BOSTON UNIVERSITY

Processing of SOFC Anodes for Enhanced Intermediate Temperature Catalytic Activity at High Fuel Utilization

Boston University – FE0026096

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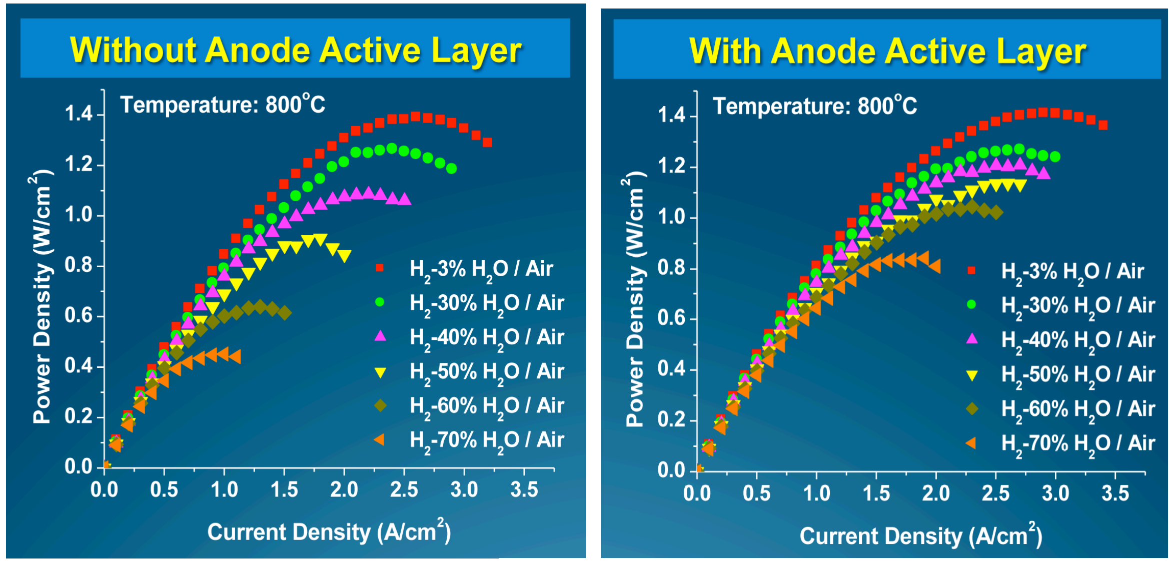
Presentation Outline

- Background/Literature
- Technical Approach
- Project Objective
- Project Structure (Tasks)
- Project Schedule
- Project Budget
- Project/Risk Management Plan

Project Background

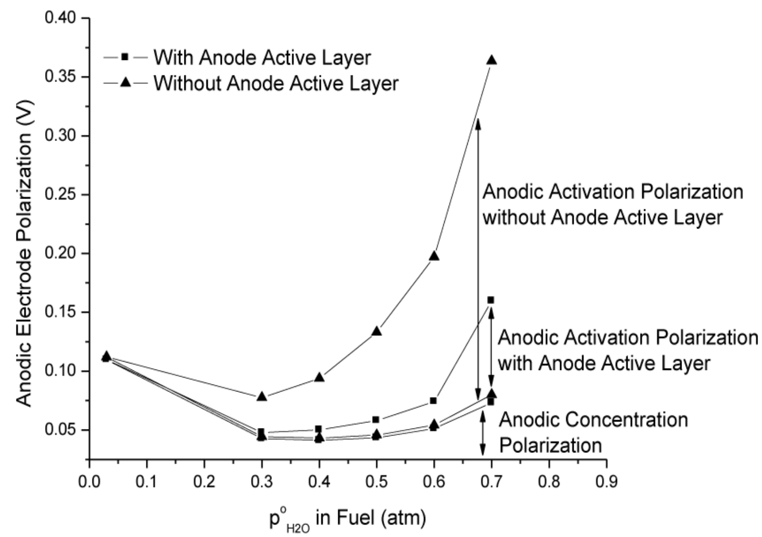
a) Reduction of power density with fuel utilization. b) Effect of refining anode microstructure.

