

Metal Interconnects for Solid Oxide Fuel Cell Power Systems

SECA Core Technology Program

Ceramatec, Inc.

Supported in part by

DOE-NETL

Presented at
Pacific Grove, CA
21 April 2005

Technical Issues Addressed

- **Technical Requirements for Metal Interconnects**
 - CTE match
 - No gas permeation
 - High temperature corrosion resistance
 - Scale conductivity
 - Scale adhesion
 - Stability in atmosphere (physical, chemical, microstructure, conductivity)
 - Stability against electrode/bond layer (poisoning effect)
 - Electrical contact with cells
 - Thermal cycle capability

Challenges

- Chromia formers preferred to provide a conductive scale
 - Continued scale growth during operation
 - Increased electrical resistance
 - Loss of adhesion
 - Porosity at interface
 - Chromium evaporation
 - Electrode Poisoning
 - Electrode compatibility
 - High resistance phase formation with electrode cations (spinel)

Approach

- **Modify intrinsic scale**
 - surface treatment and thermal process
 - Objective: Limit scale growth
- **Apply extrinsic layer**
 - low Cr activity composition (~LaCrO₃)
 - Objective: Limit Cr evaporation
- **Combine the two layers**
 - graded composition
- **Contact layer application**
 - Thermal Spray (Idaho National Lab.)

Approach

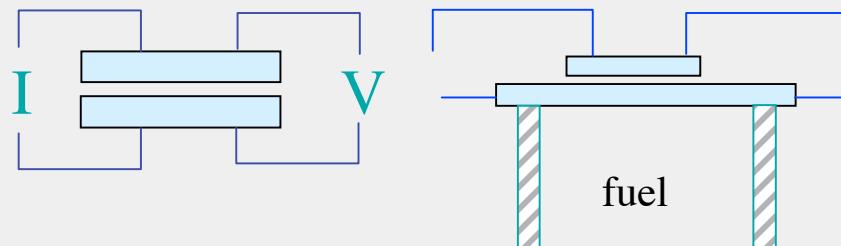
- **Alloy Selection (Fe-Cr based ferritic SS)**
 - CTE Match, Conductive scale (chromia former)
 - Choice of minor alloying elements
- **Surface Treatment & Oxidation**
 - Growth of selective oxide scale
 - Control P, T, X_i and t
 - Scale characterization

Assessment Criteria

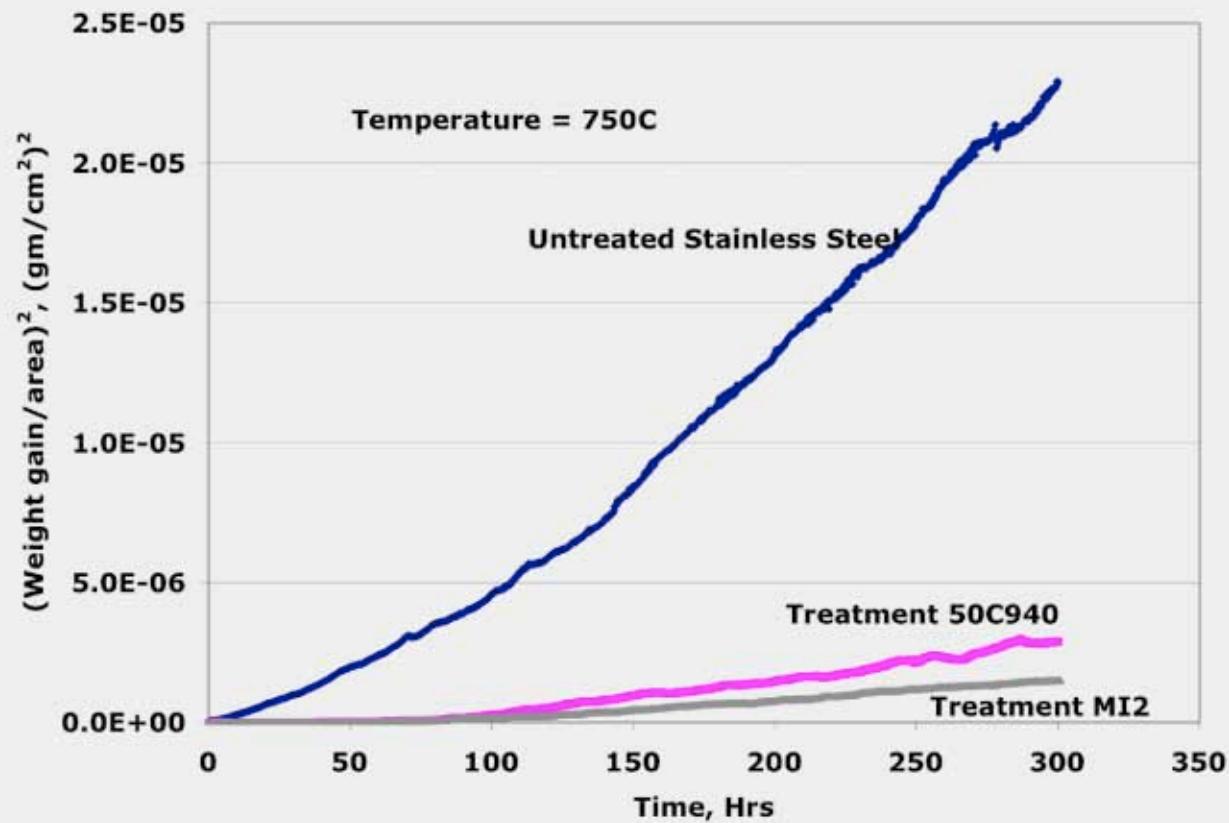
- Weight gain with time at temperature
- Scale thickness, morphology, composition
- Electrical resistance with thermal cycles
- Exposure to relevant atmospheres
- Reactivity with contact layer
- Chromium evaporation

Experimental Arrangement

TGA	Coupon Couples	Dual atm. couples	Stack
<ul style="list-style-type: none"> • Single atmosphere • No contact / electrode layers • No current • Isothermal 	<ul style="list-style-type: none"> • Single atmosphere • Contact layer • Intermittent current • Isothermal 	<ul style="list-style-type: none"> • Dual atmosphere • Continuous current • Contact layer • Isothermal 	<ul style="list-style-type: none"> • Dual atmosphere • Continuous current • Contact/electrode layers • In-plane thermal, current density gradients

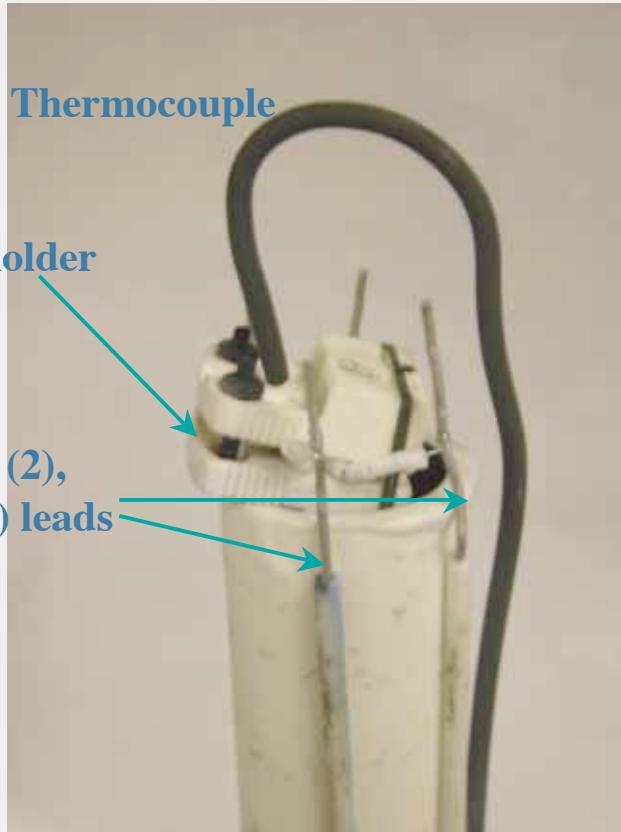
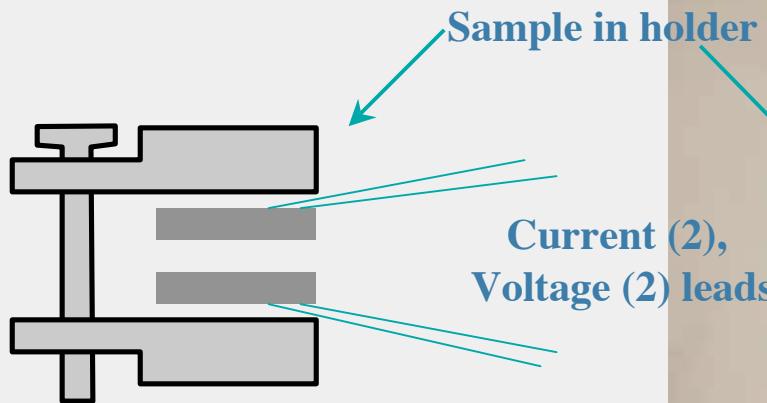


