SECA SOFC Program at GE Global Research

Matt Alinger and Seth Taylor
GE Global Research
Niskayuna, NY

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SECA SOFC Program at GE Global Research - Highlights

- Performed SOFC performance sensitivity analysis on baseline IGFC system. Results indicate 50% HHV efficiency achievable by improving SOFC performance. SOFC requirements that yield 50% efficiency are extremely challenging, but not inherently impossible.
- Identified component performance requirements that exceed today's capability.
- Evaluated cell manufacturing techniques, sintering and air plasma spray, for impact on cell performance and manufacturing cost.
- Determined, through the manufacturing down-select study, that economic feasibility of SOFC is primarily dependent upon improving long-term stability of cell performance over choice of manufacturing process.
- Demonstrated effectiveness of Co,Mn spinel coated interconnect with LSM cathodes at reducing degradation rates from ~100 to ~25mΩ-cm^2/1000h.
- Demonstrated Co,Mn spinel coated interconnect with LSCF cathodes is effective at reducing degradation rates.
- Validated effectiveness of Co,Mn spinel interconnect coating at impeding Cr bulk diffusion.
- Identified 'free' silicon in interconnect alloy as likely contributor to high performance degradation.

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SECA Coal Based System Program - Overview

Team: GE Global Research
University of South Carolina
Pacific Northwest National Laboratory

Program Objective

- Identify significant barriers to feasibility and to develop solutions to enable high performing, cost-effective solid oxide fuel cells (SOFCs).
- Develop and optimize a design of a large-scale (>100 MW) integrated gasification fuel cell (IGFC) power plant incorporating a SOFC and a gas turbine (GT) in a hybrid system that will produce electrical power from coal. The system will be:
  - Highly efficient (>50% HHV),
  - Environmentally friendly (90% CO_2 separation), and
  - Cost-effective ($400/kW projected factory cost, exclusive of coal gasification and CO_2 separation subsystems).

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Presentation Outline

- IGFC system analysis
- IGFC technology gap analysis
- Manufacturing down-select study
- Degradation testing

IGFC System Study

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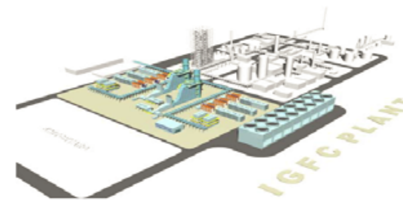
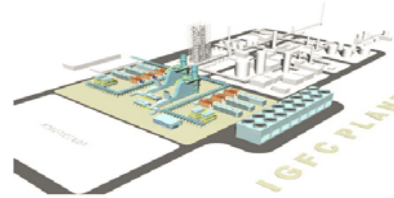
IGFC System performance



DOE Requirements

	Phase I	Phase II	Phase III
End Date	FY2008	Fy2010	FY2015
Fuel	Coal-Derived Hydrogen or Syngas		
Cost (Power Blocks)	\$600/kW	\$400/kW	\$400/kW
Efficiency (Coal HHV)	40%	45%	50%
CO2 Isolated	90%	90%	90%
Validation Test (hours)	1,500	1,500	>25,000
Degradation (/1000h)	$\leq$4.0%	$\leq$2.0%	$\leq$0.2%

IGFC System performance

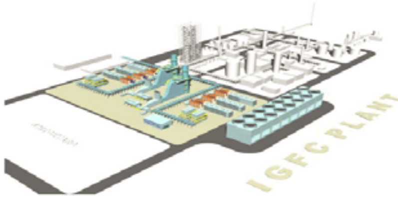


Power Summary, MW			
	Baseline System	Baseline System with 'Super' SOFC	Pressurized System
Coal Feed, HHV	1047.1	1047.1	1047.1
Total Gross Generated Power	542.5	592.9	585.8
Total Parasitic Power	71.9	69.7	64.9
Net System Power	470.6	523.2	520.9
System Efficiency	44.9%	50.0%	49.7%

*Note that all cases shown include 90+% CO2 isolation, as required.

- Baseline system (SOFC + HRSG/ST)
  - Efficiency of only 44.9% at these conditions.
  - Performance adequate for Phase I and Phase II
- “Super” SOFC (SOFC + HRSG/ST)
  - Target achieved by increasing the SOFC performance requirements
- Pressurized System (SOFC+ST+GT – 15atm)
  - Baseline stack - capable of achieving the 50% HHV efficiency target.

IGFC technology gap analysis



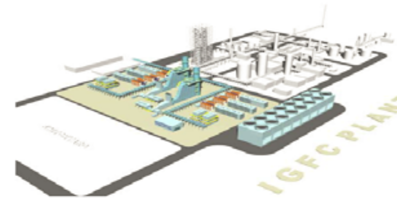
- **Coal**
  - DOE Minimum Requirement (high-rank bituminous coal - Pittsburgh No. 8)
    - Lower-rank coals result in a lower system efficiency
      - Factor to be considered

- **Gasifier**
  - Oxygen from ASU for gasification is significant efficiency driver
      - Assumption of ~10% improvement over current requires advancement in gasifier design / slurry mixing
      - High technology risk

- **Syngas Coolers**
  - Conventional RSC produce saturated steam: T_{exit} = ~650°F
  - System in analysis - RSC generates superheated steam: T_{exit} = 850°F
    - Modification not major gap but, Higher T_{op} = materials change / cost challenge
      - Moderate technology risk

- **High Temperature CO Shift**
  - Current shift reactors operate with excess steam (avoid C-containing byproducts)
    - Analysis assume no byproducts produced despite steam/carbon near equilibrium
      - Capability requires major advances in catalyst or change to new shift methods
      - High technology risk

IGFC technology gap analysis



- **SOFC**
  - Majority of gap between current technology and 50% efficient IGFC systems
  - >0.5 W/cm^2 required for economically viable IGFC systems
    - Cell voltage and fuel utilization requirements extremely challenging
      - Methods of controlling degradation at T ≥800°C must be developed
      - Achieving high UF in large stack of 100+ cells is a major engineering challenge
      - Risk of achieving SOFC performance targets extremely high

- **SOFC Recycle**
  - IGFC design ~50% recycle of the SOFC air
    - Recycle fraction huge driver on efficiency (reduce fresh air flow requirement)
    - Blowers for 800+°C do not exist at present and will need development
    - Largely reliability and cost challenge as opposed to a technology challenge
      - Reliability and cost risks significant

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Manufacturing down-select

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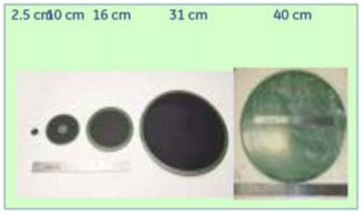
Manufacturing down-select Process

- Detailed Data Gathered by Entire SOFC Team
  - SOFC Team Risk Sensing Sessions Input
- Independent Team Review
  - Scorecard
  - Greatest Concern
  - 4 Categories on Sinter vs. Deposition
  - Risks of Technology Elements
  - Independent Assessment



Tape Calendering

Plasma Spraying

Technical Team Review Conclusions

- No meaningful difference in perceived success between cell manufacturing technologies

- Material cost and degradation solution are keys to success

- Viability of technology elements are greater challenge than manufacturing process

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SOFC degradation

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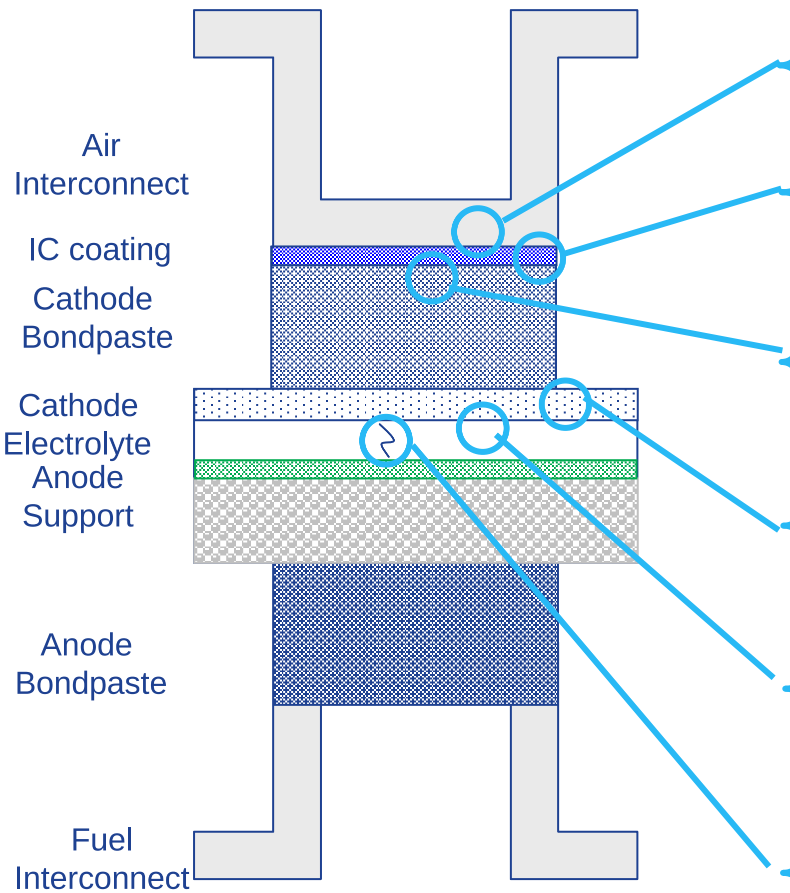
SOFC degradation - materials focus



