Low Cost PEM Fuel Cell Metal Bipolar Plates

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May 11, 2011

Project ID# : FC023

Overview

Timeline

- Project Start Date: Sept. 1, 2009
- Project End Date: Aug. 31, 2011
- Percent Complete: 70%

Barriers

- Barriers Addressed:
  - Durability
    - Resistivity < 10 mohm.cm
    - Corrosion < 1 x10^{-6} A/cm^2
  - Cost
    - < $3/kW (2015)

Budget

- Total Project Funding: $2,763,452
  - DOE Shares: $2,182,125
  - Contractor Shares: $570,533
- Funding Received in FY10: $638,083
- Funding for FY 11: $744,042

Partners

- Gas Technology Institute
- Oak Ridge National Laboratory
- SUNY, Stony Brook
- IBIS Associations, Inc.
- Ford Motor Company

Relevance

Objective

- Objective (May 10 - March 11): Develop low cost metal bipolar plates to meet 2015 performance target and cost target (<$3/kW)
  - Develop C-steel & Al plates, reduce or eliminate Au usage.
  - Demonstrate our metal plate applications in portable, stationary and automobile fuel cell stacks.

Characteristic	Unit	2010 Target	2015 Target
Cost	$ /kW	5	**3**
Corrosion	$\mu A/cm^2$	<1	**<1**
Resistivity	$ohm.cm^2$	<0.01	**<0.01**

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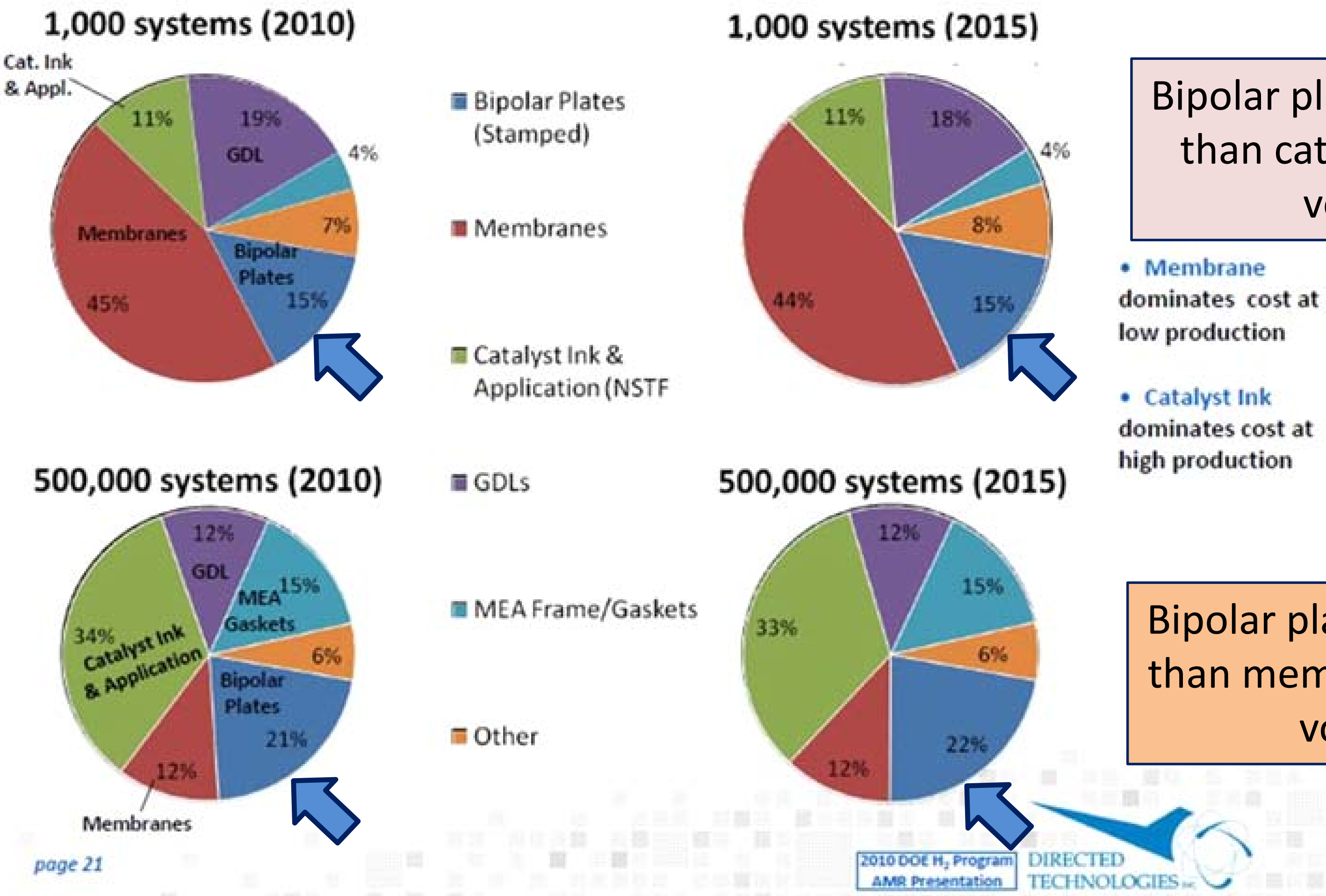
Relevance