Weight Gain Measurements



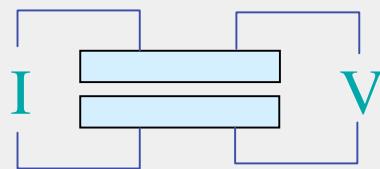
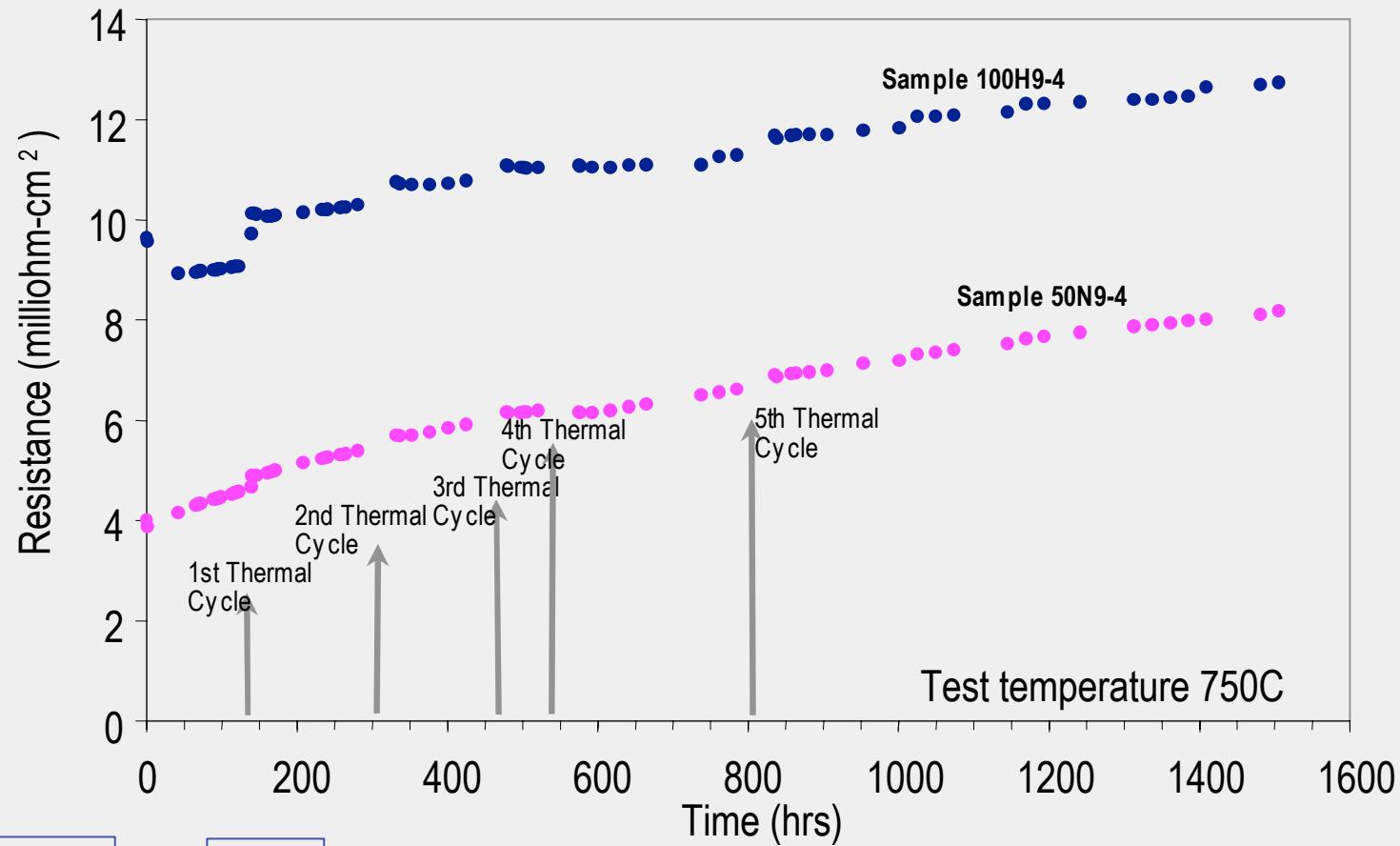
- An order of magnitude reduction in scale growth rate constant with surface treatment

Conductivity Test Rig

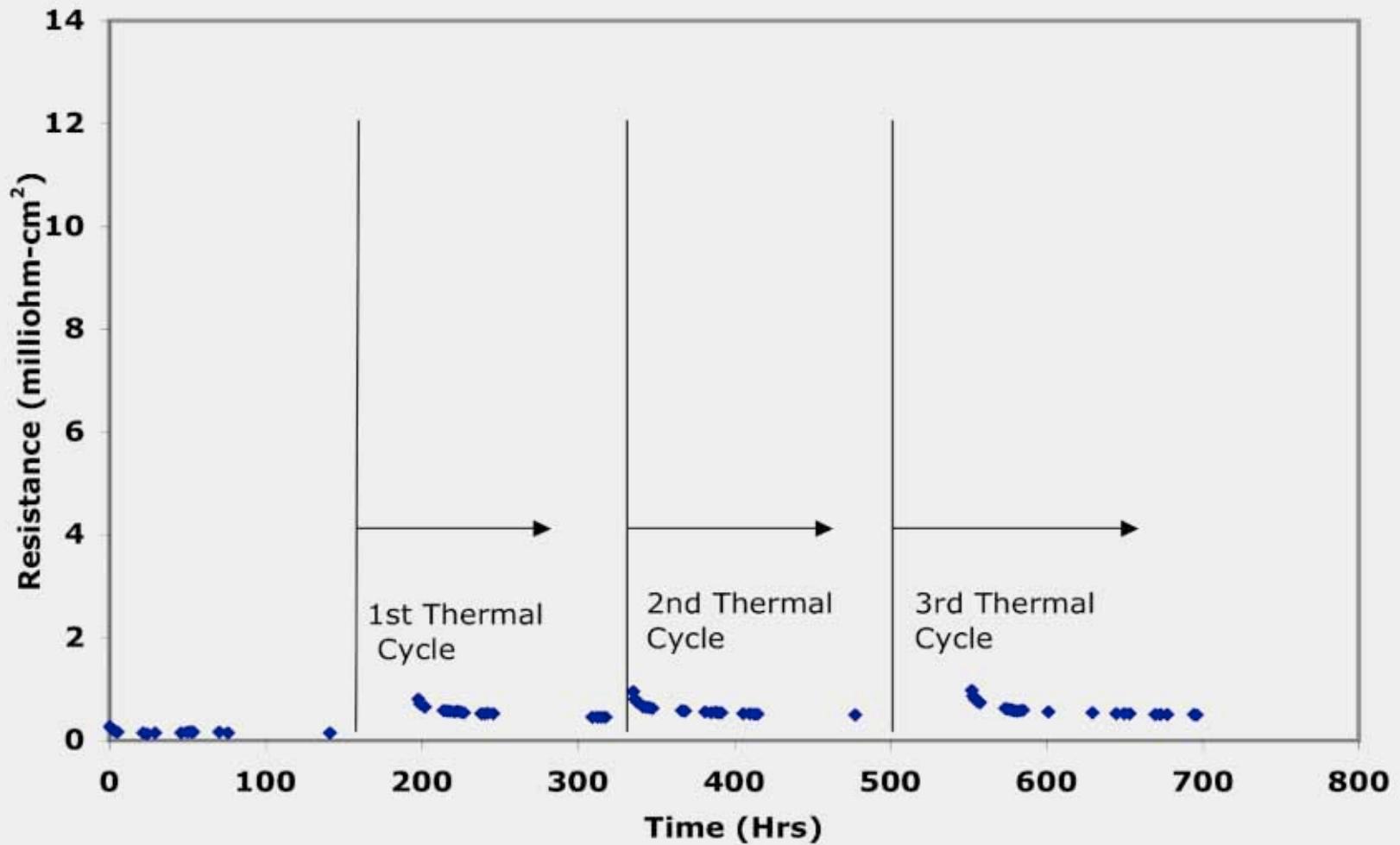


- Coupon couple to provide symmetric arrangement
- Perovskite contact layer

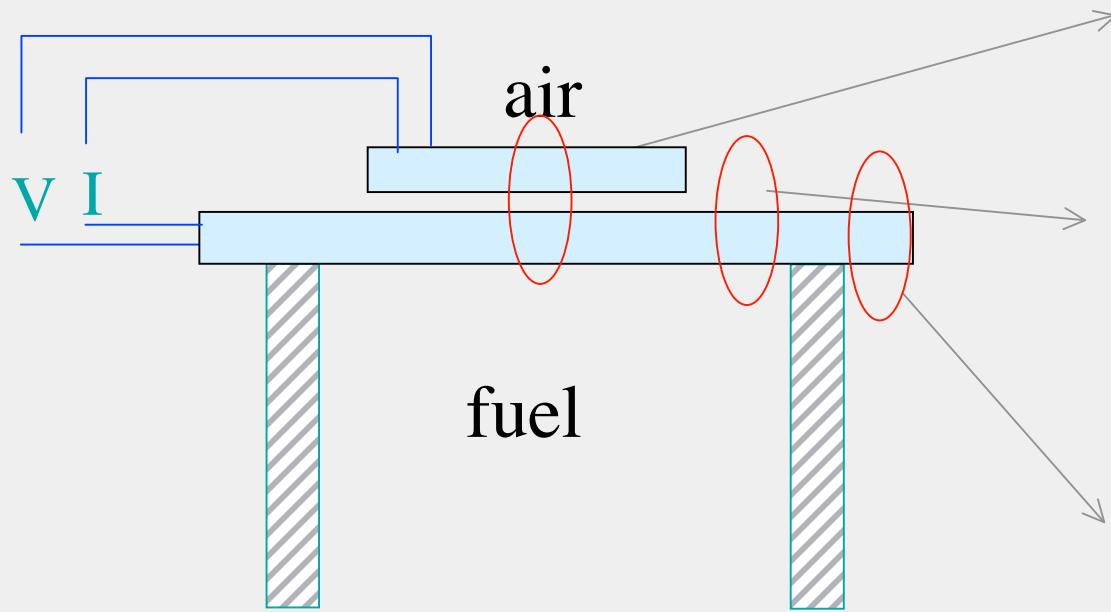
Scale Resistance in Air (coupon couples)



