Interconnects

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Core Technology Program - Interconnects

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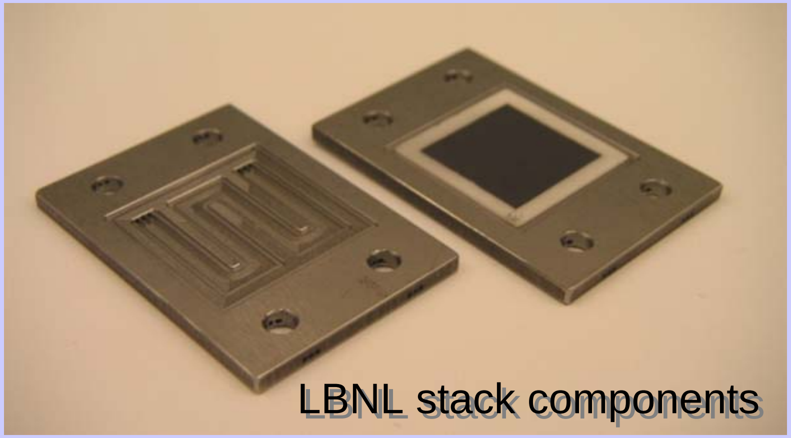
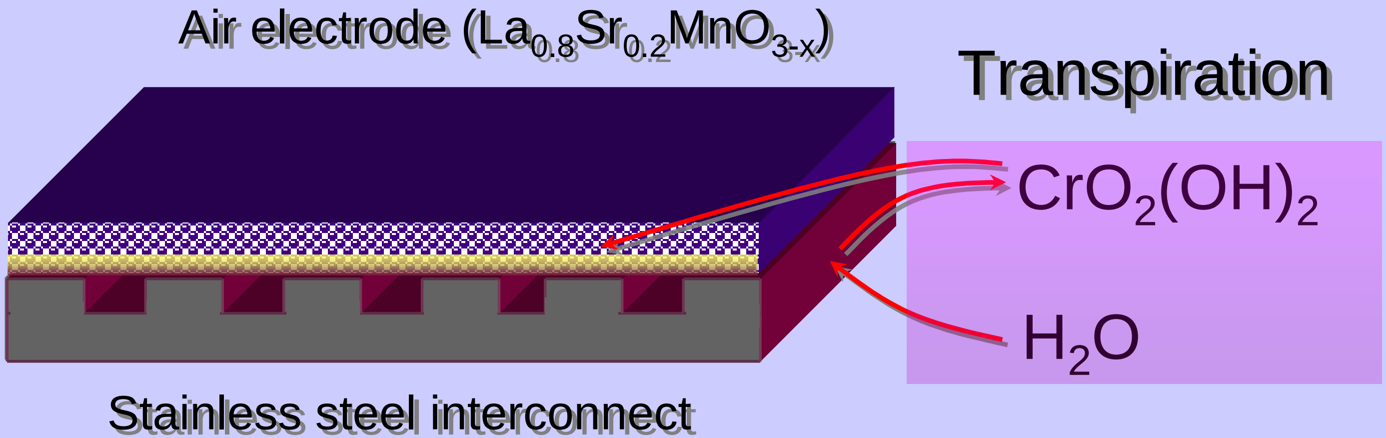
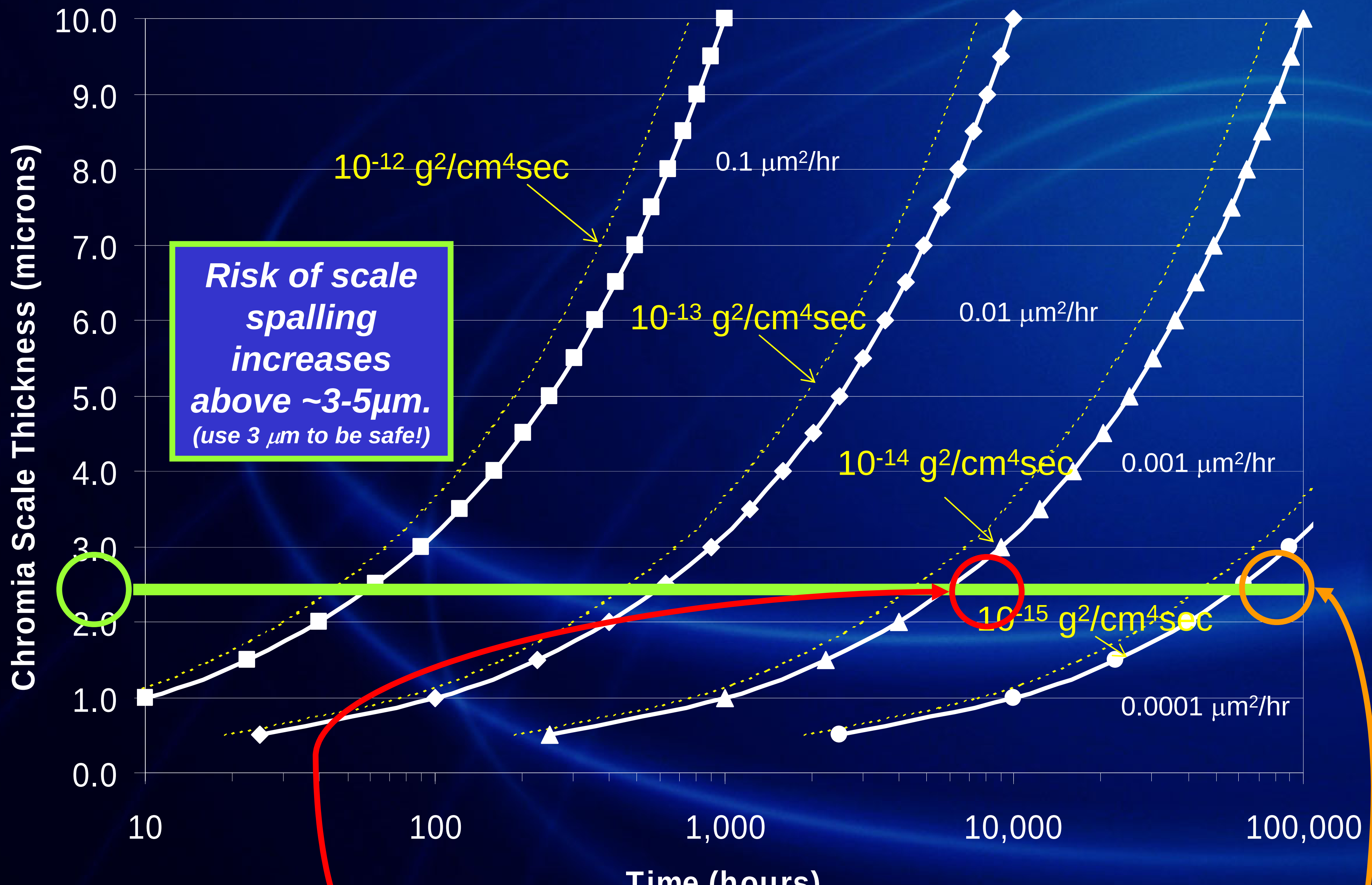
Metal Stability & Interactions



- Oxidation behavior
- Oxide spallation
- Area specific resistance
- Chromium migration



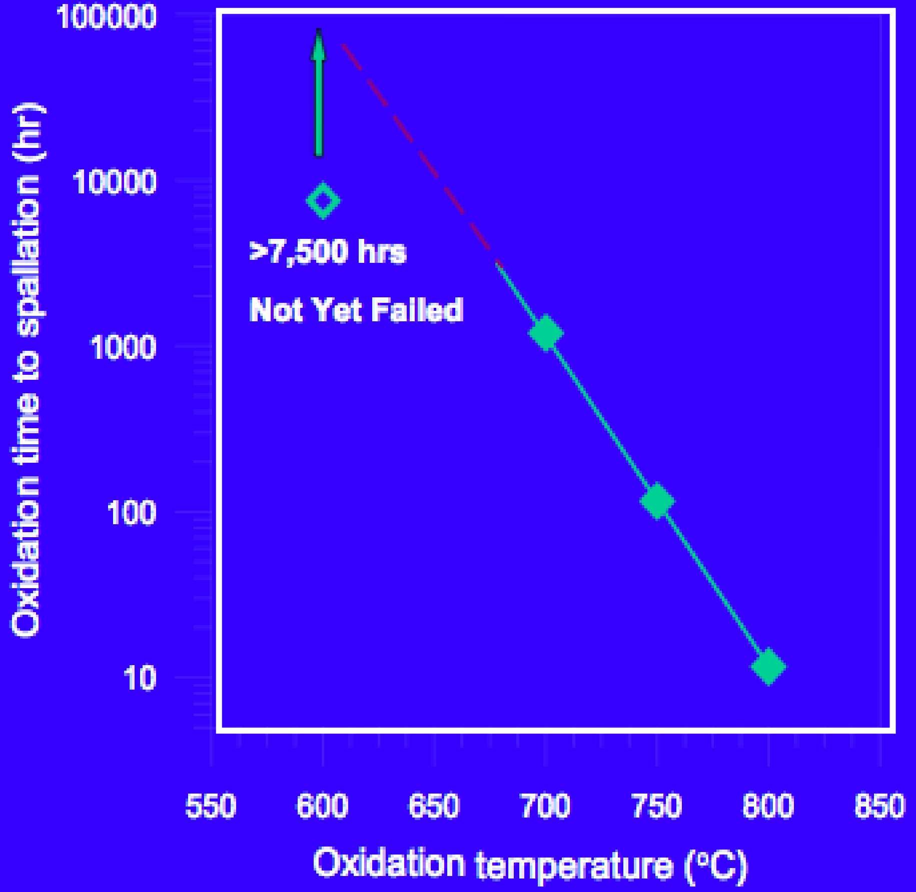
- Vapor chromium transport
- Bulk & grain boundary Cr transport
- Surface migration