Bipolar Plate Cost is a Major Portion of Stack



Bipolar plates cost more than catalyst in small volume

- Membrane dominates cost at low production
- Catalyst Ink dominates cost at high production

Bipolar plates cost more than membrane in large volume

B. James, J. Kalinoski & K. Baum, 2010 DOE H2 Program AMR Repsentation

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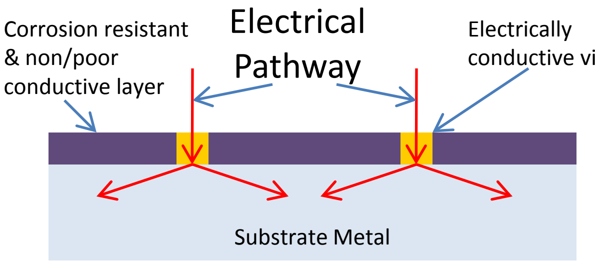
Technical Approach

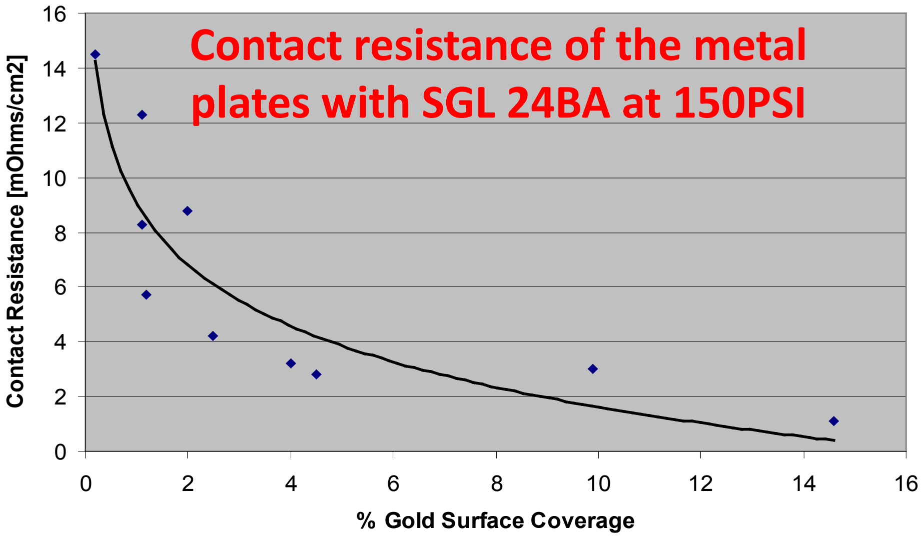
TreadStone's Metal Plate Design

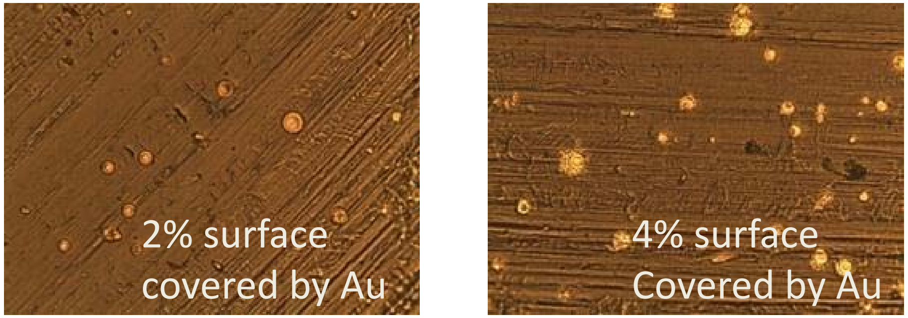
TreadStone's Plate Design



US 7,309,540, Dec. 18, 2007

- Use small conductive, corrosion resistant materials as conductive points (conductive vias) to cover a small portion of metal surface
- Use non-conductive, corrosion resistant materials to cover majority surface of the metal plates





Approach

Work Plan and Milestones (Task 1 & 2)

Milestones	Month/Year	% Comp.
Task 1: Conductive Via Processing Development		
• Palladium Vias Processing Development	12/09	100%
• Carbon Nanotube Conductive Via Development	04/10	100%
• Conductive Carbide Via Development	08/10	100%
• Conductive Vias Fabrication Processing Optimized	02/11	100%
• Metal Plate Performance Verified	08/11	10%
• Long-term Stability and Corrosion Mechanism Study	08/11	30%
Task 2: Carbon Steel and Aluminum Based Plates Development		
• Carbon Steel Plate Baseline Process Demonstration	03/10	100%
• Carbon Steel Plate Process Development	08/10	50%
• Al Plate Baseline Process Demonstration	03/11	80%
• Al Plate Process Development	08/11	0%
• Long-term Stability and Corrosion Mechanism Study	08/11	10%