Scale Resistance in H₂ - 3%H₂O



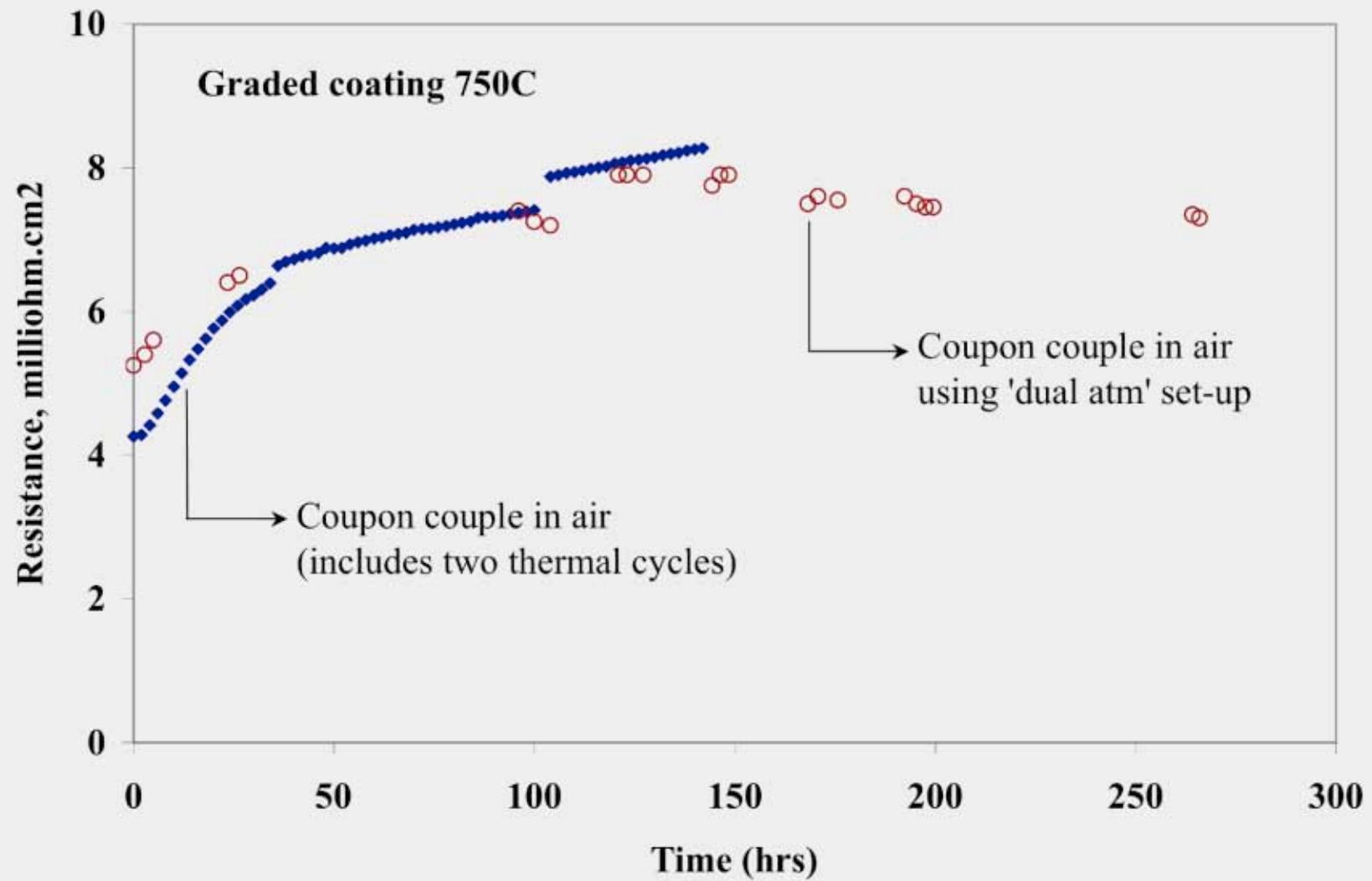
Dual atmosphere couples



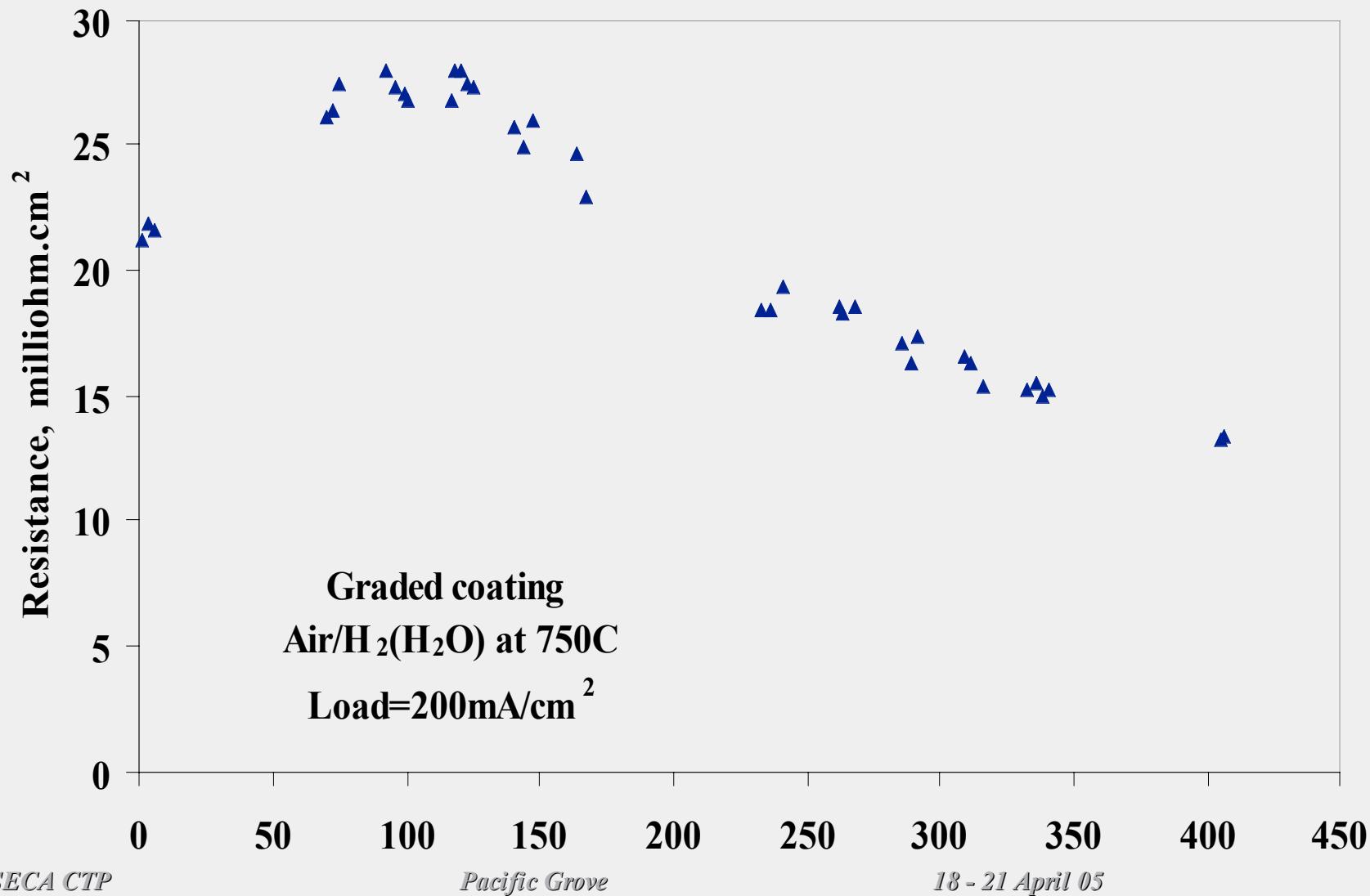
- Dual atmosphere
- Contact layer
- Continuous load (constant current)
- Dual atmosphere
- No contact layer
- No current
- Air atmosphere
- No contact layer
- No current

1x1 cm coupon on a larger (3.5x3.5 cm) blank
Identical treatment on mating surfaces
Contact layer: cobaltite

Rig Validation: Graded Coating in air



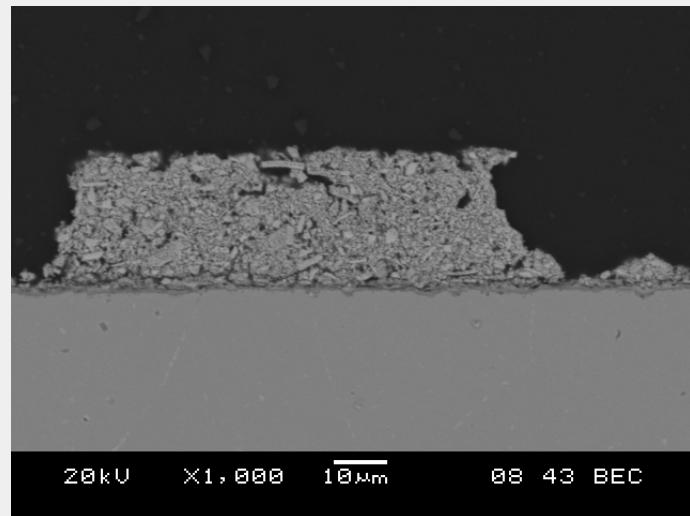
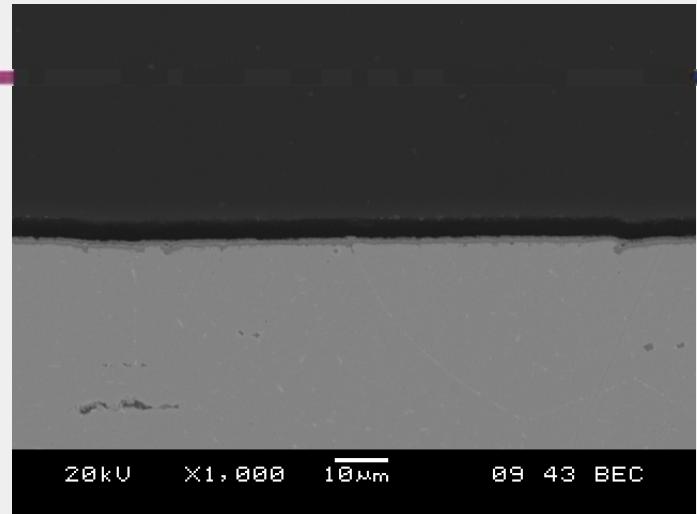
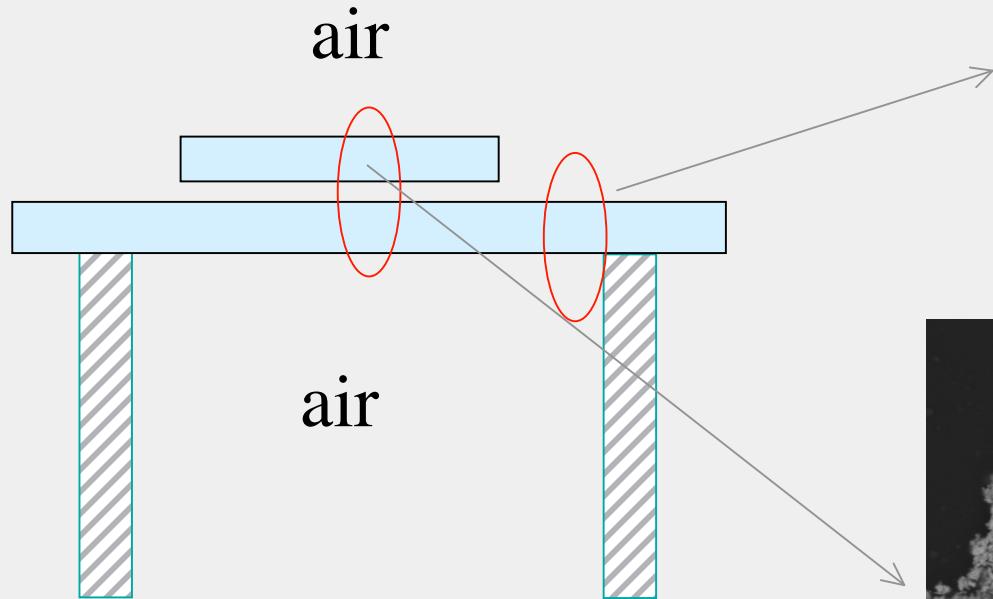
Graded Coating: Dual atmosphere



