Novel Structured Metal Bipolar Plates for Low Cost Manufacturing (SBIR Project)

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Project ID# : FC105

SBIR Phase II Project Overview

Timeline

- Project start date: May 15, 2014
- Project end date: May 14, 2016
- Percent complete: 50%

Barriers

- Barriers Addressed : Bipolar Plate Durability and cost
  - Cost: < $3/kW (2020)
  - resistivity < 10 $m\Omega\cdot cm^2$
  - corrosion < 1 $x10^{-6}A/cm^2$

Budget

- Total Funding Spent in FY 2015:
  as of 3/31/14: $230,615.10
- Total DOE Project Value: $988,784
- Cost Share Percentage: 0%

Partners

- Hawaii Natural Energy Institute, University of Hawaii.
- Ford Motor Company

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Objective of the Project

- Overall Objective: Develop lower cost metal bipolar plates to meet performance target and 2020 cost target (<$3/kW)
  - Scale up and optimize doped titanium oxide coating technology demonstrated in Phase I project
  - Full size short stack demonstration under automobile dynamic testing conditions.

Key Technical Targets

Characteristic	Unit	2011 Status	2017 Targets	2020 Targets
Cost	$ /kW	5-10	**3**	**3**
Corrosion	$\mu A/cm^2$	<1	**<1**	**<1**
Resistivity	$\Omega.cm^2$	<0.03	**<0.02**	**<0.01**

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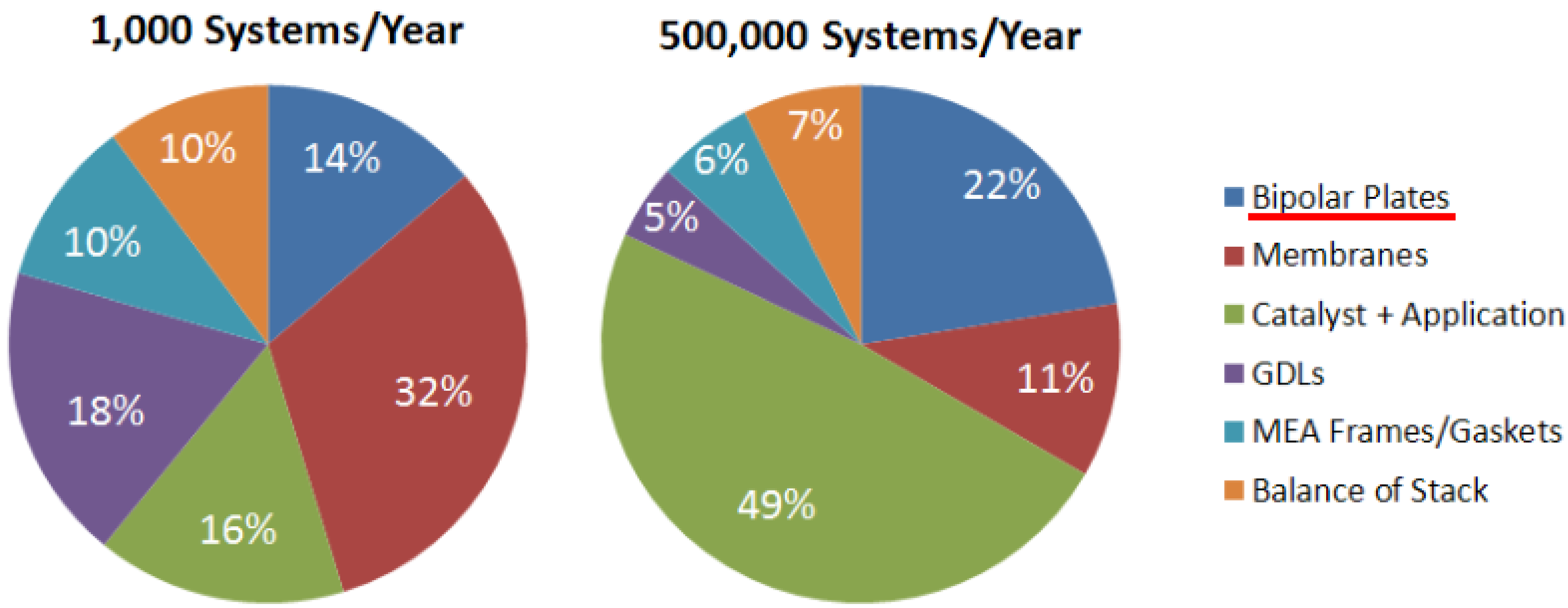
Relevance

