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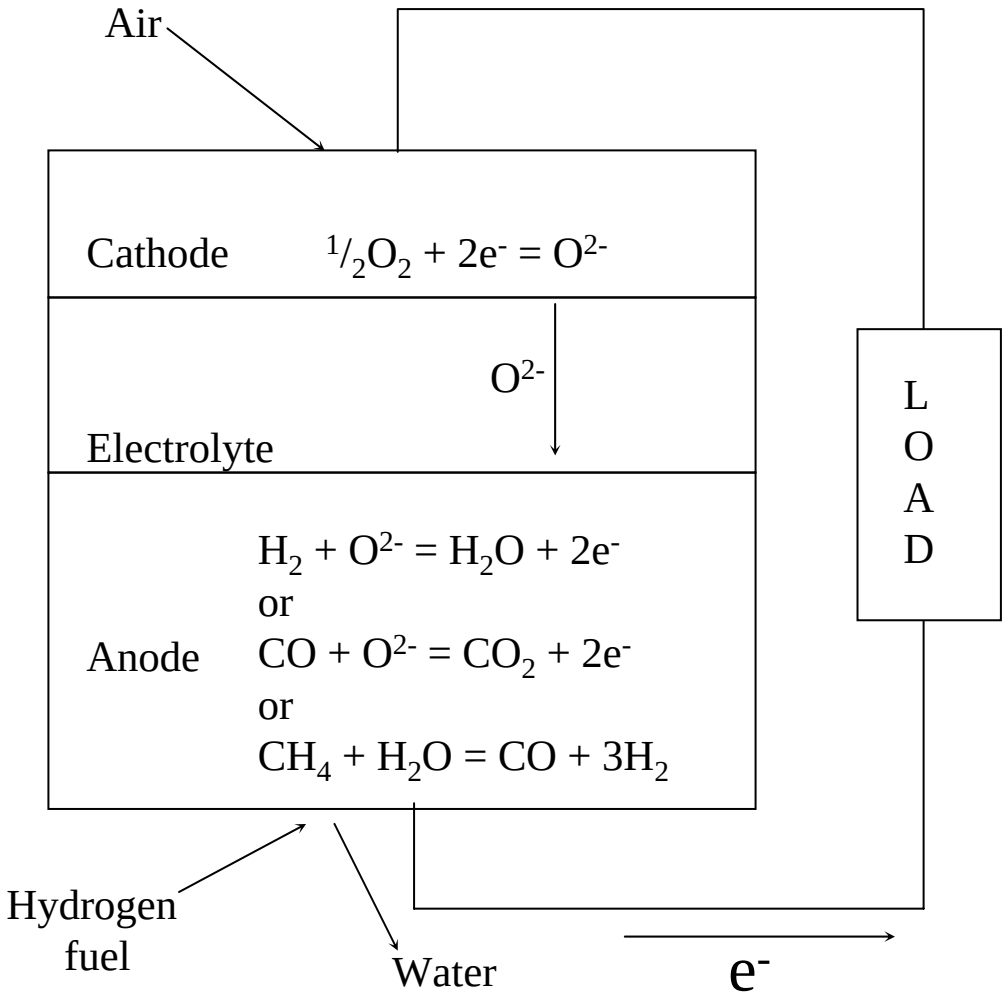
Material Interconnect Development

01/28/2005

Solid Oxide Fuel Cell (SOFC)