Graded Coating

200 mA/cm², ~300 hrs

7 milliohm.cm²

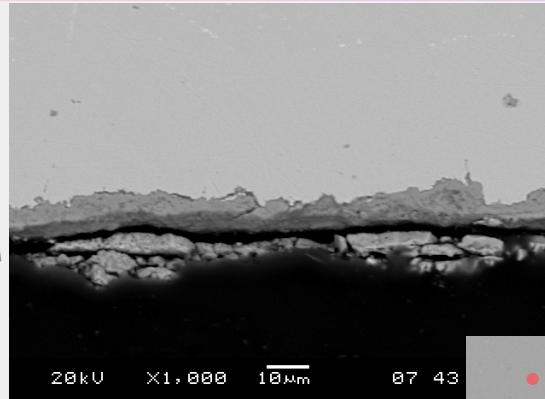
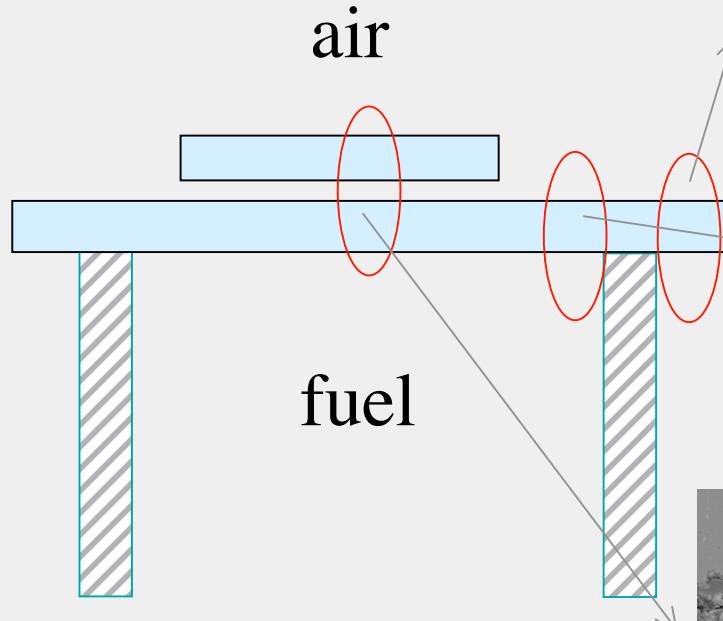


- **Thin scale (1 μm) in both regions**
- **No Sr-Cr rich phase**

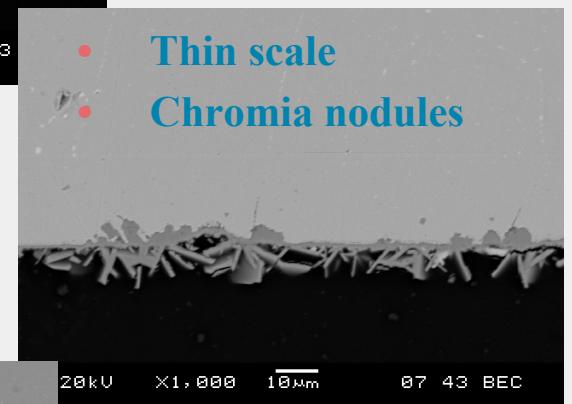
Graded coating - dual atm.

200 mA/cm², ~400 hrs

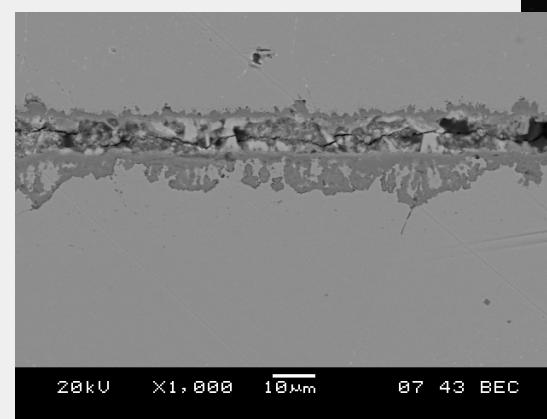
15 milliohm.cm²



- 6 µm scale
- Influence of dual atm. away from the region?

