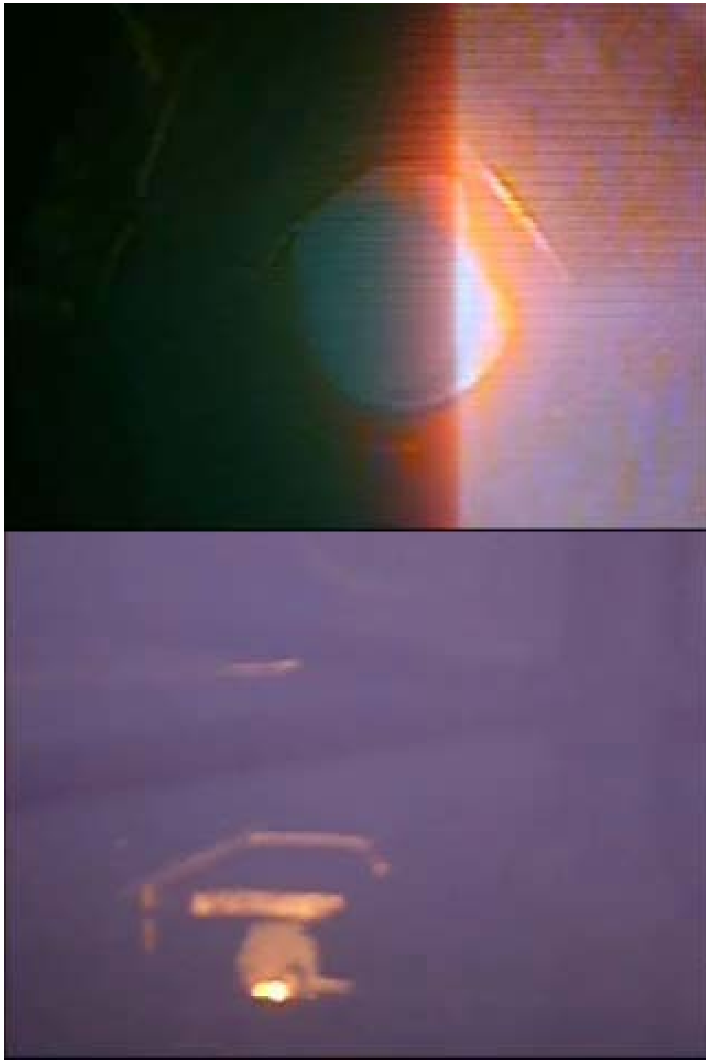
PR = Previously Reported: ICMCTF 2004, 2005; SECA Core Technology Workshops

Surface and Coatings Technology - (Volume 188-189) p55-61 2004

Filtered Arc-Assisted EBPVD:



(Side View)



Coatings Presented in this Work

		Upper Coating Layer	
		None	**1.0 um FAD-EBPVD $Mn_{1.5}Co_{1.5}O_4$**
FAD Bond Coating Layer	**None**	X	X
	0.3um Cr(5%)Al(25)Y(<0.5%)O	X	X
	3.0um Cr(5%)Al(25)Y(<0.5%)O	X	X

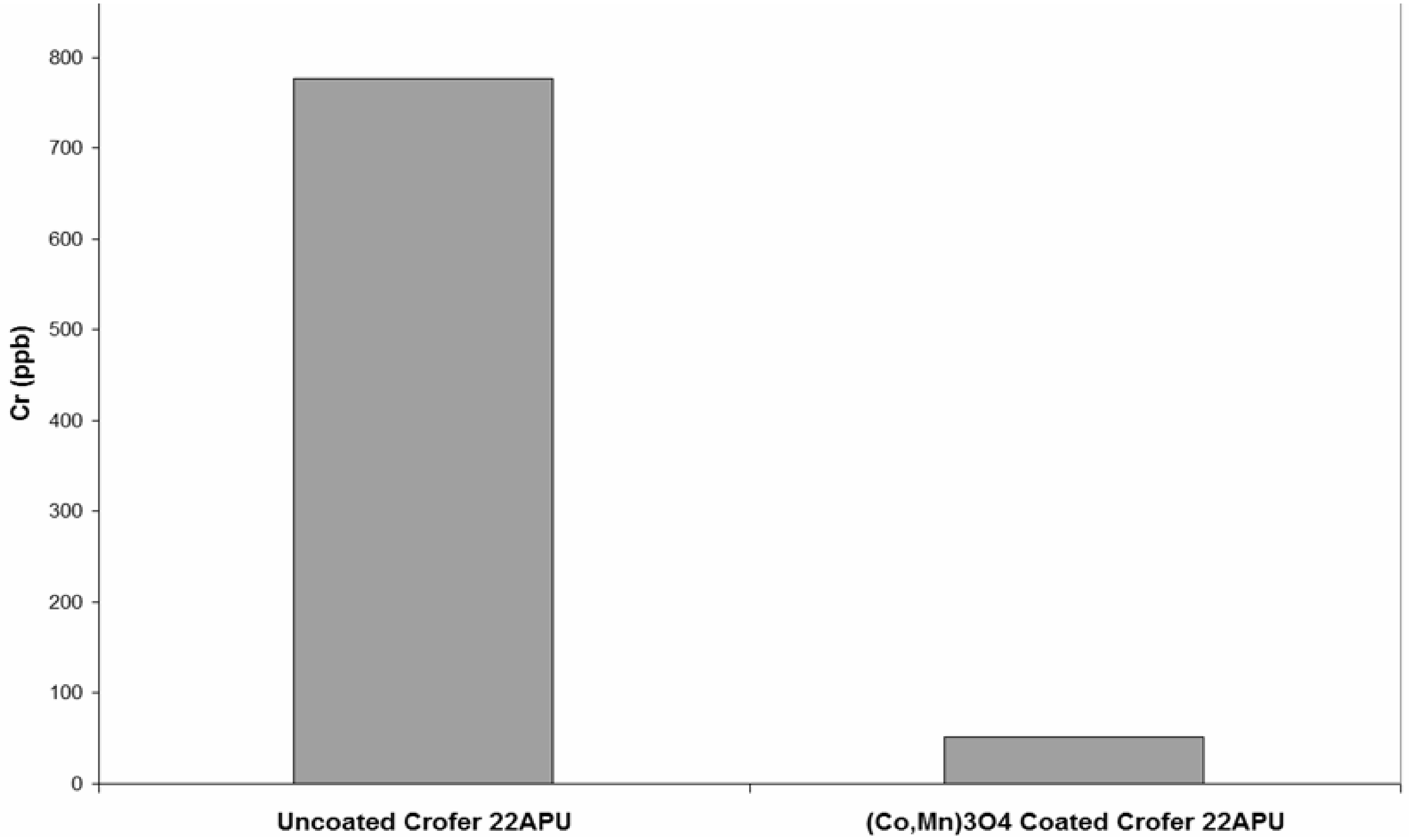
FAD-EBPVD = Filtered Arc-assisted Electron Beam Physical Vapor Deposition