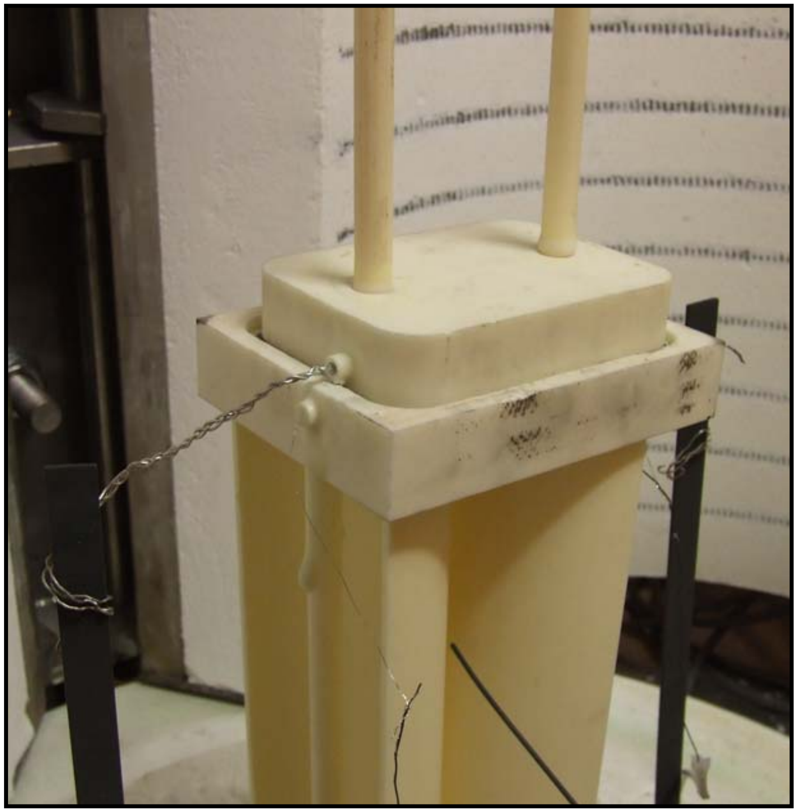
Mechanism	Type
Air Interconnect – GE-13L	
• Chromia scale resistance (Cr_2O_3)	Ohmic resistance
• Insulating scale growth (SiO_2)	Ohmic resistance
Protective Coating – MnCo spinel	
• Coating resistance (MnCo spinel)	Ohmic resistance
Cathode bondpaste - LSC / coating interface	
• $SrCrO_4$ layer resistance	Ohmic resistance
• 'other' reaction phases	Ohmic resistance
• Mechanical delamination	Active area reduction
Cathode - LSCF	
• Chromia poisoning	Electrochem. activity red.
• Coarsening	Electrochem. activity red.
Cathode / electrolyte interface	
• Zirconate resistive layer	Ohmic resistance
• Cathode poisoning	Electrochem. activity red.
• Mechanical delamination	Active area reduction
Leakage driven degradation	
• Cathode reduction	Active area reduction
• Anode oxidation	Active area reduction
• Combustion thermal	Active area reduction

Using a 'fixed' materials set: Focus on cathode side, high-impact degradation mechanisms

Ceramic Test Vehicle – The Browaller*

Idealized test fixture (2”x2” active area)

- Simulate real SOFC operating conditions
  - Known ‘boundary conditions’
- High performance (<300 mΩ-cm²)
- High utilization (80% UF)
  - Monitor fuel and air gases
- Interchangeable interconnect
  - Gold
  - Ferritic stainless steel



Provide confidence and accuracy in degradation measurement

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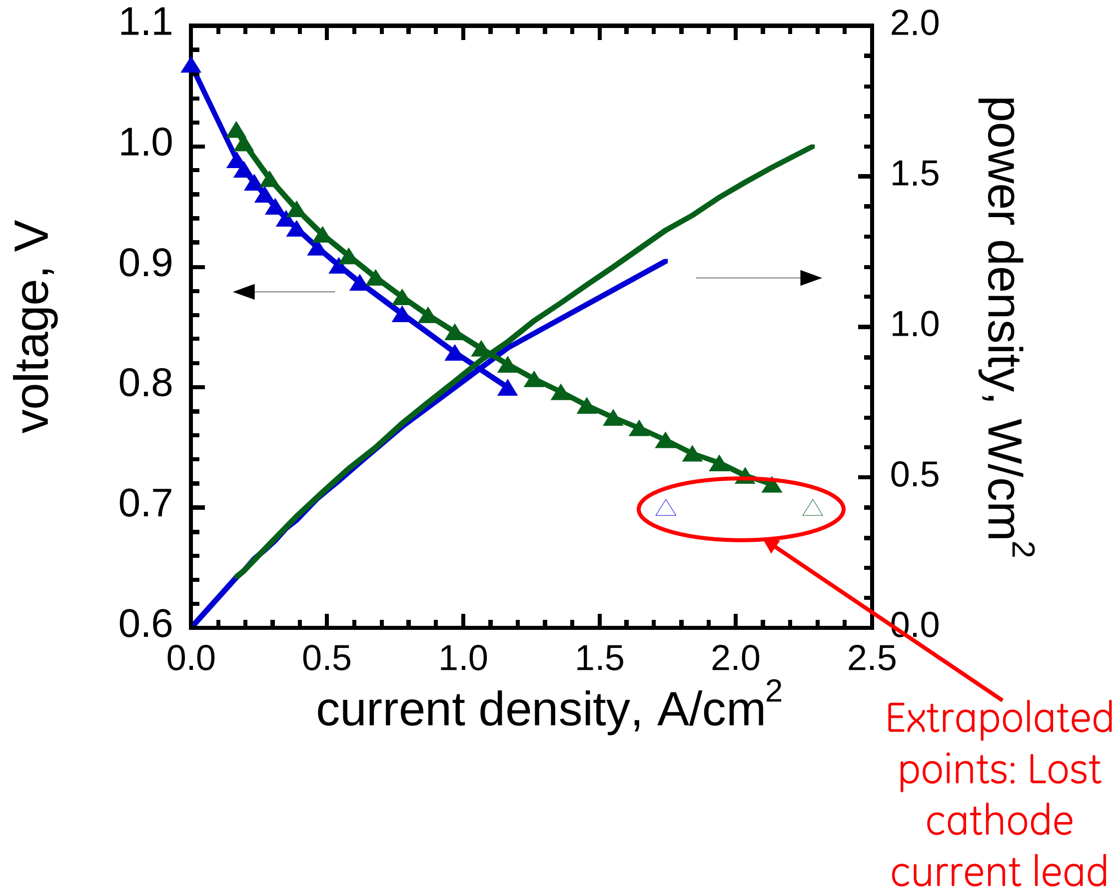
*after Ken Browall, ret 6/1/07

Browaller Test I,II

Sintered Supercell
LSCF cathode
LSC Bond paste
Au mesh CC

800°C, Low Utilization, 64% H2



ASR Data
Cell I 173 mΩ-cm² @ 0.7V
Cell II 142 mΩ-cm² @ 0.7V

Excellent cell performance – equal to buttons
Fully sealed – no leakage, cracking

