Chromium Vapor Sensor for Monitoring Solid Oxide Fuel Cell Systems

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Outline

- Project Team Introduction/Description
- Background
- Technical approach
- Project objective
- Project structure
- Project schedule
- Project budget
- Risk Management
- Technology Readiness Level (TRL)

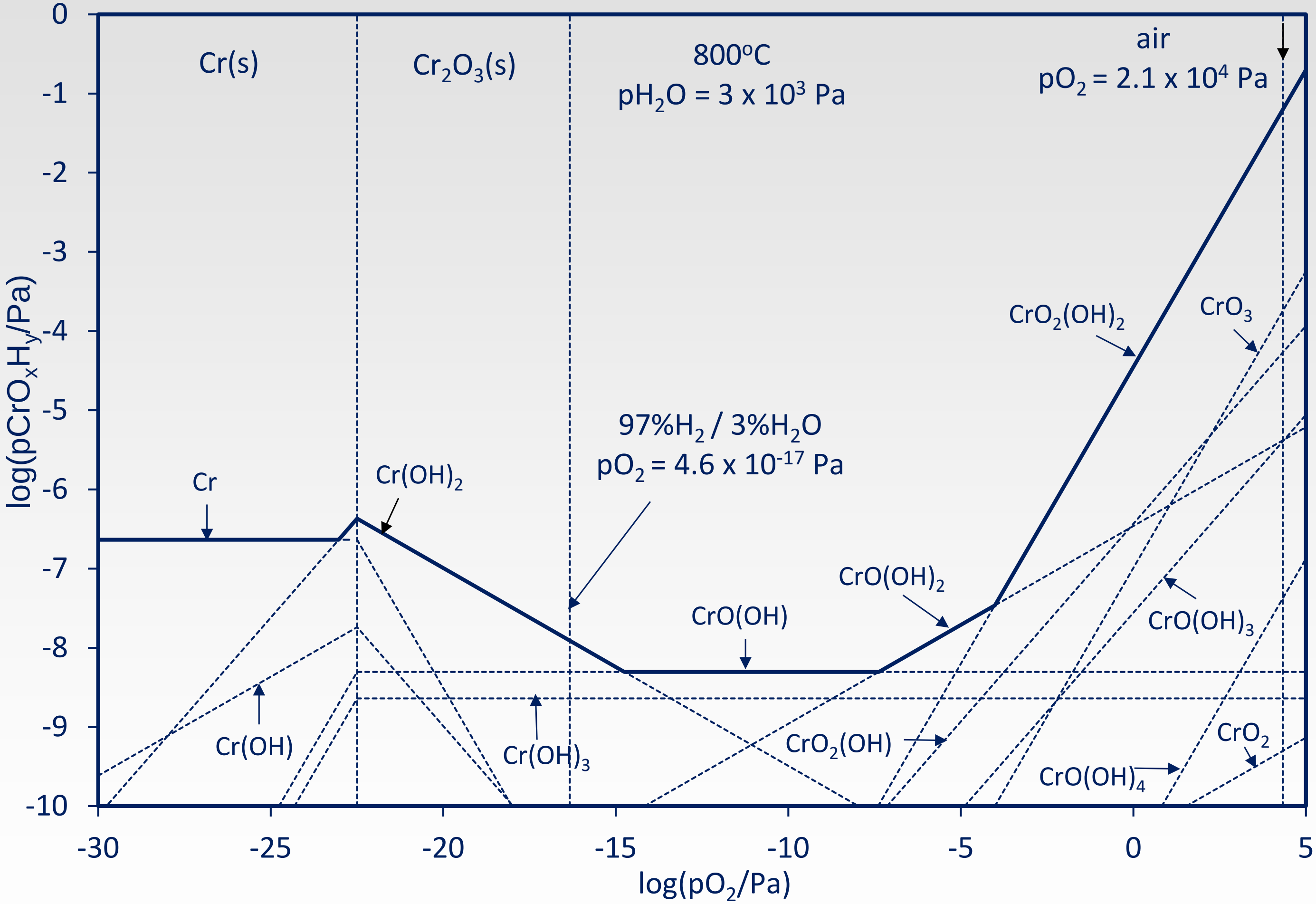
Project Team

- Phase I
  - PI: Jeffrey Fergus
  - Graduate student: Moaiz Shahzad
  - Undergraduate student: TBD
- Phase II
  - Fuel Cell Energy, Hossein Ghezel-Ayagh
  - Naval Research Lab, Fritz Kub
  - University of Connecticut, Prabhakar Singh

Background

- Source of Chromium
  - Chromia formers used for interconnect due to high electronic conductivity of Cr_2O_3 relative to Al_2O_3 and SiO_2
  - Oxidation of chromia scale (interconnect or balance of plant)
- Chromium Deposition
  - Cr^{6+} reduced to Cr^{3+} (*i.e.* Cr_2O_3) on cathode