Yoon et. al, 2008, JES



- **Existing SOFC anodes exhibit significant loss in performance at high fuel utilizations - *SOFCs need to be operated at high fuel utilizations for to compete with other energy sources***
- **Increasing triple-phase boundary by including an anode active layer improved performance at high fuel utilization**

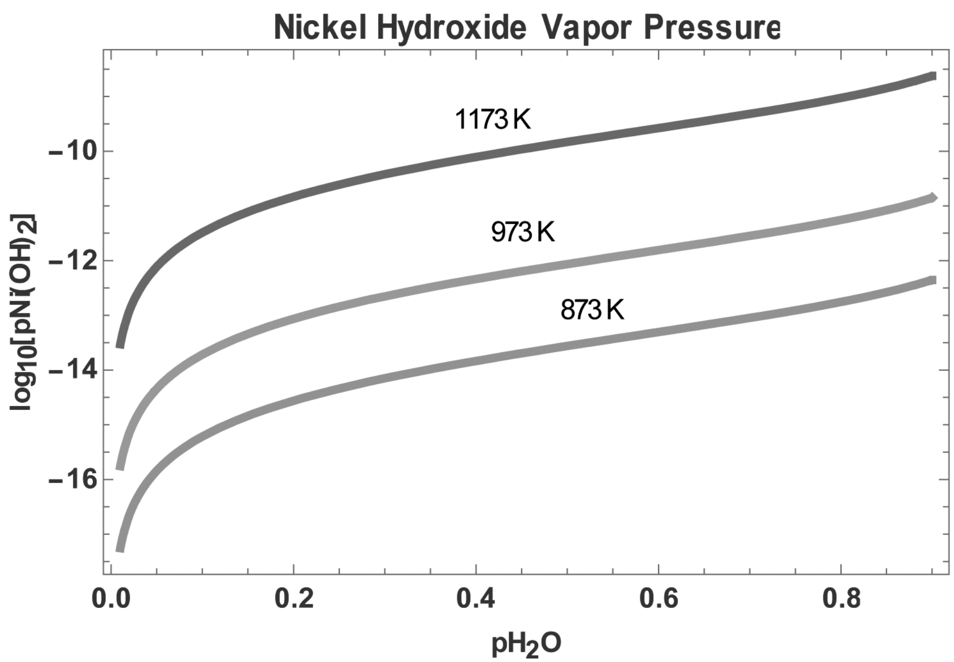
Yoon et. al, 2009, JES



Anodic electrode polarizations of the SOFC button cells with and without the anode active layer at the current density of 1.5A/cm² as a function of the H_2O partial pressure in the fuel.

Project Background

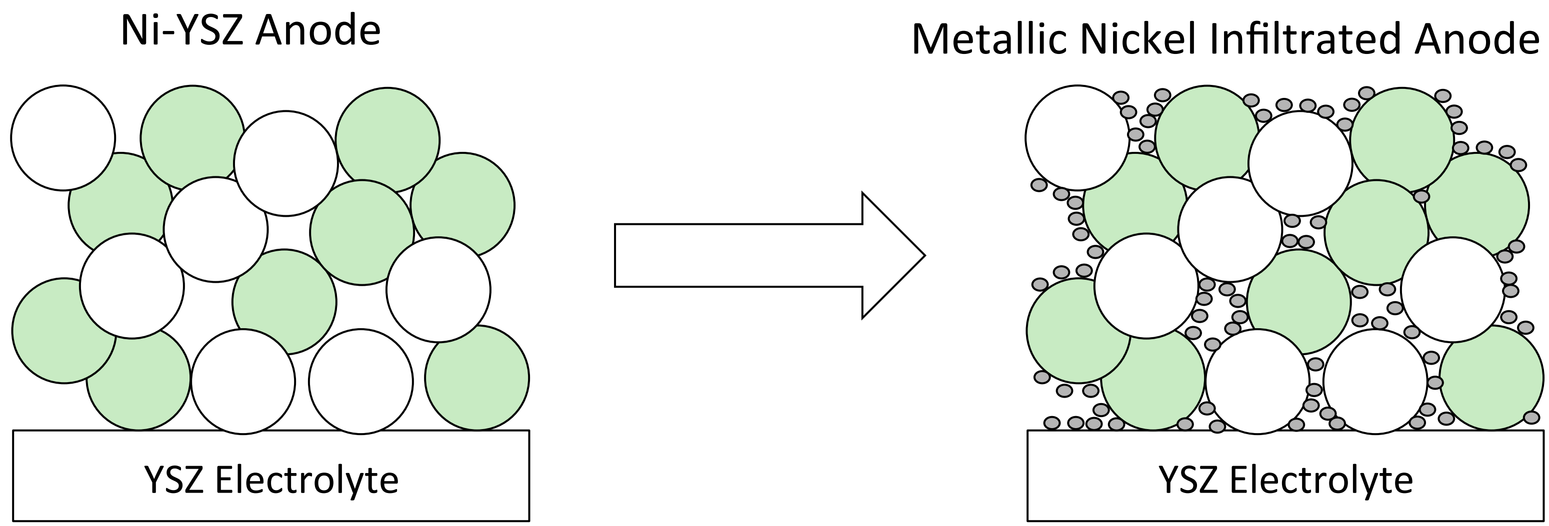
Another consequence of high fuel utilization: high pH_2O leading to Ni volatilization