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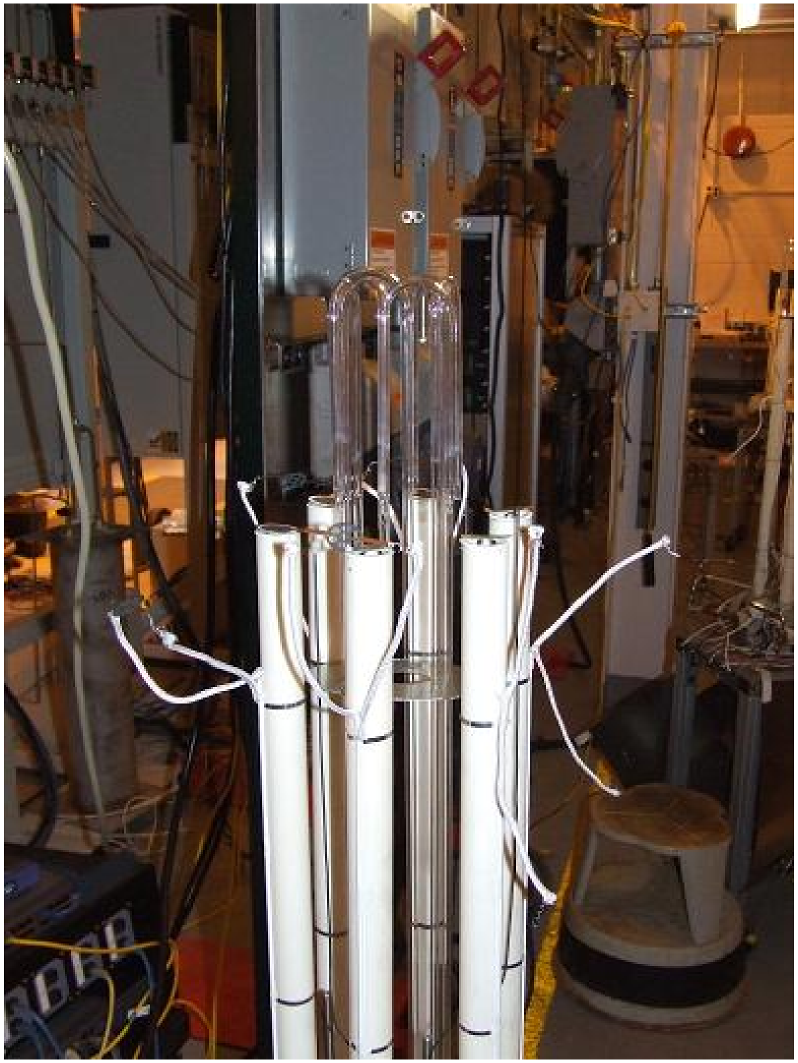
Electrochemical testing -Button Cells

800°C
Galvanostatic
LSCF Cathode
LSC Bond paste
Interconnect – Ferritic SS



‘6-gun’

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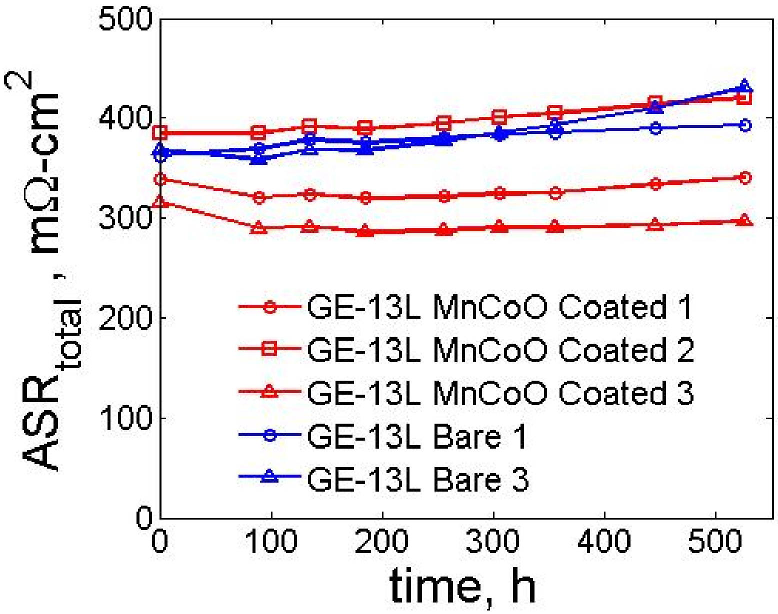
Button cells - Coated Vs Bare

GE-13L ferritic stainless steel interconnect

$(Co,Mn)_3O_4$ spinel coating



*Data from I-V curves at 0.7V and 800°C

$(Mn,Co)_3O_4$ spinel coated samples exhibit lower degradation rate with respect to bare.

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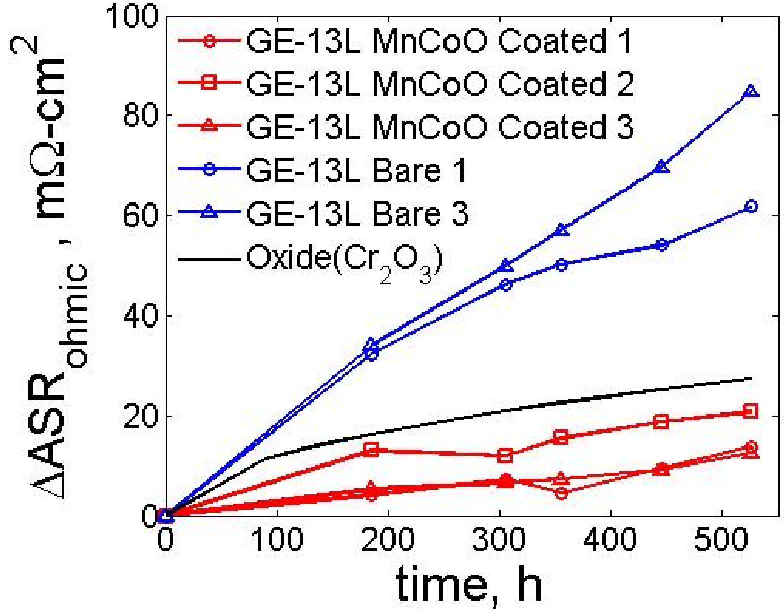
Button cells - Coated Vs Bare

GE-13L ferritic stainless steel interconnect
$(Co,Mn)_3O_4$ spinel coating



*Data from I-V curves at 0.7V and 800°C

$(Mn,Co)_3O_4$ spinel coated samples exhibit lower degradation rate with respect to bare.