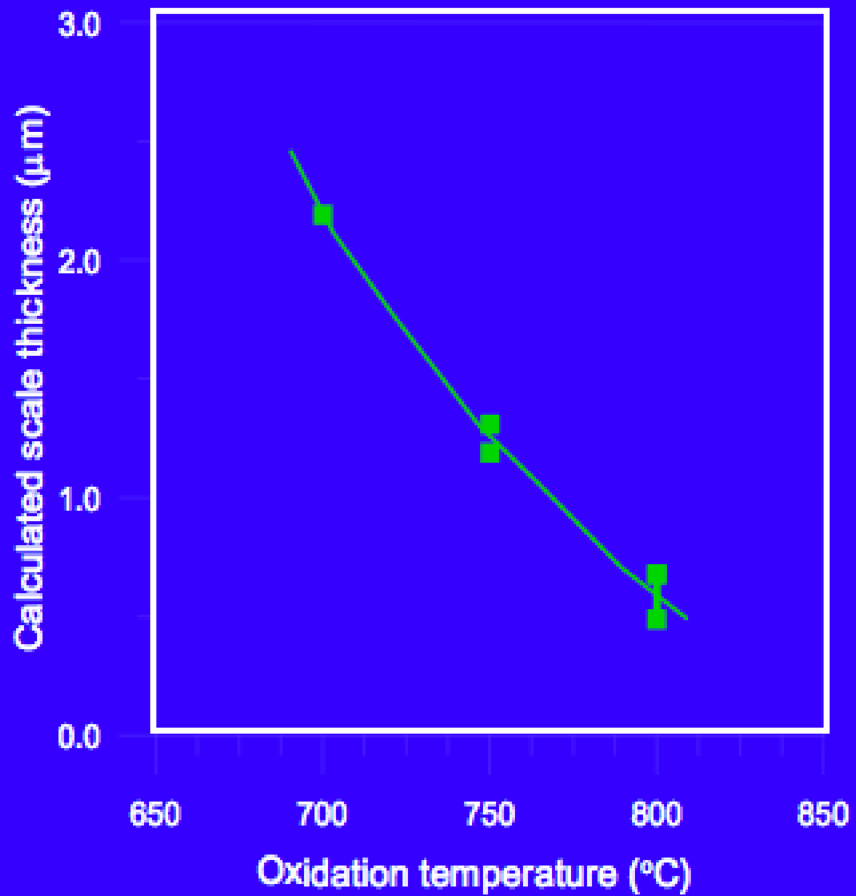


~10^{-14} g^2/cm^4sec for transportation 5,000 – 10,000 hrs

~10^{-15} g^2/cm^4sec for stationary 50,000 – 100,000 hrs

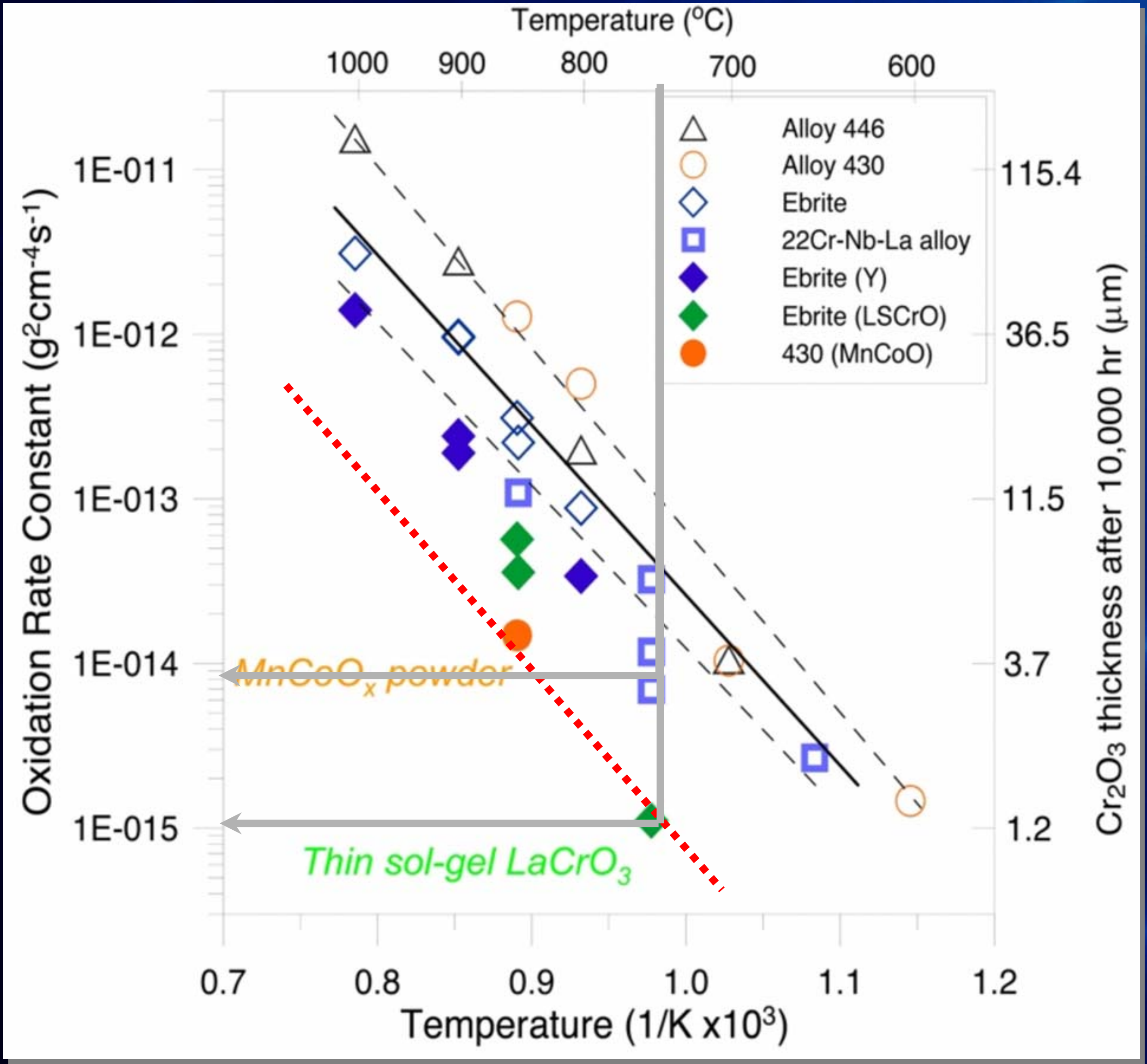
Condition for minimum spallation of scales on 430ss after isothermal oxidation and fast cooling to RT
These are small and sporadic (1%?)