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Approach

Work Plan and Milestones (Task 3)

Milestones	Month/Year	% Comp.
Task 3. Fuel Cell Stack Application Demonstration		
Task 3.1 200W Stack Development and Demonstration		
•200W Stack Initial Performance Test	02/10	100%
• Optimized 200W Stack Performance Demonstration	08/10	100%
• 200W Stack Lifetime Performance Test	08/10	30%
Task 3.1 1 kW Stack Development and Demonstration		
• 1kW Stack Initial Performance Test	02/11	100%
• Optimized 1kW Stack Performance Demonstration	07/11	50%
• 1 kW Stack Lifetime Performance Test	08/11	0%
Task 3.1 200W Stack Development and Demonstration		
• Metal Plates Demonstration for Auto. Applications	08/11	50%
→ 10-cell stack 1000 hours demonstration (Ford in-kind support)		100%
→ 20-cell stack 2000 hours demonstration (Ford)		20%

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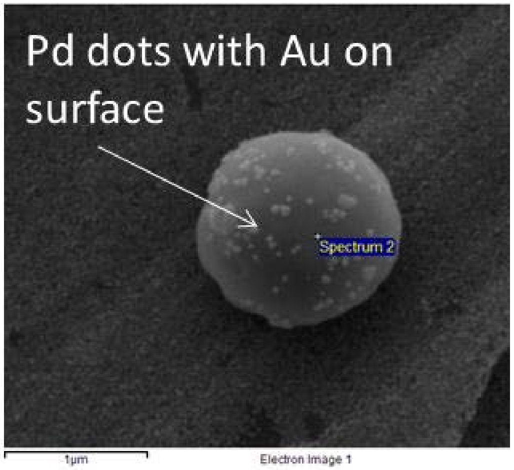
Technical Accomplishments

Reduce Gold usage with Palladium

Using Pd as the base material of conductive vias, and plating very thin layer of gold on Pd surface



Contact Resistant before and after the corrosion Test in pH2 + 5 ppm HF under 1V NHE at 80°C

Sample #	*Electrical Contact Resistance (mΩ.cm²) (at 150 psi compression)*	
	Before	*After*
#1	*2*	*2*
#2	*10*	*6*
#3	*11*	*12*
#4	*5*	*4*

Electrical contact resistance is measured under 150 psi with SGL 35 BA GDL

Pd is cheaper than Au, but still a precious metal. Similar as gold, its price has experienced high fluctuation.

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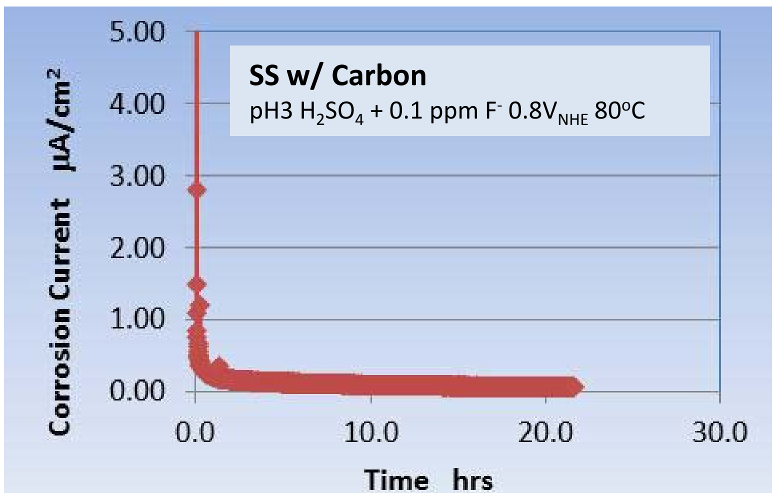
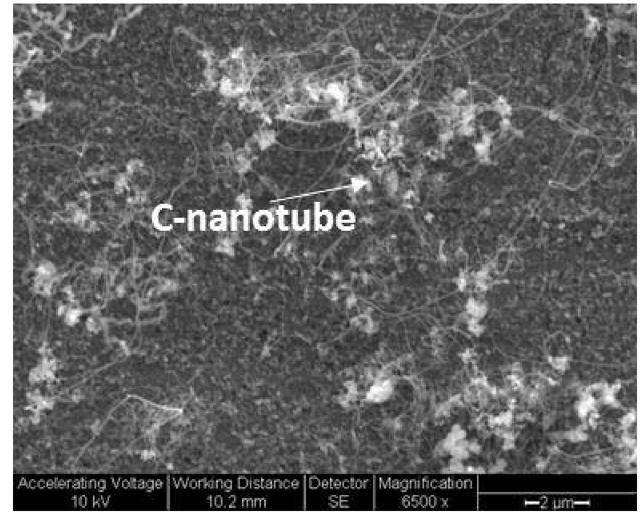
Technical Accomplishments

Eliminate Gold with Carbon Nanotubes

Grow carbon nanotubes on metal plate surface as the electrical contact points





#	*Contact Resistance ($m\Omega.cm^2$ at 150 psi)*
Original	*2*
24 hrs @ 0.8V_{NHE}	*0.5*
100 hrs @ 0.8V_{NHE}	*7*
100 hrs @ 1.0V_{NHE}	*16-32*

Electrical contact resistance is measured under 150 psi with SGL 35 BA GDL

Carbon tube adhesion on substrate is reduced after corrosion test, which indicates the risk of unreliable longterm (5000 hrs.) operation stability.

