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

PI: Conghua “CH” Wang
TreadStone Technologies, Inc.
201 Washington Rd.,
Princeton, NJ 08543

June 10, 2015

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 mΩ·cm²
  ➢ Corrosion: < 1 x10⁻⁶ A/cm²

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
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**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Unit</th>
<th>2011 Status</th>
<th>2017 Targets</th>
<th>2020 Targets</th>
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<tbody>
<tr>
<td>Cost</td>
<td>$/kW</td>
<td>5-10</td>
<td>3</td>
<td>3</td>
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<tr>
<td>Corrosion</td>
<td>µA/cm²</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
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<tr>
<td>Resistivity</td>
<td>Ω.cm²</td>
<td>&lt;0.03</td>
<td>&lt;0.02</td>
<td>&lt;0.01</td>
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</table>
Relevance

Bipolar Plate Cost is a Major Portion of Stack

DOE Fuel Cell Technology Office Record # 13012
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.

**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.

Doped TiO$_x$ semi-conductive surface layer

Ti alloy bonding layer

SS Substrate Layer

Leybold Optical's DynaLine Inline Sputtering System
**Approach: Tasks and Milestones**

**Coating Target Material Optimization**
- May ‘14 – Jan. ‘15
  - Determine the composition of the target material. (Finished)
  - Coat SS foil for ex-situ test. (Finished)

**PVD Process Development**
- Nov. ‘14 – Feb. ‘16
  - Components preparation. (start in June ‘15)
  - Long-term durability test in short stack. (start in July ‘15)
  - Demonstrate the coating in single cell test. (Finished)
  - PVD process development. (ongoing)

**Demonstrate in Auto. Fuel Cell Stack**
- Jun. ‘15 – May ‘16

**Project Duration:** 24 months
Accomplishments: PVD Process Development

**Nb-TiO\textsubscript{x} coating on SS foil surface**

DC Magnetron Sputtering

- 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\textsubscript{x} (Nb-TiO\textsubscript{x}) surface layer for low electrical contact resistance.

Cathodic Arc Deposition

- 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.

The focus is on sputtering process.
Accomplishments: Coating Materials

Sputtering coated Nb-TiO$_x$ on SS

SS with doped TiO$_x$ coating

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.

Composition and deposition methods

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

*ex-situ* Tests of Doped TiOx coated SS

in pH 3 H$_2$SO$_4$ + 0.1 ppm HF at 80$^\circ$C

- 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$_x$
Accomplishments:
Coating Stability Test in Extreme Conditions

in pH 3 H₂SO₄ + 0.1 ppm HF at 80°C

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

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

• Doped TiOₓ 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.
Accomplishments
Single Cell Test with Nb-TiOx Coated SS Plates

16 cm² active area cell using Fuel Cell Technology hardware

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

At ~30°C
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
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.
Proposed Future Work

• **Task 2. PVD Process Development**
  o 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**
  o Ford will contribute a short stack (no cost to the project) for the durability test.
  o 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