Nickel hydroxide vapor pressure as a function of temperature and water vapor partial pressure in the atmosphere.

Technical Approach

- **Deposit 10-100 nm Ni catalyst particles by anode infiltration**



- **Quantitatively characterization of the microstructure: pore volume fraction and tortuosity, Ni coverage, Ni connectivity, and TPB length**
- **Quantify charge and mass transfer kinetics at the anode at intermediate temperatures.**
- **Model the relationship between polarization losses to the anode microstructure to optimize the anode microstructure based to produce SOFC cells with a 50% improvement in power density over a conventionally processed anode at high fuel utilization.**

At intermediate temperatures, fine Ni catalysts provides the advantages of decreased polarization resistance and increased power densities at high fuel utilization without the disadvantages of particle coarsening and propensity to form vapor phase $Ni(OH)_2$.

Project Objectives

1. **Depositing 10-100 nm Ni catalyst particles increases the TPB length by 1-2 orders of magnitude over the Ni formed by conventional sintering of YSZ/NiO leading to Ni particles of ~ 1 μm.**

2. **Optimize the anode microstructure based on quantitative microstructural characterization, polarization measurements and modeling, to produce SOFC cells that demonstrate a 50% improvement in cell performance at intermediate temperatures and at high fuel utilization rates over cells with conventionally anodes, and a 1W/cm^2 power density even at high fuel utilization rates (up to 85% water vapor) at intermediate temperatures.**

Project Structure

Task 1: Project Management and Planning

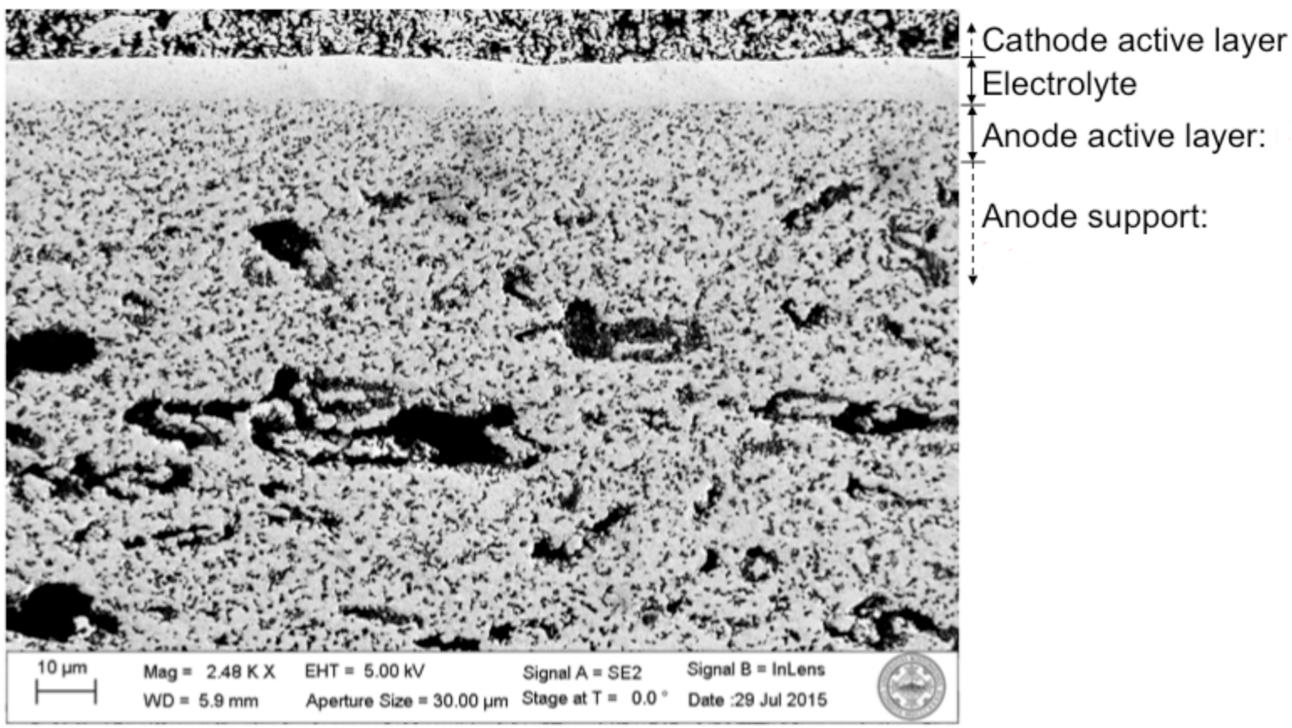
- The project management plan (PMP) will be updated at the very start of the project, based on negotiations with DOE and revised work scope if necessary
- Group meetings are held weekly at BU.
- An 'Anode Modification Research Dropbox' has been set up where critical experimental results will be shared with the entire group
- The weekly meetings will include a technical and financial summary that will be placed in the Dropbox