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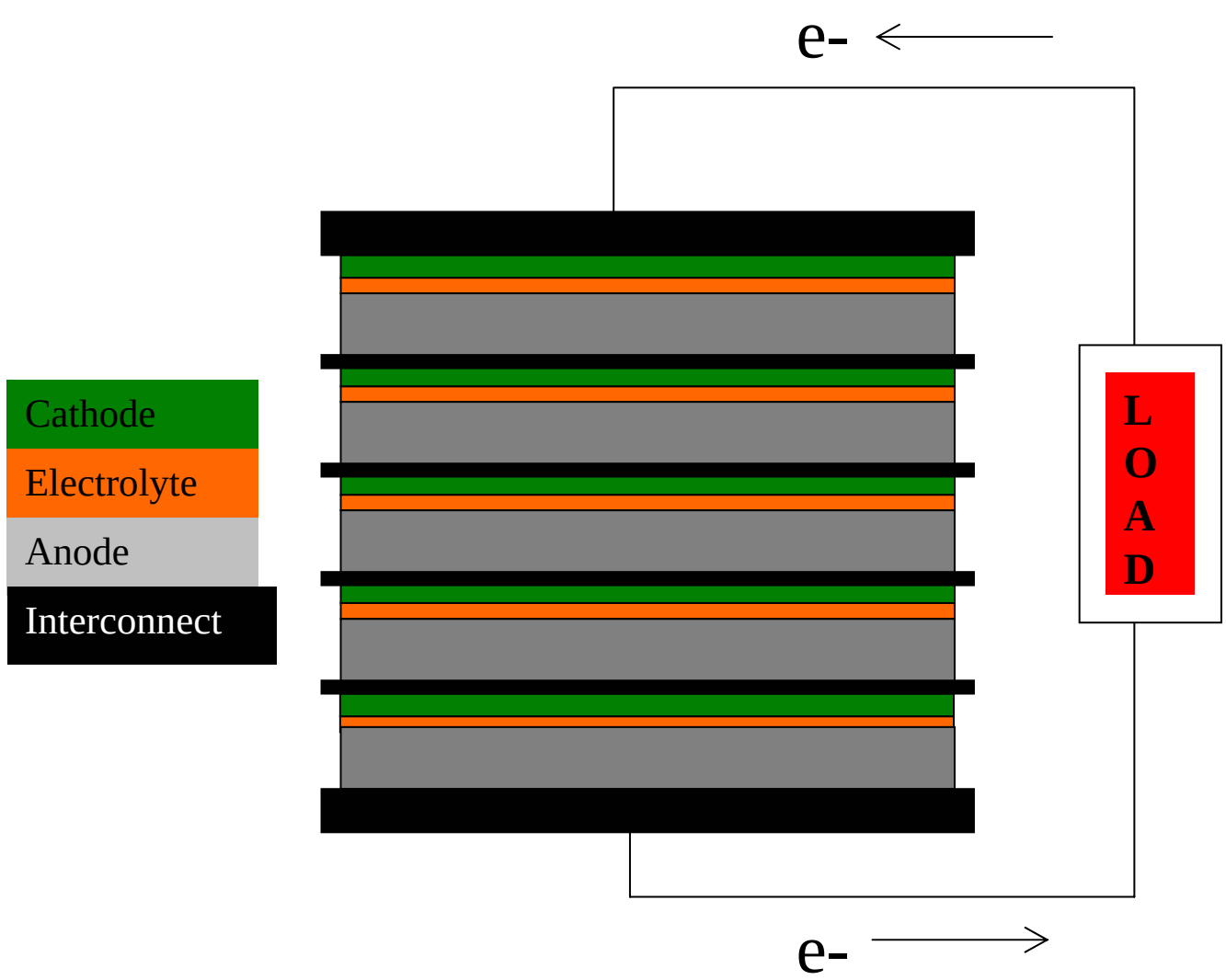
The Interconnect of an SOFC Stack

Electrically and physically connects adjacent fuel cells in an SOFC stack in electrical series.

Separates the cathode and anode gases.



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Requirements for Metallic Interconnects

1. Excellent **electrical conductivity** in both air and fuel
2. **Oxidation resistant** in both air and fuel
3. **Impermeable** to both air and fuel
4. **Chemically compatible** with sealing material and fuel cells
5. Strong **oxide scale adherence** during thermal cycling
6. Thermal expansion mismatch **(CTE)**

    Compressive sealing – can use materials without a CTE match.

    Glass sealing – must match CTE of the fuel cell components.

Delphi Interconnect Requirements

- **Stationary Application**
  - 40,000 hours
  - 100 thermal cycles
  - Accommodate thermal cycling 25^{o}C to 750^{o}C
- **Transportation Application**
  - 10,000 hours
  - 7000 thermal cycles
  - Accommodate thermal cycling 25^{o}C to 750^{o}C
- **High volume manufacturing**
- **Compatible with glass sealing technology**
- **Inexpensive**
  - less than $1.00/part (including manufacturing and materials)

Experimental Setup

- **The oxidation kinetics of several ferritic stainless steel alloys including**
  - 439, 430Ti, Crofer 22, 444, 409, Sumitomo Alloy and 434
  - and an austenitic SS 302.