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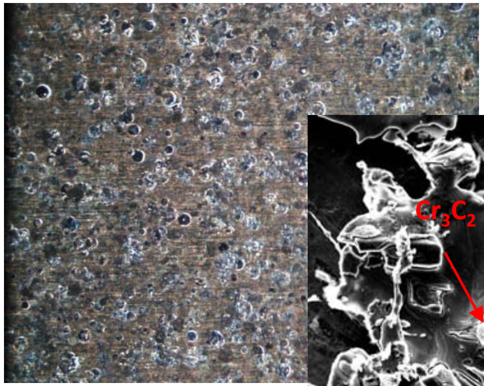
Technical Accomplishments

Using Carbides as the Electrical Contact Points

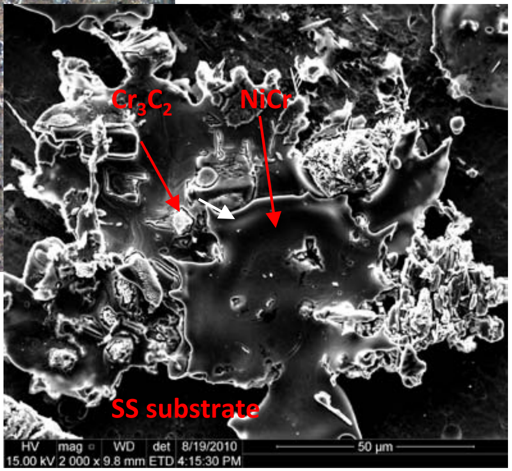
Spray conductive carbides (w/binding metal) on SS substrates

Optical Microscopy Picture

uniform, random distribution of carbides



SEM Picture



Corrosion Evaluation of plates w/ Carbides

---- in pH3+ 0.1 ppm HF at $0.8V_{NHE}$ at 80°C

Carbides on 304 SS	*Corrosion Current ($\mu A/cm^2$)*	*Contact Resistance ($m\Omega.cm^2$)*	
		Before Corrosion	*After Corrosion*
Chromium Carbide	0.08	*7-8*	*6-7*
Tungsten Carbide	~31	*12-14*	*6.9-22*

Most Promising Approach (← Chromium Carbide)

Electrical contact resistance is measured under 150 psi with SGL 35 BA GDL

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Technical Accomplishments

Cost Analysis of Alternative Materials

Plate Fabrication Process:

Stamping Cathode & Anode Plates
↓
Degrease & Cleaning
↓
Cathode & Anode Plate Welding
↓
Leak Check
↓
Plate Coating
↓
Bipolar Plates

316 SS material cost accounts over 65% of the plate cost:

- At \$2/lb (historical average)
  - SS material cost: \$1.05/plate
- At \$3.92/lb (Aug. 2010)
  - SS material cost is \$2.06/plate

Coating Cost: (based on \$1,000/oz Au)

Baseline Au dots plate:	\$0.33/plate
Pd – Au dots plate:	\$0.31/plate
Carbon fibers:	\$0.79/plate
Carbide:	\$0.30/plate

Thermal sprayed carbide approach has the lowest cost

IBIS

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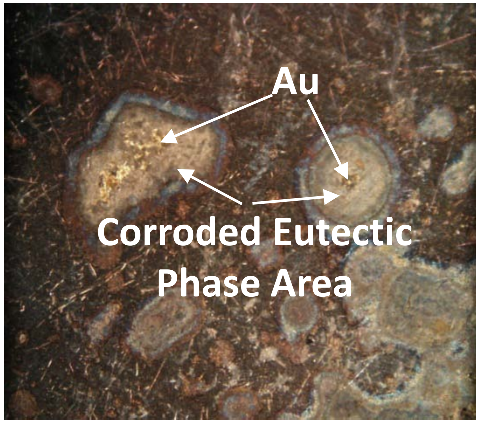
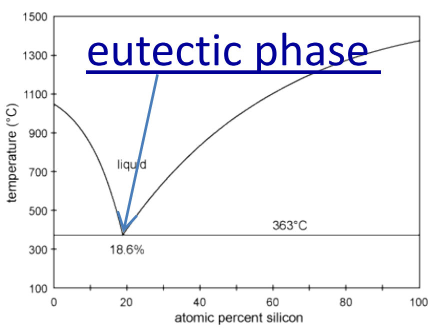
Technical Accomplishments