Scale thickness decrease because of higher thermal stresses and/or more defect formation at high oxidation temperatures

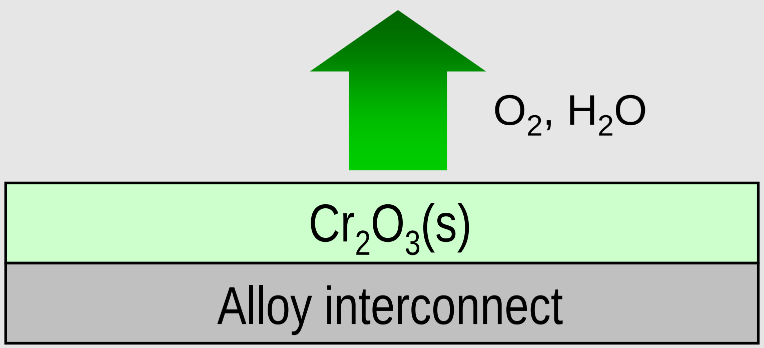
High Temperature Oxidation of Metal Components



Chromium Vaporization

- Cr gas species

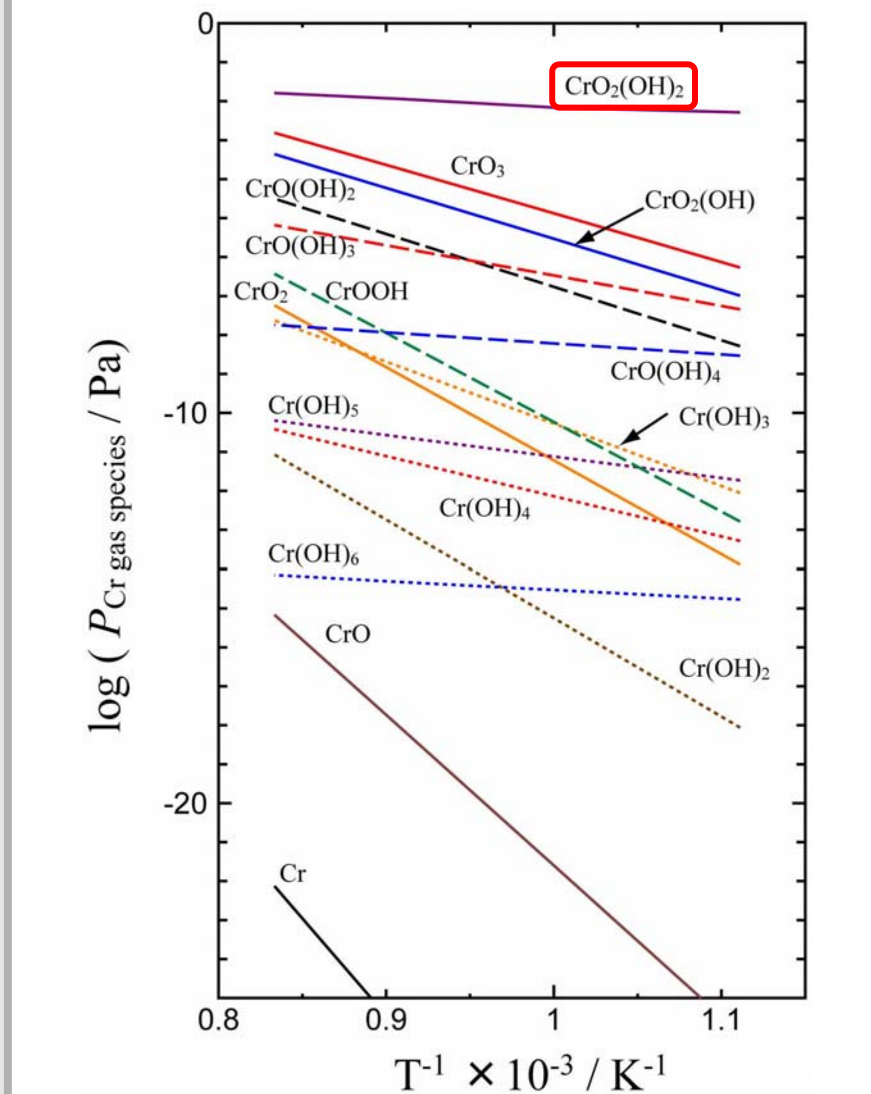
Cr	CrOH	CrOOH
CrO	$Cr(OH)_2$	$CrO(OH)_2$
CrO_2	$Cr(OH)_3$	$CrO(OH)_3$
CrO_3	$Cr(OH)_4$	$CrO(OH)_4$
	$Cr(OH)_5$	$CrO_2(OH)$
	$Cr(OH)_6$	$CrO_2(OH)_2$



B.B. Ebbinghaus, *Combus. Flame.*, **93** (1993) 119

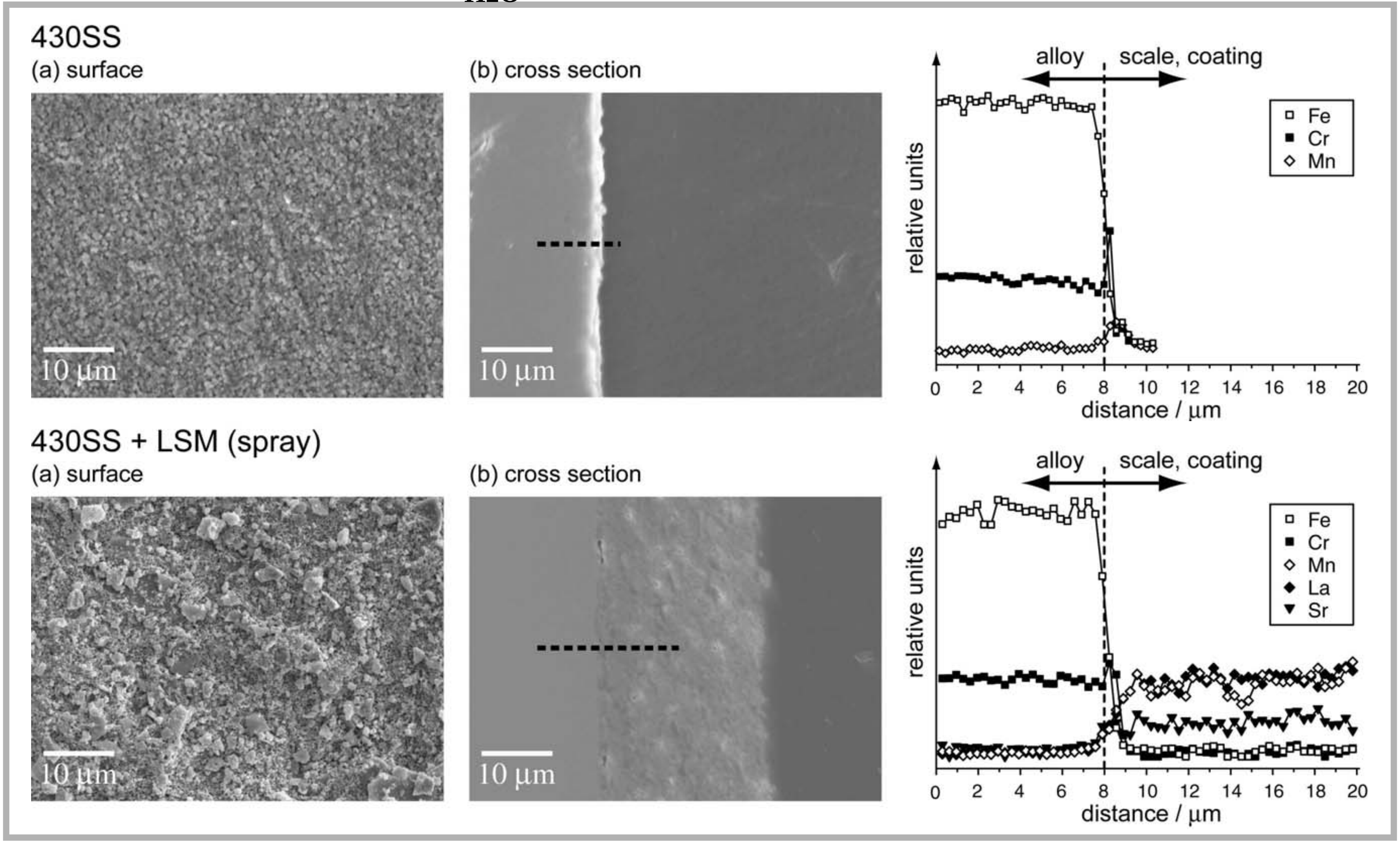
- Partial pressures of Cr gas species

Cathode side: P_{O2}= 2 x 10^4 Pa, P_{H2O}= 2 x 10^3 Pa



Results – uncoated and coated 430 -SS

- **1073 K, 86.4 ks (24 hrs), P_{H2O} = 1.0x10^4 Pa, 3.33x10^{-6} m^{3}s^{-1} (200ml/s)**



Experimental

Sample preparation

Pre-oxidation (for uncoated and coated 430SS)

1073 K, 172.8 ks, in Air

Cr vaporization test

873~1073 K (main test)

873~1273 K (preliminary test with Cr_2O_3)