Project Structure

Task 2: Preparation/procurement of YSZ/Ni and YSZ anode scaffolds

Two types of anodic scaffolds will be used:

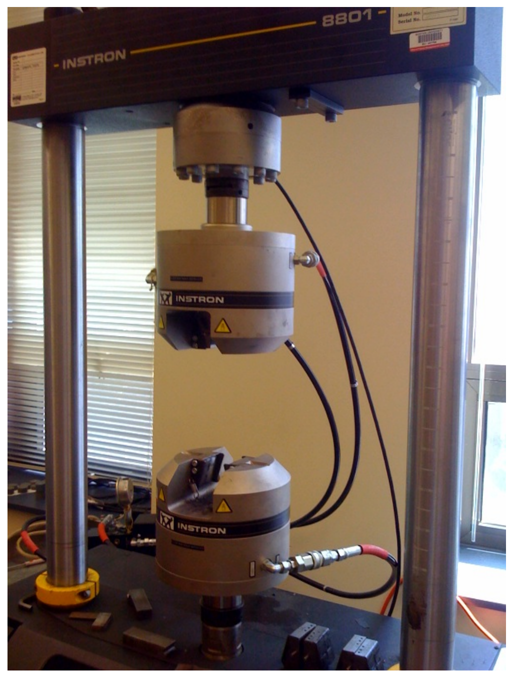
1. **Reduced YSZ/Ni anodes**
2. **Reduced and etched (to remove Ni) YSZ anodes**



Project Structure

Task 3: Mechanical property of anodic scaffolds

The fracture strength of a Ni-YSZ cermet is a function of porosity. The fracture strength of the YSZ scaffold after etching the Ni will be measured by three point bending in an INSTRON.



Project Structure

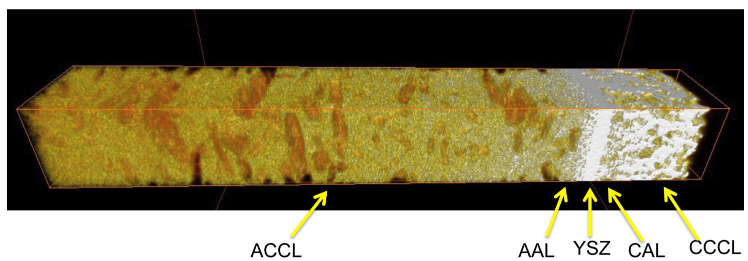
Task 4: Deposition of sub-micron nickel catalysts