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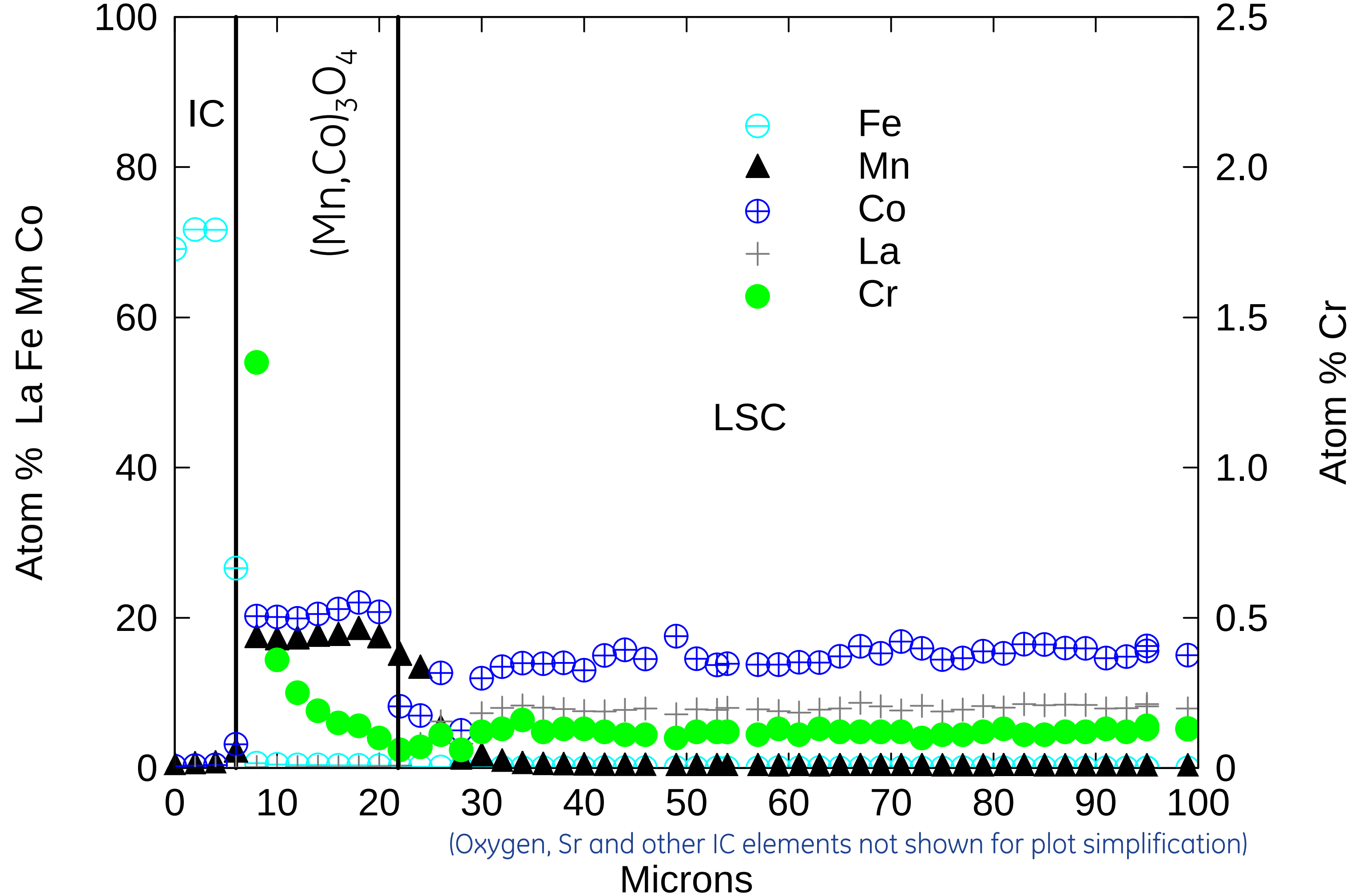
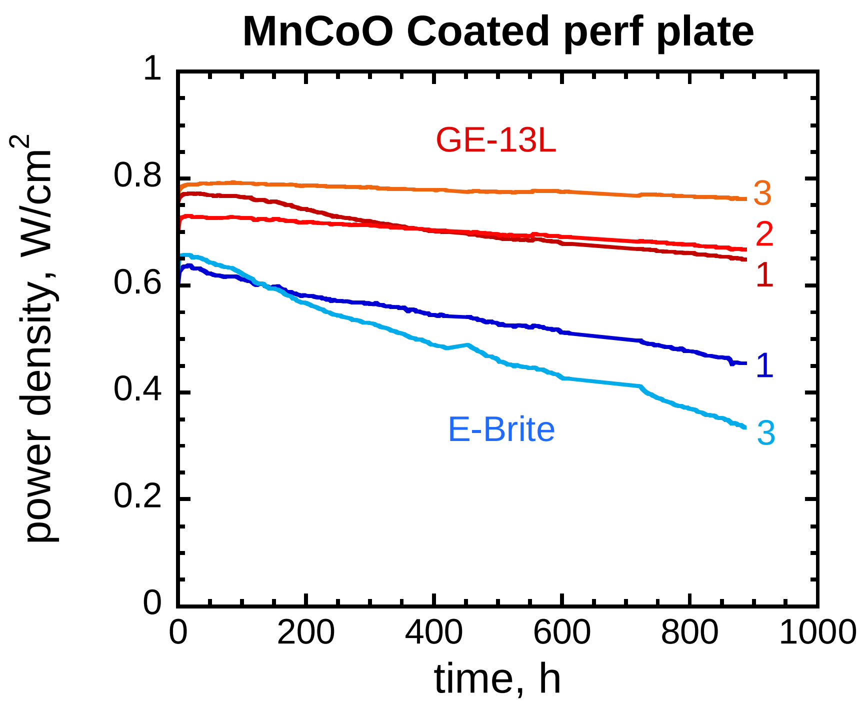
$(Mn,Co)_3O_4$ coating - Cr barrier