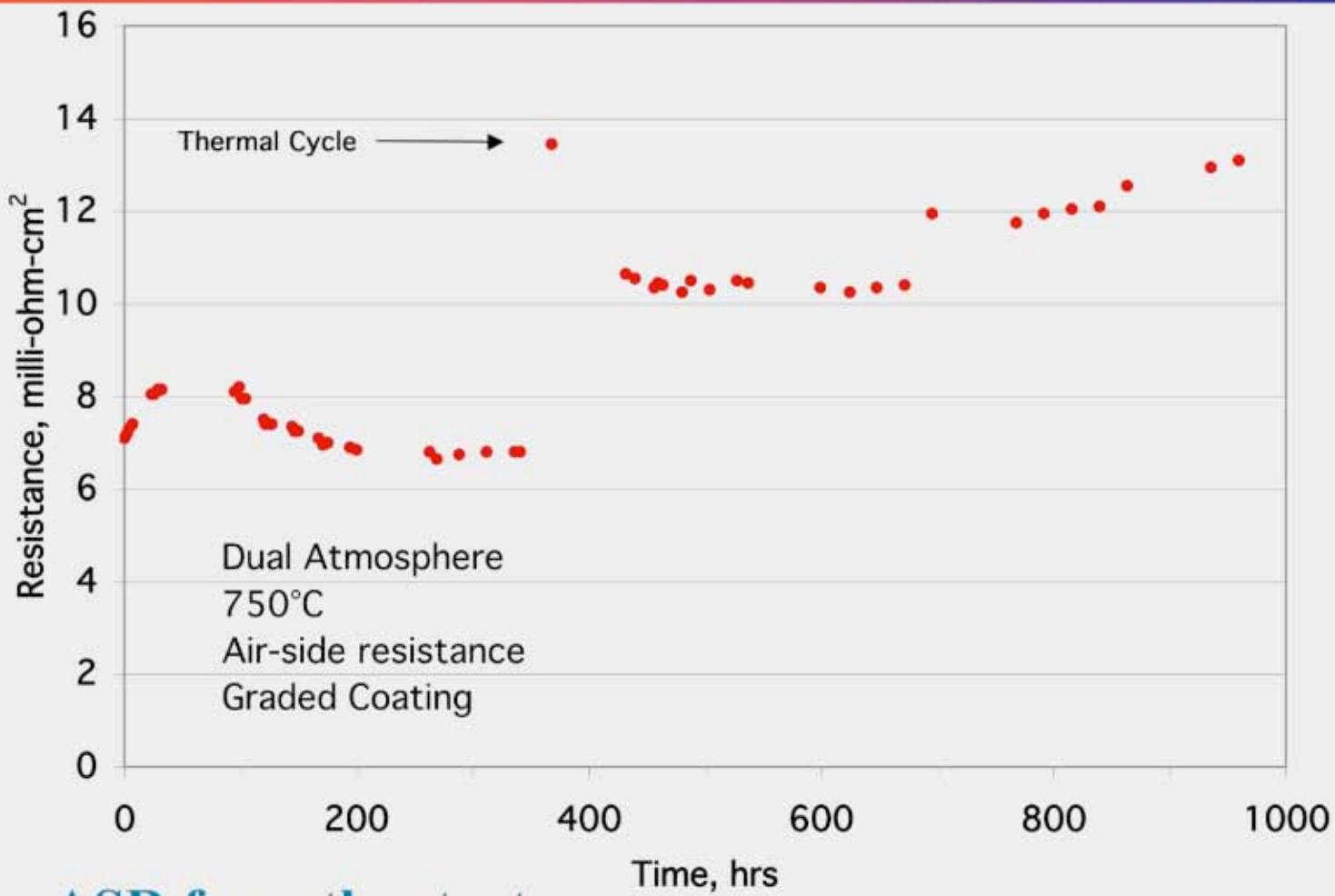


- Thin scale
- Chromia nodules



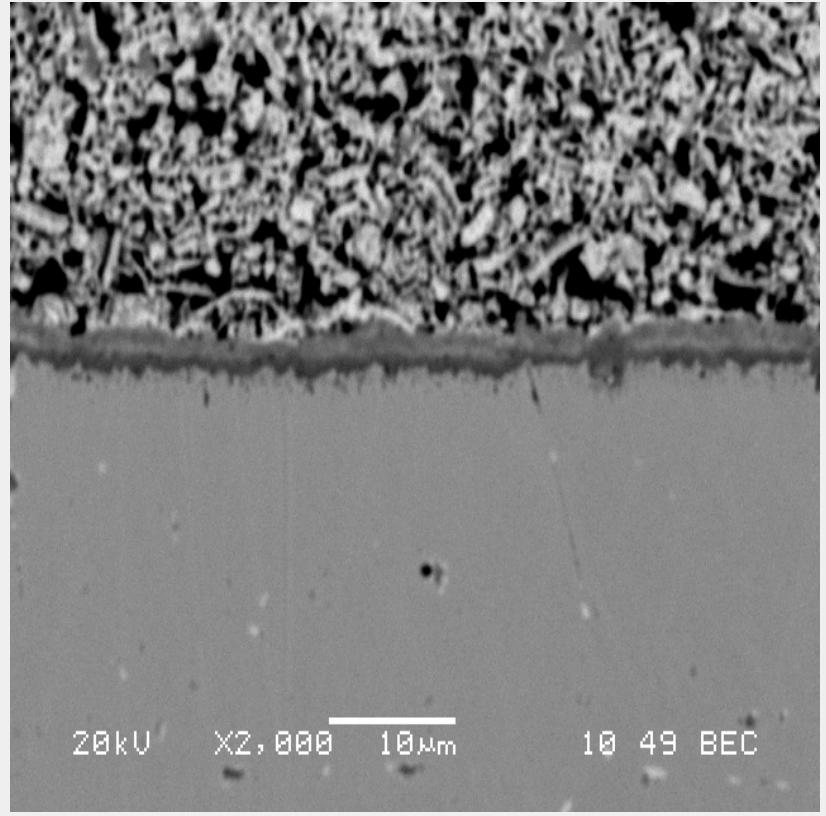
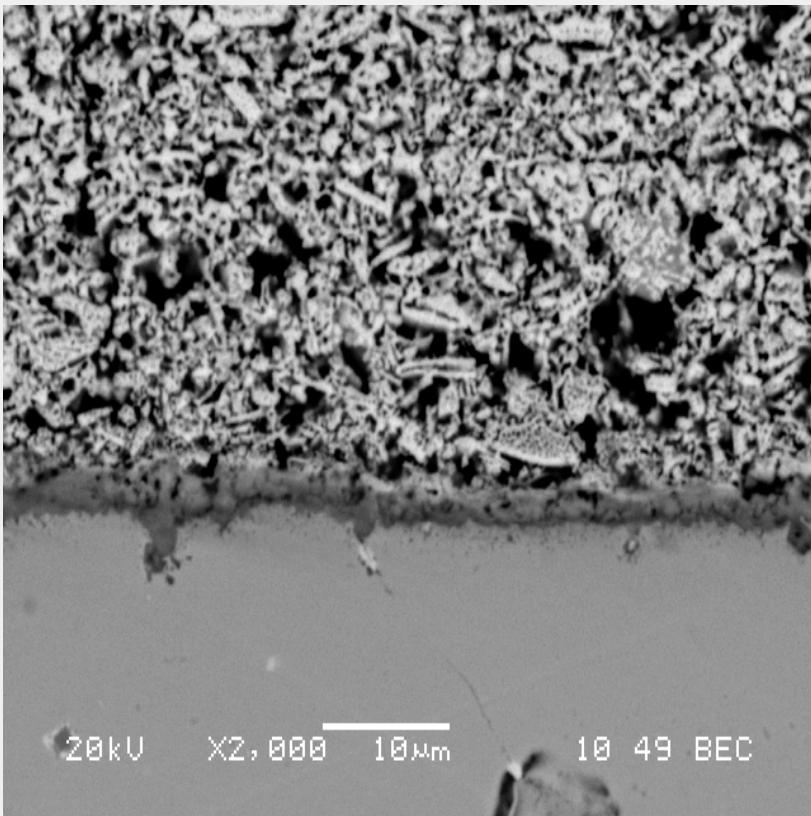
- Thin scale under contact layer
- No Sr-Cr phase at the scale

Dual Atmosphere Test - improved Coating Process



- Low ASR from the start
- Degradation after thermal cycle

1000 hr test microstructure



- Coupon sandwich area (current flow)
- 1000 hrs in dual atm.

SECA CTP

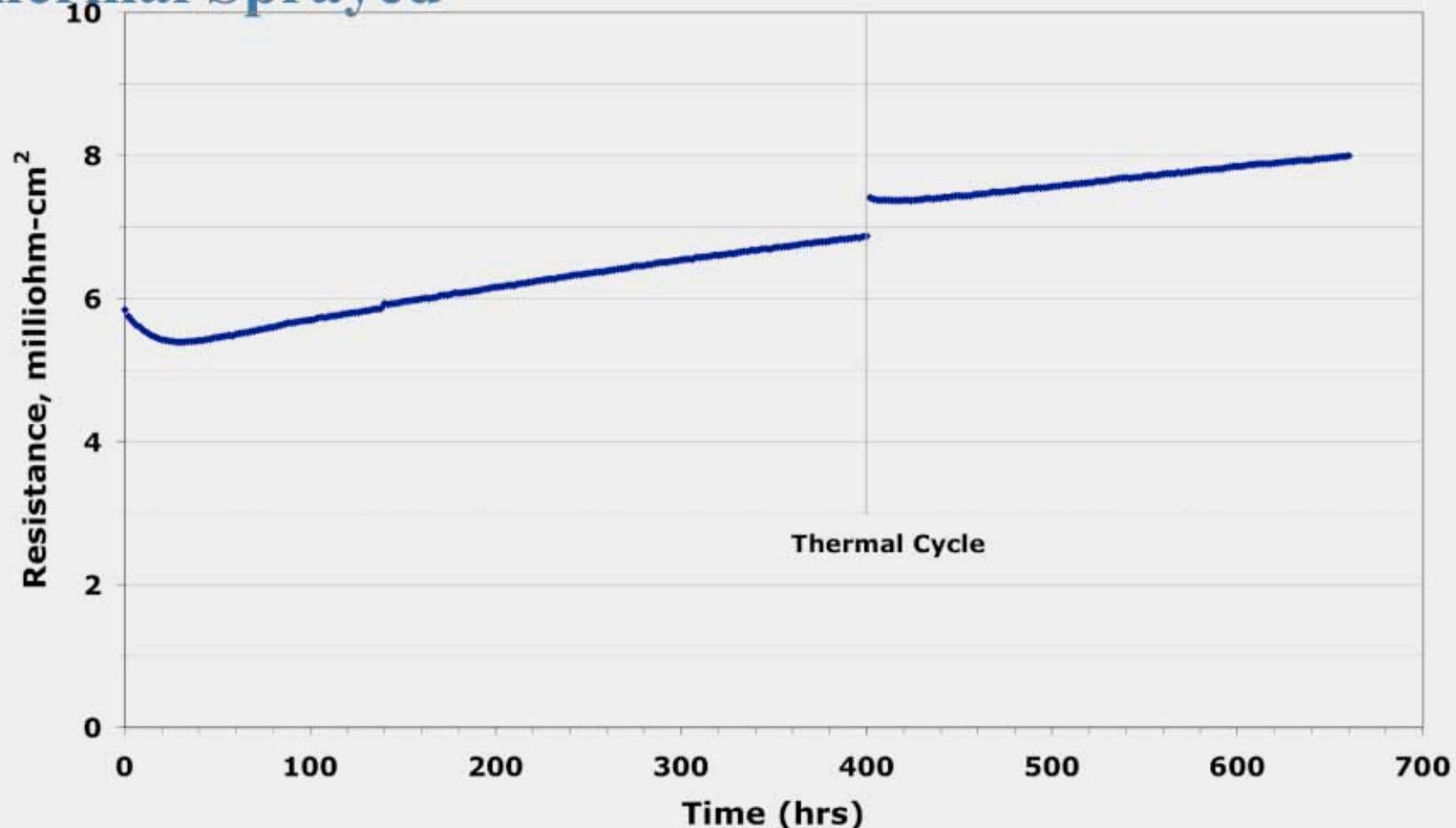
Pacific Grove

- Away from sandwich area
- 1000 hrs in dual atm.

18 - 21 April 05

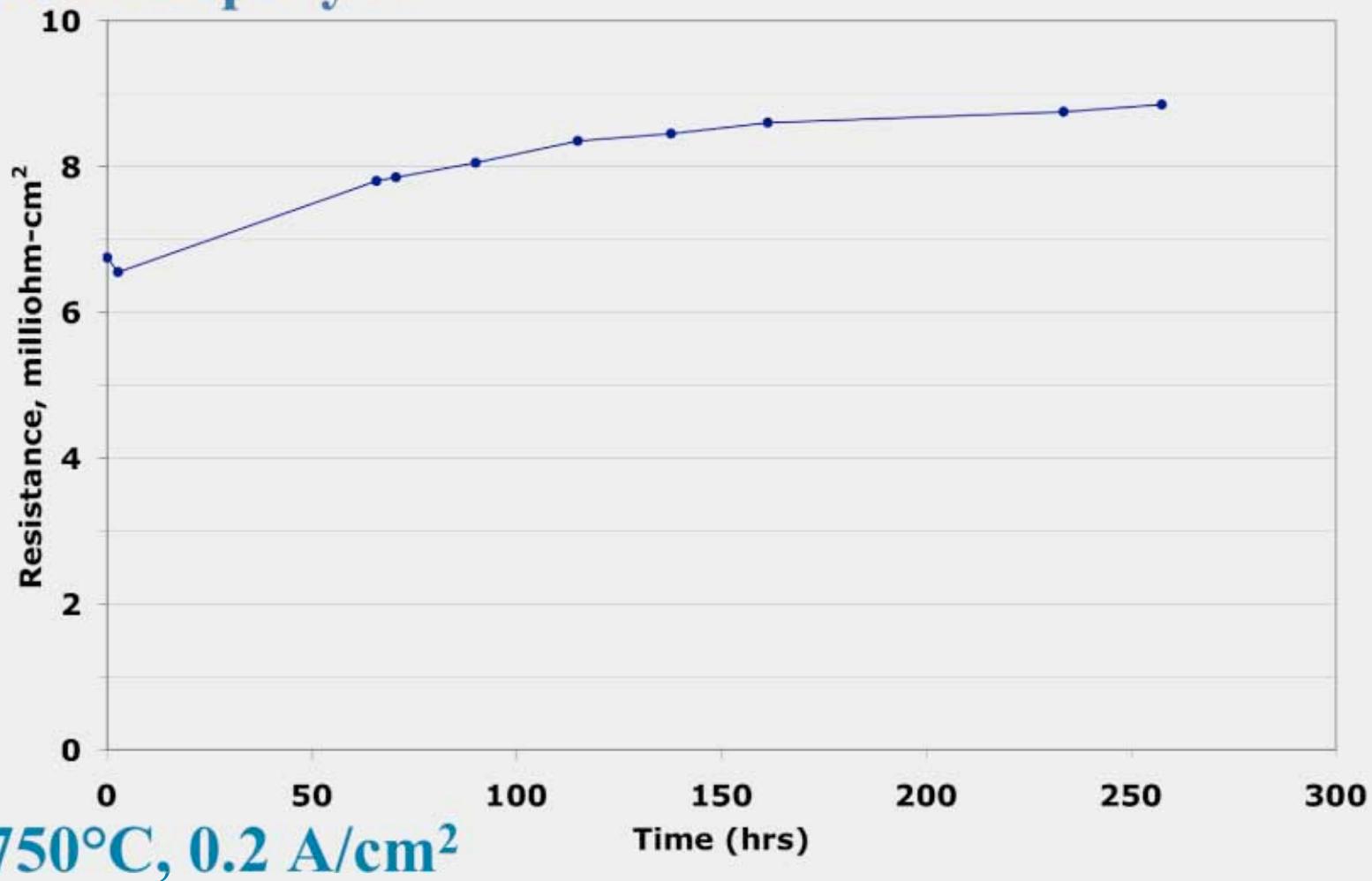
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Coupon Test: Graded Coating + LSCo Thermal Sprayed