Cr-O-H Vapor Pressures



Vapor pressures higher in oxidizing conditions

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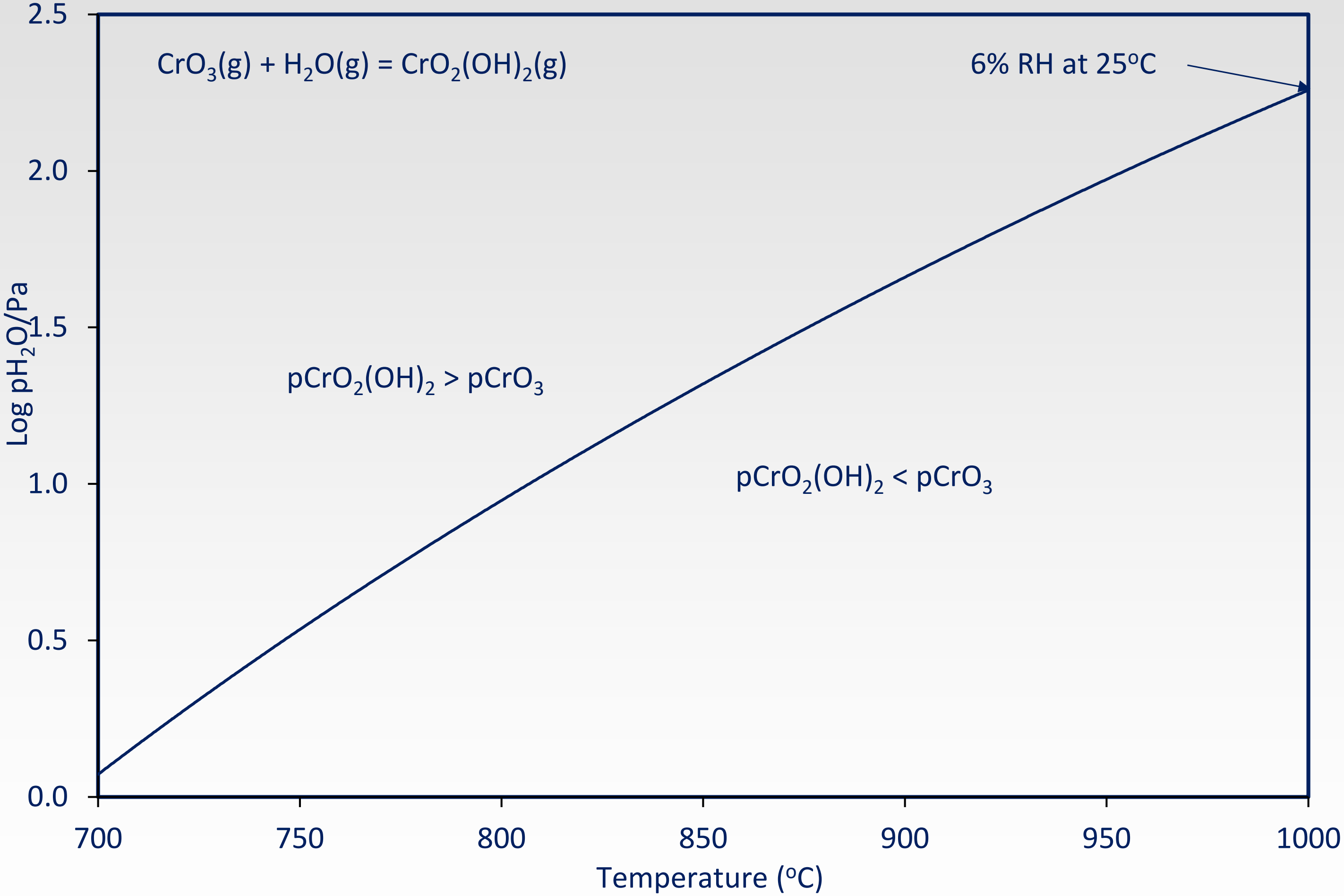
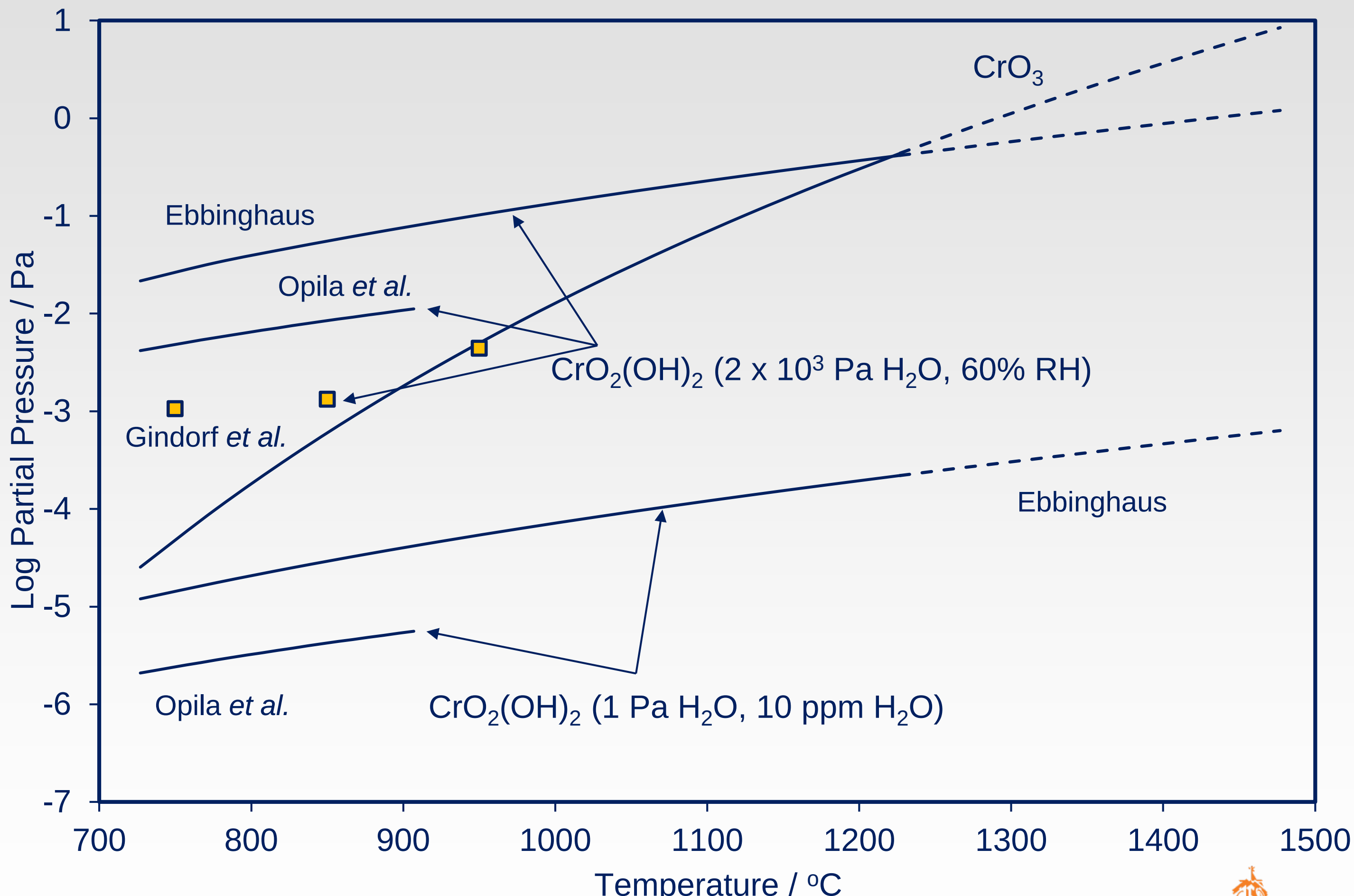
Stability of CrO_3 / $CrO_2(OH)_2$