FAD = Filtered Arc Deposition (All Bond Coatings)

Evaluation Techniques

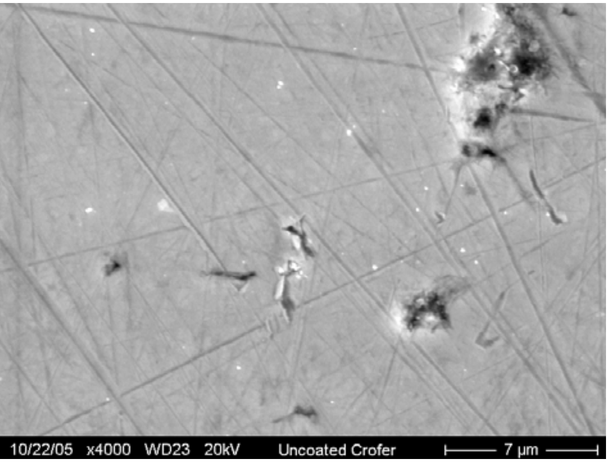
- Coating adhesion
  - Indentation methods
- Composition and Morphology
  - SEM/EDS and Ion Beam Analyses
- Electrical Conductivity
  - ASR Measurements in Air
- Oxidation Stability
  - Cross sectional Analyses
- Cr Volatility
  - Transpiration Studies (LBNL + MSU)

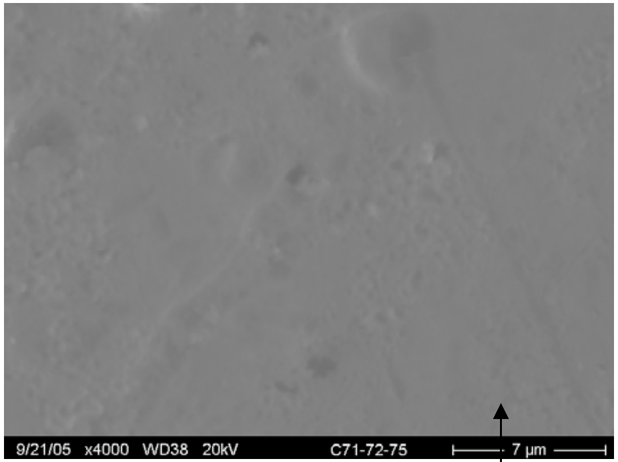
Results of Cr volatility testing on one segment $Mn_{1.5}Co_{1.5}O_4$ single sided coating deposited by hybrid FAD/EBPVD technique (Courtesy of S.Visco). The remaining leak of Cr is attributed to coating damage incurred during Ni electroplating the back (uncoated) side of sample coupon