  were investigated for comparison with
  - Inconel 718 and Haynes 230.

  for use as interconnect materials.
- **Due to possible Cr contamination issues with Delphi's cathode, a coating process and composition was investigated.**
  - Can the coating stop the diffusion of Cr from the substrate to the surface? Hence, preventing the vaporization of Cr at the metal/gas surface.
- **Does the coating adversely affect the electrical conductivity of the interconnect? If so how much?**

Experimental work

- **The oxidation kinetics of the alloys were at 750^{o}C in air and in wet hydrogen.**
- **Coupon samples were coated with LSC, a Mn-Cr spinel or Ag.**
- **Two different coating processes P1 and P2 were used.**
- **The oxidation kinetics of the coated samples were determined at 750^{o}C in air.**
- **The electrical resistance of the coated and uncoated samples in air were determined.**
- **The coated samples after oxidation for 500 hours in air were analyzed with EDS to determine the presence of Cr in the coating.**

Oxidation Kinetics in Air and Wet Hydrogen Uncoated Alloys

	Comparison of Parabolic Rate Constants k_g (thermogravimetry) 750 °C		
	Alloy	Air **g^2/cm^4-hour**	N_2-H_2-H_2O **g^2/cm^4-hour**
	302SS	1.29×10^{-12}	6.00×10^{-10}
	430Ti	5.42×10^{-13}	9.17×10^{-10}
	439	2.37×10^{-12}	-----
Lowest	Haynes 230	1.23×10^{-13}	2.87×10^{-10}
	434	1.58×10^{-12}	-----
Highest	Crofer 22	3.72×10^{-12}	2.20×10^{-09}
	Sumitomo	1.11×10^{-12}	-----
	718	5.75×10^{-13}	1.50×10^{-09}
	444	7.57×10^{-13}	-----
	625	1.54×10^{-13}	-----
	409	-----	-----

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Oxidation Kinetics of Coated Samples

Comparison of Parabolic Rate Constants coated samples (thermogravimetry) Air 750°C	
Alloy	**g^2/cm^4-hour**
Sumitomo - LSC - P2	4.83×10^{-9}
Sumitomo - silver - P1	5.96×10^{-9}
718 - LSC - P2	1.28×10^{-9}
Highest 718 – silver – P1	1.48×10^{-08}
H230 - silver - P2	1.14×10^{-9}
Lowest H230 – Mn,Cr,O – P2	7.20×10^{-10}
430Ti - LSC - P1	3.46×10^{-10}
430Ti - Mn,Cr,O, - P2	1.15×10^{-9}
302SS - LSC - P1	5.98×10^{-10}
302SS - Mn,Cr,O - P2	1.99×10^{-9}
Crofer 22 - Mn,Cr,O - P1	2.56×10^{-9}
Crofer 22 - silver - P2	1.10×10^{-8}

Ag-coated samples showed severe loss of silver after oxidation.

