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

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Subcontractors:

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

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Fiscal Year (FY) 2012 Objectives

- Reduce or eliminate the small amount of gold used in TreadStone's current corrosion-resistant metal plate technology for proton exchange membrane (PEM) fuel cell applications.
- Develop 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 Cell 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 meet 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 DOE's 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	n/a	<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 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 stainless steel foil.
[c] pH 3, 0.1 ppm hydrofluorhydric acid, 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 hydrofluorhydric acid, 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 2012 Accomplishments

- Modified the spray system for small-scale commercial production of metal plates.
- Optimized the processing condition for the quality consistency of metal bipolar plate production.
- Conducted accelerated corrosion test of metal plates with Los Alamos National Laboratory.
- Finished 40 bipolar plates for the second stack demonstration at Ford Motor Company.
- Demonstrated the application of the technology in a PEM electrolyzer, anion exchange membrane (AEM) fuel cells and flow battery applications.

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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 cell is the severe corrosion condition during stack operation. Most metals do not have the adequate corrosion resistance in 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 MEA 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 the corrosion-resistant metal bipolar plates at low cost to meet DOE's 2015 targets.

Approach

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

TreadStone takes a different approach to develop the metal bipolar plates for PEM fuel cell applications. It was found that it is unnecessary to have the entire surface electrically conductive to ensure low interfacial contact resistance (<10 mΩ.cm^2) between the bipolar plate 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 resistant and highly electrically conductive material (such as Au) forms a path 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

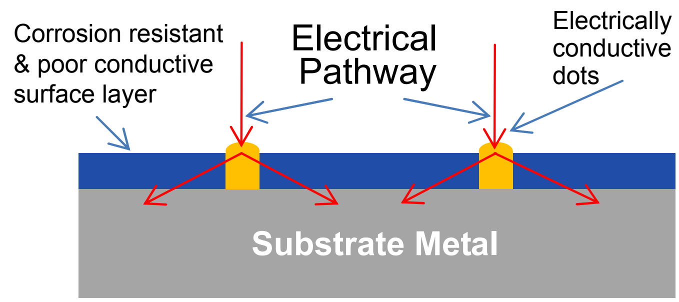

FIGURE 1. Schematic drawing of TreadStone's corrosion resistant metal plate design

micrometers, are distributed on the metal surface. The average distance between the conductive vias is 20-70 µm. The dense distribution of conductive vias ensures a uniform current distribution between the GDL and metal bipolar plate.

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

The focus of this year's project is the scale up and optimization of TreadStone's current metal bipolar plate using small amount of gold (gold dots technology) that was demonstrated in a 1,000-hour durability test by Ford Motor Company in a full-size 10-cell stack testing under dynamic driving condition in 2010. The objective is to scale up the process for small scale commercial production with good processing consistency across the large size plates and between batches.

As reported in last years' annual report, there was a small increase of through plate voltage (TPV) drop (TPV increased from 15 mV to 18 mV) of TreadStone's metal bipolar plate after the 1,000-hour test at Ford. The post-test evaluation of the plate was conducted to identify the cause of the TPV increase. It was found that some gold splats of the metal plates were lost after the test. Scanning electron microscope (SEM) observation of the plate indicates that a large amount of gold splats on Ford's bipolar plates are in spherical shape and can be removed by rubbing of the plate with a tissue (or GDL). The hypothesis is that the spherical gold splats, that have small bonding area with the stainless steel (SS) substrate as shown in Figure 1A, were rubbed off the SS substrate surface during stack assembly and testing leading to the higher TPV after the stack testing. Therefore, optimization of the process is focused on the process controls

