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

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Contract Number: 09EE0000463

Subcontractors:
- Ford Motor Company, Dearborn, MI
- Gas Technology Institute, Des Plaines, IL
- Stony Brook University, Stony Brook, NY
- IBIS Associates, Inc., Waltham, MA

Project Start Date: September 1, 2009
Project End Date: February 28, 2013

Overall 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.

Fiscal Year (FY) 2013 Objectives

- Finish the 2,000-hour durability demonstration of 20-cell short stack at Ford.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Fuel Cell Technologies Office 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 hydrogen fluoride, 80°C, peak active current <1 X 10^{-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.
[d] Includes contact resistance (on as-received and after potentiostatic experiment) measured.
n/a - not available

FY 2013 Accomplishments

Successfully demonstrated the application of TreadStone's metal plates in the 2,000-hour durability test using a 20-cell short automobile stack under dynamic operation conditions.

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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 the adequate corrosion resistance in PEM fuel cell environments, 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 (MEA) by the dissolved ions from the metal plates. Various corrosion protection techniques have been investigated to prevent 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 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 maintains the electrical conductance of the metal. The challenge of this approach is that there are only limited numbers 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 the 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 dots (yellow bars in Figure 1) 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 μm. The dense distribution of conductive vias ensures a uniform current distribution between the GDL and metal bipolar plate.

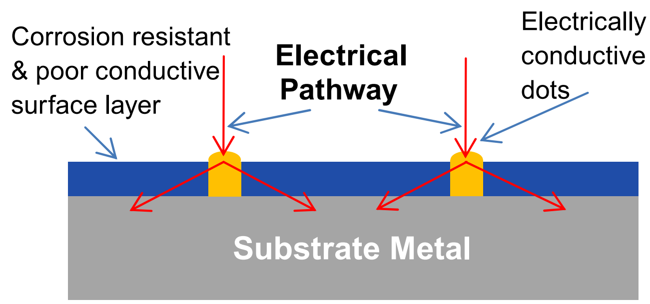

FIGURE 1. Schematic drawing of TreadStone's corrosion resistant metal plate design.

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 to finish the 2,000-hour durability test of TreatStone's metal plates in a full-size, 20-cell short stack under automobile dynamic operation conditions. The stack uses the metal plates from TreadStone and the MEA from W. L. Gore. During the test, the polarization curves were measured periodically. Figure 2 shows the polarization curves of the stack before and after 485, 750, 1,000, 1,500, 1,850, and 2,000 hours. It shows that stack voltage is slightly lower than the original stack voltage (0.624 V/cell at 1.3 A/cm^2 current density). The performance

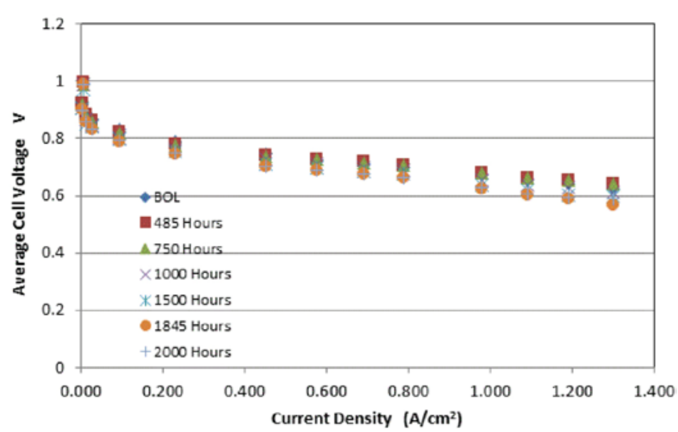

FIGURE 2. Performance comparison of the 20-cell stack using TreadStone's metal plates before (BOL) and during the 2,000-hour test.

degradation of this metal plate stack is due to the degradation of the MEAs under the testing condition using this prototype stack for components evaluation.