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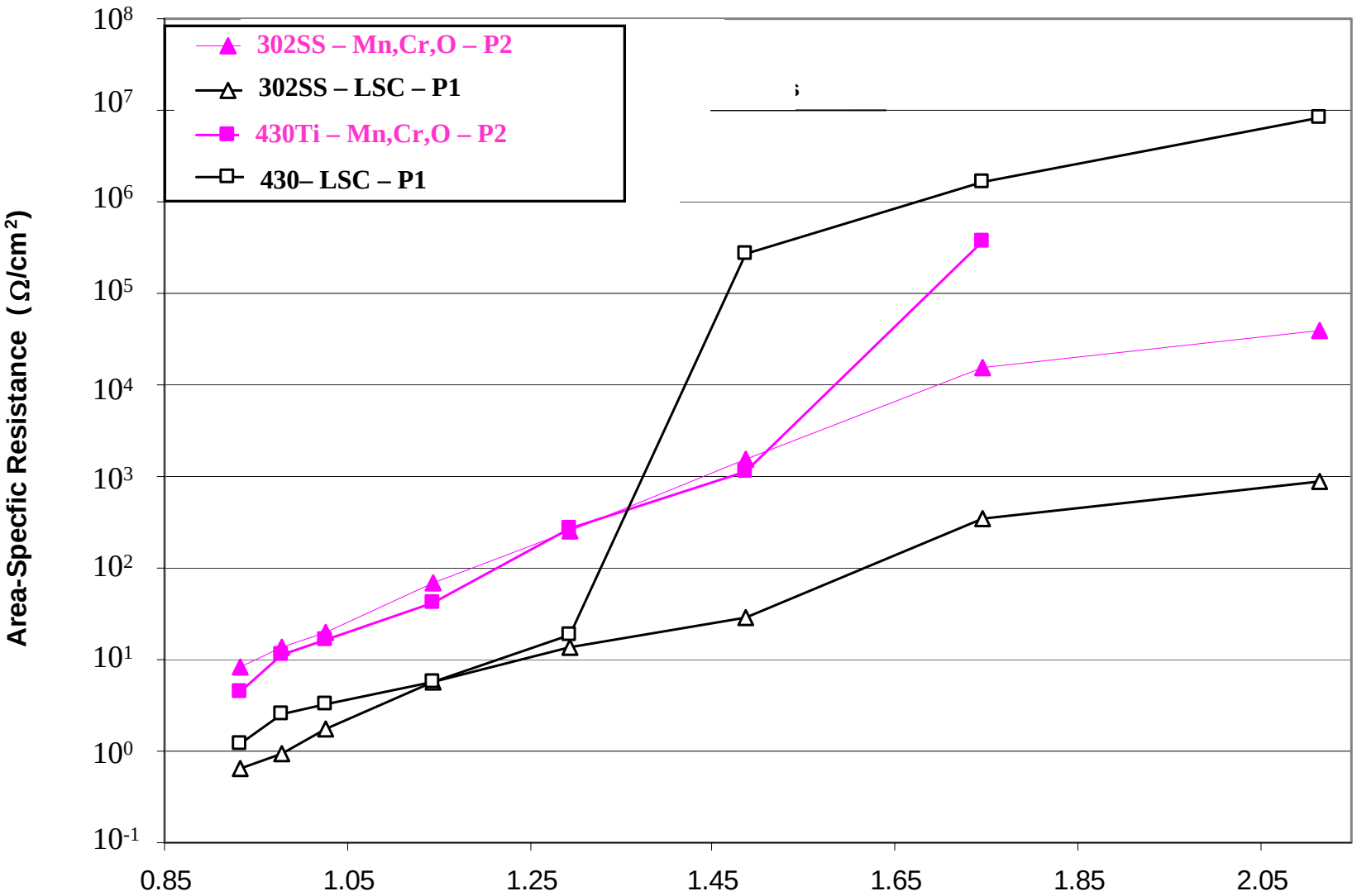
Area Specific Resistance
(Samples were oxidized for 500 hours in air)



