V.L.2 Low-Cost PEM Fuel Cell Metal Bipolar Plates

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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 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 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 meeting the performance requirements. There are a number of performance requirements to PEM fuel cell bipolar plates. The most challenging requirements for metal bipolar plates are summarized in Table 1. TreadStone's existing (2009) technology can meet DOE's 2010 target. This project is aimed to meet DOE's 2015 target.

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

Parameter	Unit	TreadStone 2009 Status	DOE Targets	
			2010	2015
Plate Cost [a]	\$/kW	$4.91	5	3
Plate Weight	kg/kW	<0.4	<0.4	<0.4
Corrosion Anode [b]	$\mu A/cm^2$	n/a	<1	<1
Corrosion Cathode [c]	$\mu A/cm^2$	<0.01	<1	<1
Resistance [d]	Ohm cm^2	<0.01	<0.02	<0.02

[a] Based on 2002 dollars, 1 W/cm^2 power density and projected 500,000 stacks per year production.
[b] 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.

Accomplishments

- Completed the low-cost conductive vias development. Demonstrated the processing technologies for Pd/Au composite vias, carbon nanotubes and conductive carbides as the conductive vias. The corrosion current of metal plates with these vias are below 1 $\mu A/cm^2$ in pH 3 H_2SO_4 + 0.1 ppm hydrofluorhydric acid (HF) solution under 0.8V normal hydrogen electrode (NHE) at 80°C.
- Developed the processing technology and the identified the coating materials for low-cost carbon steel substrate for PEM fuel cell applications.

- Demonstrate our current metal plates in portable, stationary applications, operating at ambient pressure conditions, with short stack having 30 cm^2 and 267 cm^2 active area, respectively.
- Demonstrated a 300 cm^2 active area, 10-cell, 2.5 kW short stack under utilizing durability testing cycle (including the Federal Test Procedure [FTP] cycle along with others) to mimic the automobile real world driving conditions. The stack has finished 800 hours stable operation, and continues to operate 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 the adequate corrosion resistance in the PEM fuel cell environment, which results in rapid performance degradation due to the formation of 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 performance requirements. However, it is still a challenge to have a 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 the low cost to meet DOE's 2015 targets.

Approach

Most people working on metal bipolar plates have been tried to cover 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 limited low-cost materials that could meet electrically conductive and corrosion-resistive requirements for PEM fuel cell applications, and the processing to apply these materials on metal substrate is either difficult or at 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 whole surface electrically conductive to ensure the low contact resistance (interfacial contact resistance <10 mΩ.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 (green layer in Figure 1). A corrosion-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 (not the whole land area) pass the metal plate to the other side for the cathode reaction on the cathode of the adjacent cell. The conductive vias have 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 by using a small portion (<1-2%) of the plate surface for electrical contact. It was found that it could have more than 500,000 via/in^2 on 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 ensure the low contact resistance of metal plates.

Results

TreadStone's current metal bipolar plate uses small amount of gold as the electrical contacting material in the form of conductive vias, and stainless steel as the substrate material. In this project, we plan to develop the lower cost material to reduce the gold usage, or replace gold as the contact material. We have finished the process development to use palladium/gold composite as the contact materials. We also developed

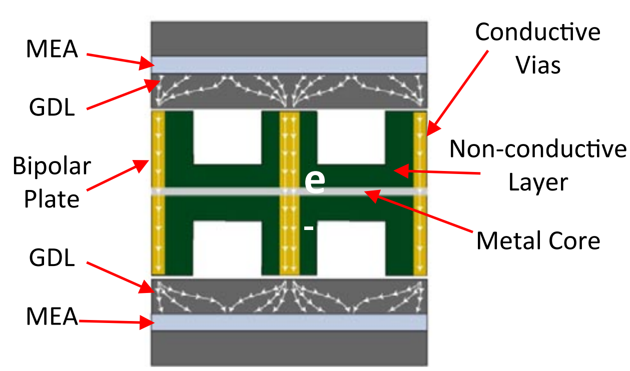

FIGURE 1. Schematic Drawing of TreadStone's Corrosion-Resistant Metal Plate Design

the process to use carbon nanotubes and conductive carbides as the conduct material.

The palladium/gold composite uses the palladium particle as the base material, and the very small amount of gold plated on the palladium surface to ensure low contact resistance of the metal plate with GDL. The gold is in the form of 10-20 nm thick on the palladium particle surface. The corrosion experiments and the electrical contact resistance measurements indicate that stainless steel with the palladium/gold composite conductive vias can meet the PEM fuel cell application. Because palladium is about 30% cheaper than gold, this approached could reduce the gold vias cost.

Using carbon nanotube and carbides as the conductive via materials can eliminate the gold on the metal bipolar plates. We have developed the processing technology to deposit carbon nanotube and carbide particles on metal plates. Figure 2 shows the microscopic pictures of carbon nanotube and chromium carbide on 304 stainless steel surface. Figure 3 shows the potentiostatic corrosion test of 304 stainless steel with carbon nanotubes on the surface in pH3 H_2SO_4 + 0.1 ppm HF solution under 0.8 V NHE at 80°C. The contact resistance of the stainless steel plates with carbon nanotube before and after 100 hours corrosion tests is below 10 mΩ.cm^2. The corrosion test of stainless steel with chromium carbides on the surface shows the similar performance that indicates these metal plates have the potential to be used in PEM fuel cells.