Carbon Steel Based Metal Plates

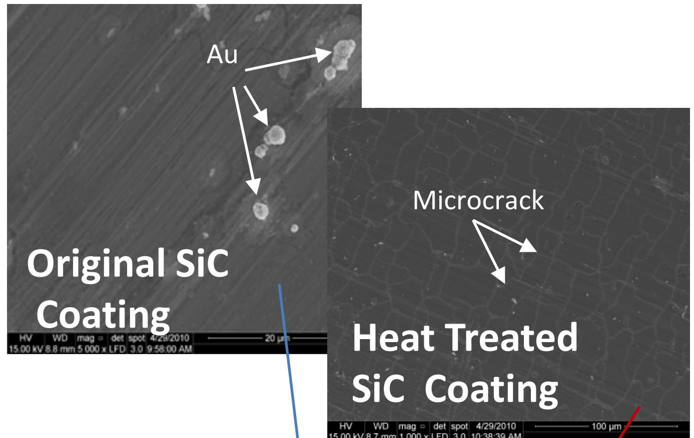
Si Coating Applied by CVD

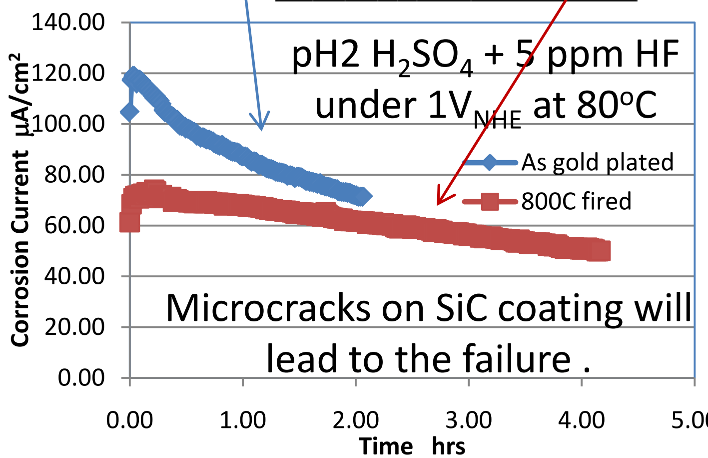


Gold reacts with Silicon to form the eutectic phase that does not have the desired corrosion resistance.



SiC Coating Applied by PECVD





Major Challenge for Vapor Based Processing:

1. C-steel rusting before coating
2. Dusts from environment

Wet chemistry process can overcome these risks.

Follow 2010 AMR reviewer's recommendation, we have held off the C-steel work to focus on Al based plate development

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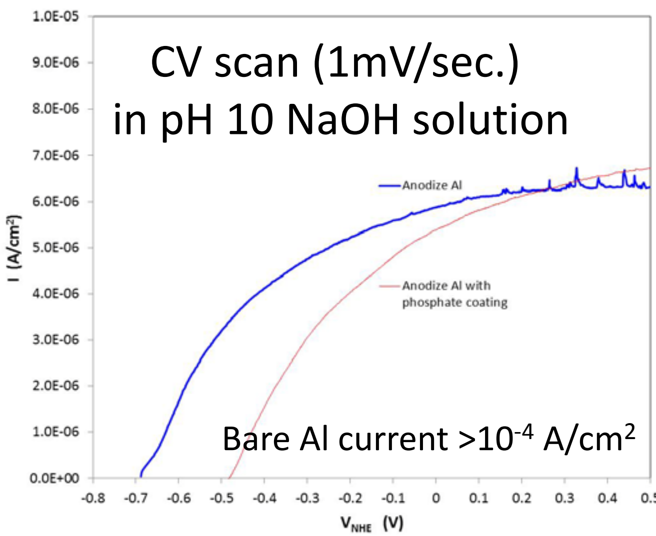
Technical Accomplishments

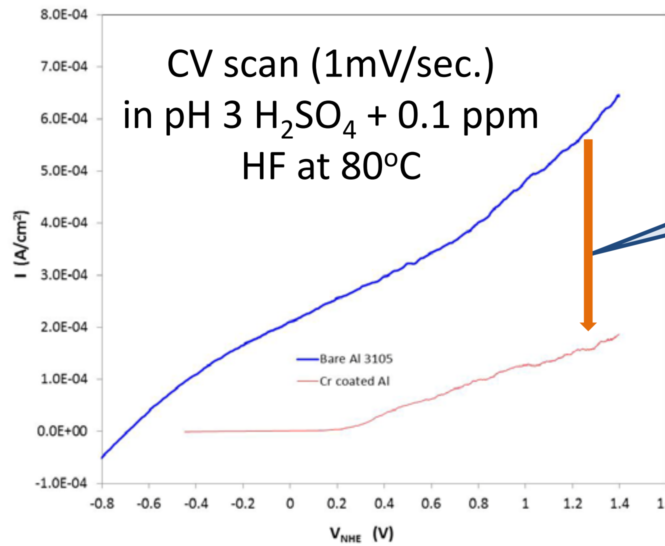
Aluminum Based Metal Plates

Anodizing & Phosphate Treatment



- No improvement of corrosion resistance in acidic solution.
- A little improvement of corrosion resistance in alkali solution.