86.4~259.2 ks (1~3 days) in Air + 10% H_2O

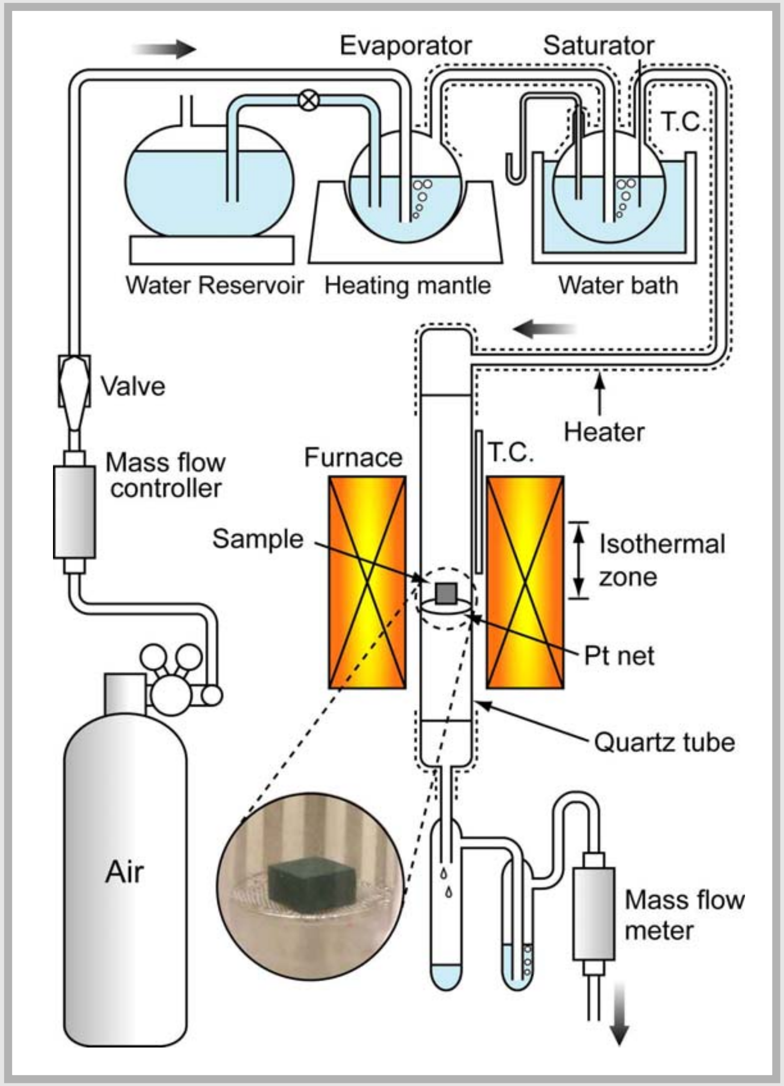
Analysis method

ICPMS (Inductively coupled plasma mass spectrometry)

SEM (Secondary electron spectroscopy)

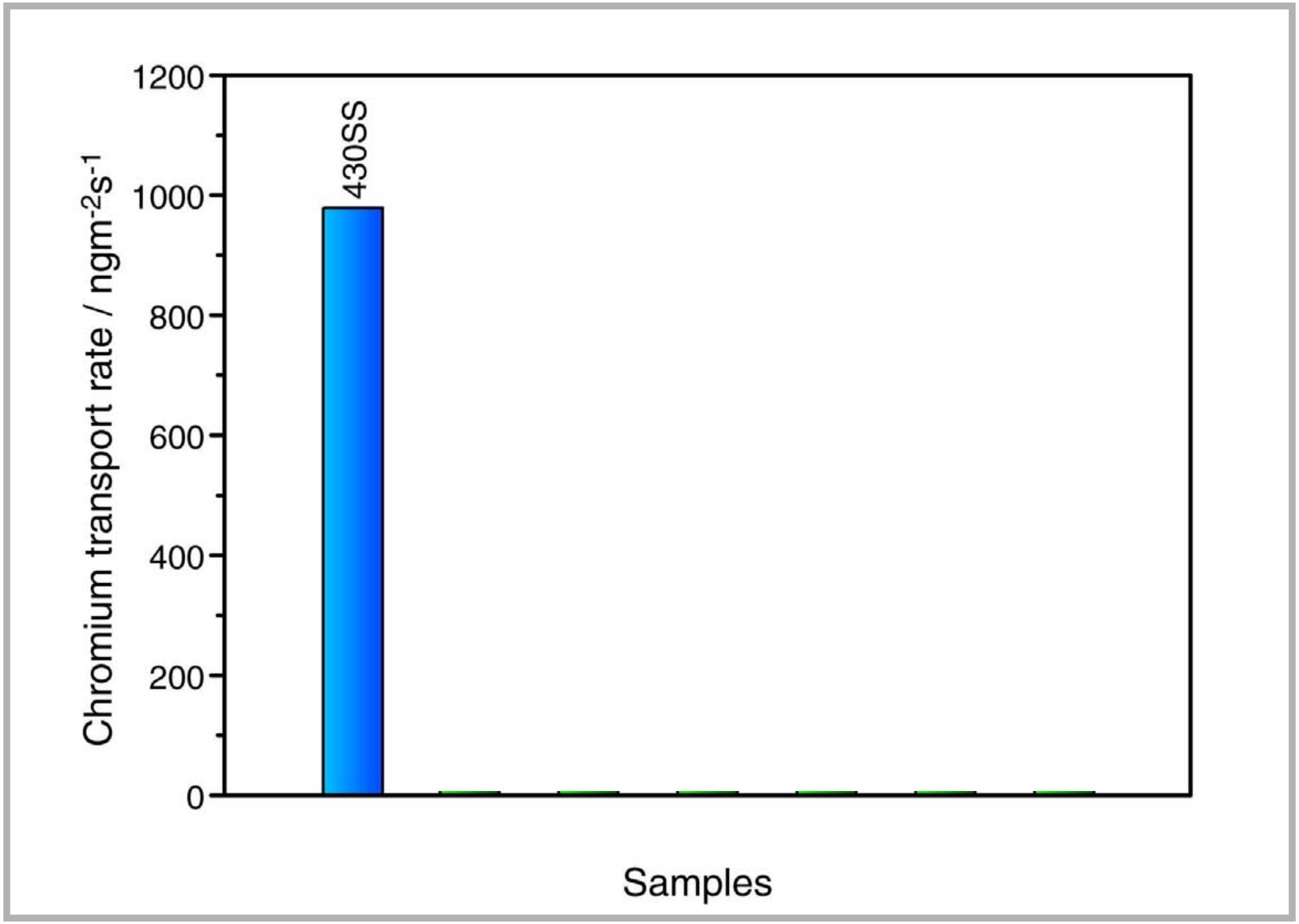
EDS (Energy dispersive spectroscopy)