$CrO_2(OH)_2$ predominant even in relatively dry conditions

Vapor Pressure of CrO_3 / $CrO_2(OH)_2$

Vapor pressure of $CrO_2(OH)_2$ high at relatively low temperatures



Objective

- Phase I
  - To design, fabricate and test a chromium sensor for monitoring the chromium vapor produced during the operation of an SOFC
- Phase II
  - Evaluate the sensors in an operating fuel cell system in collaboration with FuelCell Energy
  - Evaluate sensor in chromium getter system developed at the University of Connecticut.
  - Develop of smaller sensors based on thin-film deposition techniques will involve collaboration with the Naval Research Laboratory.

Technical Approach

- Potentiometric Chemical Sensors
  - Solid electrolyte based
  - Thermodynamic – not kinetic
    - Stable
    - Not microstructure dependent
- Auxiliary Electrode
  - Relate activity of target (Cr) to that of the mobile species (O^{2-} or Na^{+})
    - Cr / O^{2-}: $2Cr + 3O^{2-} = Cr_2O_3 + 6e^-$
    - Cr / Na^{+}: $5Cr + 3Na_2CrO_4 = 6Na^+ + 4Cr_2O_3 + 6e^-$

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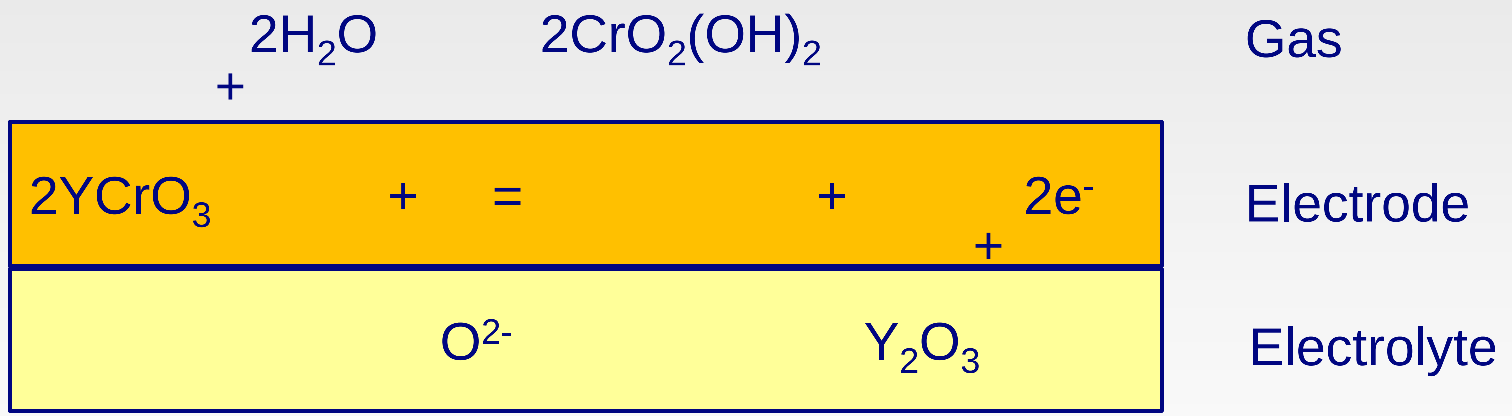
YSZ Auxiliary Electrode Reaction