Water and ethanol based $Ni(NO_3)_2$ solutions with appropriate surfactants will be explored at BU for infiltration under vacuum as a function of the number of infiltration steps and post infiltration heat treatment. The effectiveness will be characterized by SEM observations of fracture cross-sections, and by electrical conductivity measurements of the etched YSF scaffolds

Project Structure

Task 5: Characterization of anode microstructure

- **Micro-computed tomography (µCT) using a Xradia 520 Versa 3-D x-ray microscope to resolve pores 1 µm and larger in anode to estimate resistance to liquid penetration during liquid phase infiltration**



- **TEM studies of select FIB cross-sections of infiltrated anode will carried out to characterize the infiltrated Ni catalysts.**

Project Structure

Task 6: Measurement and modeling of anodic polarization losses

Measurement of anodic catalytic activity

- **Deposit same anode structure on both sides of a solid electrolyte**
- **Carry out impedance spectroscopy will be performed at different H_2/H_2O environments and temperatures to characterize the polarization losses, *R_p***
- **Due to symmetric cell geometry:**

$$\frac{R_p}{2} = \frac{RT}{2Fi_o} + \frac{RT}{2F} \cdot \frac{1}{i_{as}} \left(1 + \frac{p^o_{H2}}{p^o_{H2O}} \right)$$

- ***i_0* (exchange current density) is the measure of overall effective catalytic activity of the anode, and is an indicator of the effectiveness of the infiltrated Ni catalyst particles.**
- **To calculate *i_0*, *i_{as}* (anode saturation current density needs to be known)**
- **Since,**

$$i_{as} = \frac{2FD^{eff}_{H2-H2O}p^o_{H2(a)}}{RTl_a}$$

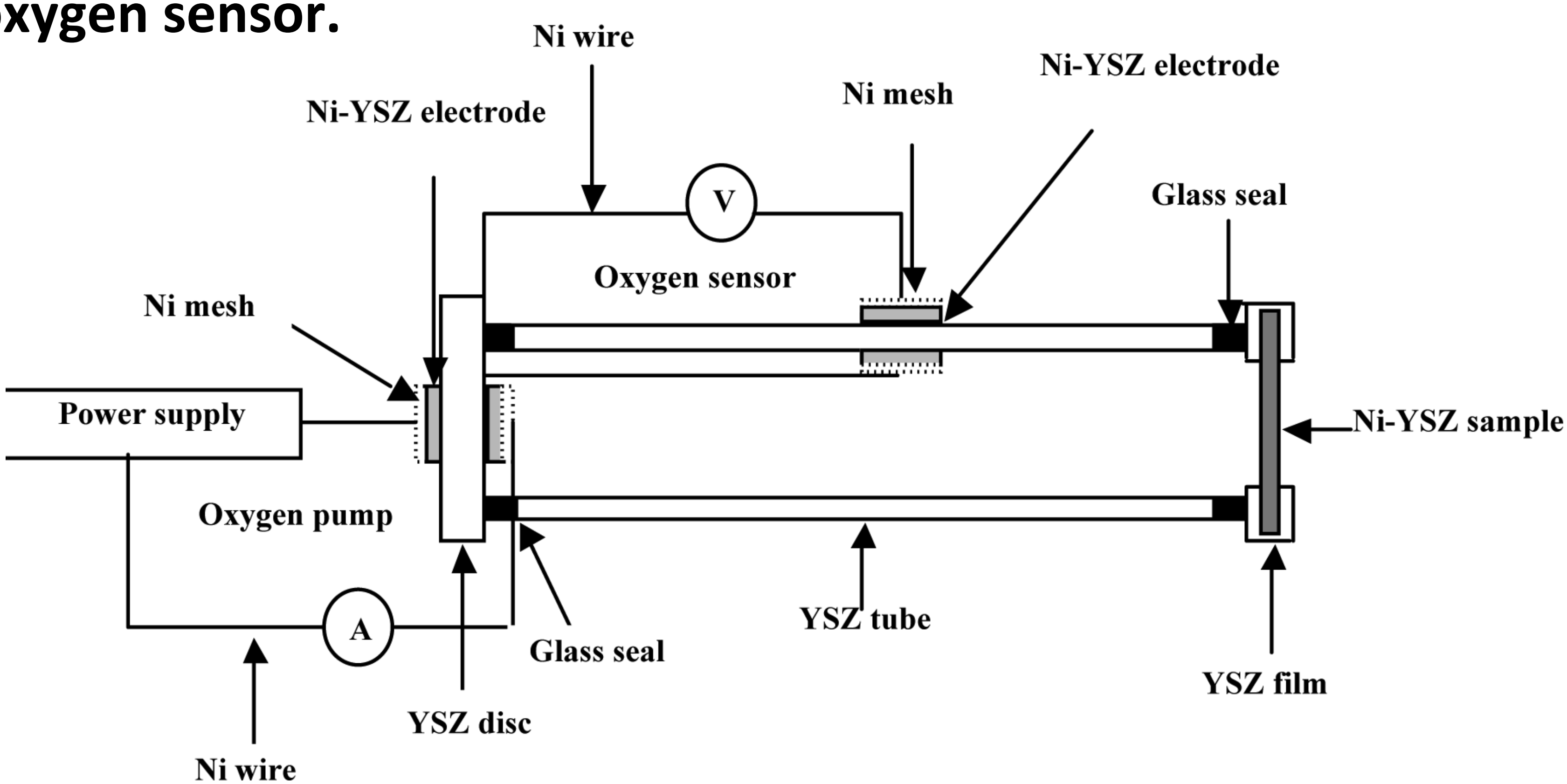
- **The effective diffusivity of the anode structure (D^{eff}_{H2-H2O}) needs to be measured.**