Bipolar Plate Cost is a Major Portion of Stack



J. Spendelow, J. Marcinkoski, "Fuel Cell System Cost – 2013"
DOE Fuel Cell Technology Office Record # 13012

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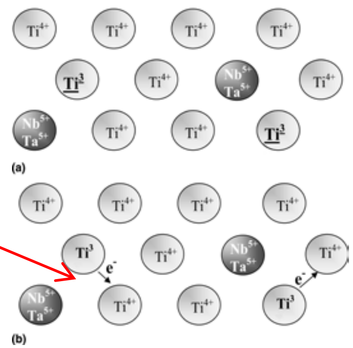
Approach: Coating Material for SS Plates

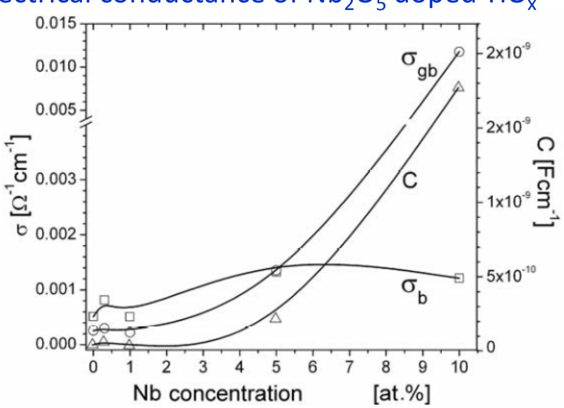
--- Doped TiO_x

Doping TiO_2 with +5 valence elements will enforce the formation of Ti^{+3} in TiO_2 lattice structure, and result in the higher electronic conductivities.

Electron hopping between Ti^{+3} & Ti^{+4} sites



Electrical conductance of Nb_2O_5 doped TiO_x



A. Trenczek-Zajac, M. Rekas, Materials Science-Poland, Vol. 24, No. 1, 2006

Challenges to use doped TiO_x coating:

1. Doped TiO_x is semi-conductive. The electrical conductivity is not high enough.
2. How to obtain reliable bonding of doped TiO_x on metal substrate surface.

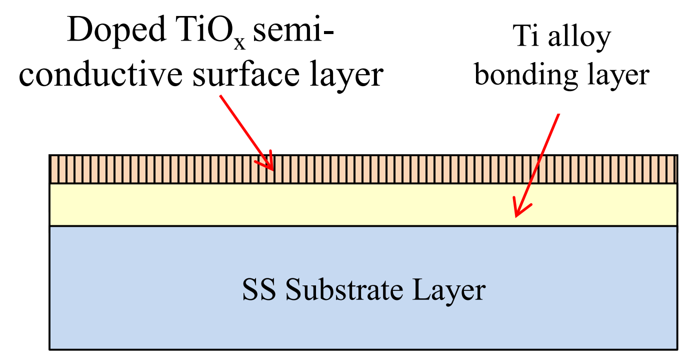
TreadStone's approach:

- To coat stainless steel substrate with Ti-Nb or Ti-Ta alloy. Then, grow the doped TiO_x surface layer on the Ti alloy coating layer.

1. The doped TiO_x on Ti alloy surface is thin and reliable.
2. Ti alloy coating has excellent adhesion on metal substrate (stainless steel or aluminum).

Approaches: Fabrication Process

- Based on industrial available Physical Vapor Deposition (PVD) technology for the coating materials deposition.
  - Ready for high volume production
- Focused on the electrical conductive and corrosion resistive doped titanium oxide as the coating materials.
  - Low cost materials.
- Focused on the deposition and post deposition treatment conditions to obtained the desired structure of the surface coating.
  - Superior adhesion of coating layer with substrate.
  - Post deposition treatment for the desired phase structure of the coating layer.