Apparatus



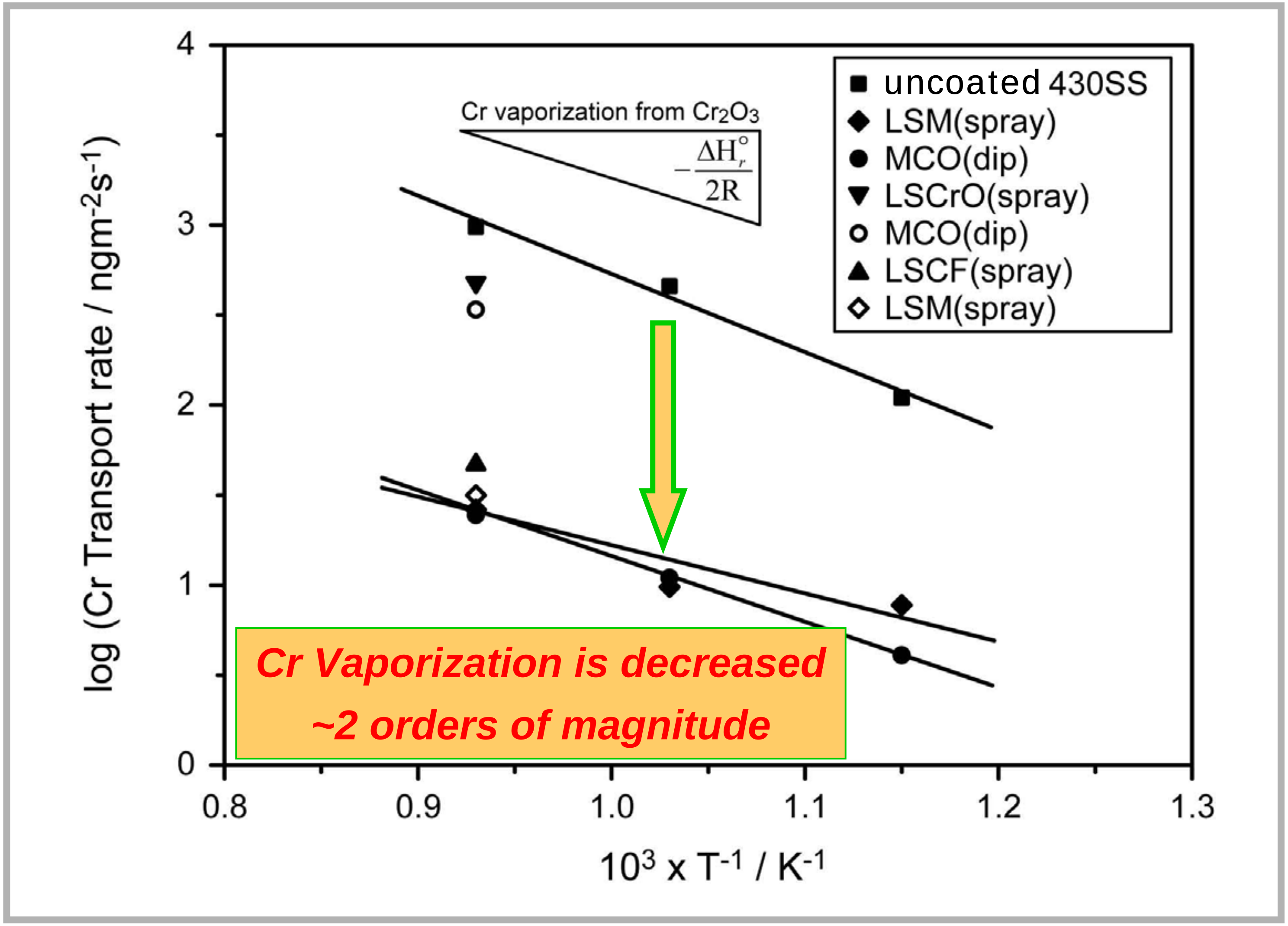
Results – uncoated and coated 430 -SS

- **800°C, 86.4 ks (24 hrs), P_{H2O} = 1.0x10^4 Pa, 3.33x10^{-6} m^{3}s^{-1} (200ml/min)**

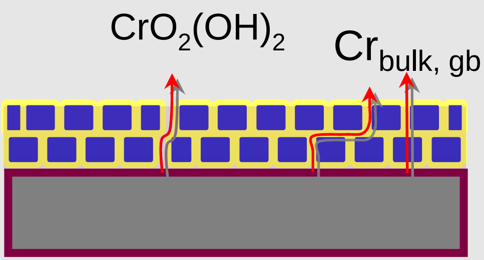


Results – uncoated and coated 430 -SS

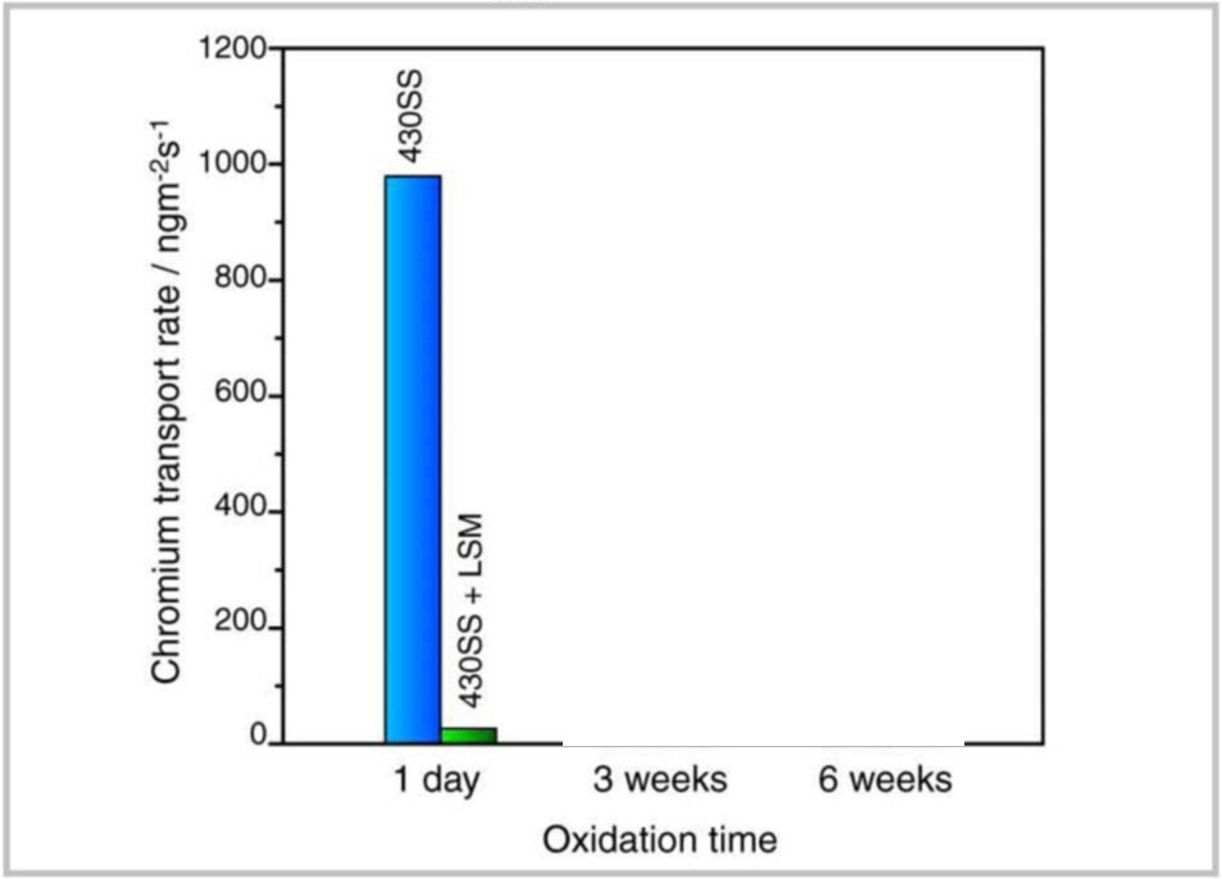
- P_{H2O} = 1.0x10^4 Pa, 3.33x10^{-6} m^{3}s^{-1} (200ml/s)



Long-term Stability of Coatings for Preventing Cr Loss

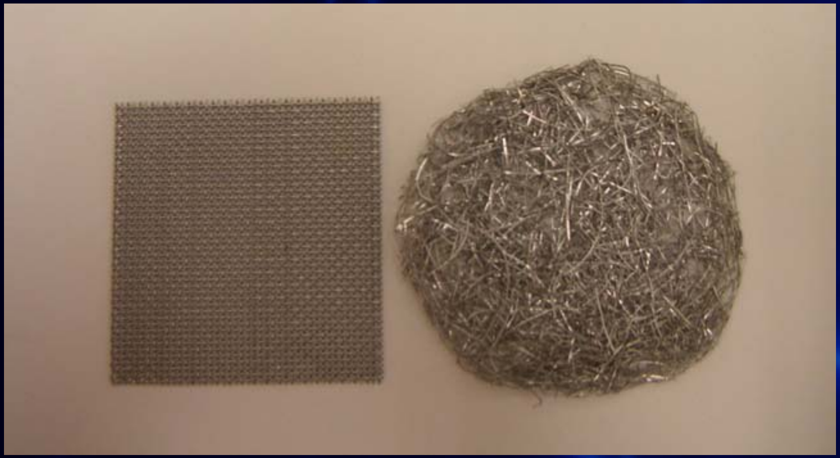


- **Oxidation: 1073 K, P_{H2O} = 2.0x10³ Pa, 3.33x10⁻⁶ m³s⁻¹ (200ml/min)**
- **Cr test: 1073 K, 86.4 ks (24 hrs), P_{H2O} = 1.0x10⁴ Pa, 3.33x10⁻⁶ m³s⁻¹ (200ml/min)**

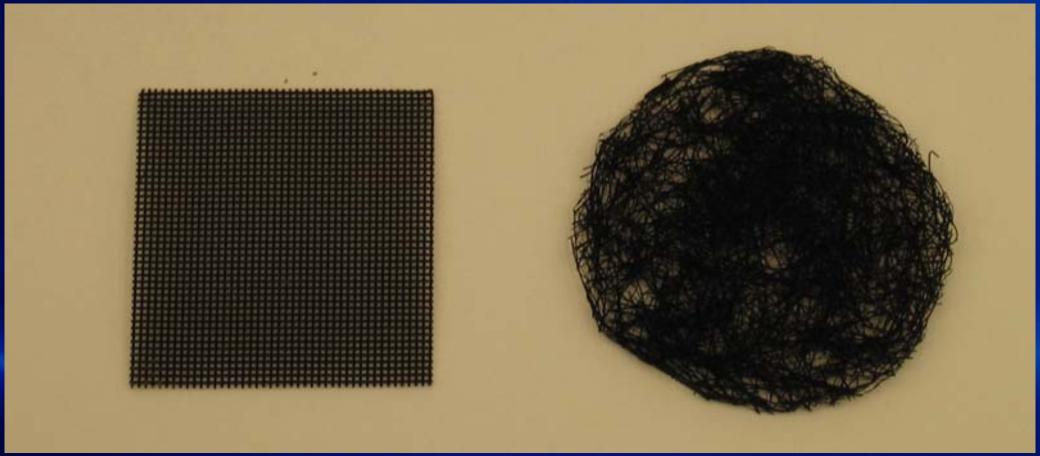


Protected LSM Spray Coat on 434 Stainless Steel Mesh and Wool (sintered at 800^oC for 1hr)