$$2YCrO_3 + 2H_2O + O^{2-} = 2CrO_2(OH)_2 + Y_2O_3 + 2e^-$$



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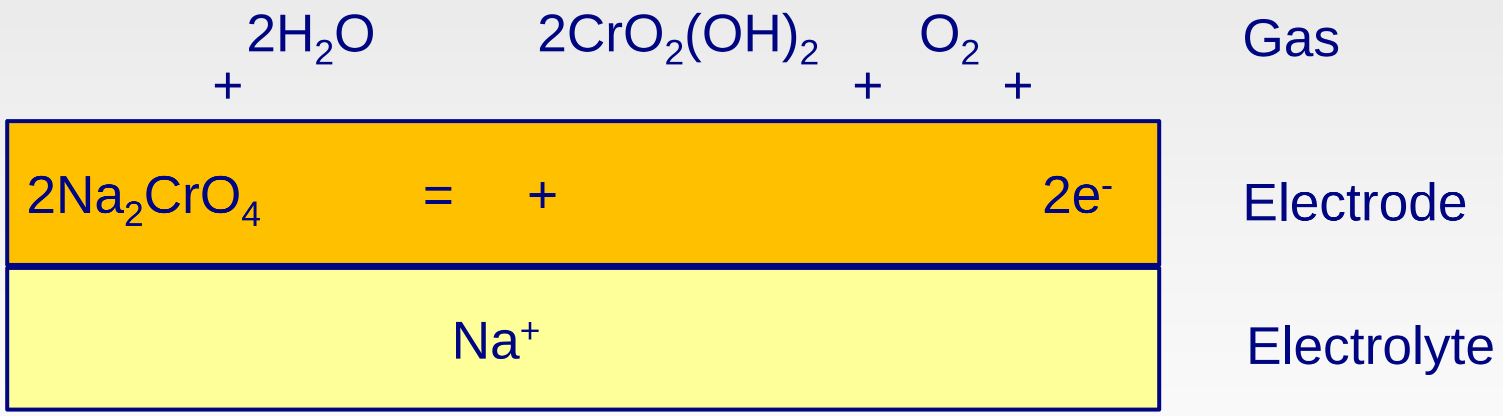