Leybold Optical's DynaLine Inline Sputtering System

Approach: Tasks and Milestones

Coating Target Material Optimization

- Determine the composition of the target material. (Finished)
- Coat SS foil for ex-situ test. (Finished)

May ‘14 – Jan. ‘15

PVD Process Development

- Demonstrate the coating in single cell test. (Finished)
- PVD process development. (on-going)

Nov. ‘14 –Feb. ‘16

Demonstrate in Auto. Fuel Cell Stack

- Components preparation. (start in June ‘15)
- Long-term durability test in short stack. (start in July ‘15)

Jun. ‘15 – May ‘16

Project Duration: 24 months

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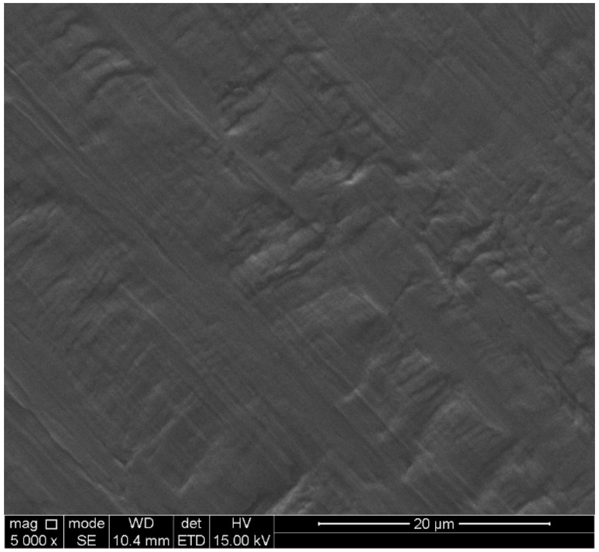
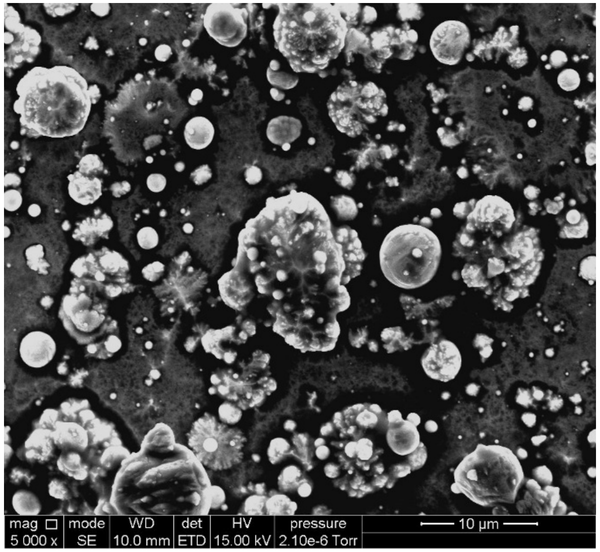
Accomplishments: PVD Process Development

Nb-TiO_x coating on SS foil surface

DC Magnetron Sputtering



Cathodic Arc Deposition



- Relative smooth coating surface.
- Alloy element segregation on the very surface layer with current sputtering process.
    - No Nb in the surface layer (5-10nm), and very high contact resistance.
- Need to etch off the surface layer to obtain the desired Nb doped TiO_x (Nb-TiO_x) surface layer for low electrical contact resistance.

- Rough surface with micron particles.
- Uniform composition of the coating surface.
- The electrical contact resistance is not as low as the etched sputtering coated SS.
- Target material utilization of Cathodic Arc is low.
- Difficult to obtain thin (<0.5 μm) coating.