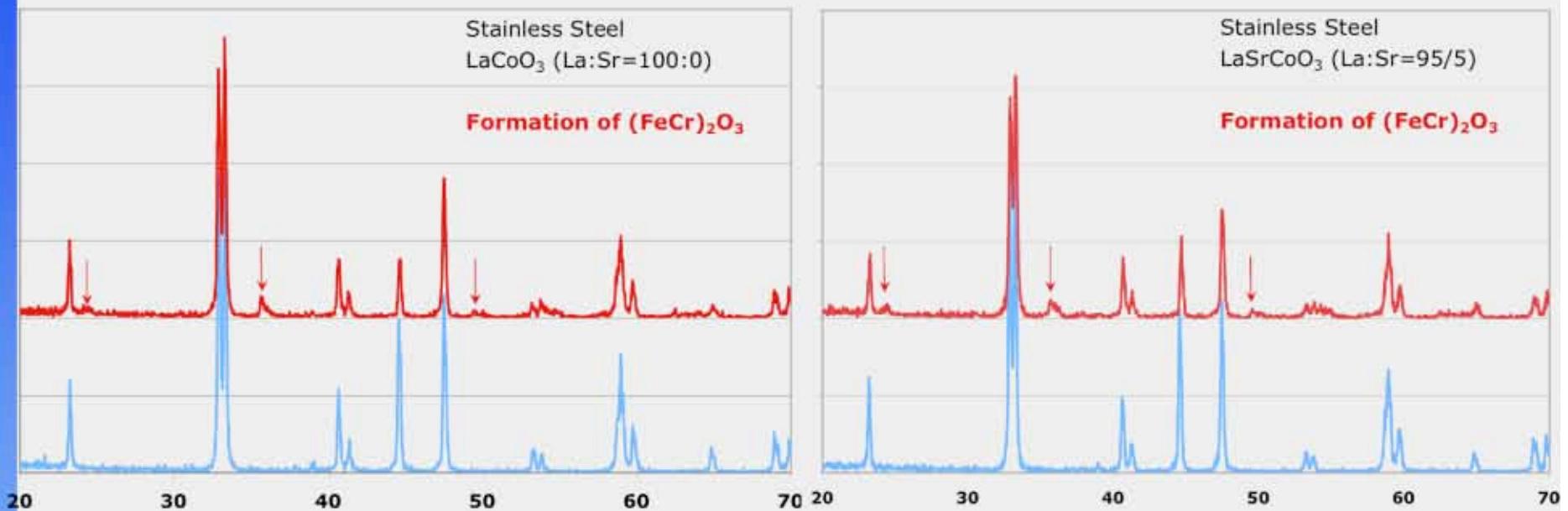


- Test condition: 750°C in Air

Dual Atmosphere Test: Graded Coating + LSCo Thermal Sprayed

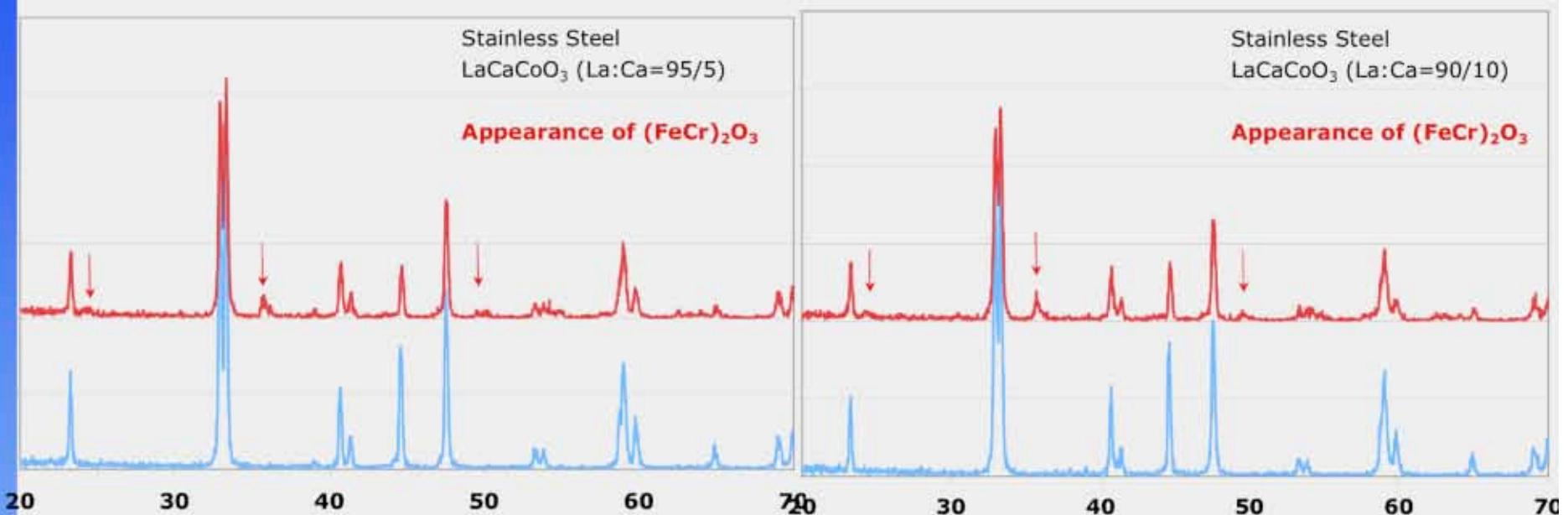


Reaction Study: Untreated SS Powder + Perovskite



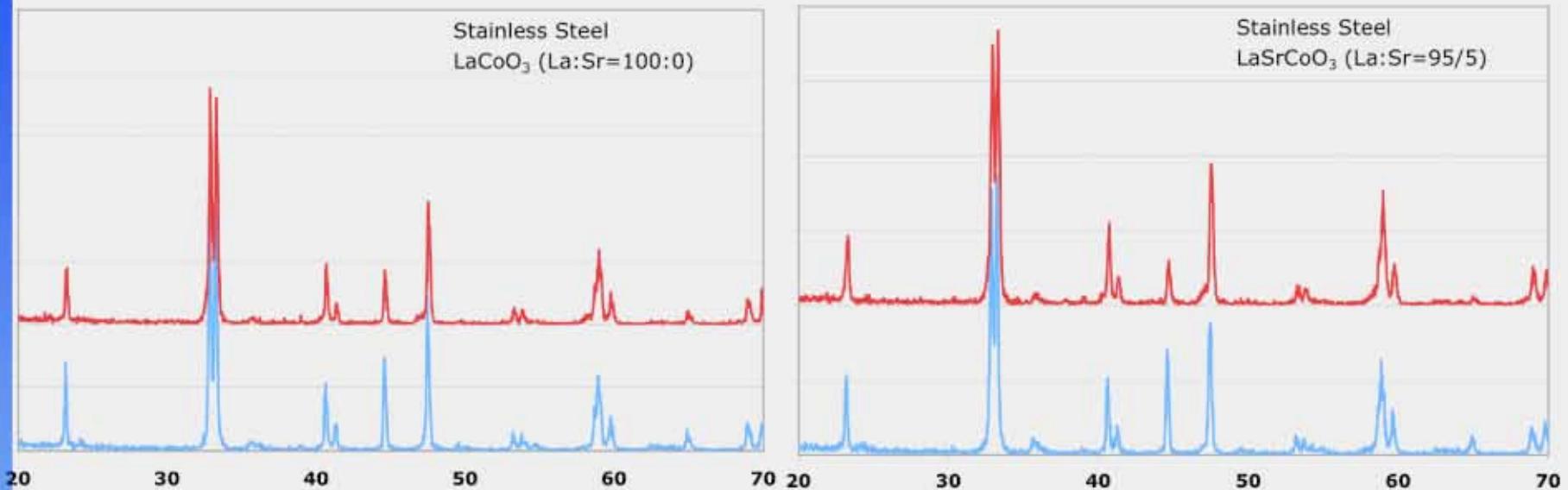
- Stainless Steel Powder (Untreated) + Perovskite Mixture
200 hrs in air
- Formation of (Fe,Cr)₂O₃
Stainless Steel powder from Hoeganaes Corporation
Bottom pattern - as mixed powders; Top Pattern - after heat treatment

Reaction Study: Untreated SS Powder + Perovskite



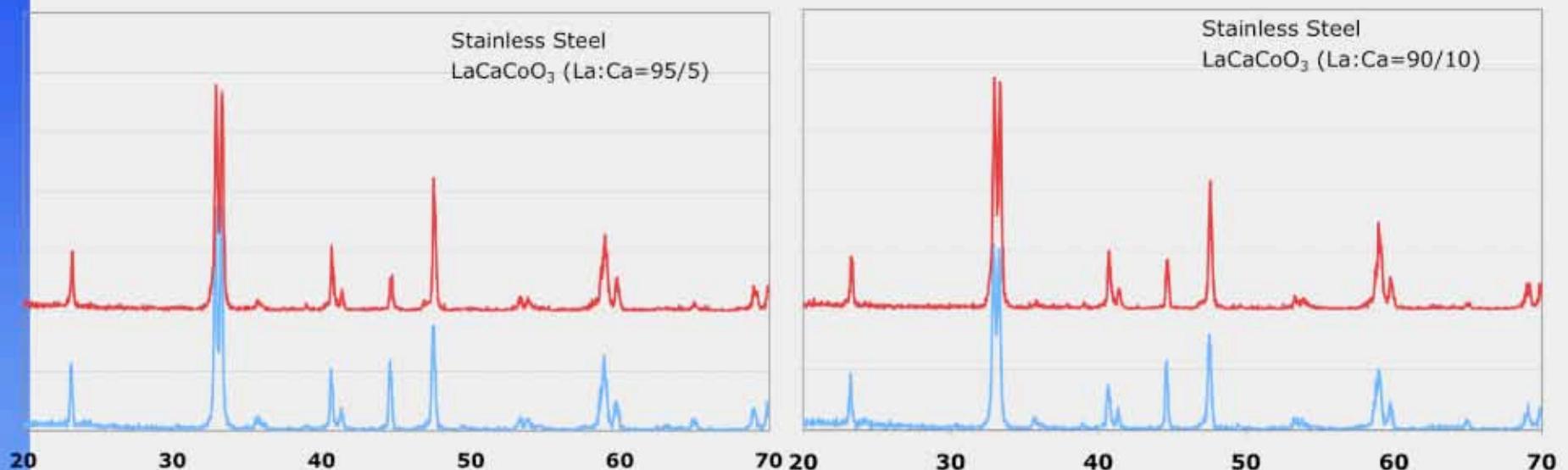
- Stainless Steel Powder (Untreated) + Perovskite Mixture
- 200 hrs in air
- Formation of (Fe,Cr)₂O₃