Project Structure

Task 6: Measurement and modeling of anodic polarization losses

Out of cell measurement of $D^{eff}_{H_2-H_2O}$

- **A YSZ chamber closed off by an oxygen pump on one side and the anode structure on the other. The YSZ chamber wall acts as an oxygen sensor.**

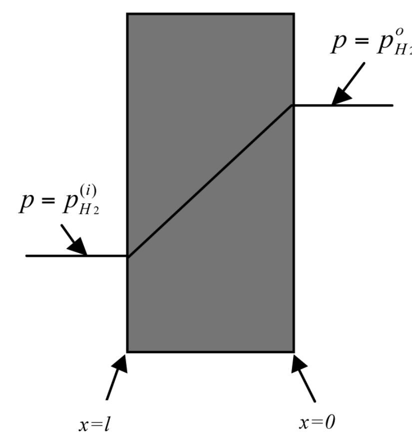


Project Structure

Task 6: Measurement and modeling of anodic polarization losses

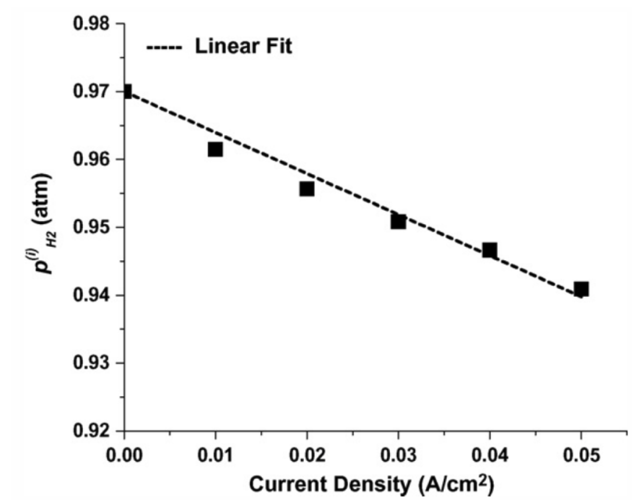
Out of cell measurement of D^{eff}_{H2-H2O}

- **After equilibration with a given H_2-H_2O atmosphere, oxygen at steady state will be electrically pumped through the YSZ disc into the chamber, decreasing the partial pressure of hydrogen and increasing the partial pressure of water vapor inside the chamber and establishing a partial pressure gradient across the anode sample.**



- **The steady state current (*i*) is :**
  $p^{(i)}_{H2} = p^{0}_{H2} – (RTl/2FD^{eff}_{H2\text{-}H2O})i$

- **The effective binary diffusivity can be calculated from a fit to a measured $p^{(i)}_{H2}$ versus *i* plot**



Project Structure

Task 7: Processing complete cells with optimized anodes

- **LSCF/GDC/YSZ/Ni-YSZ cells will be purchased, and the anodes will be infiltrated with Ni nano-catalysts under the optimal conditions for 600-800°C operation**

