Development and Manufacturing for Precious Metal Free Metal Bipolar Plate Coatings for PEM Fuel Cells

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TreadStone Technologies, Inc.

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DOE Hydrogen Program

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Project ID# : FC345

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Project Goal

- Reduce the manufacturing cost of PEM fuel cell metal bipolar plate in order to meet DOE's cost target of < $5kW.
  - Using low grade stainless steel and aluminum as the substrate material.
  - Develop precious metal-free coating technology.
  - Develop the coating process that is suitable for roll to roll (R2R) manufacturing process.
- Meet the performance and durability requirements for HDV application.
  - Develop the accelerated stress test (AST) protocols for rapid evaluation of PEM fuel cell bipolar plates.
  - Investigate the coating electrical conductance and degradation mechanism.

Project Overview

Timeline and Budget

- Project Start Date: 09/17/2021
- Project End Date: 09/30/2023
- Total Project Budget: $1,769,112
  - DOE Share: $1,415,162
  - Cost Share: $353,950.00
  - DOE Funds Spent*: $187,540
  - Cost Share Funds Spent*: $99,302

* As of ~ 03/31/2022

Partners

Project Lead: PI: CH. Wang
TreadStone Technologies, Inc.
Coating Process Development

Co-PI:
T. Rockward, Los Alamos National Lab.
BP AST Protocol Development
C. Smith, Pacific Northwest National Lab
Aluminum Based BP Development
G. Gu, Univ. Tenn. Knoxville
Degradation Mechanism Investigation
Y. Yang, Austin Power
Manufacturing Cost Analysis

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Relevance/Potential Impact

- Bipolar plates are the second most expensive component in PEMFC stacks.
- Low-cost metal bipolar plates and fabrication techniques are critical to meet HFTO 2030 cost and performance targets for heavy-duty applications.

Barriers	DOE Targets	Project Impacts
Cost	<\$5/kW	Develop precious metal free coating technology to enable low grade stainless steel and aluminum based metal plate to meet the cost target.
Durability	>25,000 hrs	Develop rapid AST protocol for rapid evaluation.
Performance	Corrosion Current: $< 1\ \mu A/cm^2$ Contact Resistance: $<10\ m\Omega.cm^2$	Investigate the coating degradation mechanism to achieve the superior performance.

Project objectives and impacts directly contribute to meet HFTO 2030 Targets

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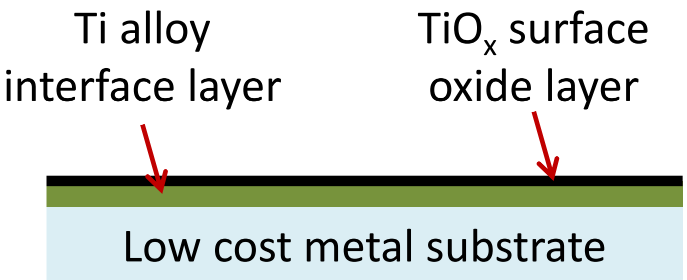
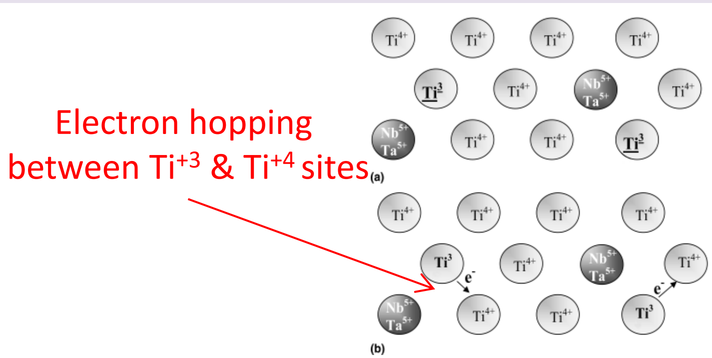
Approach

Coating Structure



Doping TiO_2 with +5 valence elements 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. The week bonding of doped TiO_x to metal substrate surface.