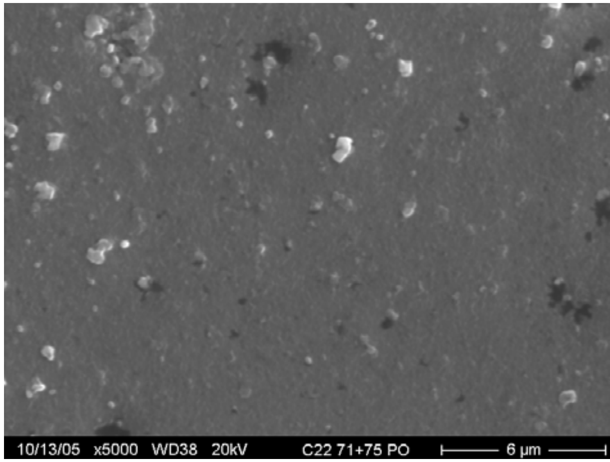


No Substantial Change in Coating Morphology after 100 hrs@800C

Crofer22APU



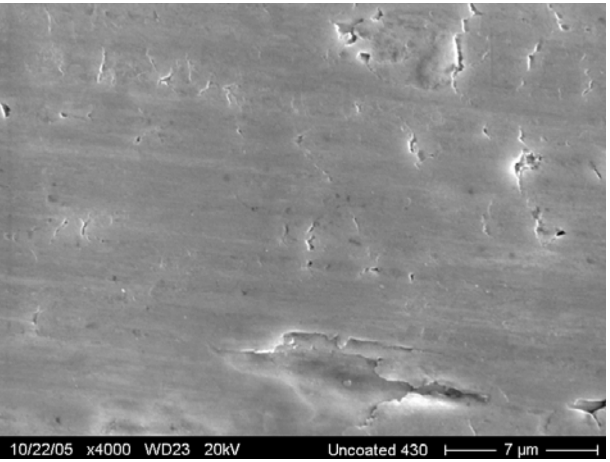


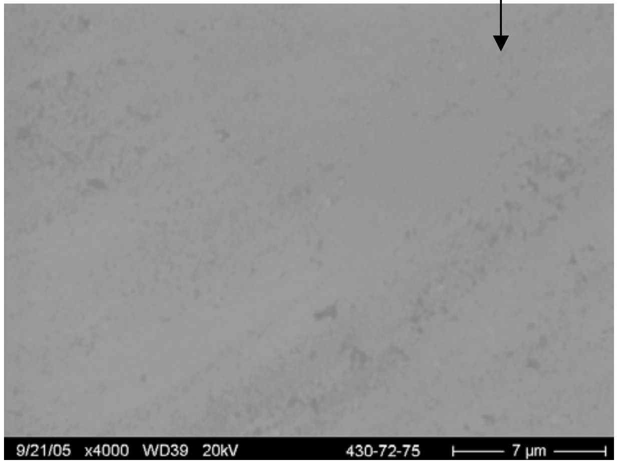


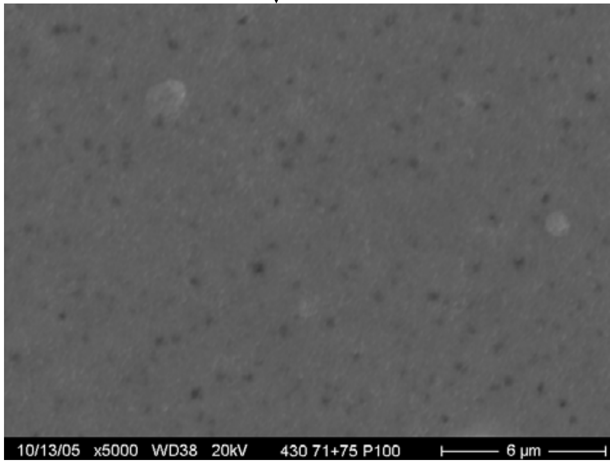
Uncoated

2-Segment Coatings: As-Deposited

Post 100hrs @800C



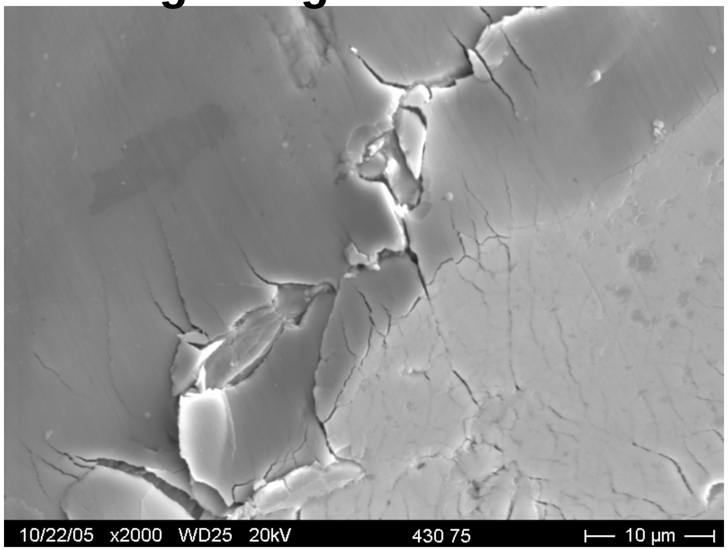




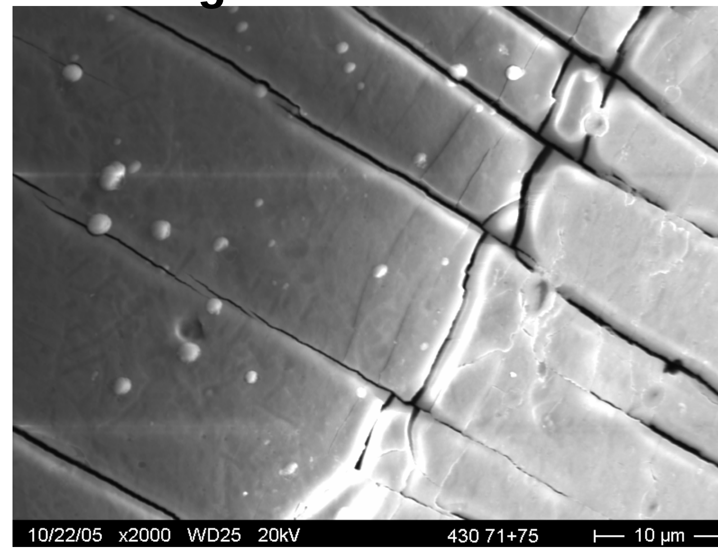
430SS

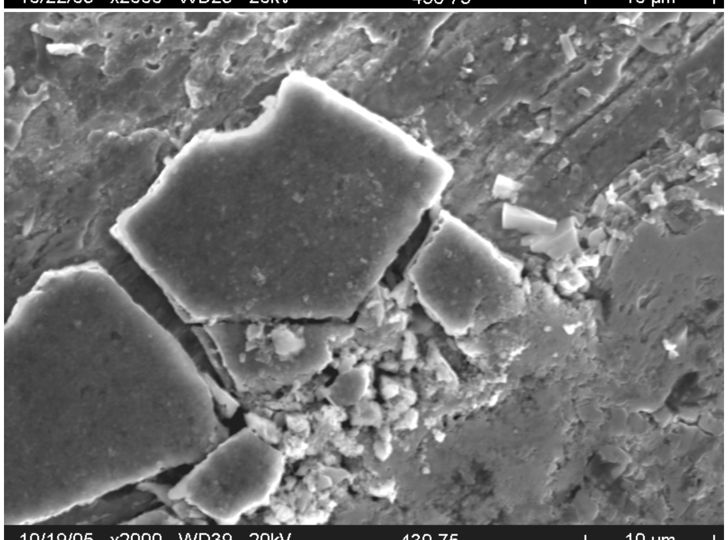
Rockwell C 145 kg indentation test demonstrates improved adhesion of dual segment CrAlYO+MnCoO coating