Reaction Study: Coated SS Powder + Perovskite



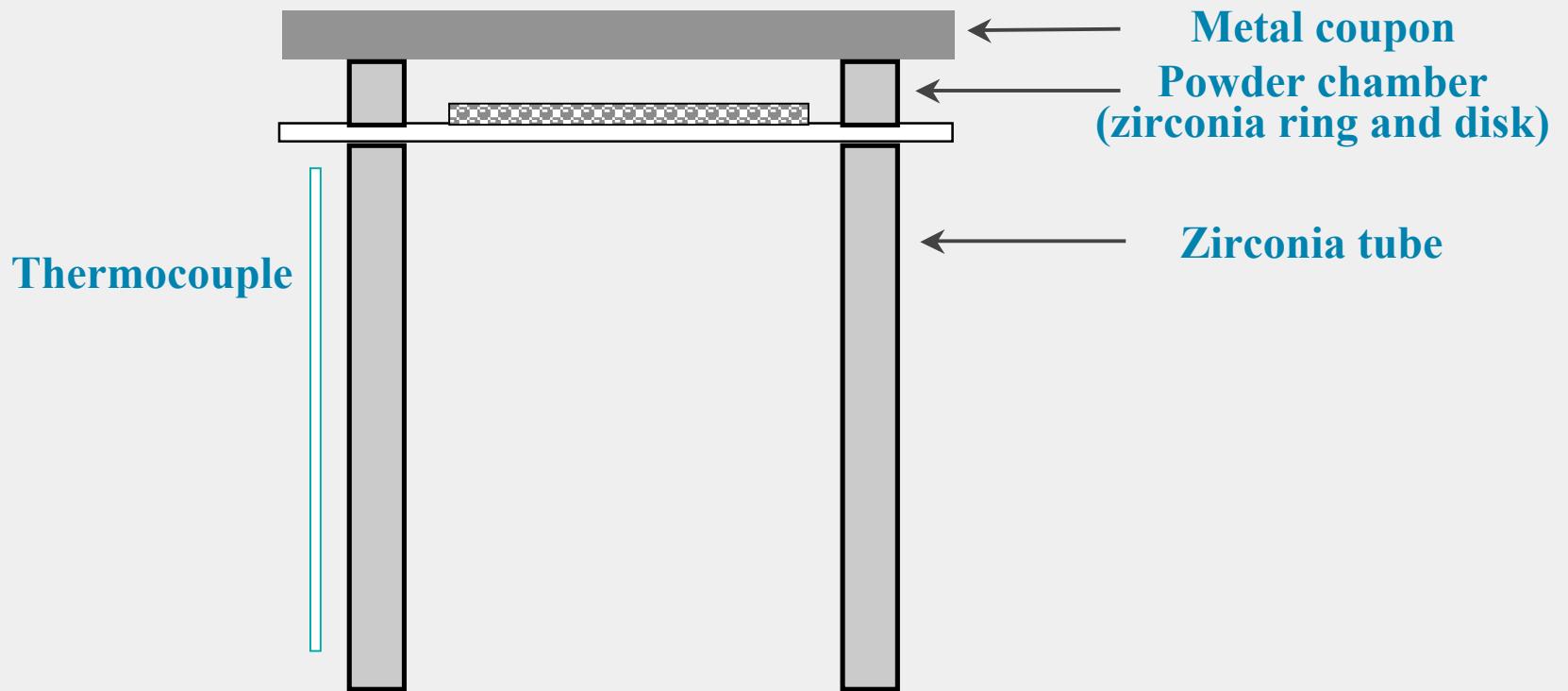
- Stainless Steel Powder (Graded Coating) + Perovskite Mixture
- 300 hours in air
- No significant reaction product

Reaction Study: Coated SS Powder + Perovskite



- Stainless Steel Powder (Graded Coating) + Perovskite Mixture
- 300 hours in air
- No significant reaction product

Chromium Evaporation Test Rig



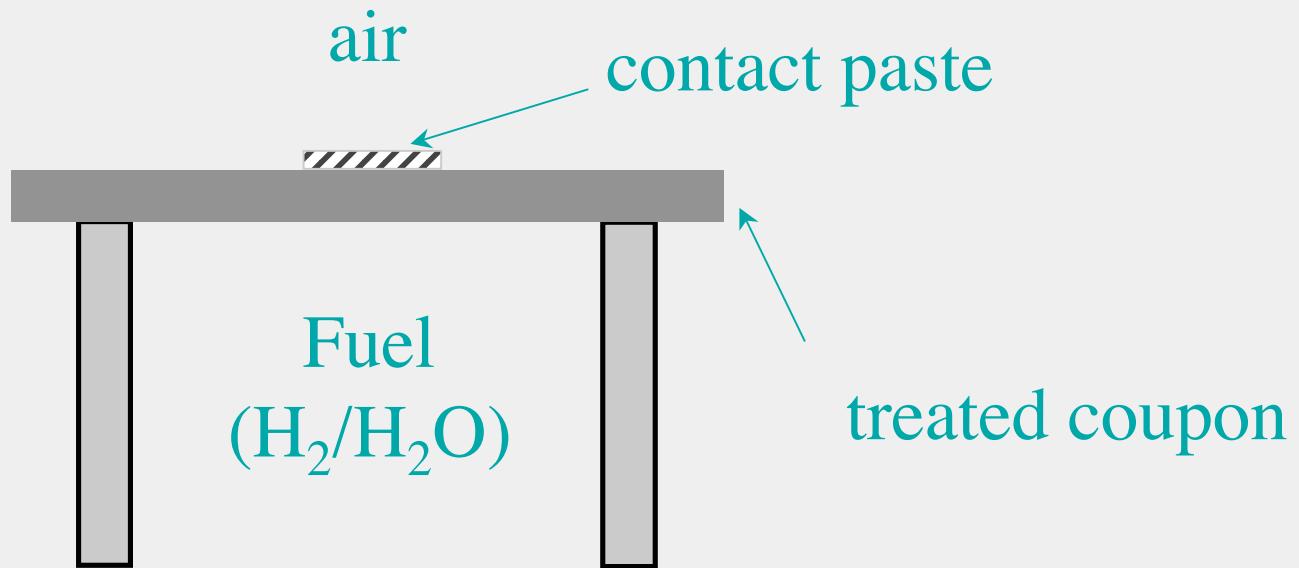
- MgO used as Cr getter

Cr Evaporation Test Summary

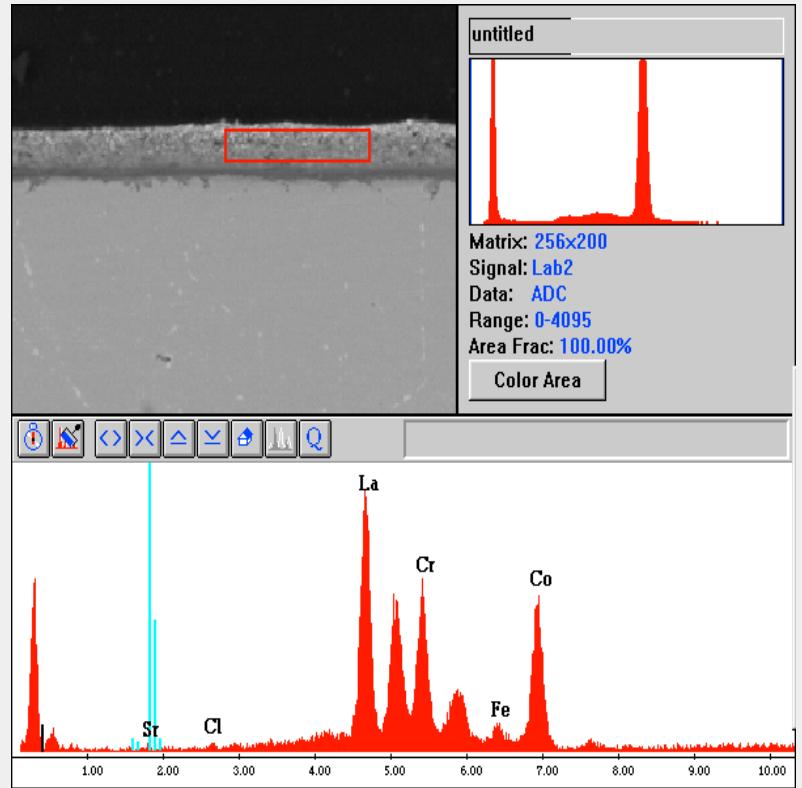
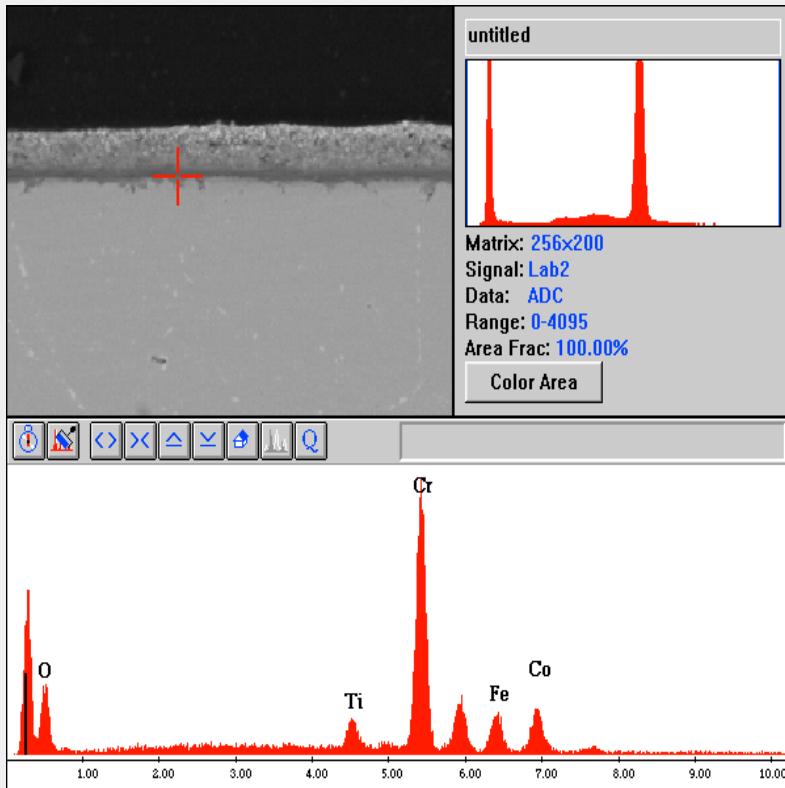
	Baseline powder	Powder exposed to untreated coupon	Powder exposed to treated coupon	Powder exposed to treated and LSCo thermal sprayed coupon
Cr	< 0.5	250	140	4.1
Mn	< 0.25	3.4	< 2.5	0.74
Sr				1.8
Co				<10
Fe				<2.0