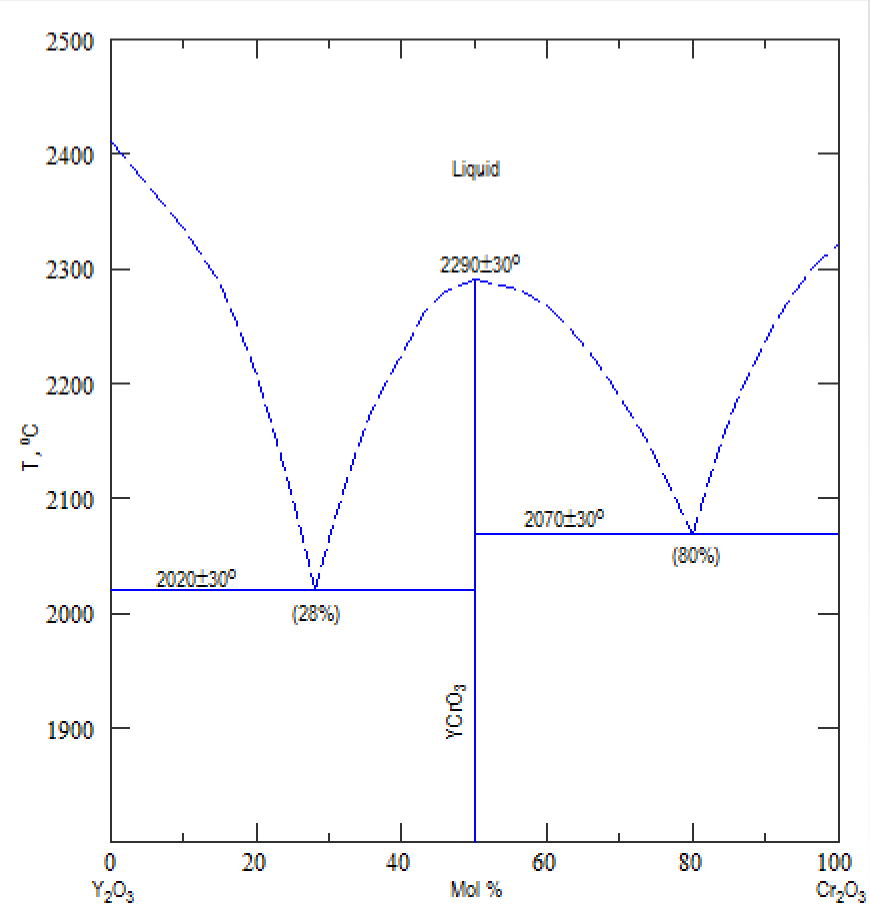
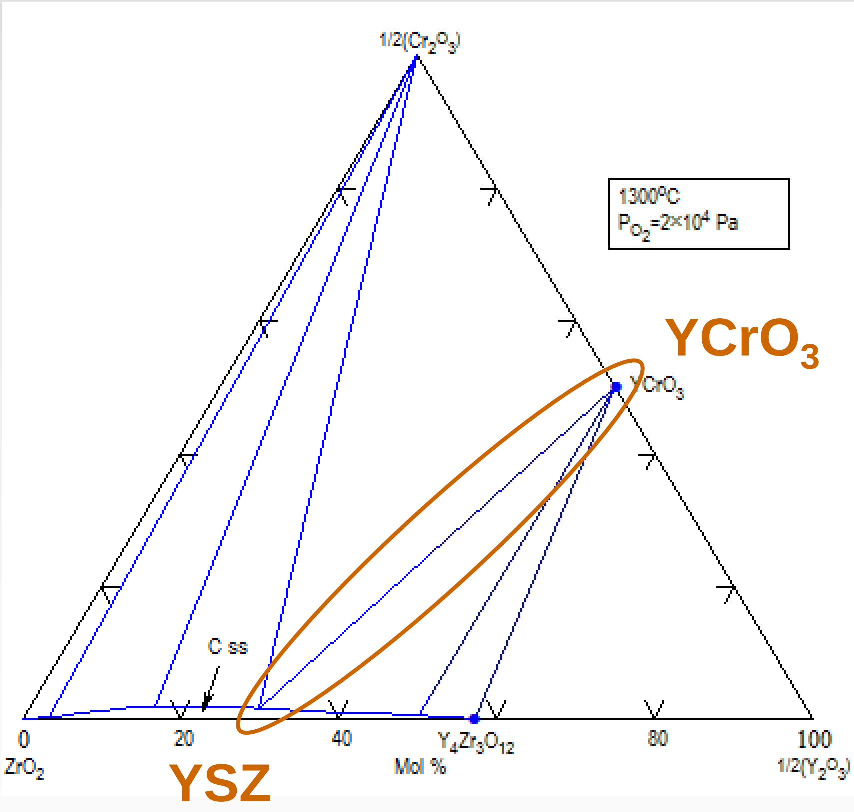
Beta Alumina Auxiliary Electrode Reaction