TreadStone's approach:

- Coat metal 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. Investigate the TiO_x electrical conducting mechanism to guide the coating structure development.
3. Develop AST protocol for rapid evaluation of metal BPs long term durability.

Milestones and Go/no-go Decisions

Year 1 Milestones and Go/No Go decision points				
Task Number and Title		Milestone Type*, Number and Description		Anticipated Time
1.1	Coating Material Preparation	M 1.1	Prepare the Ti-Nb powder as the coating material	M3, Q1
1.2	Coating Process Development	M 1.2	Develop the Nb-TiOx coating process	M12, Q4
3.2	Characterization of Nb-TiOx thin film structure	M 3.1	Determine the nano structure and composition of Nb-TiOx surface layer	M6, Q2
3.3	Local Resistivity Mapping	M 3.2	Determine the relation of TiOx coating properties with local resistivity	M9, Q3
G/N 1	Deliver Nb-TiOx thin film bipolar plate coating on low cost metal substrate which meets initial cost, ICR, corrosion resistance and manufacturing scalability requirements.	a. Finish the preliminary manufacturing cost analysis. At least one process is identified that will meet the bipolar plate cost target of < \$5/kW b. Demonstrate at least one set of coating material that meets the ICR ($<5 m\Omega.cm^2$) and corrosion ($< 0.5 \times 10^{-10}$ $mol/cm^2/hr$ ion leaching rate and <1 $\mu A/cm^2$ corrosion current) targets in ex-situ tests. c. Develop one metallic BP AST protocol that is relevant to meeting heavy duty application durability requirement.		M12 Q4

Year 2 project is based on the funding availability.

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Accomplishments and Progress

--- Coating Process Development

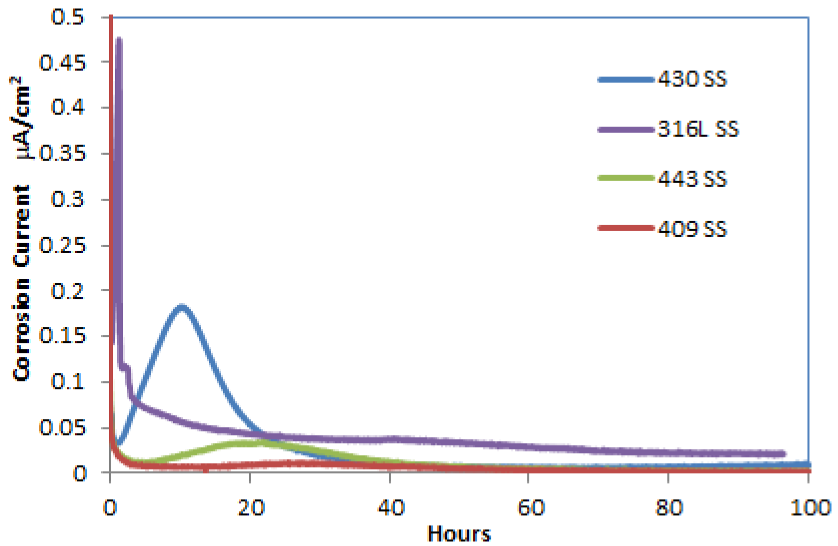
- The project focus is on the direct particle bonding (DPB) process development for BP manufacturing.
  - Precisely control coating layer composition and structure.
  - Suitable for R2R process with minimum capital cost.
- The coating process has been demonstrated on small size (3”x3”) metal plate.
  - The coating has been applied on 409, 430, 443 stainless steel (Ni < 0.5%) and 316L stainless steel as the baseline material.
  - Interface contact resistance and corrosion resistance meet DOE’s targets.
  - The AST test and electrical conductance mechanism investigation are on going.