Single Segment CoMnO | **Dual Segment CrAlYO+MnCoO**

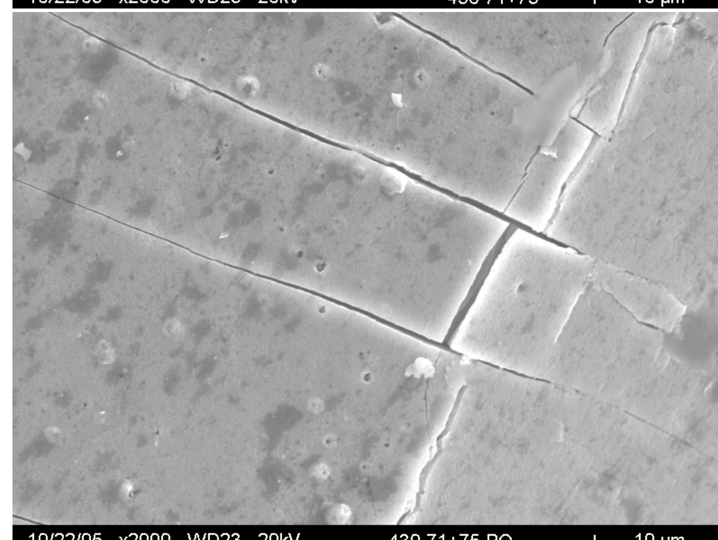


As-Deposited



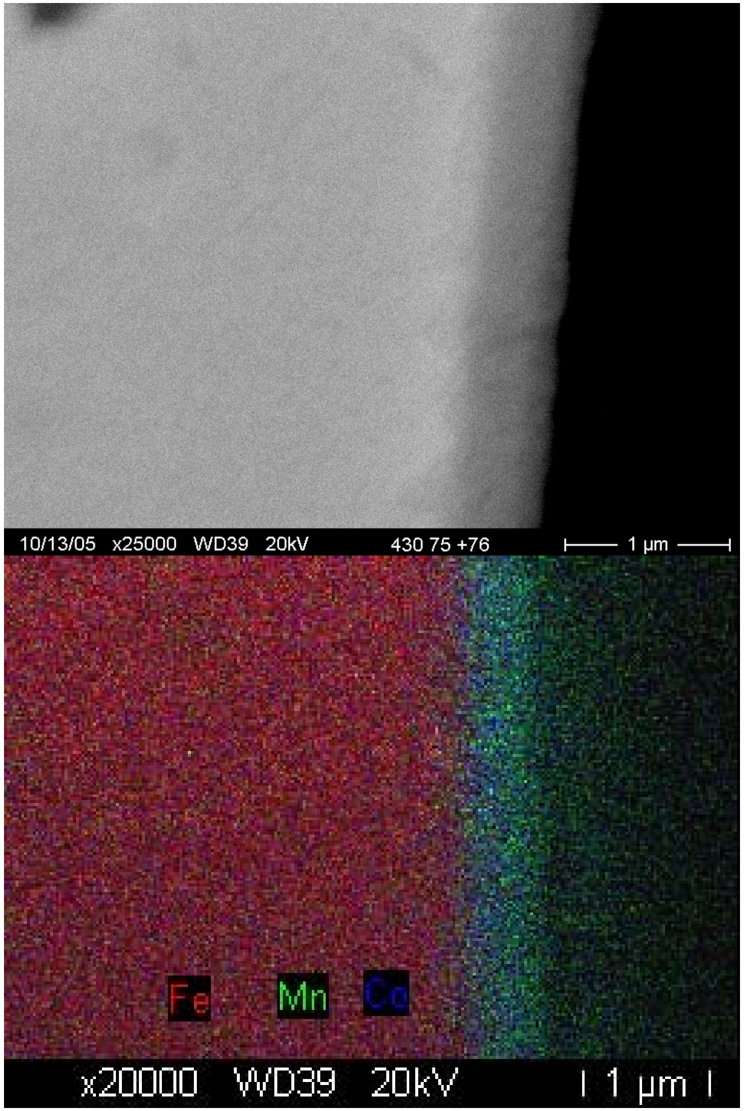


Post 100hours at 800C in Air

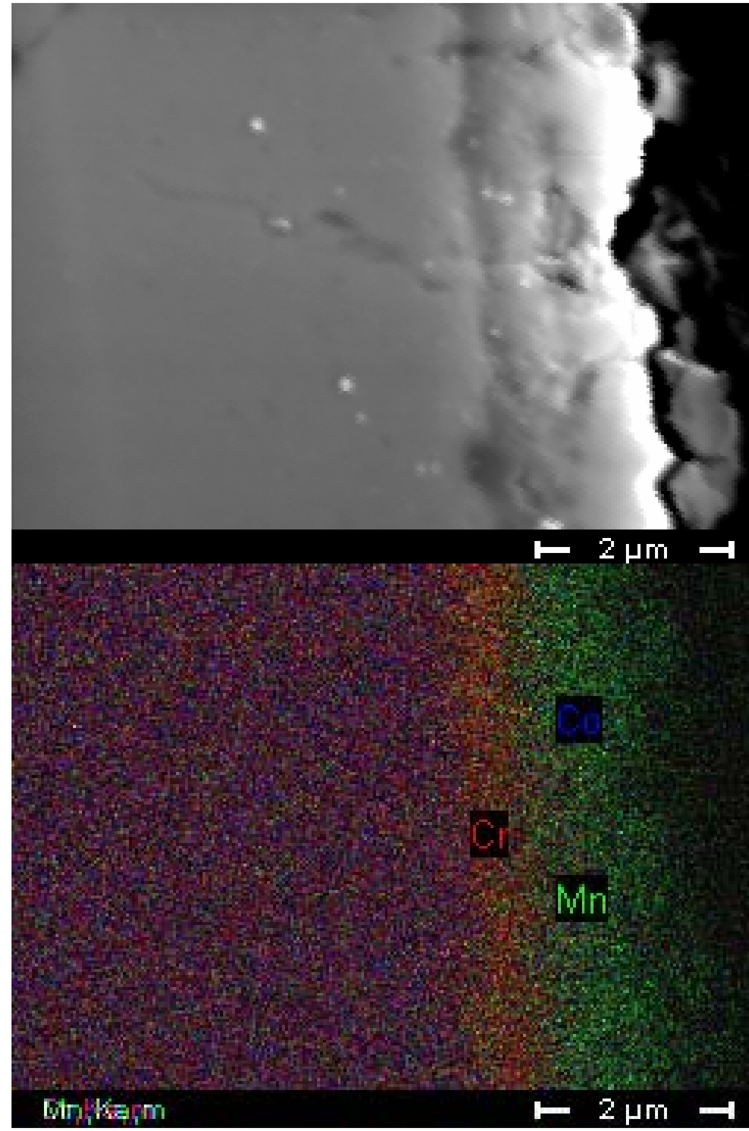


1 um MnCoO – only: shows Chromia scale growth under MnCoO coating