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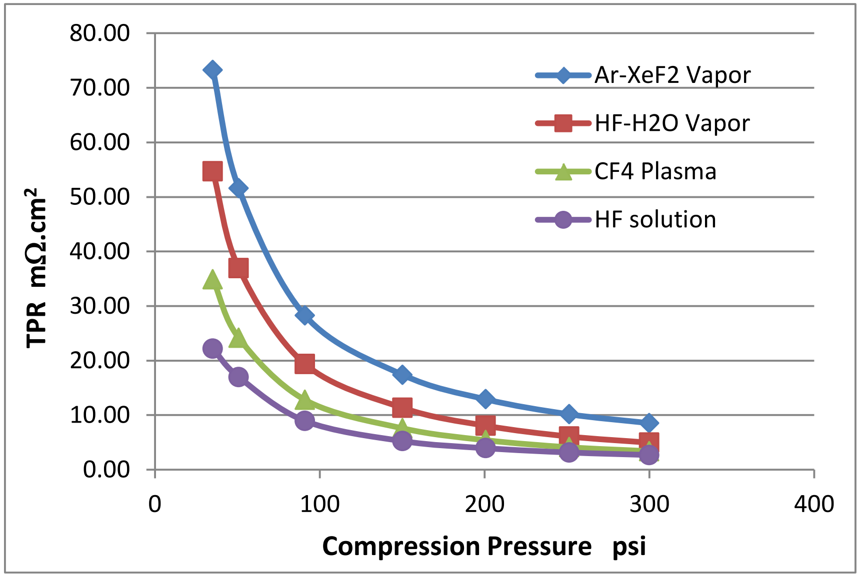
The focus is on sputtering process.

Accomplishments: Coating Materials

Sputtering coated Nb-TiO_x on SS

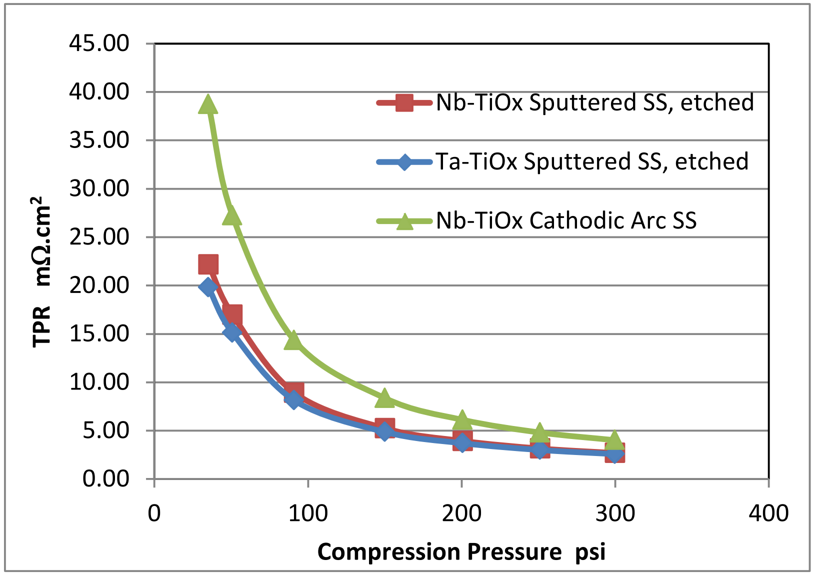
Etching method comparison



- Hydrofluoric acid etching is more repeatable and has lowest surface contact resistance.
- Vapor etching is easier to be integrated with PVD process. More developments are needed.

SS with doped TiO_x coating

Composition and deposition methods



Note: TPR, through plate resistance measured of the plate in contact with TGP-H-060 Toray Paper.

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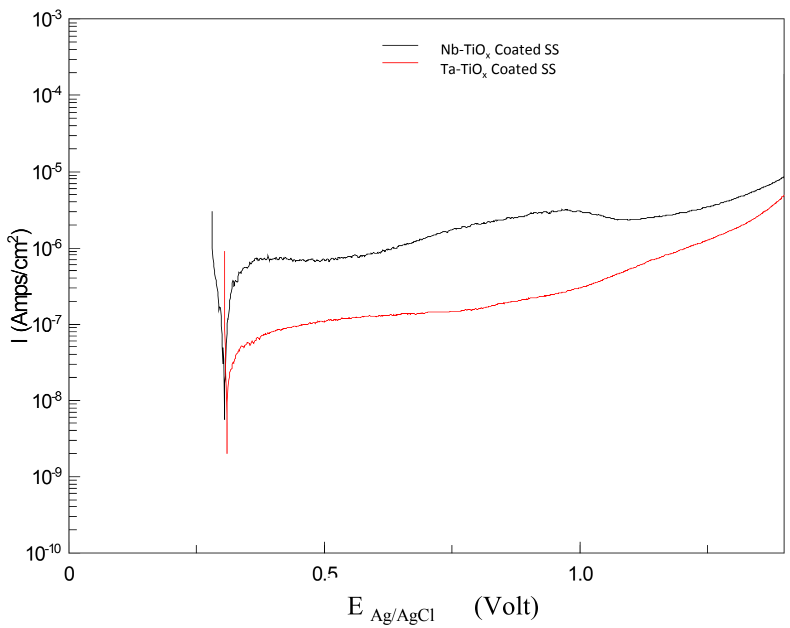
Accomplishments