Chromium Plating

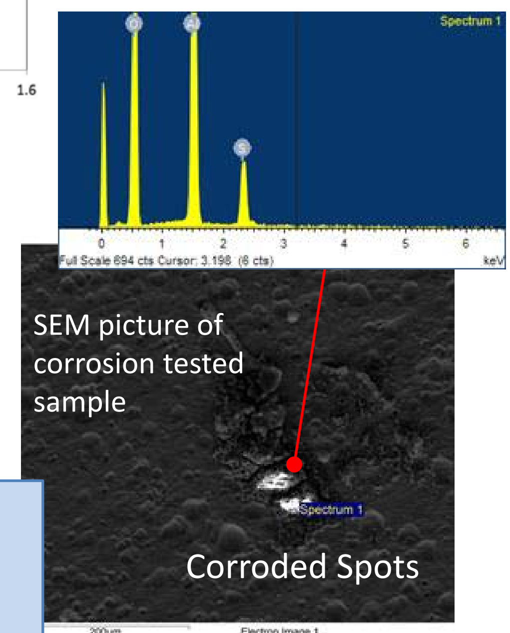


- Cr plating can protect Al plate.
- Eliminating coating defects is critical

- Cr plated area shows no corrosion.
- Need to eliminate coating defects.

Corroded spots

Sulfide inclusion, no Cr plated on the surface.



The coating process is down selected to Cr plating. TreadStone's SS based technology can be applied on the Cr coated surface.

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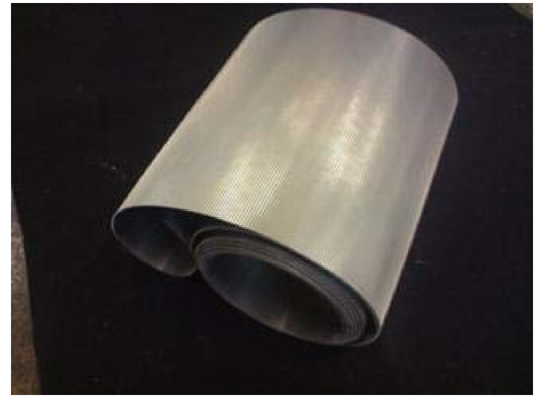
Technical Accomplishments

Portable and Stationary Stack Optimization

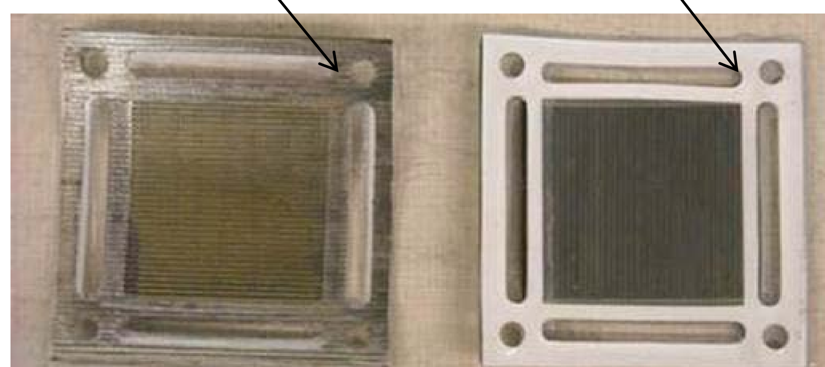
- Using rolled stainless foil as the plate substrate to eliminate the plate stamping cost.
- Conductive coating on coolant side as well to eliminate the laser welding
- Hot rolled plastic gasket for bond and seal the anode/cathode plates with water-cooling channels. This method enables fast, continuous metal bipolar plate manufacturing and fuel cell assembly at low cost.