- **For high power densities at lower (intermediate) temperatures (600-750°C), LSCF/SDC[a]/ScDZ[b]/Ni-YSZ cells will be fabricated, and the anodes select cells will be infiltrated to form Ni nano-catalysts**

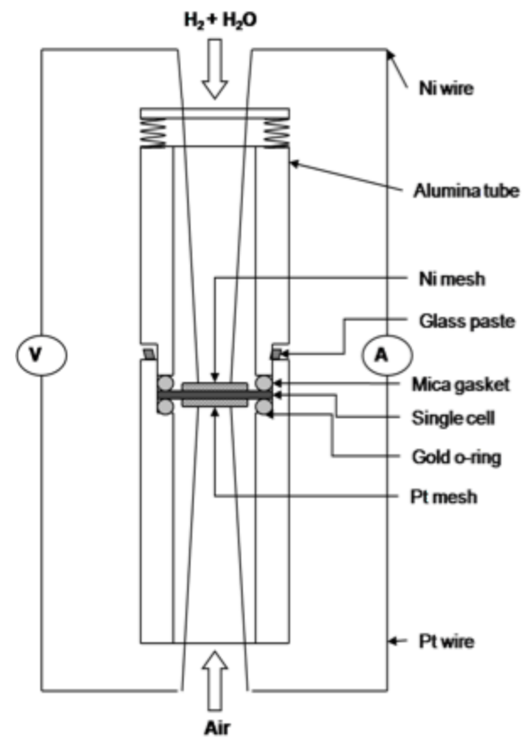
[a]Sm doped ceria, [b]Sc doped zirconia

Project Structure

Task 8: Demonstrating improved power density in optimized cells

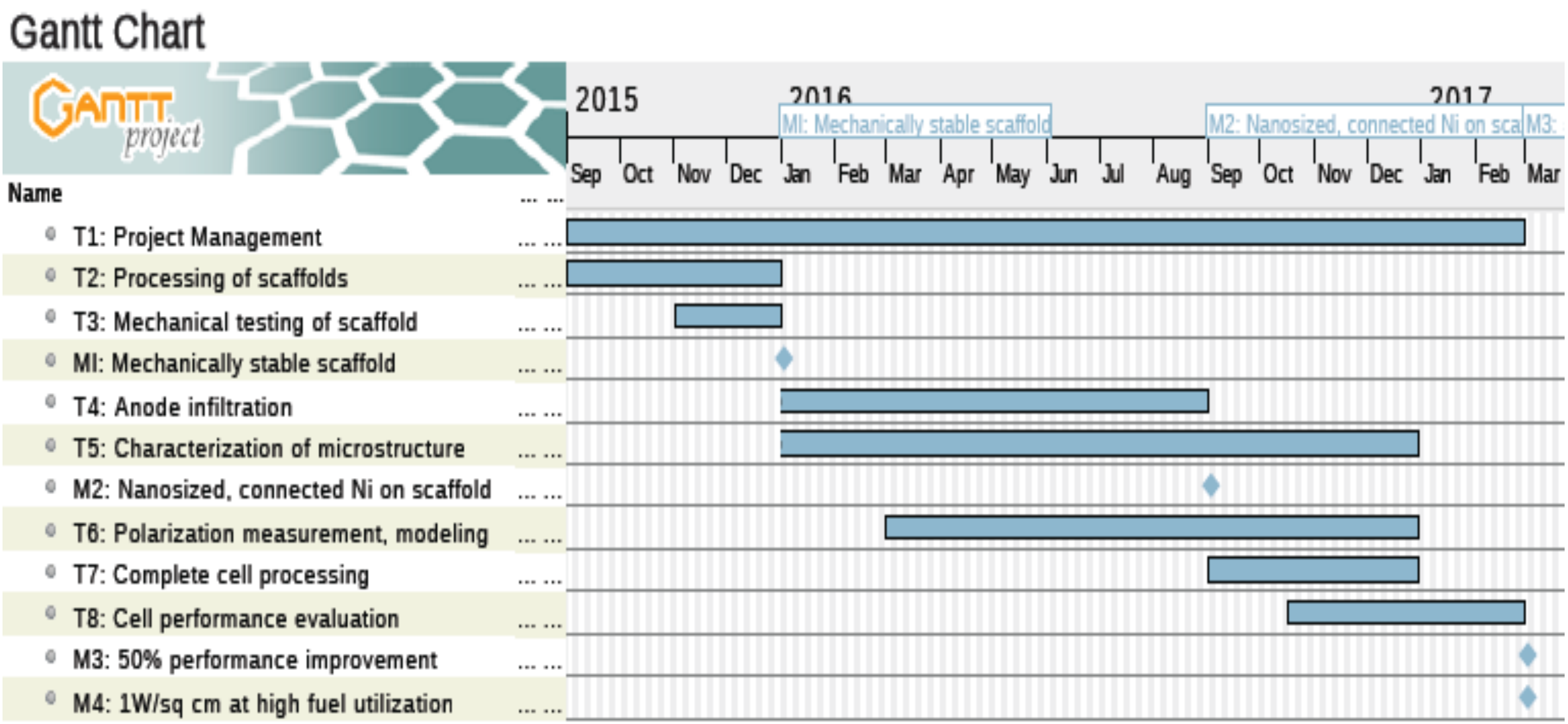
- LSCF/GDC/YSZ/Ni-YSZ cells with and without anode infiltration will be tested under high fuel utilization conditions to demonstrate a 50% improvement at 600°C due to anode infiltration.