As-deposited

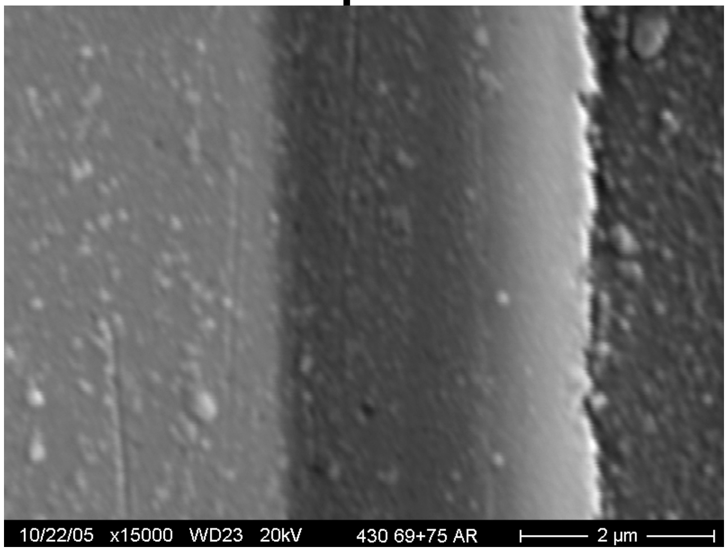


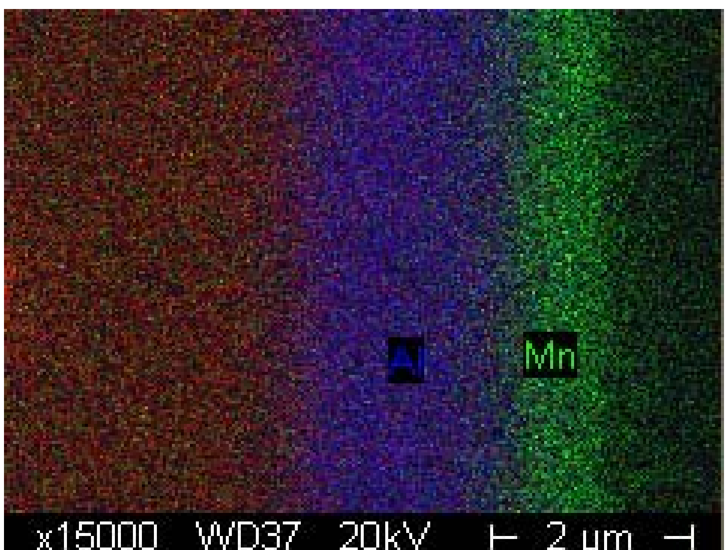
Post 100 hours at 800C in Air



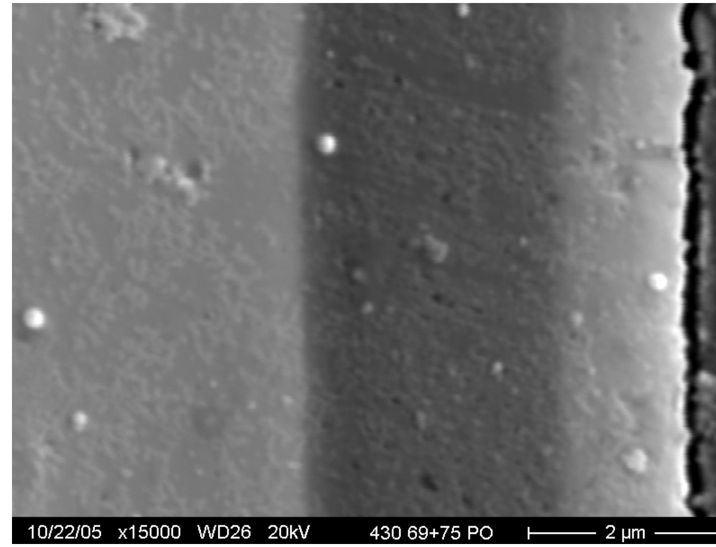
3.0um CrAlYO + 1 um MnCoO: no chromia TGO scale growth; no substantial change in coating structure after high temperature exposure