Rolled stainless steel plate

Thermoplastic hot pressed metal plat

Foam gasket



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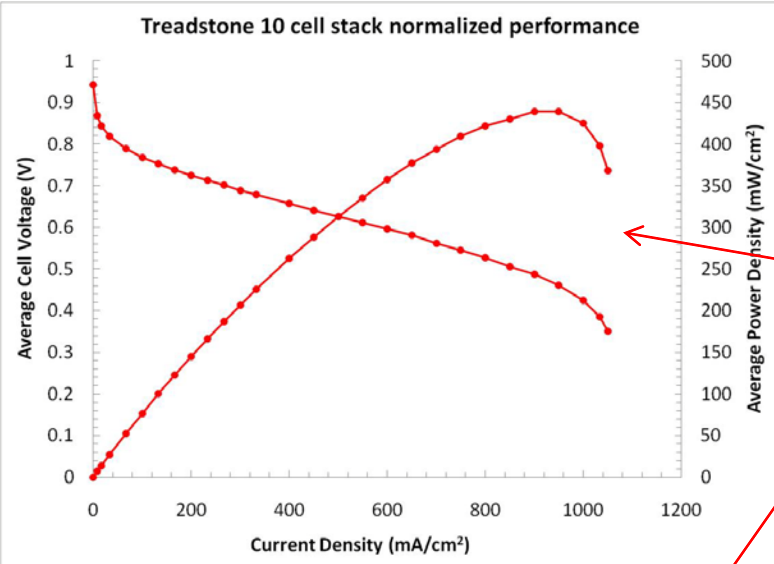
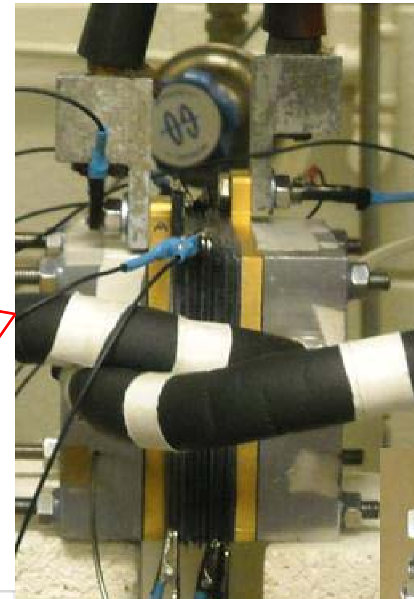
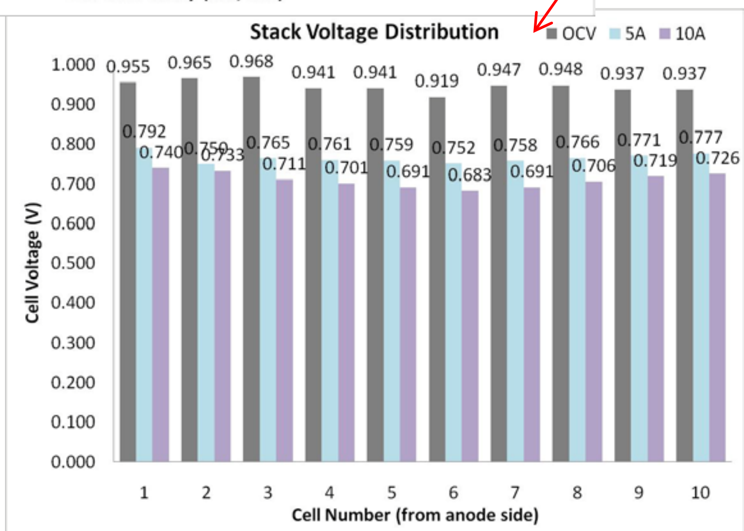
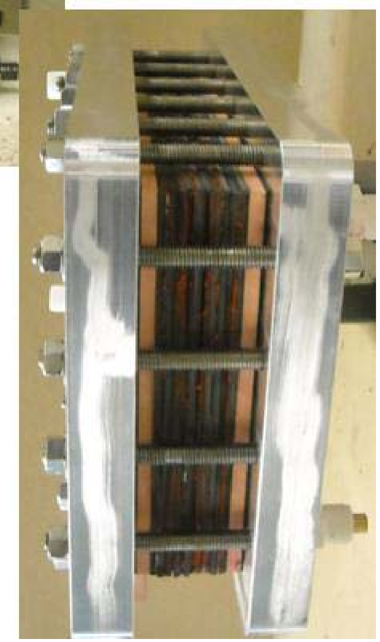
Technical Accomplishments

Portable and Stationary Stack Demonstration









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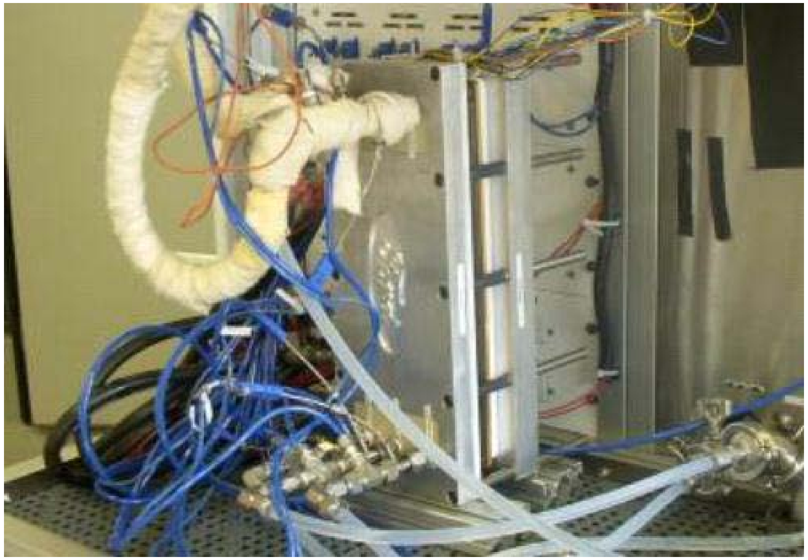
Technical Accomplishments

In-situ Test of TreadStone Au-Dots Baseline Material

- A 10 cell short stack was assembled with TreadStone Au-Dots baseline material for *in-situ* durability test.
- Ford designed metal bipolar plates w/SS316L substrate,
  - Coating: TreadStone Au-dot Baseline Material
  - 300 cm^2 active area
  - Substrate thickness: 0.1 mm
- Durability Cycle:
  - The stack is being tested for durability utilizing durability cycle (which includes FTP cycle along with others) mimicking real world operating conditions.