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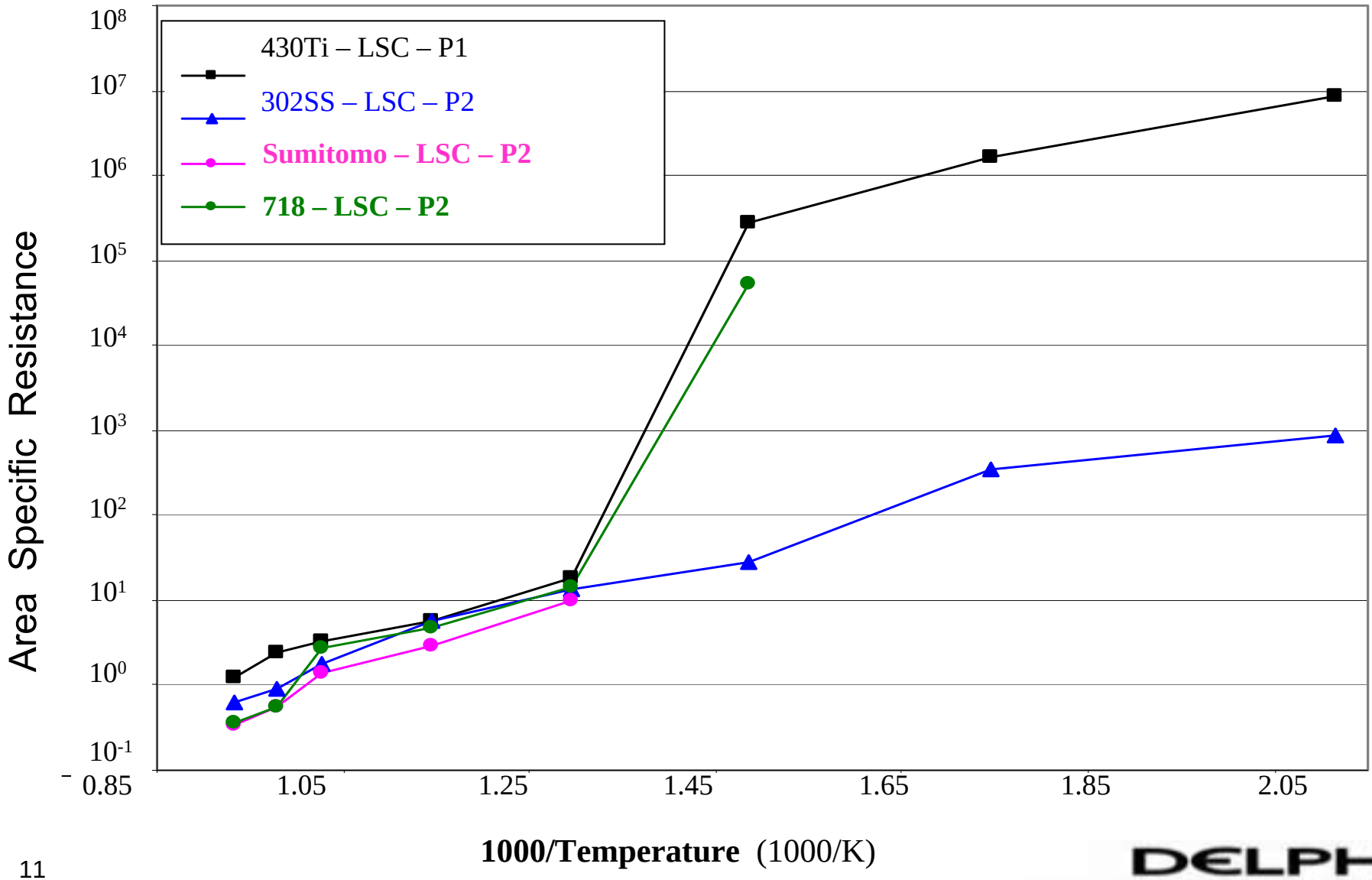
Area Specific Resistance (Ω/cm^2)

(samples were oxidized for 500 hours in air)