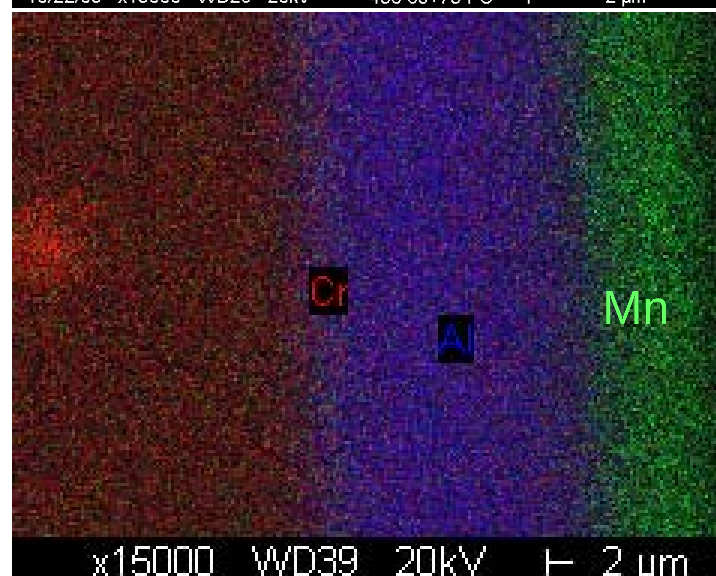
As-Deposited





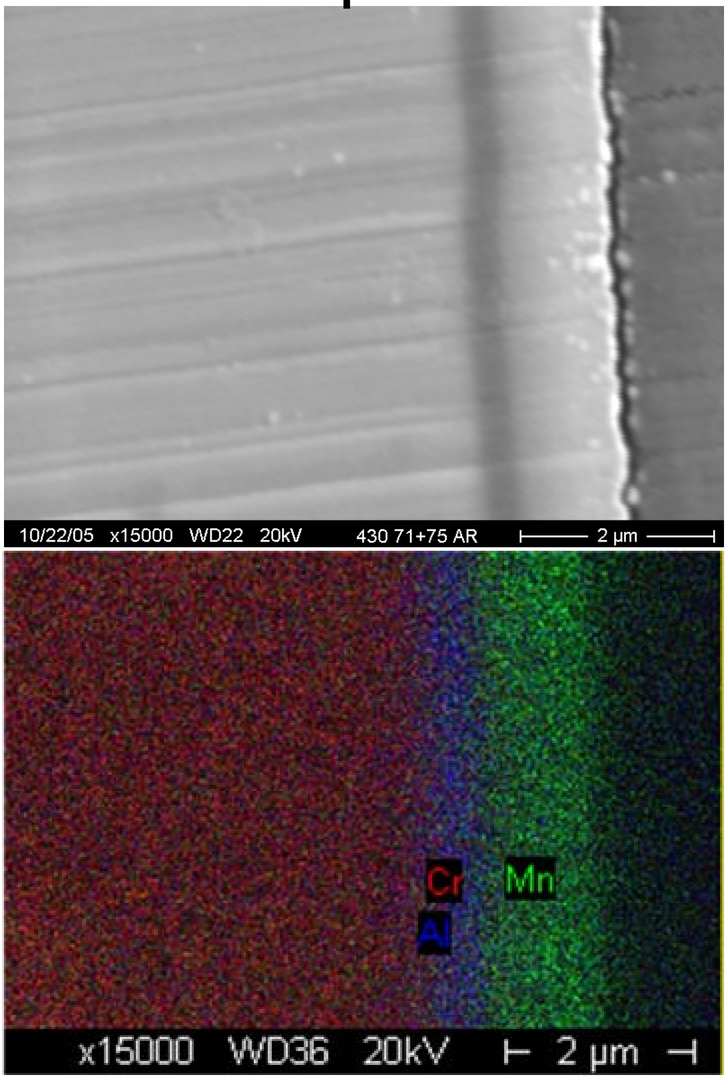
Post 100 hours at 800C in Air



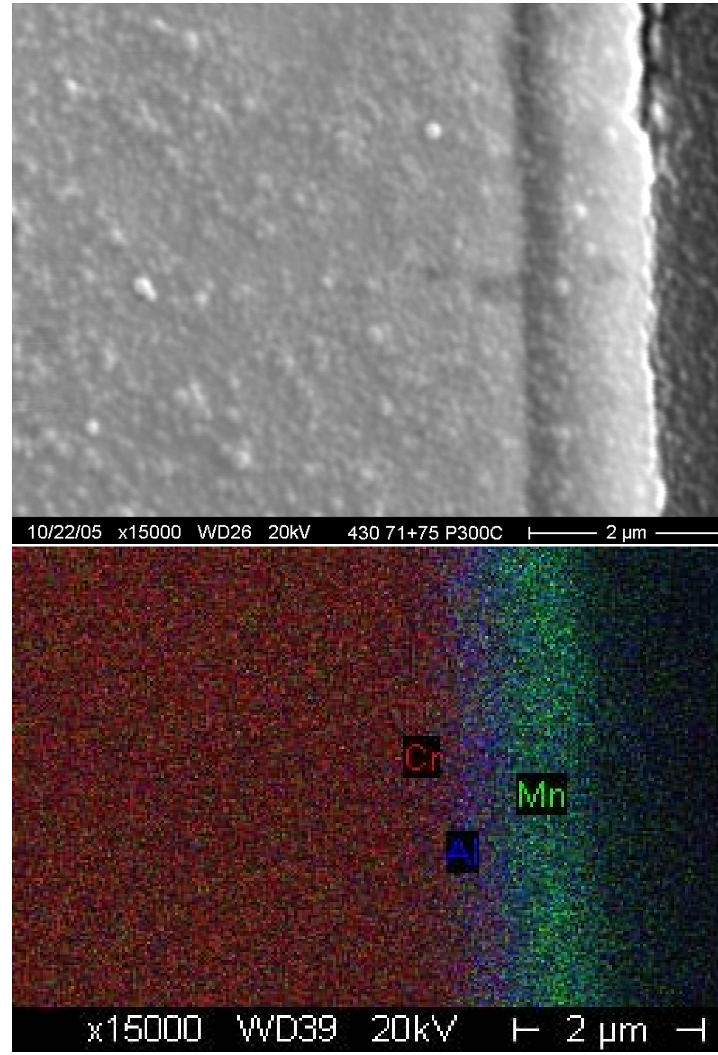


0.3um CrAlYO + 1 um MnCoO: no chromia TGO scale growth; no substantial change in coating structure after high temperature exposure