No measurable Cr found in the LSC Bond Paste after 886h at 800°C

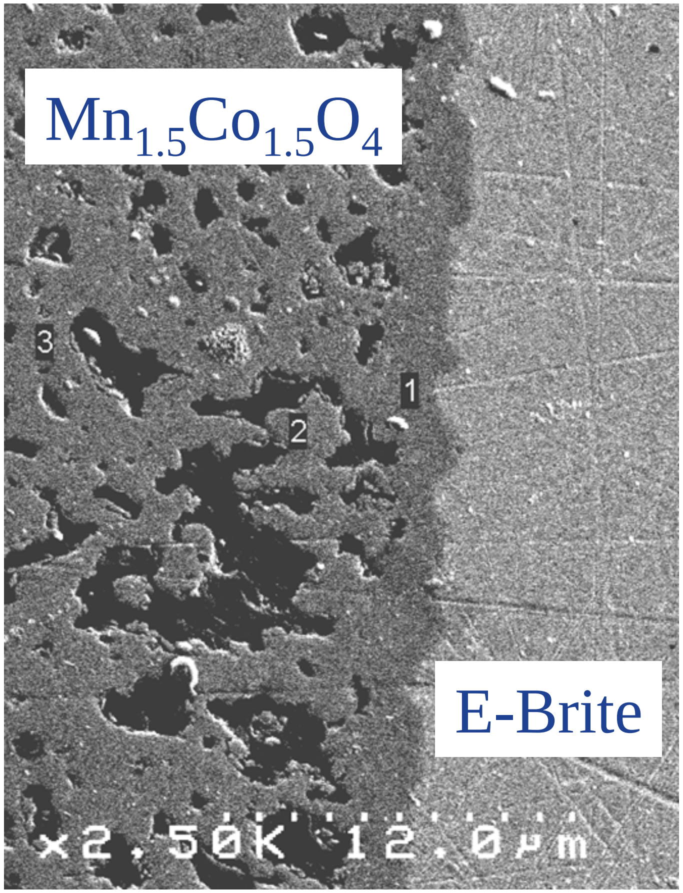
Button cells - Coated E-Brite Vs GE-13L

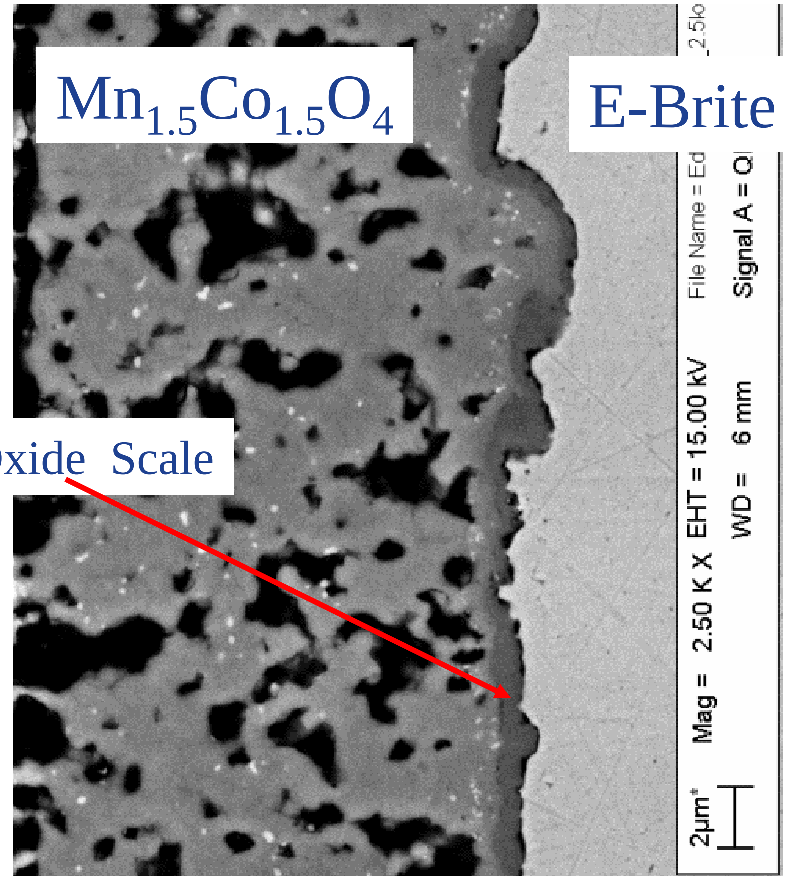
$(Mn,Co)_3O_4$ spinel coating



GE-13L exhibits higher performance over E-Brite

Mn,Co Spinel Coated E-Brite

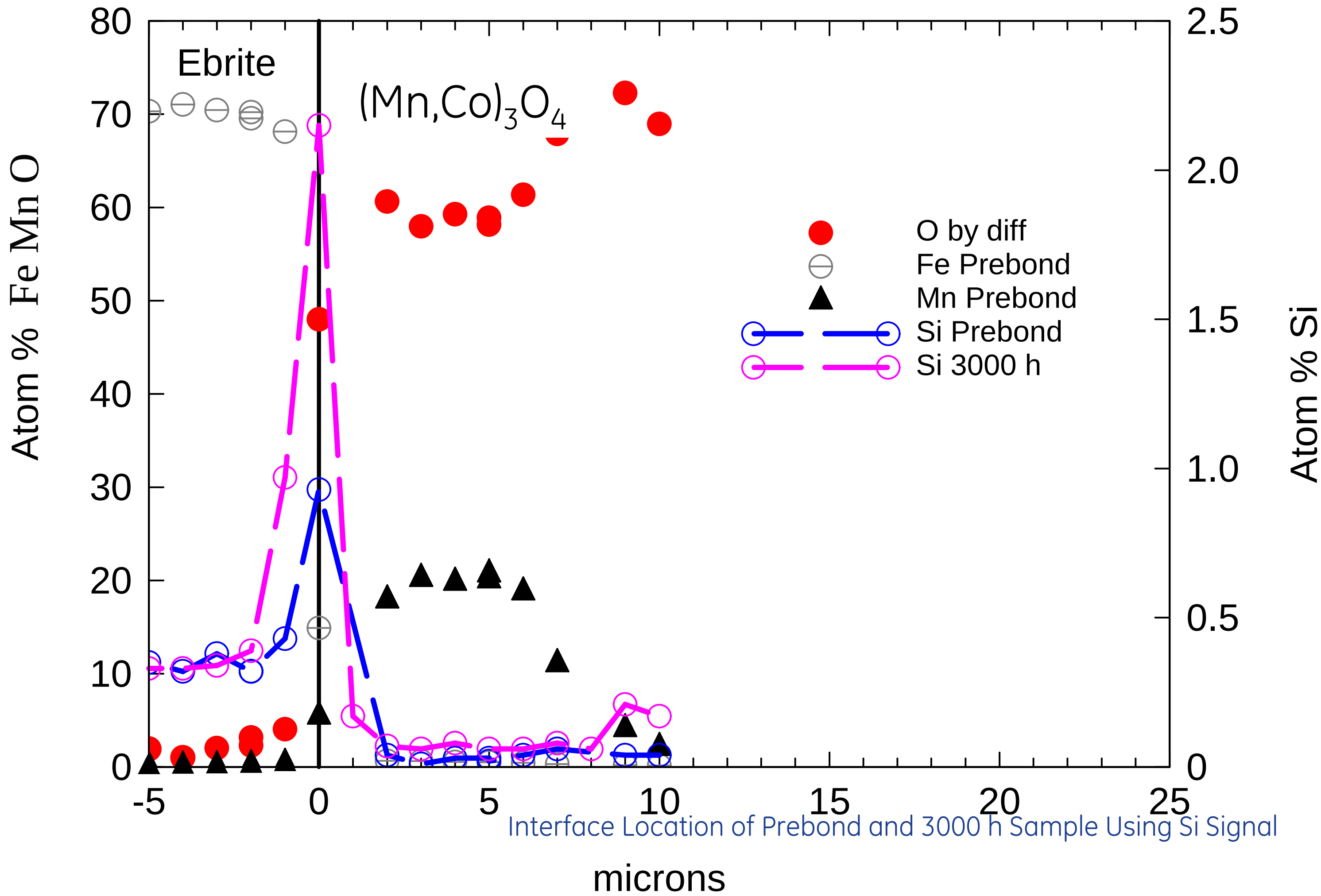




Cathode BP, Spinel Coating on E-Brite shown after 900C 24h

Button Cell Test after 886h at 800 C - 1 A/cm^2

Mn,Co Spinel Coated E-Brite



Interface Location of Prebond and 3000 h Sample Using Si Signal

Increased Si at E-Brite interface after 3000 h test.

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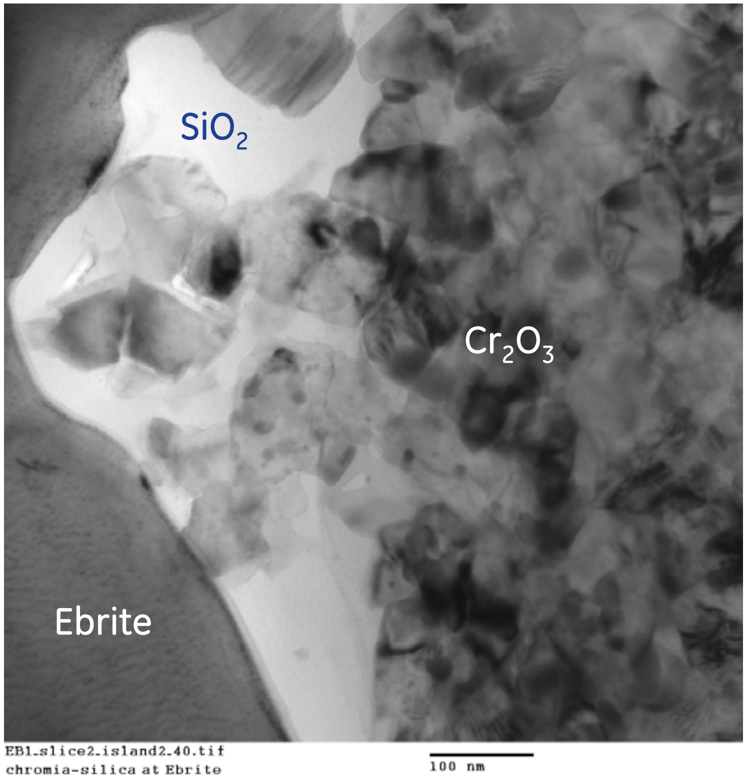
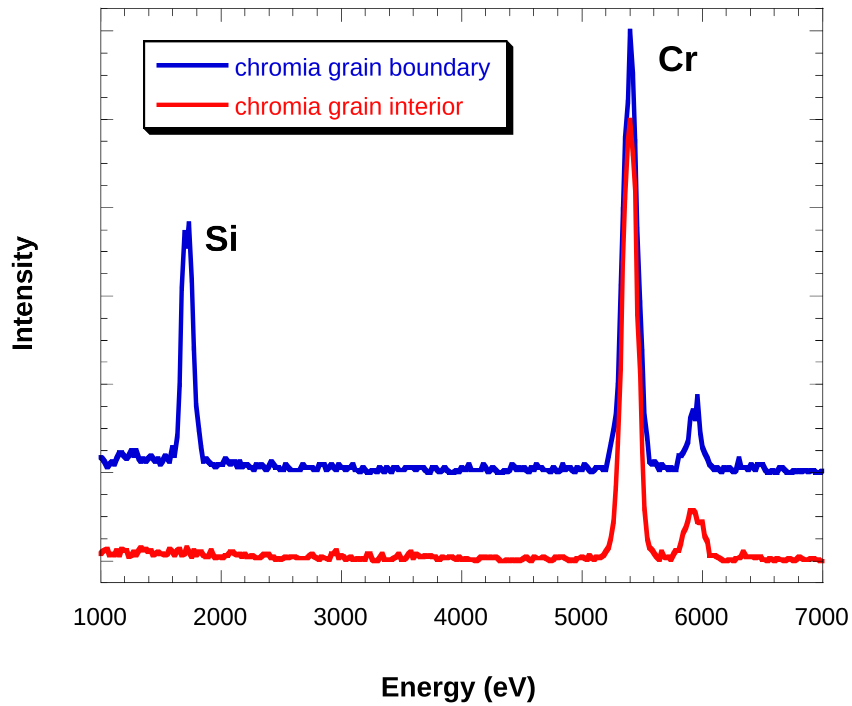
E-Brite – Cr_2O_3 / SiO_2