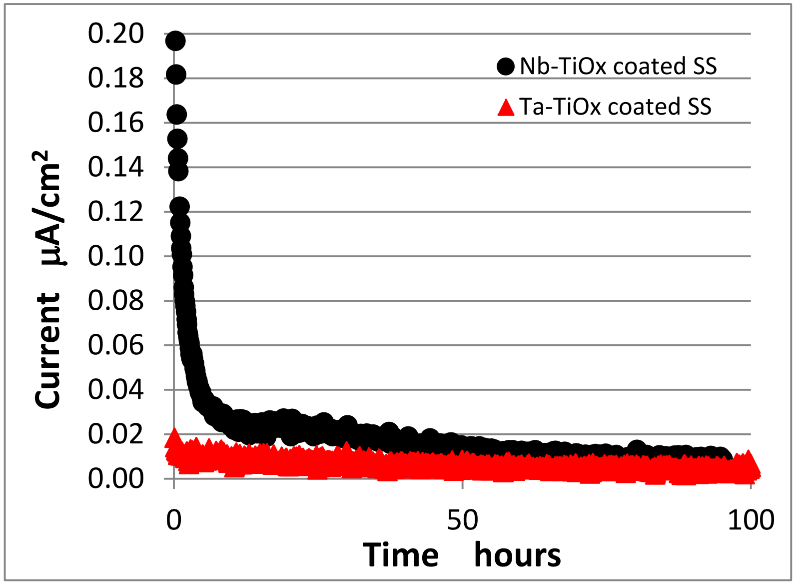
ex-situ Tests of Doped TiOx coated SS

in pH 3 H_2SO_4 + 0.1 ppm HF at 80^oC

Potentiodynamic Test (@10 mV/min)



Potentiostatic Test (@0.8V_{NHE})



- Both Nb and Ta doped TiO_x coated SS can meet the corrosion current target (<1 $\mu A/cm^2$)
- Ta-TiO_x coated SS has lower corrosion current than that of Nb-TiO_x

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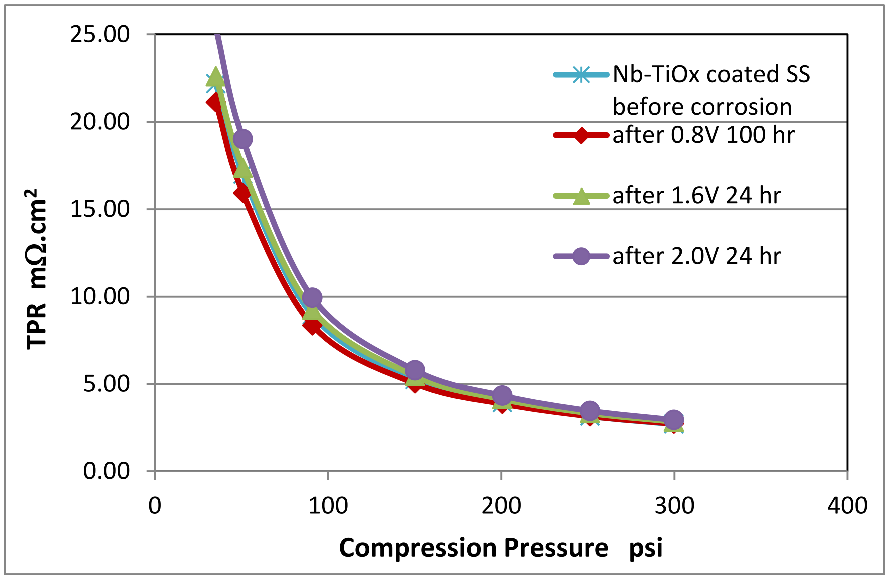
Accomplishments:

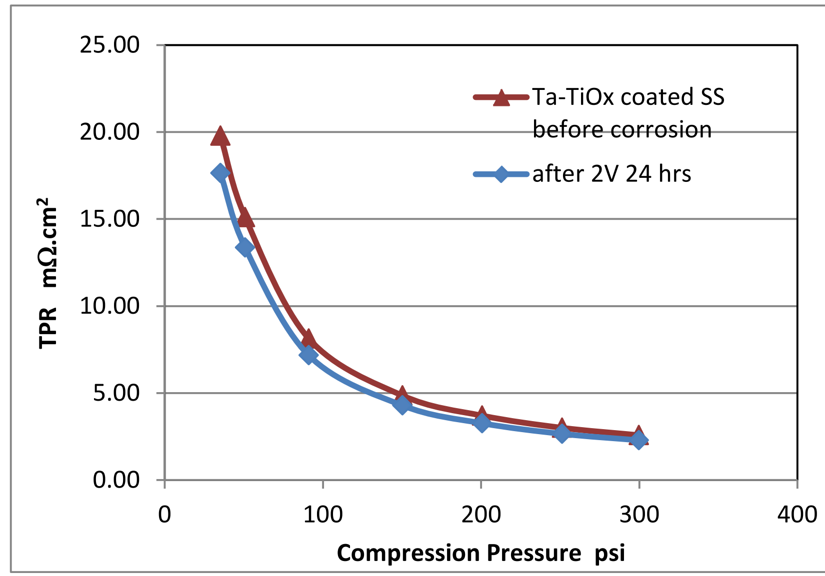
Coating Stability Test in Extreme Conditions

in pH 3 H_2SO_4 + 0.1 ppm HF at 80°C

316L SS with Nb-TiO_x coating
before and after corrosion tests



316L SS with Ta-TiO_x coating
before and after corrosion tests



- Doped TiO_x coated SS has low surface electrical contact resistance.
- The coated SS has superior corrosion resistance for PEM fuel cell applications.
- The extreme corrosion condition (@ $1.6V_{NHE}$ or 2 V_{NHE}) *ex-situ* tests are not included in regular standard, but it is very attractive to OEMs.

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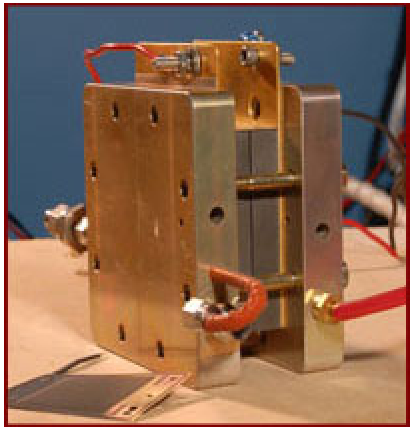
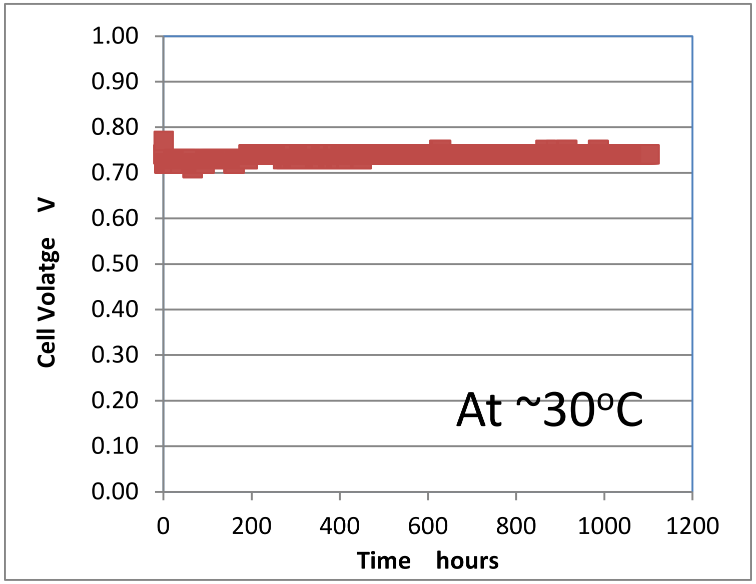
Accomplishments