$$2Na_2CrO_4 + 2H_2O = 4Na^+ + 2CrO_2(OH)_2 + O_2 + 2e^-$$



Zr-Y-Cr-O Phase Equilibria

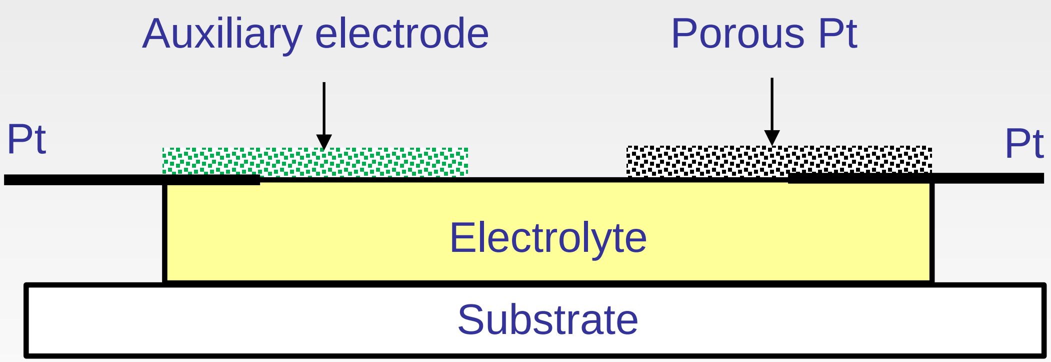




Sensor Schematic - Planar

$2YCrO_3 + 2H_2O + O^{2-} =$
$2CrO_2(OH)_2 + Y_2O_3 + 2e^-$

$O^{2-} = O_2 + 2e^-$



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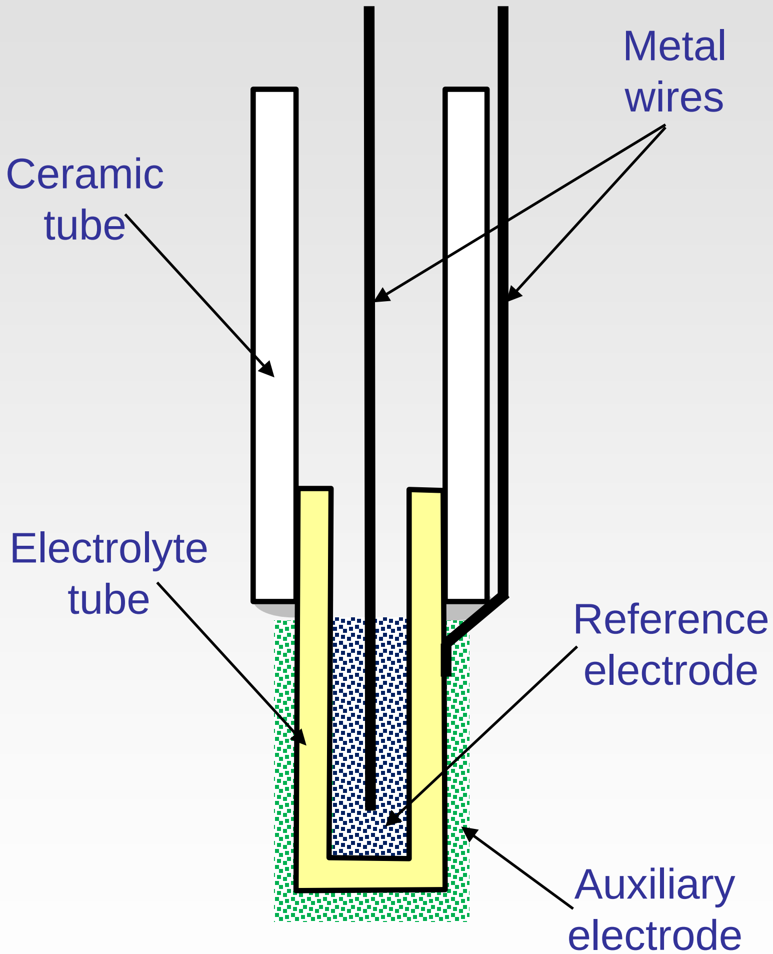
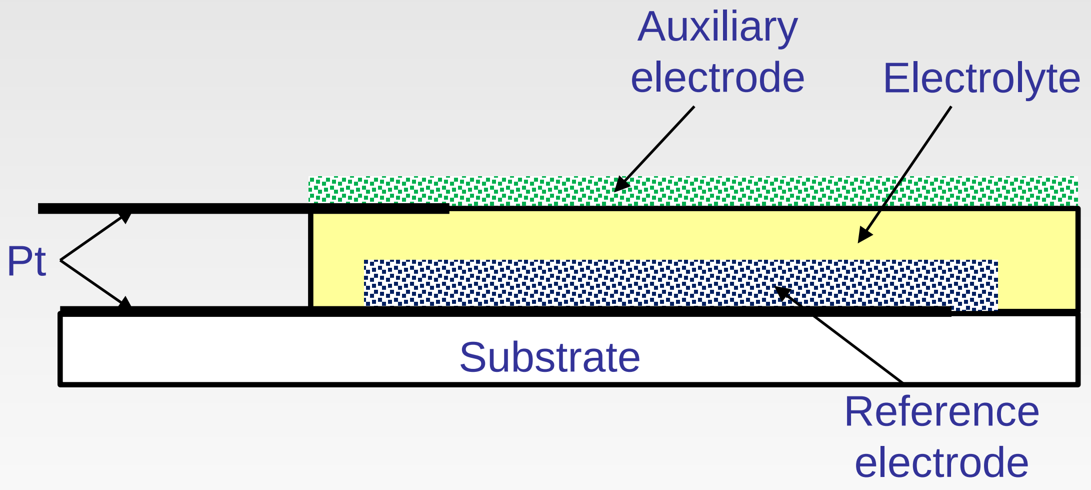
Sensor Schematic - Tubular