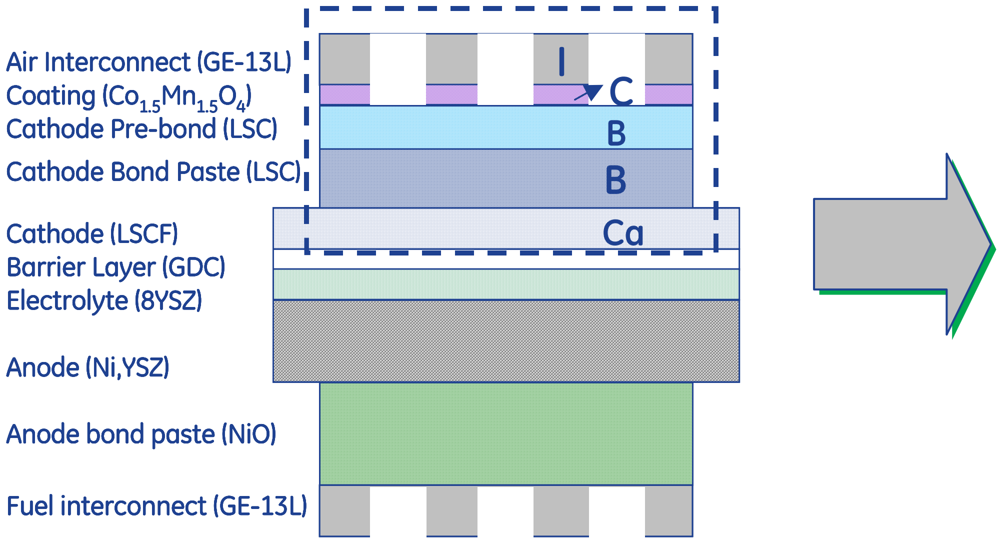
Si content:
E-Brite ~0.2wt%
GE-13L <0.1wt%

Significant SiO_2 concentrations are observed at Cr_2O_3 interface on E-Brite.

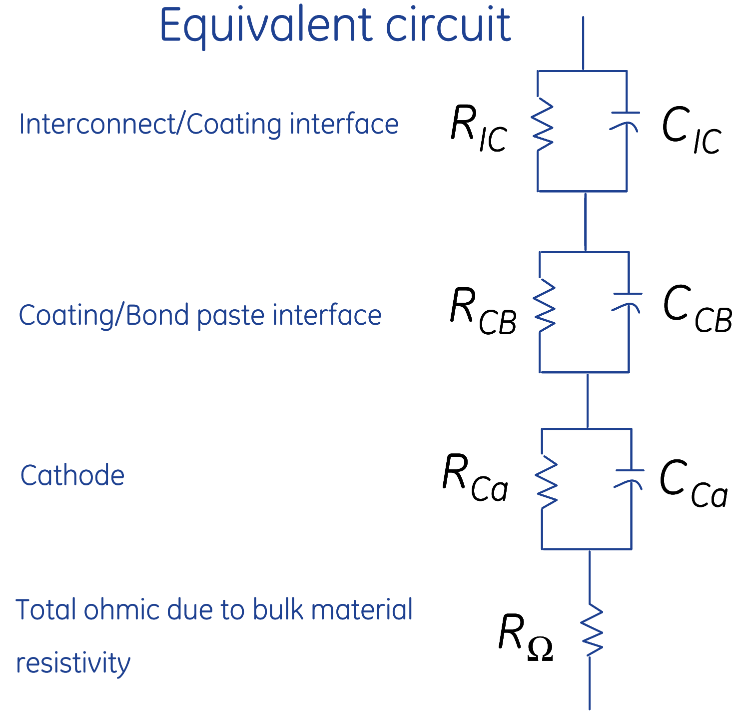
(off-line testing)

Ohmic losses
-Contact resistance testing

Electrochemical cell configuration



Equivalent circuit



Direct measurement of interface contribution for ASR breakdown

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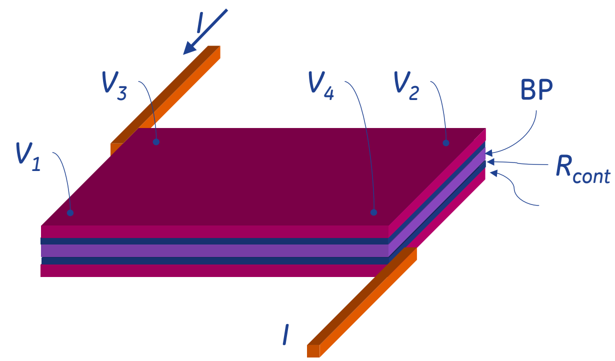
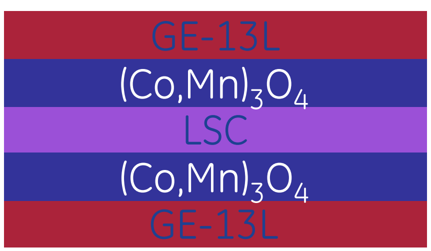
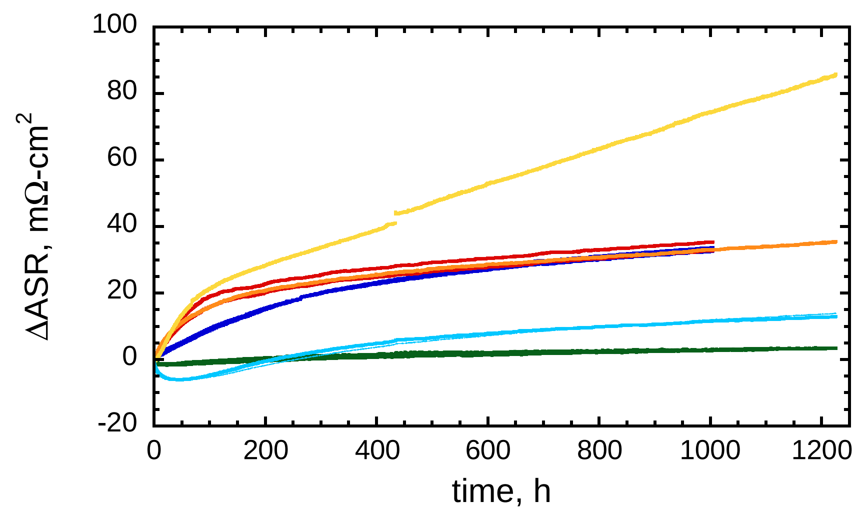
(off-line testing)