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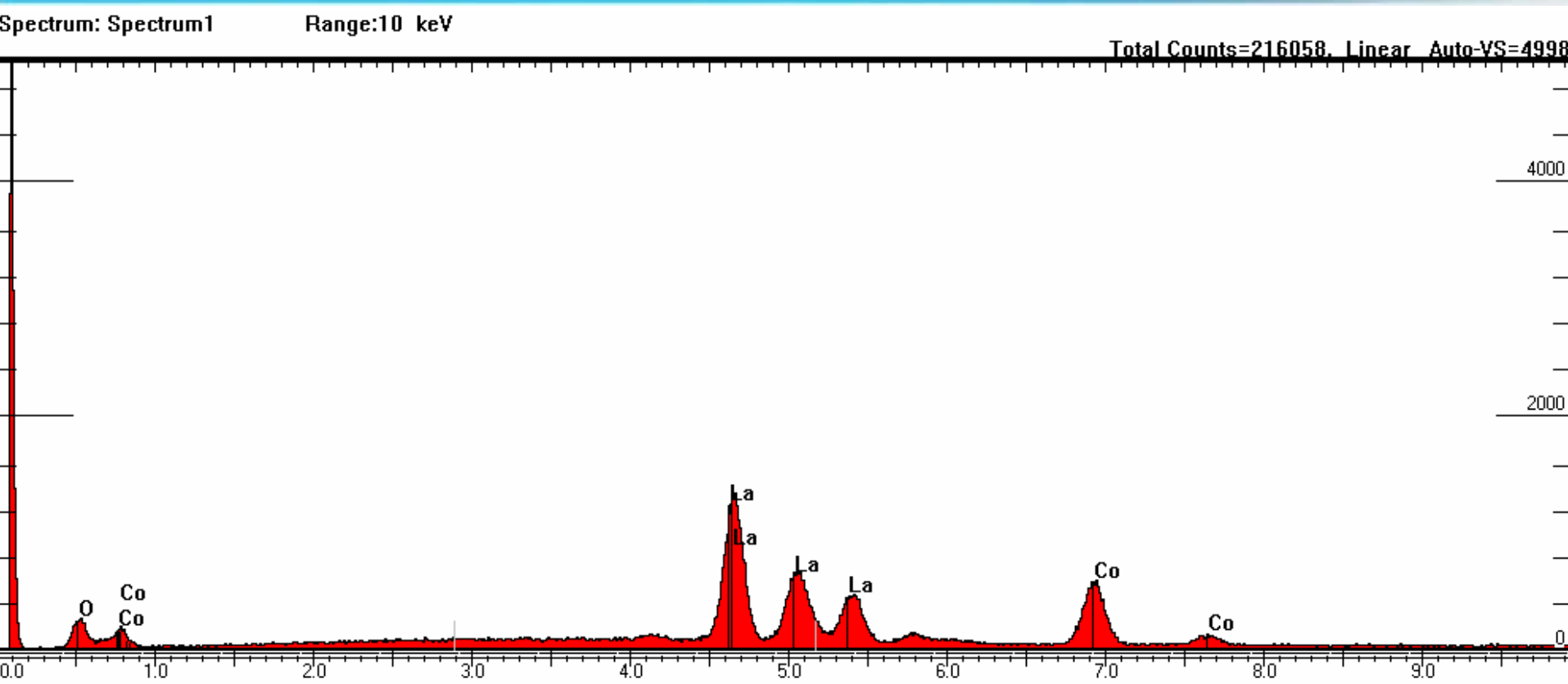
LSC-Coated 718 with P2 Coating Process



The Energy Dispersive Spectrum, EDS of the LSC-coated, P2 , Inconel 718 sample after 500 hours of oxidation at 750^{o}C in air. No Cr was detected in this sample.

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Cr Diffusion Through the Coating

- **Sumitomo alloy**
  - showed significant amounts of Cr in the EDS analysis after 500 hours of oxidation in air.
  - regardless of coating composition or process.
- **430Ti alloy**
  - showed significant amounts of Cr in the EDS analysis after 500 hours of oxidation in air.
  - regardless of coating composition or process.
- **718 alloy with the LSC coating using the P2 process**
  - no Cr was detected in the coating after 500 hours of oxidation in air.
- **H230 alloy was also coated with LSC using the P2 process**
  - no Cr was detected in the coating after 500 hours of oxidation in air.

The Material Issue

Ferritic SS

- Advantages
  - » CTE match to fuel cell components
  - » Can be used with glass sealing systems
  - » Cheaper than Ni-based superalloys
- Disadvantages
  - » Oxidation kinetics are too fast above 650 ^{o}C.
  - » Vaporization of Cr.
  - » Severe spalling of oxide scale
  - » Cr diffused through all coatings

Ni-Based Superalloys

- Advantages
  - » Slower oxidation kinetics
  - » More stable oxide scales
  - » Less spalling of oxide scale
  - » Cr was hindered using an LSC coating and a coating process
- Disadvantages
  - » CTE mismatch is too great for use of glass sealing
  - » More expensive than SS counterparts.

Austenitic SS

- Advantages
  - » Less spalling of oxide scale from substrate
  - » Comparable cost to ferritic SS.
- Disadvantages
  - » CTE mismatch is too great for use of glass sealing
  - » Cr diffused through all coatings

Summary

- The oxidation kinetics of ferritic stainless steels, austenitic stainless steels, and Ni-based superalloys were compared.
- A coating and a coating process were developed at Delphi which hindered the diffusion of Cr through the coating to the surface.
- The prevention of Cr diffusion to the coating/gas surface will prevent the vaporization of the Cr.
- The coating process was as important to the success of the coating as the coating material.
- The diffusion of Cr from the Ni-based superalloys is far less than that from the ferritic and austenitic stainless steels.
- This work allowed the creation of new interconnect designs for an SOFC stack.

- **Future work**
  - **Determine length of time at temperature that Cr diffusion is hindered.**
  - **Determine the resistance increase over longer time periods between the coated and the uncoated samples.**