Sensor Schematic – Thin Film (Phase II)



Structure – Phase I

- Development of Chromium Sensor
  - Solid electrolytes
    - Yttria-stabilized zirconia
    - Beta” alumina
  - Electrodes
    - Pt
    - $YCrO_3$
    - $Na_2Cr_2O_4$
  - Geometries
    - Tubular
    - Planar

Structure – Phase II

- Evaluation in SOFC System
  - Fuel Cell Energy
- Integration into chromium capture system
  - University of Connecticut
- Miniaturization using thin films
  - Naval Research Lab

Schedule

Activity	2016			2017												2018		
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2 YSZ based planar sensor																		
2.1 Auxiliary electrode	■	■																
2.2 Planar cell			■	■	■	■												
3 YSZ based tubular sensor																		
3.1 Reference electrode							■	■										
3.2 Tubular cell									■	■	■	■						
4 Beta alumina -based sensor																		
4.1 Auxiliary electrode													■	■				
4.2 Reference electrode															■			
4.3 Tubular cell																■	■	■
1 Demonstrate planar sensor with YSZ electrolyte																		
2 Demonstrate tubular sensor with YSZ electrolyte																		
3 Demonstrate tubular sensor with beta alumina electrolyte																		

Risk Management

- Suitability for application – low risk
  - Solid electrolyte sensors have been demonstrated in aggressive environments
    - Oxygen dissolved in molten steel
    - Oxygen in exhaust gas
- Selective response to chromium – higher risk
  - Reactions involve O_2 / H_2O
  - Mitigation
    - Screen auxiliary electrodes for any chromium response
    - Evaluate oxygen and sodium ion conductors

Technology Readiness Level

- Design similar to commercially available sensors
  - Oxygen sensor for molten steel
  - Automotive exhaust gas sensor
- Collaboration with company will be needed for scale up of fabrication and commercialization

Questions, Comments, Suggestions?