Ohmic losses
-Contact resistance testing

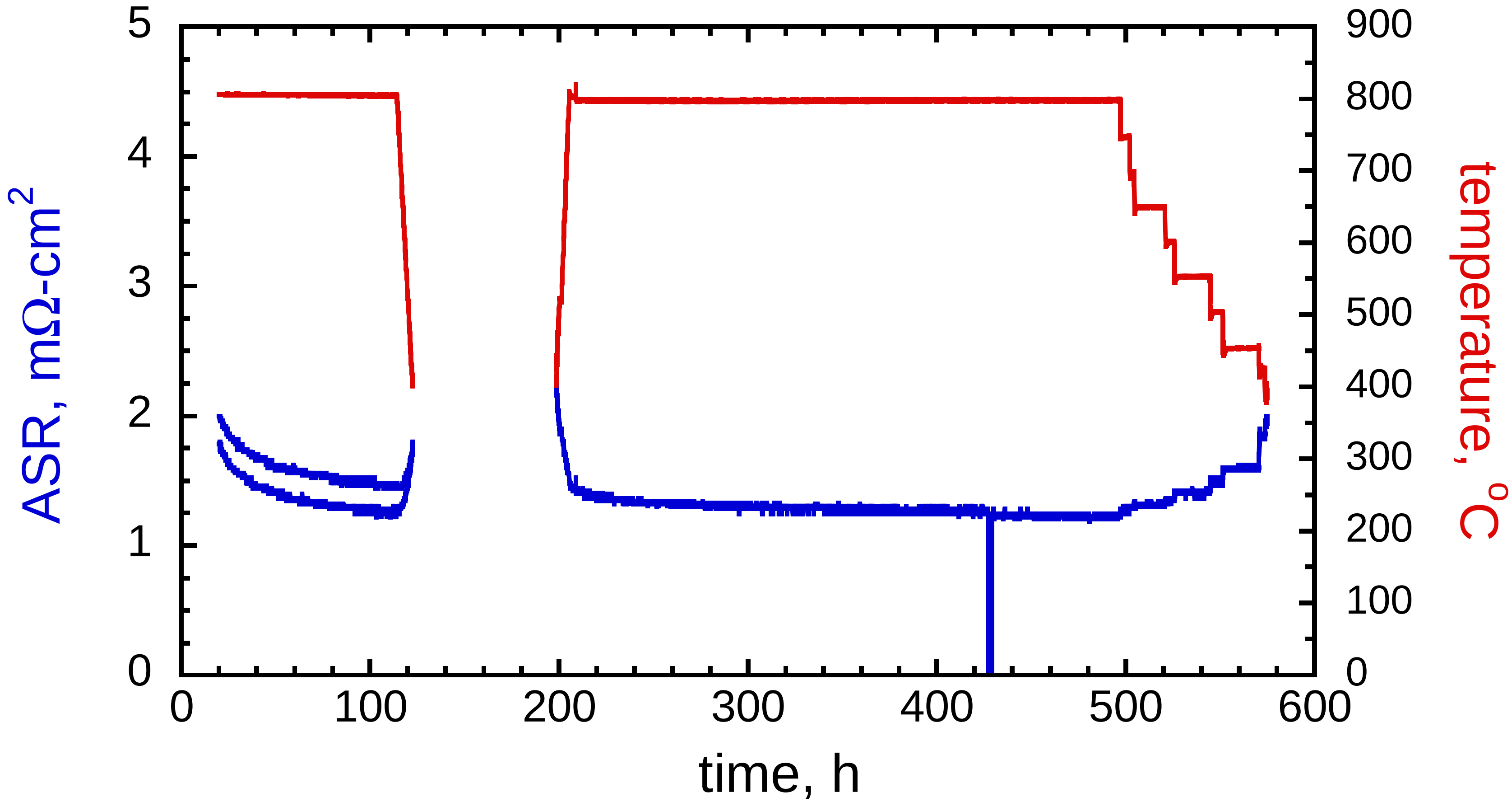






Direct measurement of interface contribution for ASR breakdown

Bond Paste Conductivity



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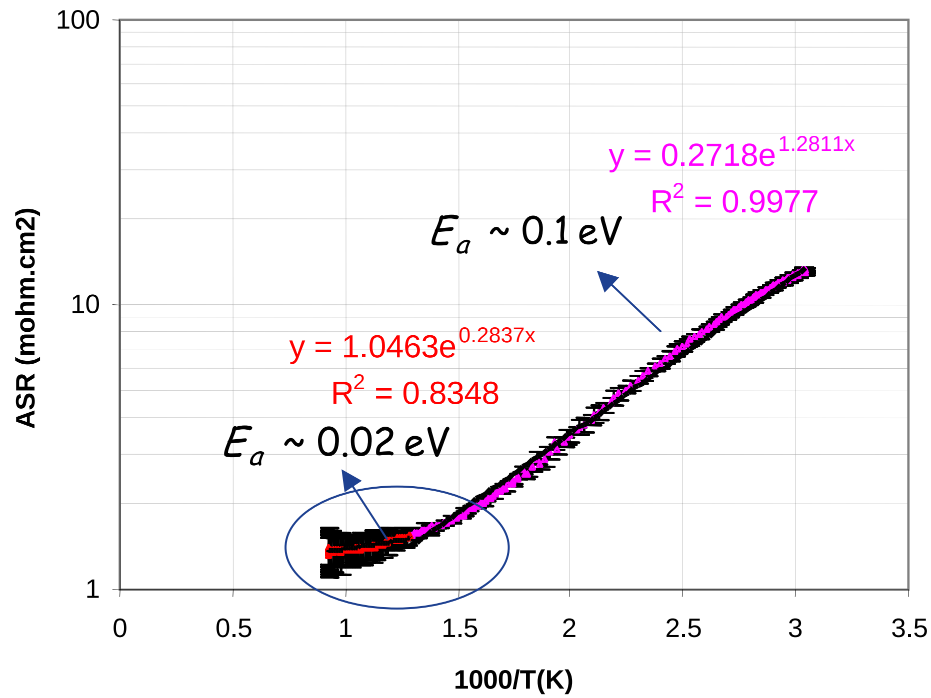
Stable bond paste (no increase in resistance over time)

Bond Paste Conductivity

Gold
LSC
Gold

Activation Energies



Literature values for LSC at 800 C and pO_2=1 atm:

Bulk electrical conductivity ~ 1585 S/cm

Activation energy ~ 0.015 eV in pure O_2 – (Excellent agreement)

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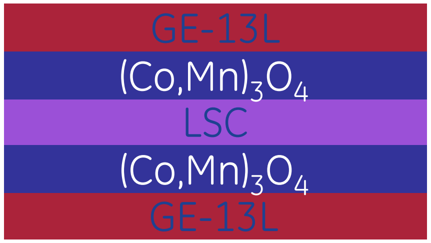
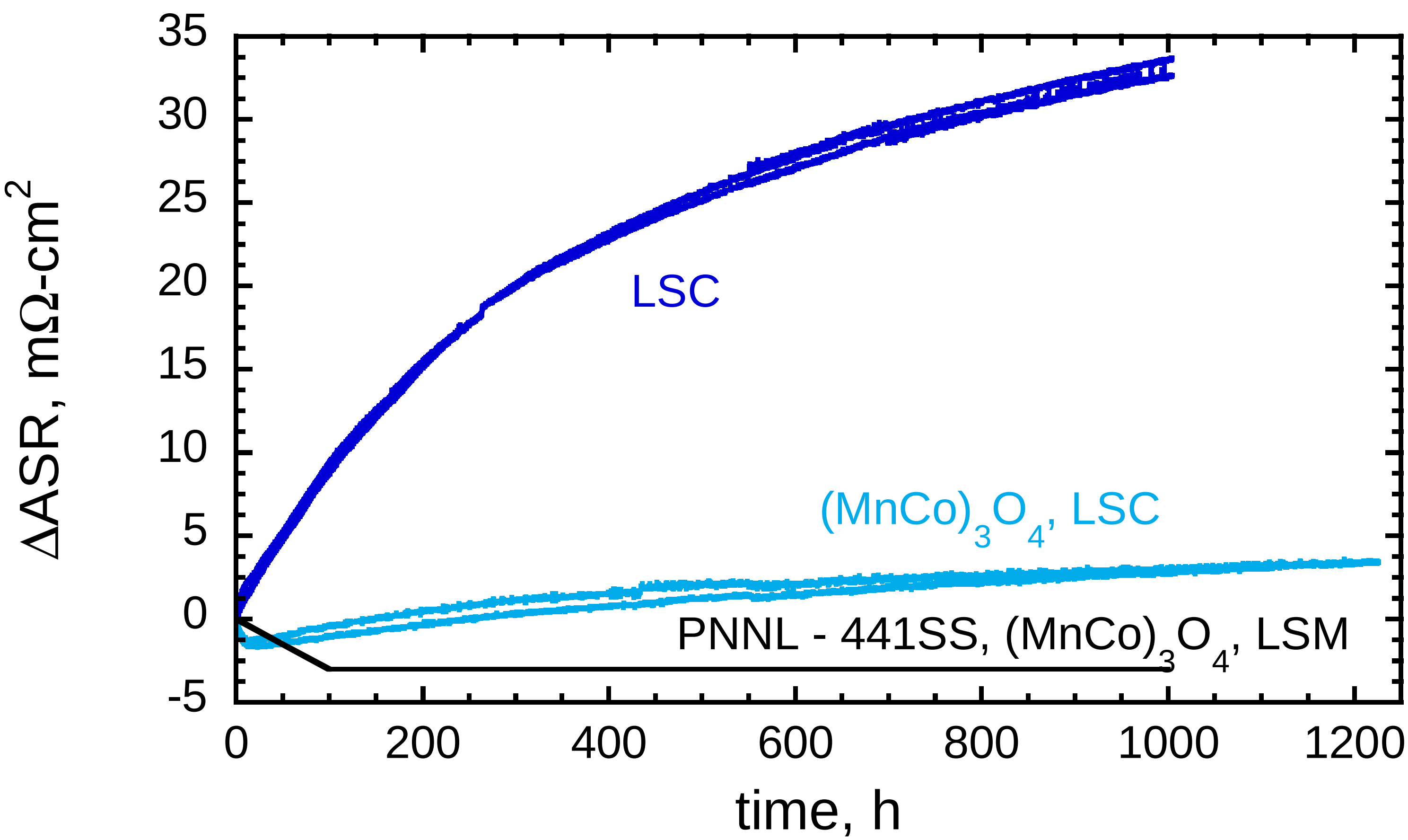
Bond paste resistivity negligible