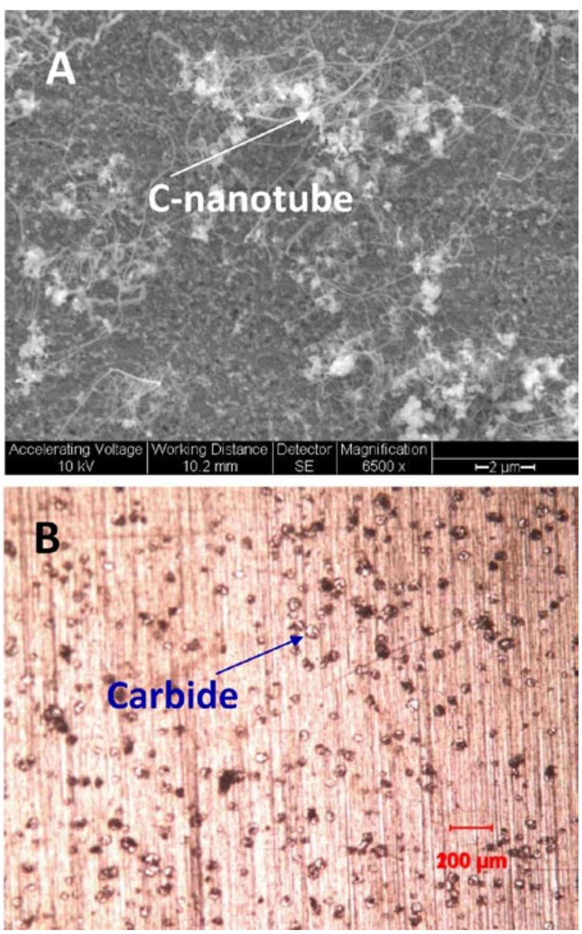

FIGURE 2. Microscopic Pictures of (A) Carbon Nanotubes and (B) Conductive Carbides on Stainless Steel Surface

Stainless steel substrate cost is the major cost item (accounting for 50-60%) in the metal bipolar plate, even using the commercially available lower cost 304 stainless steel foil. We plan to develop lower cost carbon steel or aluminum-based substrate material for PEM fuel cell applications. In the first year of the project, we have developed the processing technology to apply a corrosion-resistant, non-conductive coating material and gold or palladium conductive vias to prevent the substrate material corrosion while maintain the desired electrical conductance requirement.

Short stacks using TreadStone's metal plates have been designed, and assembled for portable, stationary and automobile applications. The portable power stack has 30 cm^2 active area on each cell. The designated power is 200 W with open cathode for air cooling. The stationary stack has 263 cm^2 active area on each cell. The designated power is 1 kW with liquid cooling. The initial short stacks have been assembled, and their performance has been evaluated. The experiments are continuing to demonstrate the long-term stability of the stack using Treadstone's metal bipolar plates.

A 10-cell, 2.5 kW short stack for automobile application has also been assembled and tested at Ford Motor Company. Figure 4 shows the picture of the stack in the testing station. The stack has 300 cm^2 active area on each cell, and operates under high pressure. The stack is being tested for durability (which includes the FTP cycle along with others) mimicking real-world

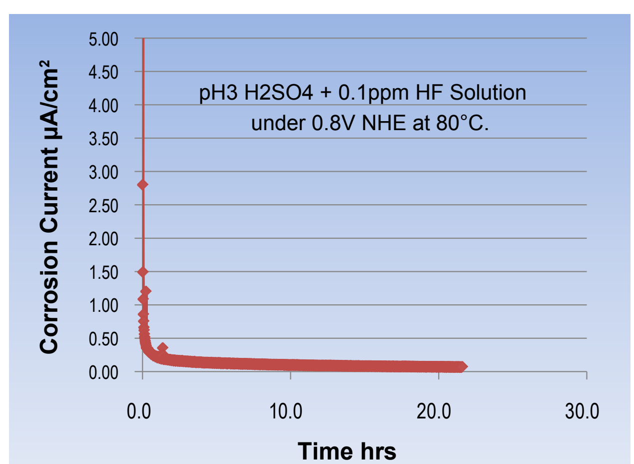

FIGURE 3. Pontentiostatic Corrosion Current of Stainless Steel Plate with Carbon Nanotubes

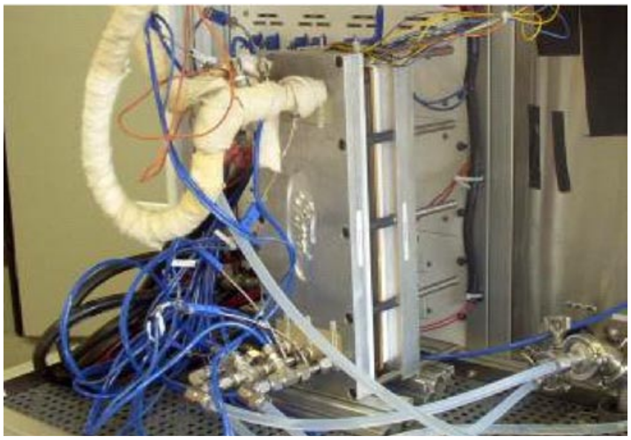

FIGURE 4. Picture of the 10-cell Short Stack under Long-term Stability Test at Ford

driving conditions. It has finished 800 hours of stable operation, and continues to operate.

Conclusions and Future Directions

Treadstone's unique corrosion-resistant metal bipolar plates have demonstrated stable operation for PEM fuel cells in portable, stationary and automobile applications. The processes to use lower cost materials have been demonstrated to further reduce the metal plate cost to meet DOE 2015 targets. Further development will be focused on:

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

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