Before Treatment

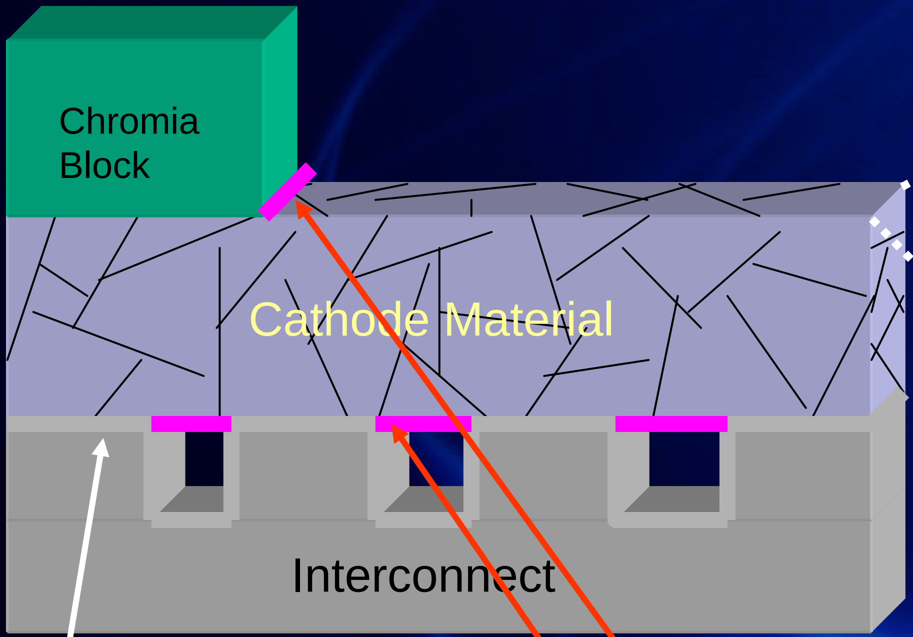


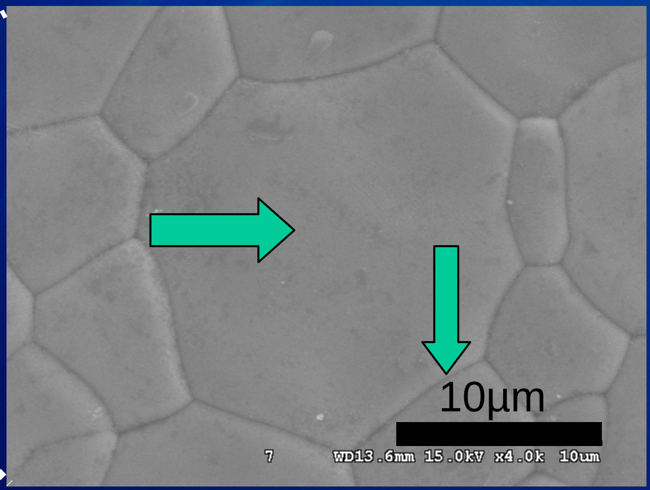
After Spray and Sinter



Oxidation resistant, compliant current connects

Solid State Chromium Transport on Cathode Materials

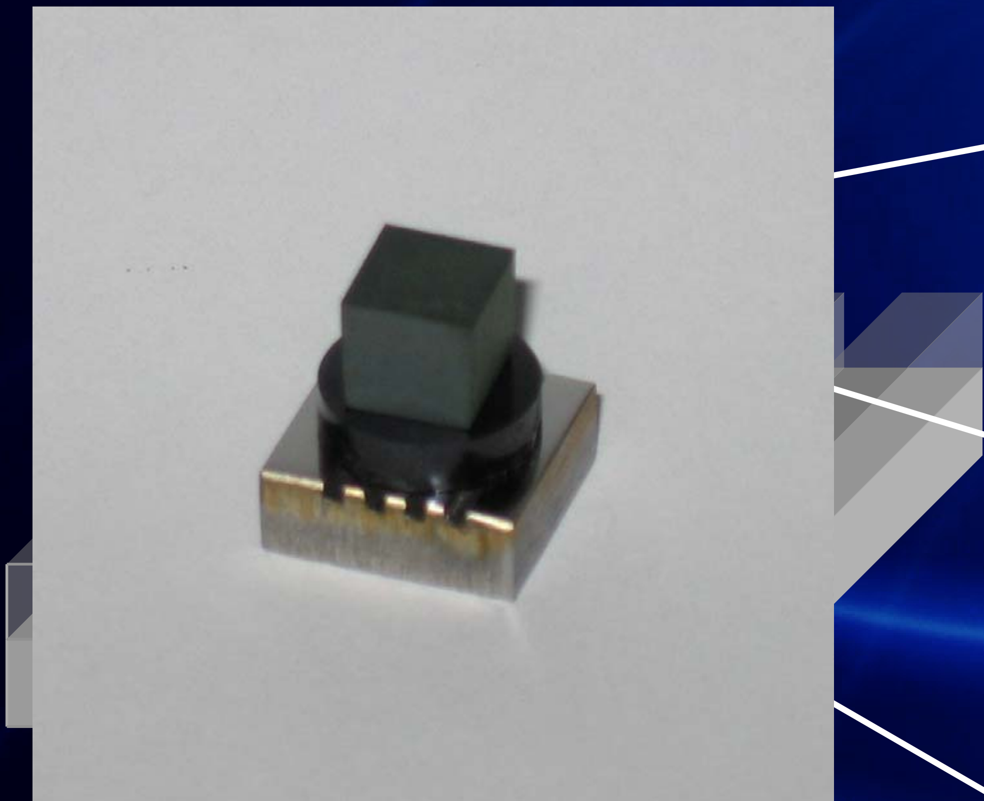




Bulk or grain boundary diffusion at the edge of chromia block and interconnect.

Suppression of Cr Transport by coating with Ag? Pt? Sacrificial Material?

Solid State Diffusion Transport of Chromium on Cathode Materials Experimental Setup



Sinter in the furnace at 700^{o}C, 750^{o}C, 800^{o}C respectively for 500 hr.

Benefits of Coatings

- Decrease oxidation rate >10 x
- Decrease Cr vaporization by 10-100 x
- Decreases spallation (thermal cycling)
  - RE improve adhesion
  - Outer layer prevents buckling
- Decreases contact resistance