- Cr content in ppm by weight in MgO

Reactivity of Contact Paste (300 hrs)

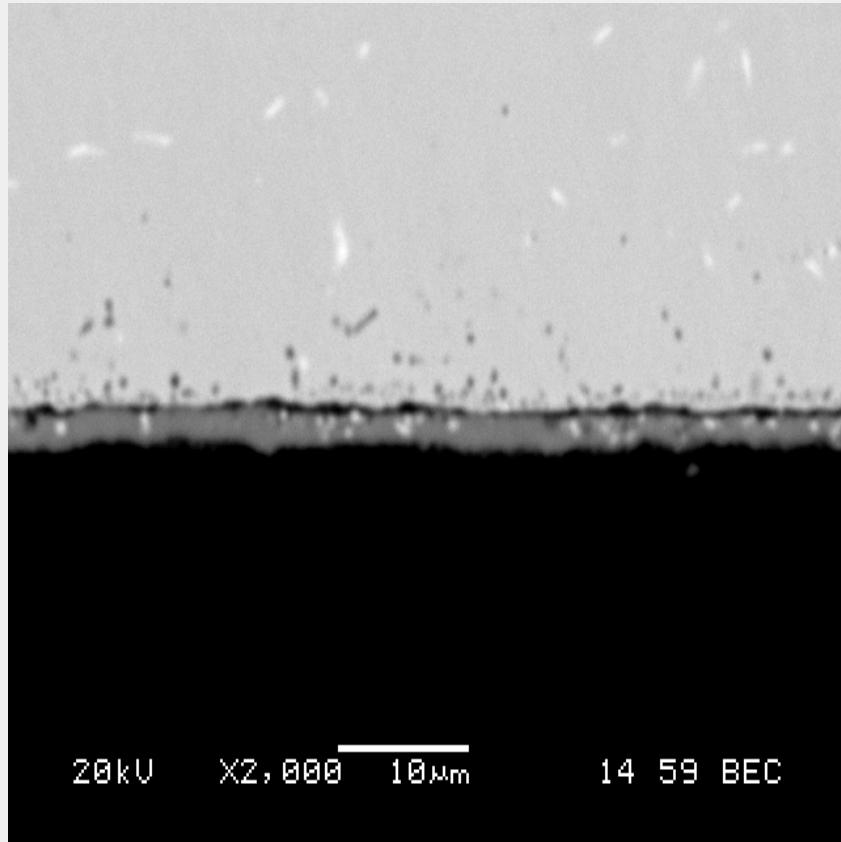


Contact Paste Interaction

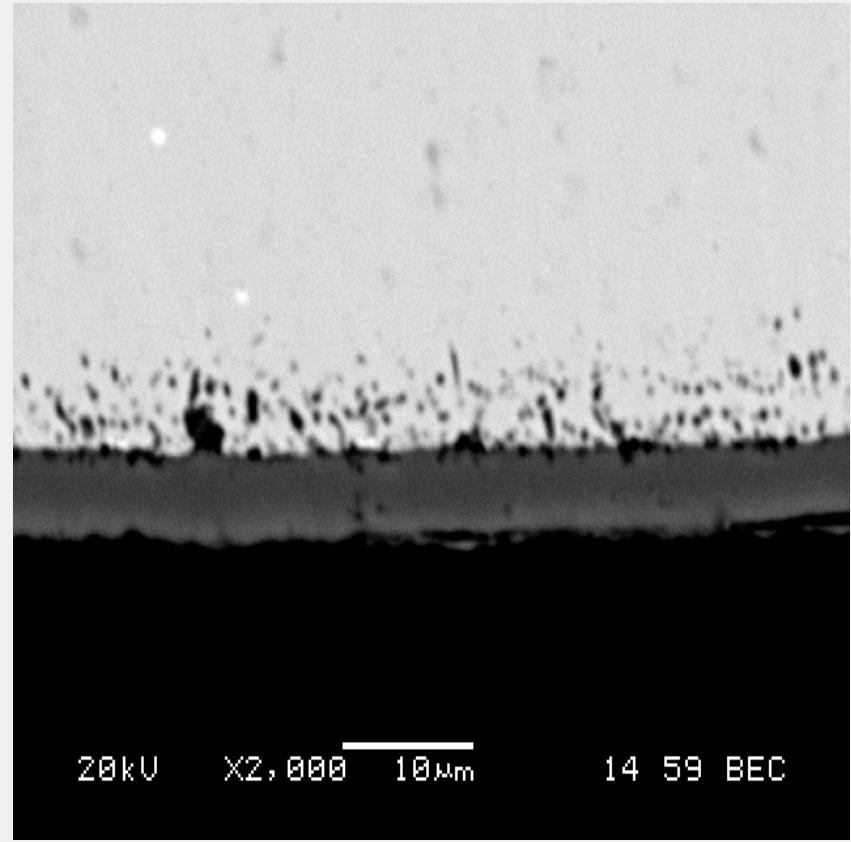


- Treated surface shows good adhesion with LSCo
- Cr diffusion into LSCo layer (due to porosity?)

Fuel Exposure

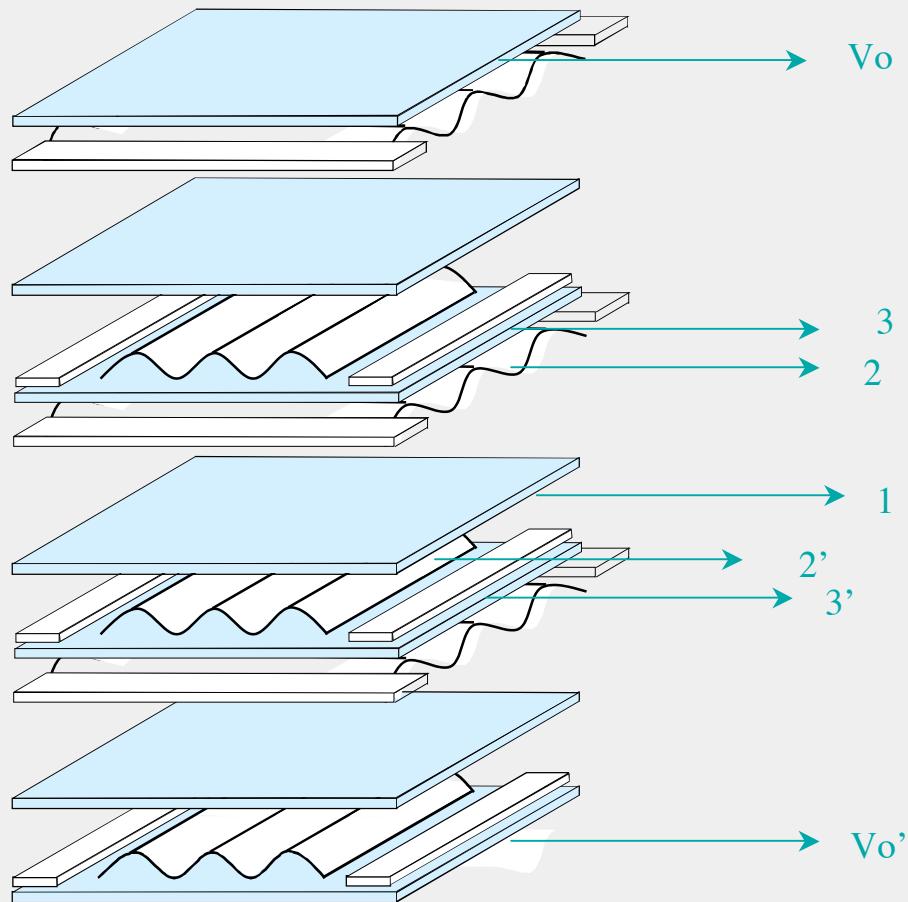


Syngas Exposure
750°C - 250 hrs



Syngas + H₂S Exposure
750°C - 250 hrs

Resistance Stack



- **Repeat Unit**
 - Interconnect + ‘pseudo cell’ made of separator plate
- **Voltage probes to monitor resistance of interfaces**
- **Dual atmosphere**
- **Initial Data:**
 - Air interface ~ 100 milliohm-cm 2
 - Fuel interface ~ 50 milliohm-cm 2
 - Scatter in data due to inconsistent contact

Summary

- **Commercial stainless steel with graded coating shows**
 - Low, stable interface resistance through several thermal cycles
 - Low air-side resistance in dual atmosphere
 - Modified treatment process provides stable microstructure on the air-side in dual atmosphere exposure
 - Powder mixture heat treatment shows no observable reactivity with potential contact materials (perovskites)
 - Limits chromium evaporation
 - Sulfur tolerance needs further investigation
 - Resistance stack provides resistance information in a stack arrangement

Acknowledgement

- Ceramatec team
- DOE-SECA project managers
Project Manager: Lane Wilson
- CTP teams
- SECA industrial teams