Accomplishments and Progress

--- Corrosion Resistance of different SS with TiOx coating

0.8V_{NHE} of TiO_x coated SS in pH3 H_2SO_4 + 0.1 ppm HF at 80°C.

- Corrosion current is < 0.01 μA/cm² of all SS with TiO_x coating, <0.001 μA/cm² for 409 SS, after 100 hours test.
- ICR is <10 mΩ.cm²
- 409 SS has the lowest corrosion current of all SS materials.
  - ➢ The lowest Cr content of 409 SS results in the lowest cost and high elongation.



Chemical formulation of low grade and 316L stainless steel (typical value %)									
#	Cr	Ni	Ti	Cu	Mo	C	Si	Mn	Fe
430	17.0	<0.5	-	<0.5	<0.5	<0.12	<1	<1	Bal
JFE443CT	21.0	0	<0.3	<0.4	-	-	-	-	Bal
JFE409L	11.0	<0.5	-	-	-	<0.08	<1	<1	Bal
316L	18.0	14.0	-	-	<3.0	<0.03	<0.75	<2.0	Bal

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Responses to Previous Year Reviewer's Comments

- This project was not reviewed last year.

Collaborations

TreadStone
Project Management
Coating Process Development & Corrosion Tests

LANL
BP AST Protocol Development & Test

Austin Power
Manufacturing Cost Analysis

PNNL
Aluminum Based BP Development

UT. Knoxville
Degradation Mechanism Investigation

Remaining Challenges and Barriers

- Rapid testing method to predict the long term (25,000 hrs.) durability of the BP for HDV applications.
- Coating conductance mechanism understanding, which is necessary to convince OEMs adapting the technology before finishing 25,000 hours durability tests.
- Manufacturing cost reduction.

Proposed Future Work

- Coating process optimization.
  - coating quality control (2022)
  - further cost reduction (2023).
- Accelerated Stress Test (AST) development
  - Test protocol development (in 2022).
  - Cell test in normal operation and AST test conditions (2023)
- Coating layer microstructure characterization
  - TiOx coating structure and composition (2022)
  - The relationship of composition with processing conditions (2023)
- Electrical conductance mechanism investigation
  - Local resistivity mapping (2022)
  - Quantitative modeling (2023)
- Manufacturing cost analysis (2023)

Any proposed future work is subject to change based on funding levels.

Summary

- ***Objective:***
  - Develop low cost fabrication process of the doped TiO_x coating on low cost metal substrate for PEM fuel cell HDV applications.
  - Develop AST protocol for rapid evaluation of BPs for HDV applications.
  - The coating conductance mechanism investigation
- ***Relevance:*** Reducing the metal bipolar plate cost to DOE's performance and cost target.
- ***Approach:*** Using doped TiO_x coating on low nickel content SS and aluminum surface for HDC fuel cell applications.
- ***Accomplishment:***
  - Demonstrated the coating process for low cost metal substrates.
  - *The AST and conductance mechanism investigation are underway.*
- ***Future Work:***
  - Finish the AST protocol development and use it as the rapid evaluation method.
  - Investigation the TiOx coating conductance mechanism.
  - Further development of the coating process to reduce the process cost.

Technology Transfer Activities

TreadStone has an established reputation in metal bipolar plate corrosion protection technology development and commercialization.

<u>TreadStone's technology transfer strategy is two-fold.</u>

- Scale up the production capability internally and licensing to large industrial coating companies for rapid market penetration.
  - ✓ Scaled up the DOT coating technology at TreadStone for 100 MW PEM electrolyzer, and will further increase to 500 MW capacity by the end of 2022.
  - ✓ Licensed DOT technology to Ionbond, a global industrial coating company, headquartered at Switzerland, focusing on the market development in Europe.
- Expand into similar, but different markets.
  - ✓ DOT technology: originally developed for PEM fuel cells, is used in PEM electrolyzers now.
  - ✓ DuraC technology: originally developed for PEM fuel cells, expands into flow batteries now.