Short stack on the test stand at Ford

Ford

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Technical Accomplishments

In-situ Test of TreadStone Au-Dots Baseline Material

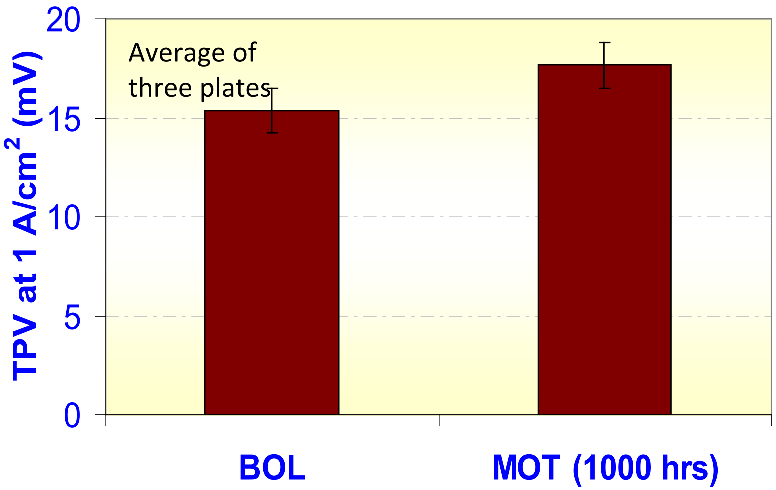

Plate TPV at BOL and EOT (1000 hrs)

- TPV (Through Plate Voltage-drop) at 1.0 A/cm^2 was measured at BOT (Beginning of Test) and EOT (End of Test).
- BOT TPV of stamped bipolar plate with baseline material was 15.4 mV.
- TPV increase (~2-3mV) was observed after 1000 hrs of testing. The average TPV was still meeting DOE requirement (<20 mV at 1 A/cm^2). TreadStone will improve coating materials to meet TPV targets (less than 10 mV) for 2nd year of the project.
- Metal cations in the stack effluent water (anode, cathode, and coolant) were below detectable limit of ICP analyzer (~ppb).

Collaborations

Gas Technology Institute

- Stack Design and Demonstration using Metal Plates for Portable and Stationary Applications

Dr. Chinbay Fan

SUNY, Stony Brook

- Thermal Spray Process Development for Metal Plate Fabrication

Prof. Sanjay Sampath

Oak Ridge National Lab.

- Corrosion Mechanism and Failure Model Study

Dr. Dane Wilson

IBIS Associates, Inc.

- Fabrication Cost Analysis

Mr. Tony Mascarin

Ford Motor Company

- Automobile Fuel Cell Applications

Dr. Shinich Hirano

Proposed Future Work

- **FY11**
  - Scale up the metal plate fabrication process.
  - Full performance evaluation of the plates produced with the scale-up process.
  - Cr plating on Al substrate process optimization to eliminate the Cr coating defects. Then, TreadStone's SS based technology (gold dots or carbide particles) will be applied on the Cr coated surface.
  - Optimized 1 kW stationary stack, and 200W portable stack demonstration.
  - Demonstration of a 20-cell stack, 2000 hours operation at Ford.

1. TreadStone will improve the coating of metal bipolar plate to meet corrosion resistance and electrical conductivity requirements.
2. Ford will conduct the *ex-situ* evaluations of the corrosion resistance for these improved materials, including +1.6 V_{NHE} (Air) and +0.5 V_{NHE} (H_2) potentiostatic.
3. The stamped metal bipolar plates with improved materials have to meet the electrical conductivity target (TPV <10 mV at the current density of 1.0 A/cm^2).
4. Ford will conduct a 20-cell short stack for the *in-situ* evaluation with 20 cell short stack (5 kW) for the improved materials, including 2000 hour durability testing.

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Summary

- ***Relevance:*** Reducing the metal bipolar plate cost to meet FY15 requirements.
- ***Approach:*** Using conductive dots on metal plates surface for fuel cell applications..
- ***Accomplishment:***
  - Demonstrated 1000 hours stable operation in automobile fuel cell stacks under dynamic operation condition.
  - Demonstrated the feasibility of using conductive carbides to replace gold as the conductive dots material.
  - Selected Cr plating on Al plates basic process, gold dots or carbides particles will be applied on the Cr plated Al plate surface to reduce the electrical contact resistance.
- ***Collaborations:***
  - Teaming with GTI for stack demonstration, SUNY Stony Brook for thermal spray process development, ORNL for corrosion mechanism study, and IBIS for fabrication cost study.
  - New partnership with Ford Motor Company for automobile application demonstration.
- ***Future Work:***
  - Optimize and demonstrate the Al based metal plate.
  - Scale-up the metal plate production process.
  - Demonstrate the metal plate application in portable and stationary stacks.
  - Demonstrate 2000 hours stable operation in 20-cell automobile stack at Ford.