- The optimized LSCF/SDC/ScDZ/Ni-YSZ cells with anode infiltration will be tested at intermediate temperatures (600-750°C) to demonstrate power densities of 1W/cm^2 at intermediate temperatures at high utilization rates (up to 85% water vapor).



Electrochemical cell test setup

Project Schedule



Project Budget

DOE Share	Year 1		Year 2		Total Phase 1	
Total Salary	$	50,343	$	28,546	$	78,889
Total F/B	$	5,869	$	2,712	$	8,581
Other Costs	$	21,333	$	13,374	$	34,707
Total F&A Costs	$	49,396	$	28,431	$	77,827
Grand Total	$	126,939	$	73,061	$	200,000

BU Cost Share	Year 1		Year 2		Total Phase 1	
Total Salary	$	15,800	$	8,137	$	23,937
Total F/B	$	4,361	$	2,246	$	6,607
Total F&A Costs	$	12,842	$	6,614	$	19,456
Grand Total	$	33,003	$	16,997	$	50,000

TRAVEL: The budget includes $5,000 for travel over the course of the project to enable the investigators and graduate students to attend yearly DOE review meetings in Pittsburgh, and to attend meetings of professional societies for dissemination of research results.

Project/Risk Management Plan

DELIVERABLES: The periodic, topical, and final reports shall be submitted in accordance with the 'Federal Assistance Reporting Checklist' and the instructions accompanying the checklist.

BRIEFINGS/TECHNICAL PRESENTATIONS: The Recipient shall prepare a detailed kick off meeting and semiannual briefings (based upon the quarterly Progress Reports) for presentation to the DOE Project Officer at the NETL facility located in Morgantown, WV or Pittsburgh, PA or via WebEx. Briefings shall be conducted by the Recipient to explain the plans, progress, and results of the effort. The Recipient shall present the project results orally as a presentation or as a poster at annual programmatic workshops, as required. Presentation materials shall be provided to the DOE Project Officer as needed for internal NETL use or DOE Office of Fossil Energy Headquarters use.

Project/Risk Management Plan

Risk 1 (Description): It may be difficult to ensure connectivity of the Ni particles on the YSZ (non-conducting) scaffold surface to ensure good electrical conductivity of the anode.

Risk 1 (Mitigation strategy): We will also start with Ni-YSZ scaffolds that will provide conductivity. The nano-sized Ni catalysts deposited by infiltration will still increase the TPB length by 1-2 orders of magnitude, and still contribute to better cell performance at high utilization rates. The infiltrated Ni particles will not see the NiO sintering temperature, and will not coarsen.

Risk 2 (Description): It may take many infiltration and annealing steps to fully load anode scaffold.

Risk 2 (Mitigation strategy): Alternate Ni carriers such as nickel acetate, which has high nickel solubility will be explored. Other options are to explore i) ultrasonic atomization of the solution (with NETL) and ii) vapor phase deposition of Ni.