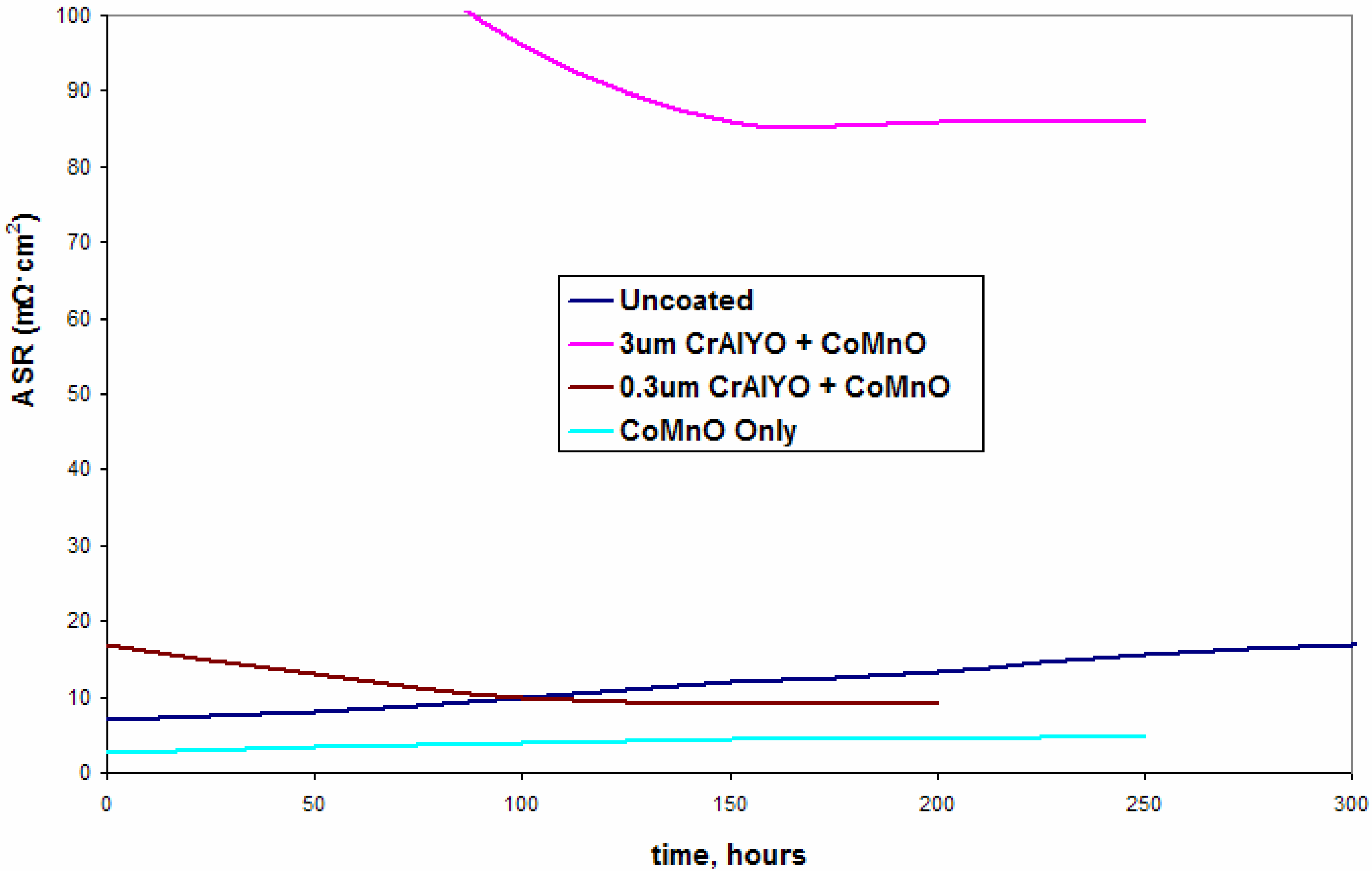
As-Deposited



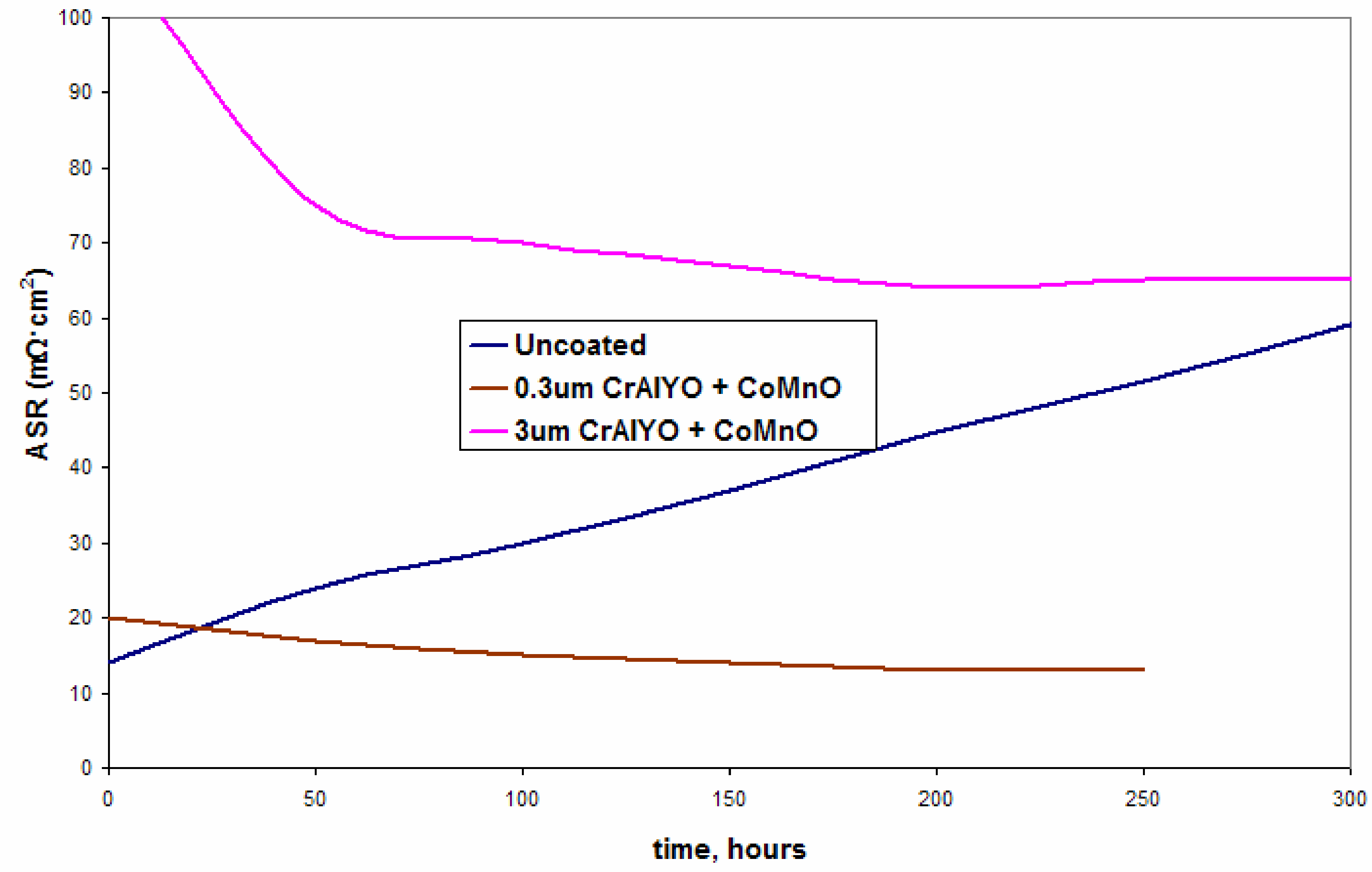
Post 100 hours at 800C in Air



Crofer 22APU - ASR



430 SS - ASR



100
90
80
70
60
50
40
30
20
10
0
ASR (mΩ·cm²)
Uncoated
0.3um CrAlYO + CoMnO
3um CrAlYO + CoMnO
0
50
100
150
200
250
300
time, hours

Summary

- Dense, dual segment CrAlYO + MnCoO coatings with controlled thicknesses can be deposited on SOFC(IC) candidate steels by FAD plasma assisted PVD technology
- Single segment MnCoO coating – lower and more stable ASR, mitigate Cr volatility, slow TGO scale growth; however, continued TGO scale growth beneath CoMnO
- Dual segment CrAlYO + CoMnO coatings demonstrate excellent adhesion both before and after high temperature exposure, further decrease (or mitigate) TGO formation beneath CoMnO top segment and exhibit stable ASR values
- Dual segment coating improved high temperature adhesion favorable to thermal cycling applications
- These coatings can be applied to SOFC Industrial Teams' interconnect plates for further prototypical evaluation

Future Considerations:

- Coating Matrix Evaluation/Optimization
  - Top segment – Different FAD plasma assisted hybrid PVD processes and Co/Mn ratios
  - Bond segment – Vary thickness and composition to maximize diffusion barrier and conductivity properties
- SOFC Prototypical Performance Characterization
  - Dual atmosphere exposure
  - Accelerated thermal cycling studies
  - Interconnect/cathode and interconnect/seals interfacial studies (with PNNL)
- Economic Feasibility Investigation
  - ROI for technology transfer scenarios

Acknowledgements

Travis Shultz, Lane Wilson, A. (Mani) Manivannan

Z.Gary Yang, Gordon Xia, Jeffery Stevenson, Prabhakar Singh, Larry Pederson, Gary McVay

Steven Visco, Craig Jacobson, Hideto Kurokawa

Profs. Max Deibert, Dick Smith, and Stephen Sofie