Co,Mn coated Vs Bare

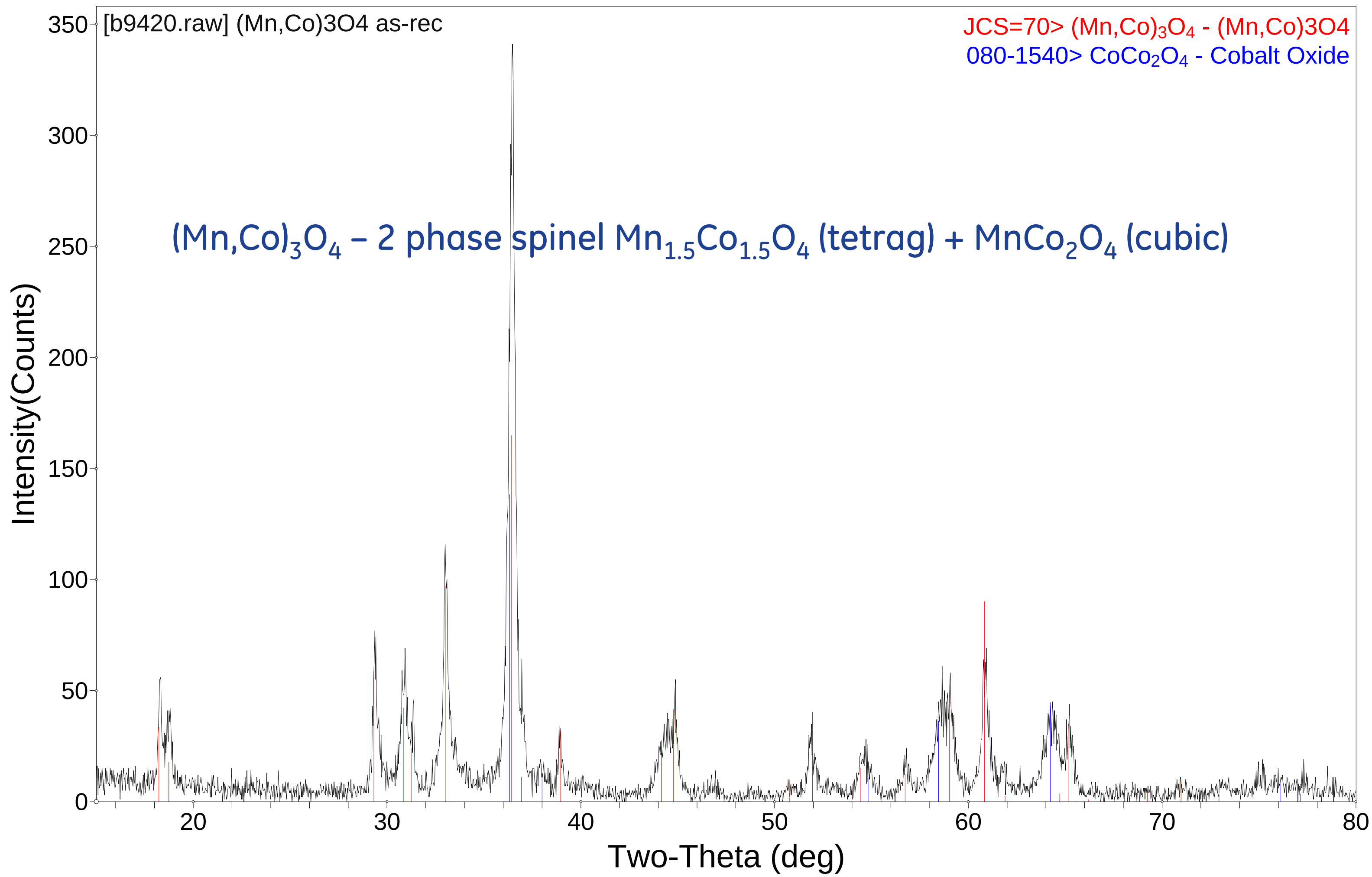


$(Mn,Co)_3O_4$ – spinel coating



Coating effective for LSC samples
Commercial 441SS very promising

$(Mn,Co)_3O_4$ Stability Study – As-Received



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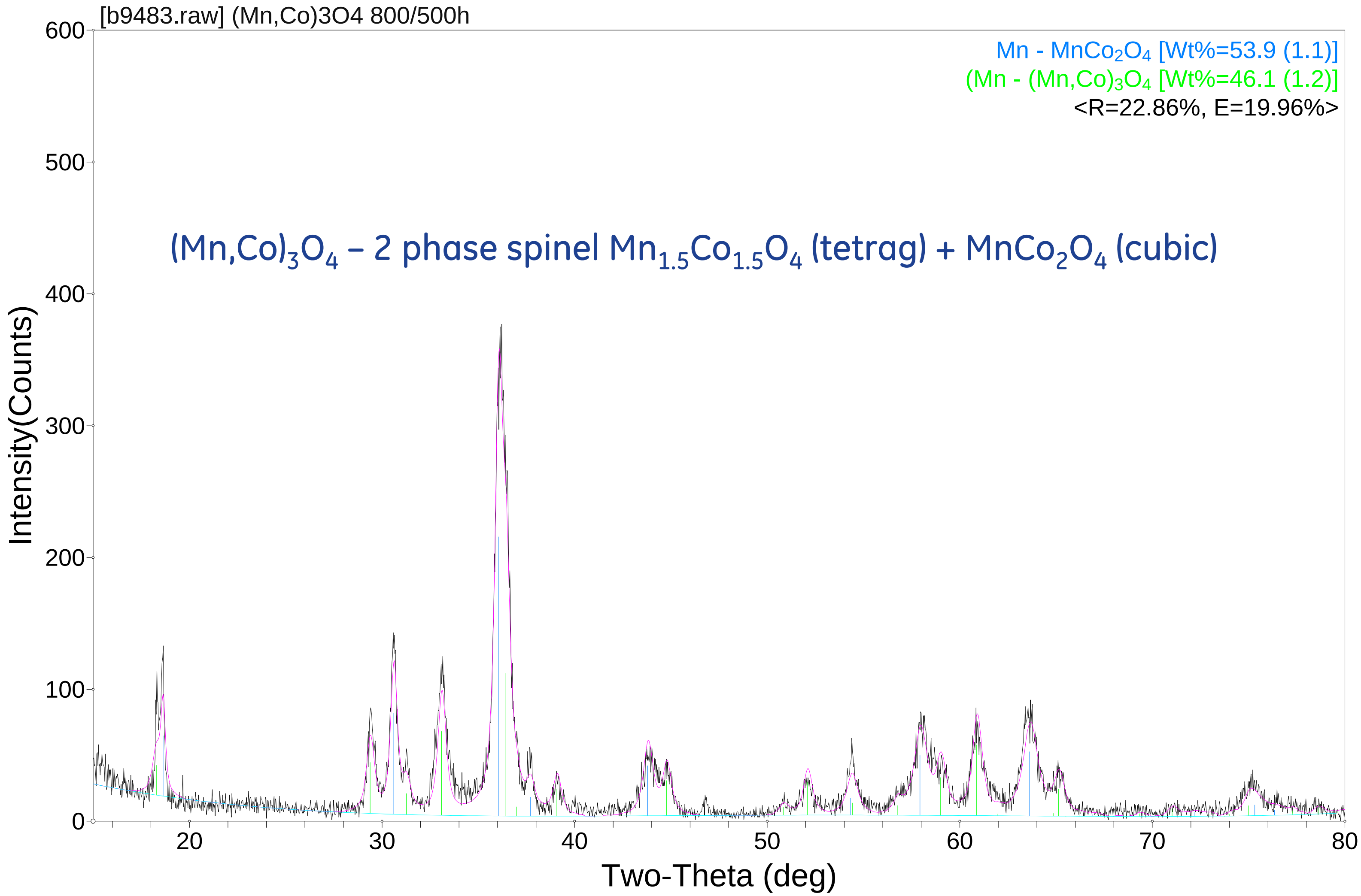
Sample shows spinel and tetragonal phases present initially.

$(Mn,Co)_3O_4$ Stability Study – 500h, 800°C



Sample shows both spinel and tetragonal present in near 50-50 wt% mixture.

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Summary

- Performed SOFC performance sensitivity analysis on baseline IGFC system
  - 50% HHV efficiency achievable by improving SOFC performance
  - SOFC requirements for 50% efficiency are challenging, but not impossible
- Identified component performance requirements exceeding current capability
- Evaluated cell manufacturing techniques, sintering and air plasma spray, for impact on cell performance and manufacturing cost
  - Determined economic feasibility of SOFC primarily dependent on improving long-term stability of cell performance over choice of manufacturing process
- Demonstrated Co,Mn spinel coated interconnect with LSCF cathodes is effective at reducing degradation rates
- Validated effectiveness of Co,Mn spinel interconnect coating at impeding Cr bulk diffusion
- $(Mn,Co)_3O_4$ coating effective at reducing degradation rate in LSCF SOFCs
- Free silicon in interconnect alloy results in detrimental SiO_2 at IC/Cr_2O_3 interface

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