V.H.1 Low-Cost PEM Fuel Cell Metal Bipolar Plates

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Contract Number: 09EE0000463

Subcontractors:
- Gas Technology Institute, Des Plaines, IL
- The State University of New York, Stony Brook, Stony Brook, NY
- IBIS Associations, Inc., Waltham, MA
- Ford Motor Company, Dearborn, MI

Project Start Date: September 1, 2009
Project End Date: August 31, 2011

Fiscal Year (FY) 2011 Objectives

- Reduce or eliminate the small amount of gold used in TreadStone's current corrosion resistant metal plate technology for polymer electrolyte membrane (PEM) fuel cell applications.
- Develop the low-cost metal bipolar plates using commercially available low-cost carbon steel or aluminum as the substrate materials.
- Optimize the fabrication process for large scale manufacture.
- Demonstrate TreadStone's low-cost metal plate technology in the applications of portable, stationary and automobile fuel cell systems.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Durability
(B) Cost
(C) Performance

Technical Targets

The focus of this project is to further develop TreadStone's proprietary corrosion resistant metal plate technology reducing the metal plate cost to <$3/kW, while still meeting the performance requirements. There are a number of performance requirements for PEM fuel cell bipolar plates. The most challenging requirements for metal bipolar plates are summarized in Table 1. The status of TreadStone's low-cost metal plates is summarized in the table as well.

TABLE 1. TreadStone's Metal Plate Status and DOEs Targets

Parameter	Unit	TreadStone 2010 Status	DOE Targets	
			2010	2015
Plate Cost [a]	$/kW	$3.82	5	3
Plate Weight [b]	kg/kW	<0.4	<0.4	<0.4
Corrosion Anode [c]	μA/cm^2	not available	<1	<1
Corrosion Cathode [d]	μA/cm^2	<0.01	<1	<1
Resistance [e]	Ohm cm^2	<0.01	<0.02	<0.02

[a] Based on 50% utilization of active area on the whole plate surface, stainless steel (SS) foil cost at historical average of $2/lb, 1 W/cm^2 power density and projected 500,000 stacks per year production.
[b] Based on the 0.1 mm thick SS foil.
[c] pH 3, 0.1 ppm hydrofluorhydric acid (HF), 80°C, peak active current <1X10^{-6} A/cm^2 (potentiodynamic test at 0.1 mV/s, -0.4 V to +0.6 V (Ag/ AgCl)) de-aerated with Ar purge.
[c] pH 3, 0.1 ppm HF, 80°C, passive current <5X10^{-8} A/cm^2 (potentiostatic test at +0.6 V (Ag/AgCl)) for at least 24 hours, aerated solution.
[d] Includes contact resistance (on as-received and after potentiostatic experiment) measured.

FY 2011 Accomplishments

- Completed the low-cost, gold free conductive vias development. Demonstrated the processing technologies for carbon nanotubes and conductive carbides as the conductive vias. The corrosion current of metal plates with these vias are below 1 μA/cm^2 in pH 3 H_2SO_4 + 0.1 ppm HF solution under 0.8 V normal hydrogen electrode (NHE) at 80°C.
- Completed the large fabrication-scale cost analysis of metal plates using the gold-free vias technologies.
- Developed the processing technology and the identified the coating materials for aluminum substrate for PEM fuel cell applications.
- Demonstrated the current gold dots metal plates in portable and stationary applications, operating at ambient pressure conditions, with a small (30 cm^2 active

area of each cell) 200 W and a large (267 cm^2 active area each cell) 1 kW stack, respectively.

- Demonstrated 1,000 hours stable operation of the gold dots metal plate in a 300 cm^2 active area, 10-cell, 2.5 kW short stack under durability testing cycle (including the Federal Test Procedure [FTP] cycle along with others) to mimic the automobile real world driving conditions at Ford Motor Company.

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Introduction

It has been reported that using metal bipolar separate plates can reduce the PEM fuel cell stack weight and volume by 40-50%, comparing with current graphite-based bipolar plates [1]. The major barrier to use metal bipolar plates in PEM fuel cells is the severe corrosion condition during stack operation. Most metals do not have adequate corrosion resistance in a PEM fuel cell environment, which results in rapid performance degradation due to the formation of the electrically resistive surface oxide scale, and potential contamination of the membrane electrode assembly by the dissolved ions from the metal plates. Various corrosion protection techniques have been investigated to prevent the metal plate corrosion in PEM fuel cell environments [2-7]. Some of these technologies have developed corrosion-resistant metal plates that can meet the performance requirements. However, it is still a challenge to have the metal bipolar plate that can meet both the performance and cost requirements. The focus of TreadStone's project is to develop corrosion resistant metal bipolar plates at the low-cost to meet DOE's 2015 targets.