But…

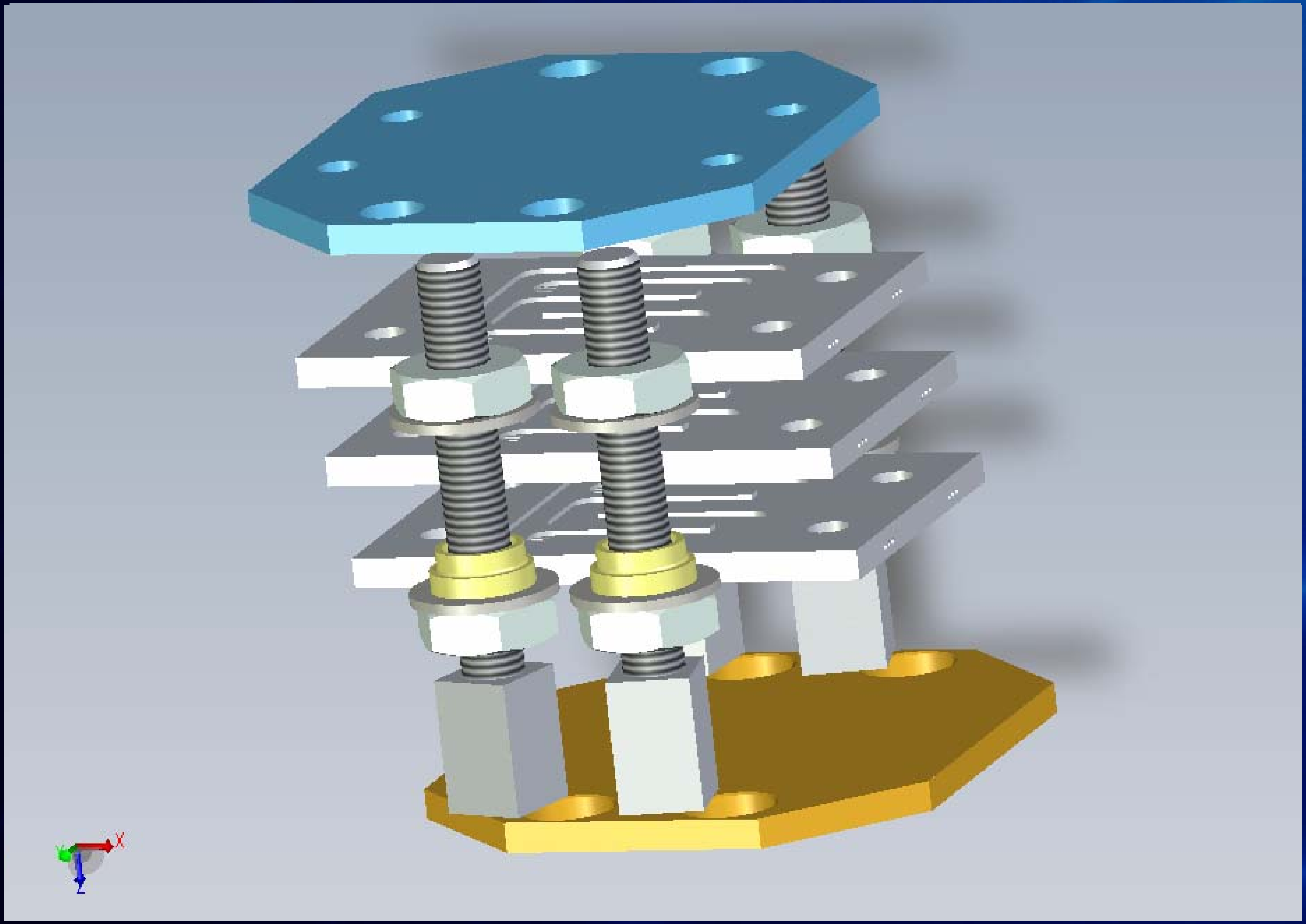
Cost effective?

Complete coverage?

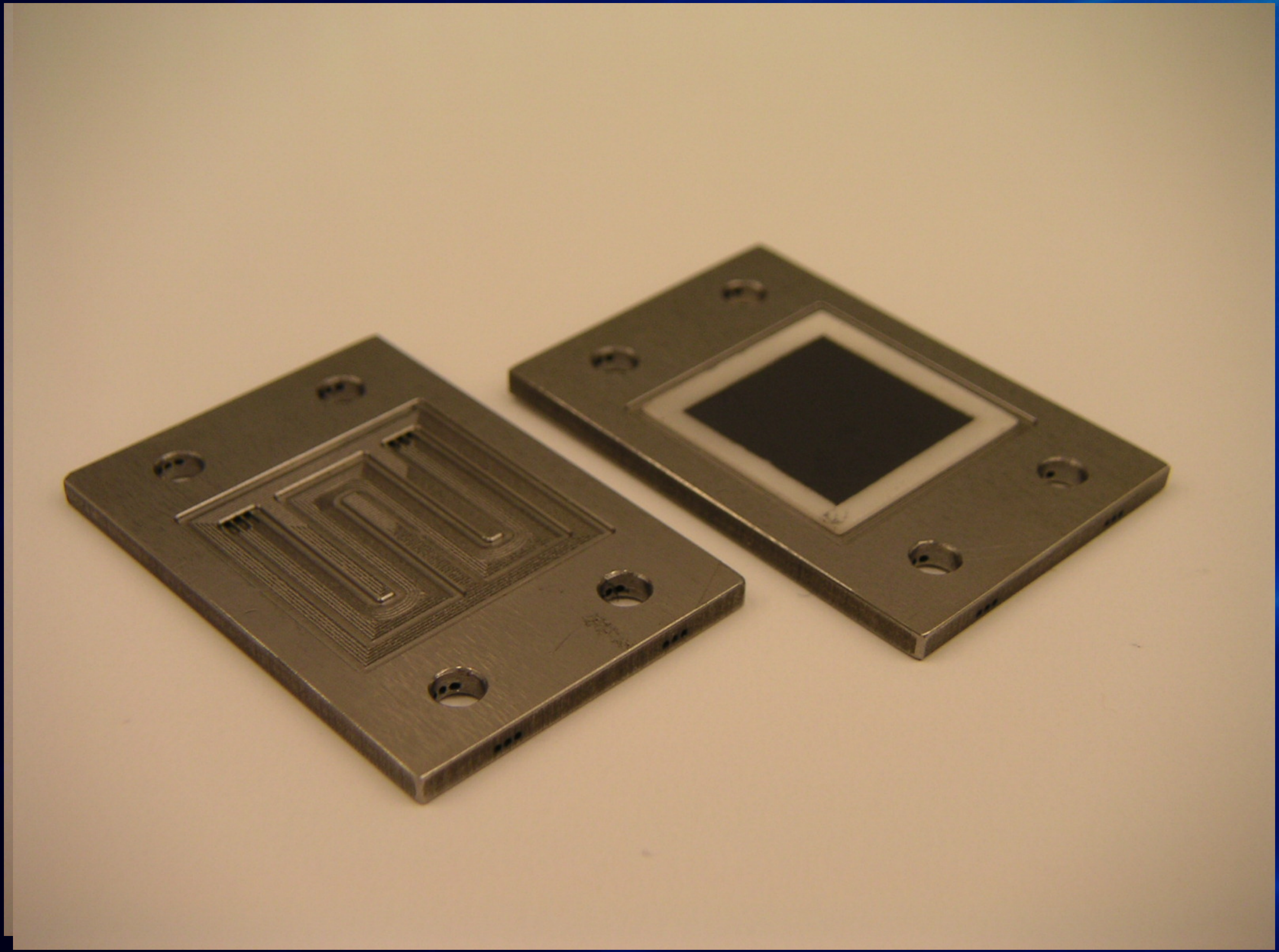
In-situ repair if fails?

Long-term stability?

National Laboratory Stack Test Platform

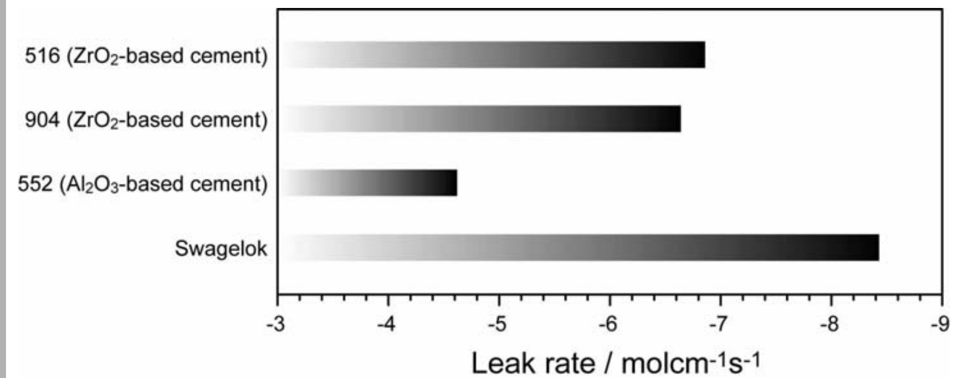


National Laboratory Stack Test Platform

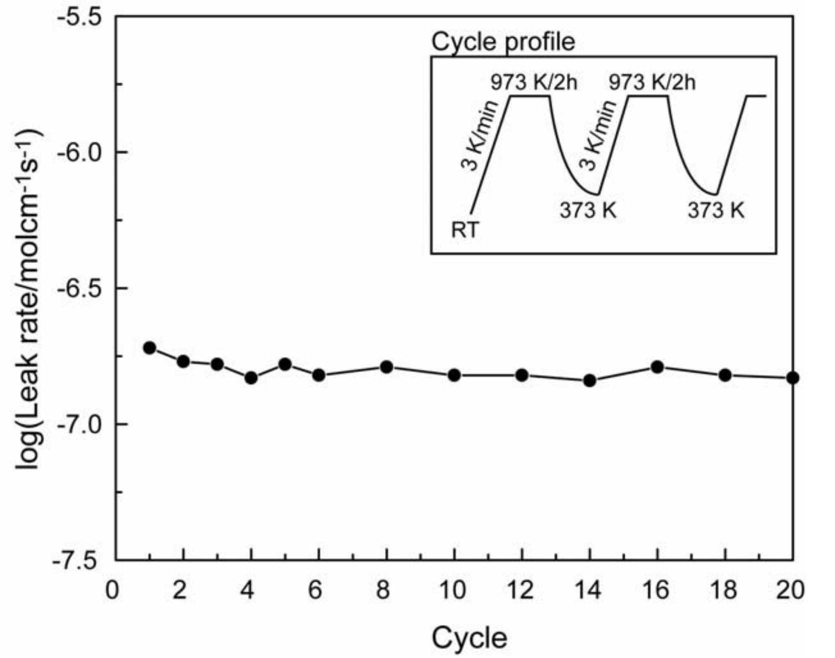


Vacuum leak test of ceramic cements for sealing

Test rig for vacuum leak test
(plate: 430, tube: 316, welded with Nioro)