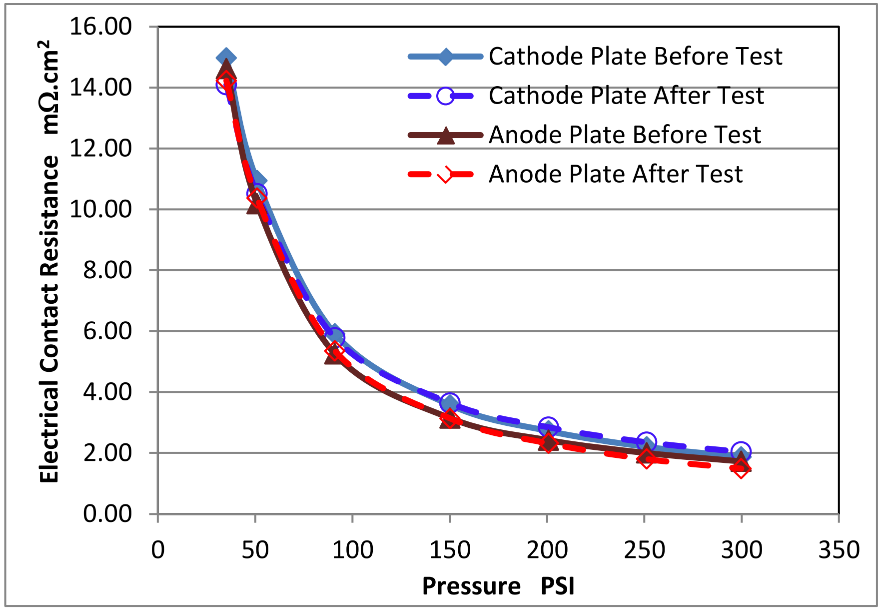
Single Cell Test with Nb-TiOx Coated SS Plates



16 cm^2 active area cell using Fuel Cell Technology hardware

Contact Resistance with GDL before and after 1,100 hrs. single cell test





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Responses to Previous Year Reviewer's Comments

This Project was not reviewed last year.

Collaborations

Team Partner:

HNEI, Univ. Hawaii

5 kW stack testing under automobile dynamic operation conditions.

Dr. Jean St-Pierre

Industrial Supporter:

Ford Motor Company

Independent *ex-situ* test evaluation

Provide automobile stack for durability test

Mr. Shinichi Hirano

Mr. Mark Ricketts

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Remaining Challenges and Barriers

- **Large scale fabrication process.**
  → Current PVD + hydrofluoride acid etching process may not be suitable for large scale fabrication.
  → The second year of the project will develop a simpler process, in addition to the planned stack durability demonstration.

- **Fundamental understanding of the coating material.**
  → The performance of the coating material is much better than expected. What is the scientific principles behind it?
  → The fundamental study is not included in this SBIR project.

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Proposed Future Work

- **Task 2. PVD Process Development**
  - Simplify current coating process, evaluate the coating properties by *ex-situ* corrosion tests and single cell tests.

- **Task 3. Demonstration in Automobile Stack Durability Tests**
  - Ford will contribute a short stack (no cost to the project) for the durability test.
  - The stack tests will be conducted at U. Hawaii with the technical supports from Ford.

Summary

- ***Objective:*** Develop a low cost metal bipolar plate coating that does not need to use precious metals.
- ***Relevance:*** Reducing the metal bipolar plate cost to meet FY20 requirements.
- ***Approach:*** Using doped TiO_x coating on metal plates surface for fuel cell applications..
- ***Accomplishment:***
  - Identified the high performance, stable coating material.
  - DC Magnetron Sputtering and cathodic arc processes have been used for the coating material deposition.
  - *Ex-situ* tests indicate that the coated stainless steel has superior stability.
    - Corrosion resistance easily meet the targets.
    - Electrical contact resistance is low and stable after aggressive *ex-situ* corrosion tests.
    - The superhydrophilic surface properties has additional benefits to plate flow field design.
  - 1100 hours single cell evaluation demonstrate its durability in PEM fuel cells.
- ***Collaborations:***
  - Teaming with HNEI, Univ. Hawaii for stack long term durability test.
  - Ford will contribute a full size, short stack for the demonstration.

Acknowledgements

- DOE EERE Fuel Cell Team.
- Team Members. HNEI, U. Hawaii
- Industrial Partners. Ford