Approach

Most research on metal bipolar plates has been focused on covering the whole plate surface with an electronically conductive and corrosion-resistant material to protect the metal from corrosion and maintain the electrical conductance of the metal. The challenge of this approach is that there is only a limited number of low-cost materials that can meet electrical conductivity and corrosion resistance requirements for PEM fuel cell applications. In addition, the processing required to apply these materials on metal substrate is either difficult or at high cost.

TreadStone takes a different approach to develop metal bipolar plates for PEM fuel cell applications. It was found that it is unnecessary to have the whole surface electrically conductive to ensure the low contact resistance (interfacial contact resistance $< 10\ m\Omega.cm^2$) between bipolar plates and the gas diffusion layer (GDL). TreadStone's approach is based on this principle, as shown in Figure 1.

The majority of the metal surface area is covered with the low-cost corrosion-resistant but non- (or poor) conductive material (purple layer in Figure 1). A corrosion

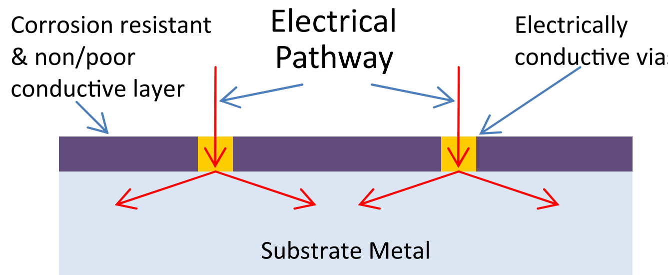

FIGURE 1. Schematic Drawing of TreadStone's Corrosion Resistant Metal Plate Design

resistant and highly electrically conductive material (such as Au) forms the paths for electron transport, in the form of small conductive vias (yellow bars) penetrating through the non-conductive layer. Electrons generated from the anode reaction will flow through the GDL to the conductive vias (illustrated as red arrows) passing through the metal plate to the other side for the cathode reaction on the cathode of the adjacent cell. The conductive vias, having a dimension as small as several micrometers, are distributed on the metal surface. The average distance between the conductive vias is 20-70 μms. The dense distribution of conductive vias ensures a uniform current distribution between the GDL and metal bipolar plates.

TreadStone's approach is unique because it uses only a small portion (<1-2%) of the plate surface for electrical contact. It was found that more than 500,000 via/in^2 cover the metal plate surface as the electrical contact point of metal plate with GDL, when small (<5 μm) conductive vias are used. It is because of the high amount of the contact points that enable the low contact resistance of metal plates.

Results

TreadStone's current metal bipolar plate uses a small amount of gold as the electrical contacting material in the form of conductive vias, and SS as the substrate material. In this project, we plan to develop a lower cost material to reduce the gold usage, or replace gold as the contact material. We have finished the process development to use a palladium/gold composite as the contact materials. We also developed the process to use carbon nanotubes and conductive carbides as the conduct material. All of the approaches have met the performance requirements. Figure 2 shows the scanning electron microscope (SEM) picture of the chromium carbide particles that are bonded on the SS surface using chromium-nickel alloy.

The large-scale fabrication cost analysis of the metal plates using alternative conductive vias was conducted based on a post-forming coating process. The assumptions of the cost analysis are based on 50% utilization of active area on the whole plate surface, stainless steel foil cost at historical average of $2/lb, 1 W/$cm^2$ power density and projected 500,000 stacks per year production. The fabrication flow