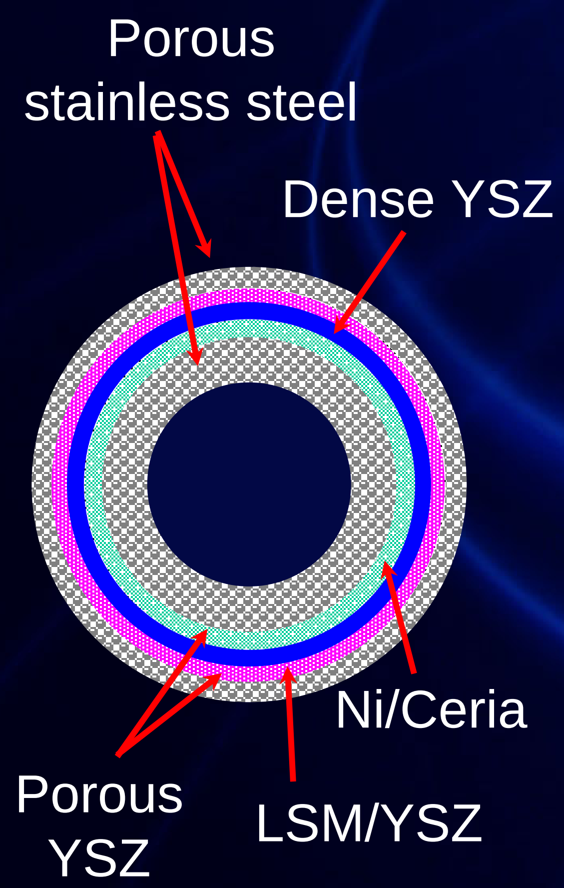


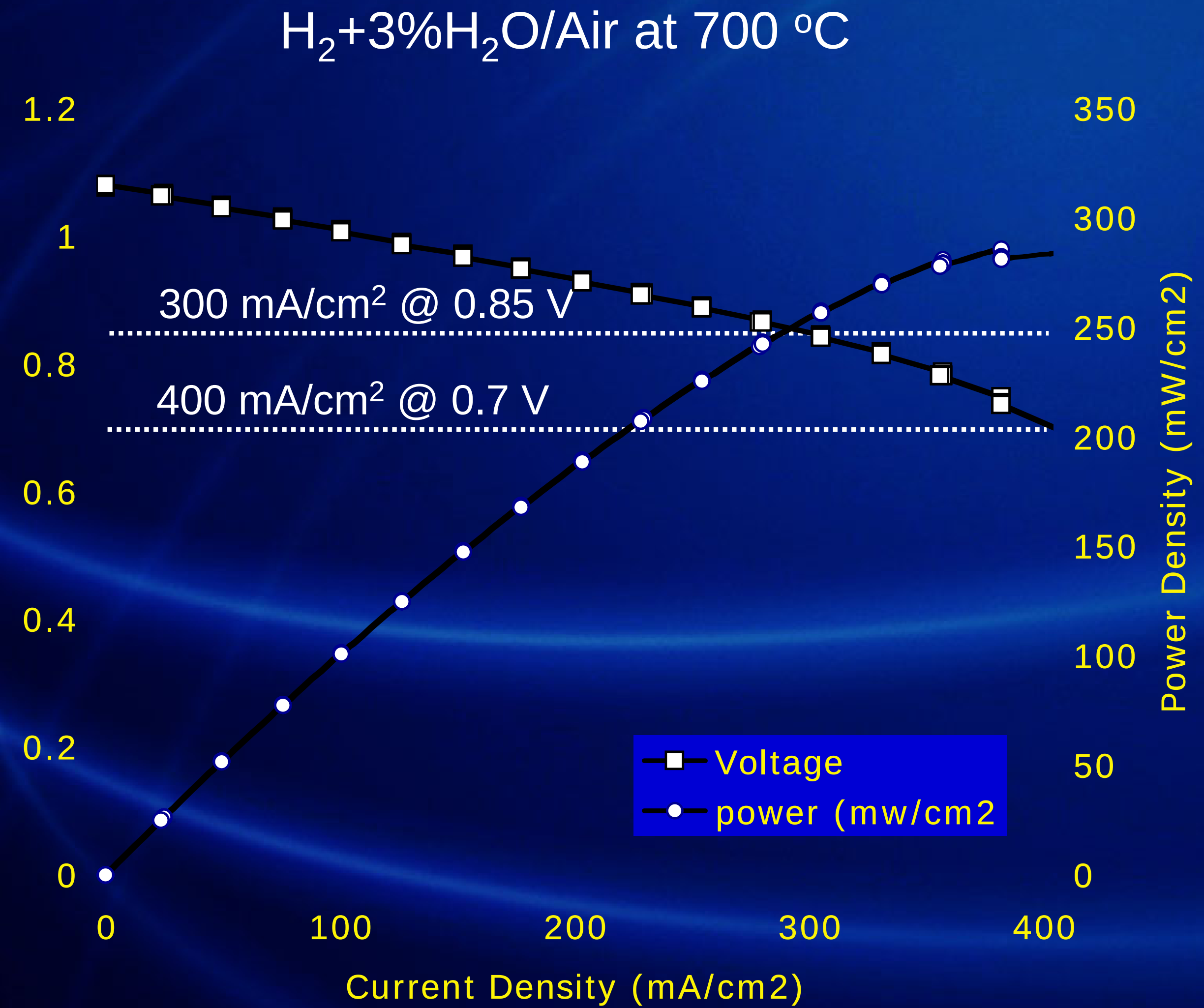
Leak rates of samples at 973 K



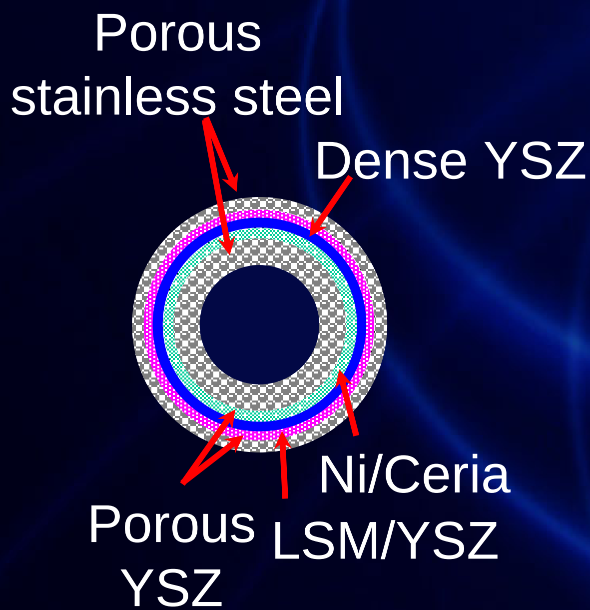
Leak rate of 904 cement at 973 K during cycle test

Metal Supported Tubular SOFC w/Infiltrated Electrodes





Metal Supported vs. Ceramic SOFCs



Summary

- SOFC Applications
  - Degradation rates of cells/stacks continue to decrease but further work is needed for stationary power applications
  - Transportation is near term but issues with thermal cycling must be addressed.
  - Feedback on failure mechanisms in stacks is needed
- Corrosion
  - The SOFC community is accumulating the necessary knowledge and understanding
  - More work on long term oxidation (effect of Si, etc) is needed
  - Basic research on interdiffusion, effects of g.b. etc is needed
- Protection
  - Coatings appear to resolve many issues with interconnect, if they can be cost effective

Team:

Investigators:

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Lutgard De Jonghe	Co-PI

Scientists:

Peggy Hou	High temperature corrosion
Velimir Radmilovic	NCEM FIB/SEM/TEM

Post Doc:

Hideto Kurokawa	Cr transport phenomena
Ken Lux	Air electrode stability

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Mike Tucker	Metal supported SOFC development
Grace Lau	Processing and analysis
Inna Belogolovsky	Processing and testing

Graduate Students:

Tal Sholklapper	Nano-particulate catalysts
Liming Yang	Novel anode catalysts
Xuan Chen	Infiltration of cathode catalysts

Acknowledgements

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•Thanks to Lane Wilson for helpful discussions on Cr issues and model stack construction