The direct parameter of the metal plate performance is the monitoring of the through-plate voltage (TPV) drop during the stack tests. In order to do it, one plate was taken out of the stack every 500 hours for the TPV measurement and visual inspection for any corrosion marks. By the end of the 2,000-hour test, the stack was dissembled for the TPV measurement and inspection of all plates. Table 2 summarizes the TPV of all plates (except the end plate on the first and last cell) under 1 A/cm^2 @ 90 psi compression force at the beginning of life (BOL) and the middle of life (MOL). It shows that there was not any increase of the plate TPV during the 2,000-hour test. Actually, the average plate TPV reduced from 8.83 mV (equal to through-plate resistance of 8.83 $m\Omega.cm^2$) to 6.37 mV (equal to through plate resistance of 6.37 $m\Omega.cm^2$) after the stack durability test. The reason for the TPV reduction is that gold splats were slowly compressed and turn flatter under the high compression force of the assembled stack, which would improve the electrical contact between the plates and GDL, resulting in the lower electrical contact resistance and TPV. Figure 3 shows the scanning electron microscope pictures of the gold splats in the valley (A) and land (B) areas of a tested plate. It shows that gold splats in the valley keep the original morphology because they were not pressed by the GDL. On the other hand, gold splats on the land area are flatter and bigger, after pressed by the GDL in the stack. The gold splat morphology change leads to the higher area coverage of gold on metal plates and results the lower plate resistance.

The reduction of the through-plate resistance after the 2,000-hour test indicates that TreadStone's metal plate is suitable for automobile fuel cell applications.

TABLE 2. Comparison of Plate TPV at BOL and MOL

Plate ID	Testing Time, hours	TPV mV	
		MOL	BOL
Average		6.37	8.83
# 01	2,000	7.53	9.68
# 02	2,000	6.52	10.32
# 03	2,000	6.28	8.52
# 04	2,000	5.73	9.15
# 05	2,000	5.88	8.32
# 06	2,000	7.80	8.79
# 07	2,000	7.38	9.55
# 08	2,000	6.10	9.52
# 09	2,000	5.58	8.59
# 10	2,000	7.42	9.25
# 11	2,000	6.50	7.69
# 12	2,000	6.15	10.72
# 13	2,000	5.82	8.25
# 14	2,000	5.92	8.39
# 15	2,000	5.68	7.99
# 16	2,000	5.67	8.12
#17	1,500	5.93	7.42
#18	500	5.90	9.09
#19	1,000	7.21	8.49

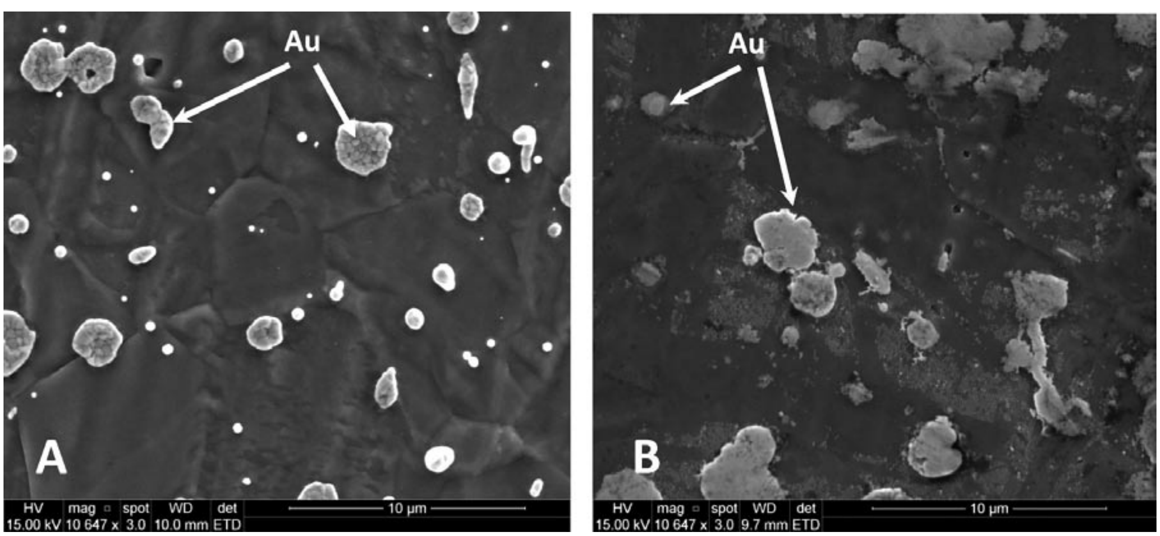

FIGURE 3. Scanning electron microscope picture of gold splats (A) in the valley, and (B) on the land area of a plate tested in the 20-cell short stack.

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, anion exchange membrane 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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