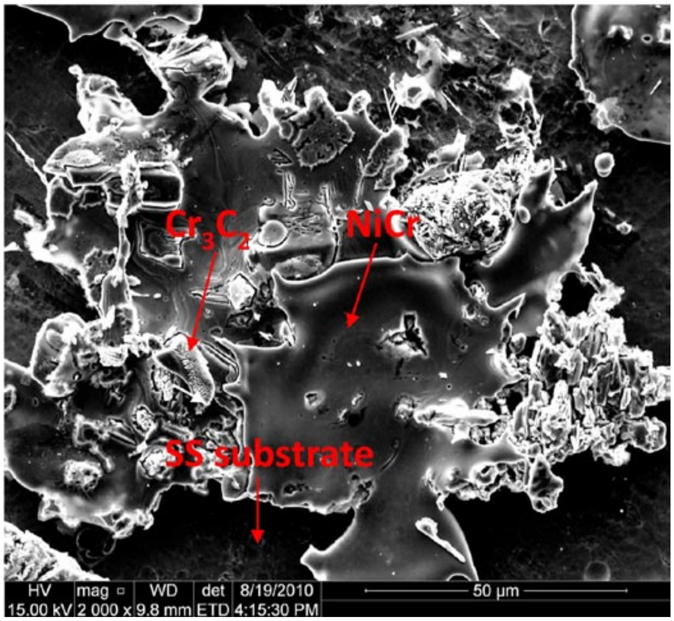

FIGURE 2. SEM Picture of Chromium Carbide Particles Bonded on SS Substrate

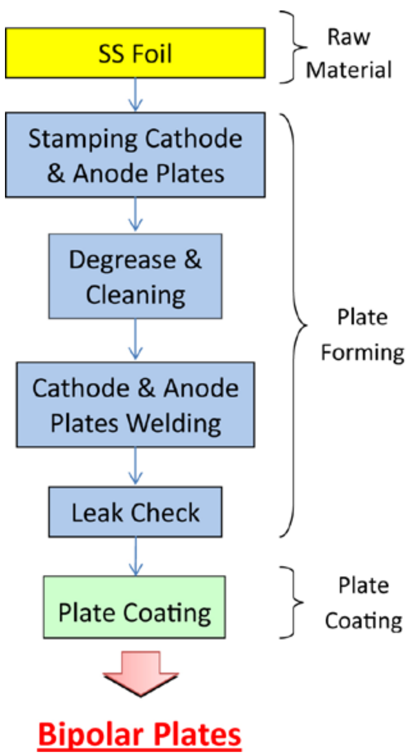

FIGURE 3. Fabrication Flow Diagram for Cost Analysis

diagram is shown in Figure 3. It includes the raw material (SS foil), bipolar plate forming step, and coating step. The cost of each portion is listed in Table 2.

TABLE 2. TreadStone Metal Plate Large-Scale Fabrication Cost Components

Process Step	316 SS foil	Forming	Coating		
			Pd/Au	C-tube	Carbides
Cost[1]	$0.75	$0.48	$0.31	$0.79	$0.30

[1] The cost is $/plate, based on 400 cm^2 active area on each plate.

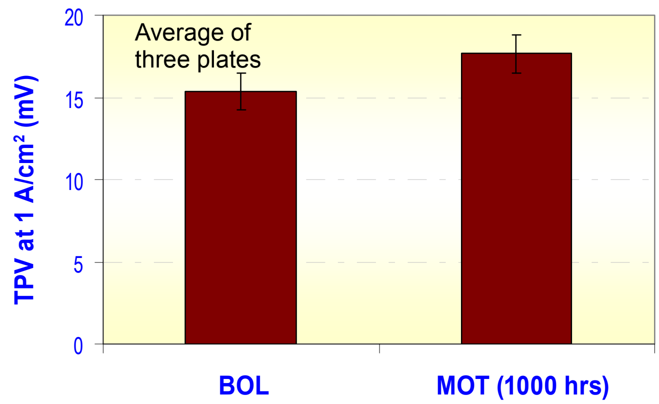

FIGURE 4. Comparison of the TPV Drop of TreadStone's Metal Plates before and after the 1,000 hr Stack Durability Test under Dynamic Loading Conditions at Ford

Table 2 shows that metal plate coating cost using TreadStone's technology can be as low as $0.30/plate, which is a minor part of the bipolar plate cost. SS substrate material cost is the major cost item that accounts of ~50% of the total plate cost, even using the commercial available lower cost 304 SS foil. The metal forming (including laser welding and leak checking) cost is very high as well. Therefore, using lower cost substrate materials, such as carbon steel or aluminum substrate is very useful to reduce the bipolar plates cost. Alternative, low-cost forming process is also important for the low-cost bipolar plate production.

The stacks using TreadStone's metal plates have been designed, and optimized for portable, stationary and automobile applications. The portable power stack has 30 cm^2 active area on each cell. The peak power is 200 W. The stationary stack has 263 cm^2 active area on each cell. The peak power is 1 kW. The initial performance of these two stacks has been characterized. The long-term durability tests of the stacks are underway.

A 10-cell, 2.5 kW short stack for automobile application has also been assembled and tested at Ford Motor Company. The stack has 300 cm^2 active area on each cell, and operates under high pressure. The stack is being tested for utilizing durability cycle (which includes the FTP cycle along with others) mimicking "real-world" driving conditions. After finishing 1,000 hours of stable operation, the stack was disassembled for inspection of all components. There was no sign of corrosion of the metal plates after the 1,000-hour test. The comparison of the through-plate voltage drop

(TPV, under 1 A/cm^2) before beginning of life (BOL) and after the middle of test (MOT) for the 1,000 hours durability test is compared in Figure 4. The TPVs meet the DOE's requirement (<20 mV), although there is small increase (from 15 mV to 18 mV) after the test.

Conclusions and Future Directions

TreadStone's unique corrosion-resistant metal bipolar plates have demonstrated stable operation for PEM fuel cell applications in portable, stationary and automobile applications. The processes can reduce the metal plate coating cost to as low as $0.30/plate. Further development will be focused on:

- Scale up of the lower cost conductive vias processing technique for the large-scale production.
- Demonstration of the low-cost carbon steel and aluminum plates based bipolar plates.
- Demonstration of the long-term operation stability of the TreadStone's low-cost metal plates in PEM fuel cell applications.

Publications

1. L. Zhang, J. Finch, G. Gontarz and C. Wang, "Development of Low Cost PEMFC Metal Bipolar Plates" presented at 218th Meeting of Electrochemical Society, Oct. 2010, Las Vegas, NV.

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