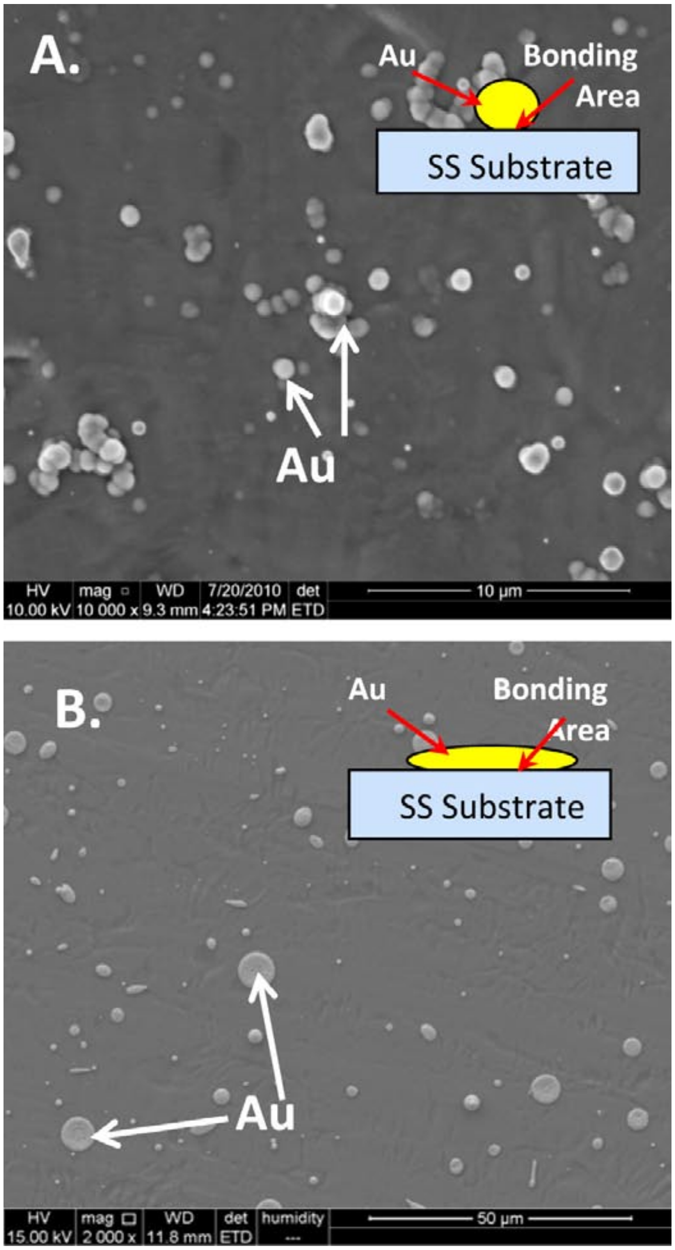

FIGURE 2. SEM pictures and schematic drawings of gold splats on SS substrate. A: spherical gold splats that have small bonding area with SS substrate, and B: flat gold splats that have large bonding area with SS substrate.

to obtain the flat gold splats that have much large bonding area with SS substrate, as shown in Figure 2B.

In conjunction with the process optimization, we have modified the spray system for small volume commercial production. We have finished the system modification and processing optimization to produce metal plates with consistent quality. Using this modified system, we processed 40 bipolar plates with the optimized processing condition, for the second 20-cell stack demonstration at Ford. The picture of the plate and comparison of TPV of five plates at four spots

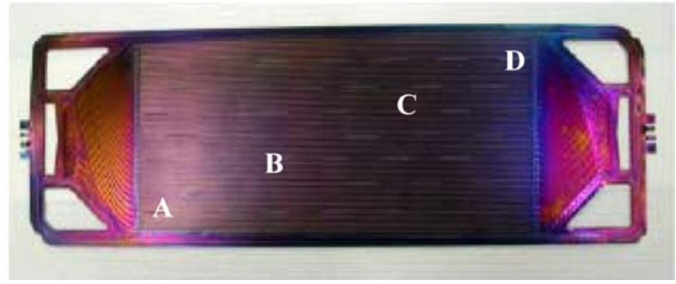

Plate #	TPV mV (@ 1A/cm^2)				
	A	B	C	D	Average
#1	6.75	6.14	6.64	6.45	6.50
#2	5.36	6.25	6.95	6.60	6.29
#3	7.60	7.12	7.00	6.40	7.03
#4	7.00	6.40	6.00	7.40	6.70
#5	7.60	6.90	7.50	7.50	7.38

FIGURE 3. Picture of the SS bipolar plate and the comparison of TPV at four spots of the plate for five plates

on each plate is shown in Figure 3. It shows that all plates have very low TPV and is uniform across the plate.

We have conducted the accelerated corrosion of TreadStone's metal plates at Los Alamos National Laboratory. The experiment is conducted with 30,000 cycles of the cell current between 0 A (open circuit voltage) and 1.2 A/cm^2. It was found the performance of the cell using TreadStone's metal plates is similar as the cell using standard graphite plates. The post-test analysis indicates that TreadStone's metal plates are stable in normal PEM fuel cell operational conditions.

The development of metal bipolar plate using carbon steel and aluminum substrates using TreadStone's metal plate design focused on the coating process development to protect the metal substrate from corrosion in PEM operational conditions. Different from other technologies, the only requirement of the coating for TreadStone's metal design is corrosion resistance. The electrical contact resistance can be reduced using gold (or other conductive materials) dots as demonstrated in the SS substrate. We treated the carbon steel and aluminum substrates using anodizing, phosphate treatment and chromium plating. It was found that anodizing and phosphate treatment could provide a stable surface in alkaline conditions, but not in low pH (pH 2-3) PEM fuel cell conditions. Chromium plate surface can meet the corrosion resistance requirements for PEM fuel cells, but it is difficult to obtain defect-free coating. There were pin-holes in a thin chromium coating layer, and micro-cracks in thick chromium coating layer.

In addition to PEM fuel cells, we have demonstrated the application of this technology in similar applications, including PEM electrolyzer, AEM fuel cells and some flow battery systems. These demonstrations have shown that TreadStone's metal plate technology can meet the requirements of high corrosion resistance and low electrical contact resistance of metal plates at low cost. We will continue the technology development in these areas.

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 process has been optimized for small-scale commercial production. In addition to the PEM fuel cell applications, we have demonstrated the application of this technology in other similar application, such as electrolyzer, AEM fuel cells and flow batteries. Further development will be focused on:

- Identify a manufacturing partner for large-scale commercial fabrication of the metal plates.
- Further evaluation with more industrial partners.
- Extend the application into electrolyzer and flow battery markets.

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