TreadStone Technologies, Inc.

Low Cost PEM Fuel Cell Metal Bipolar Plates

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TreadStone Technologies, Inc.

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May 16, 2013

Project ID# : FC105

Overview

Timeline

- Project Start Date: Sept. 1, 2009
- Project End Date: Feb. 28, 2013
- Percent Complete: 100%

Barriers

- Barriers Addressed:
  - Durability
    - Resistivity < 10 mohm.cm
    - Corrosion < 1 x10^{-6} A/cm^2
  - Cost
    - < $3/kW (2020)

Budget

- Total Project Funding: $2,763,452
  - DOE Shares: $2,210,761
  - Contractor Shares: $552,690
- Funding Received in FY10: $1,264,748
- Funding Received in FY 11: $917,377
- Funding Received in FY 12: $0
- Funding Received in FY 13: $0

Partners

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

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Relevance

Objective

- Objective (May 2012 – Feb. 2013): Demonstrate the metal plate in a 20-cell stack under dynamic operation condition at Ford.
  - 2000 hours durability test
  - Check plate properties every 1000 hours

Key Technical Targets

Characteristic	Unit	2011 Status	2017 Targets	2020 Targets
Cost	$ /kW	5-10	**3**	**3**
Corrosion	$\mu A/cm^2$	<1	**<1**	**<1**
Resistivity	$\Omega.cm^2$	<0.03	**<0.02**	**<0.01**

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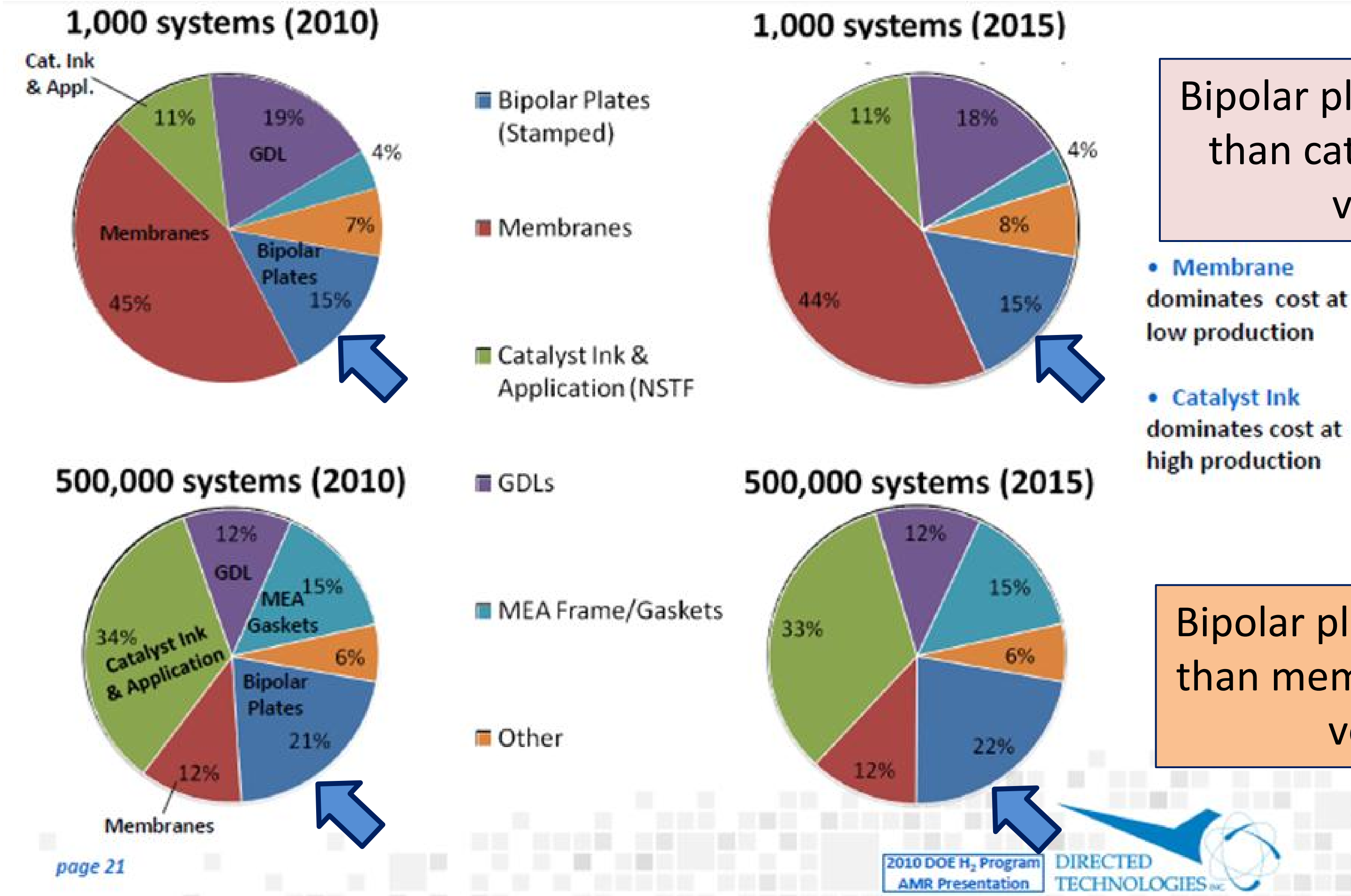
Relevance

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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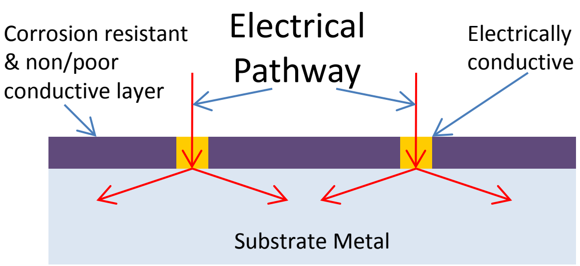
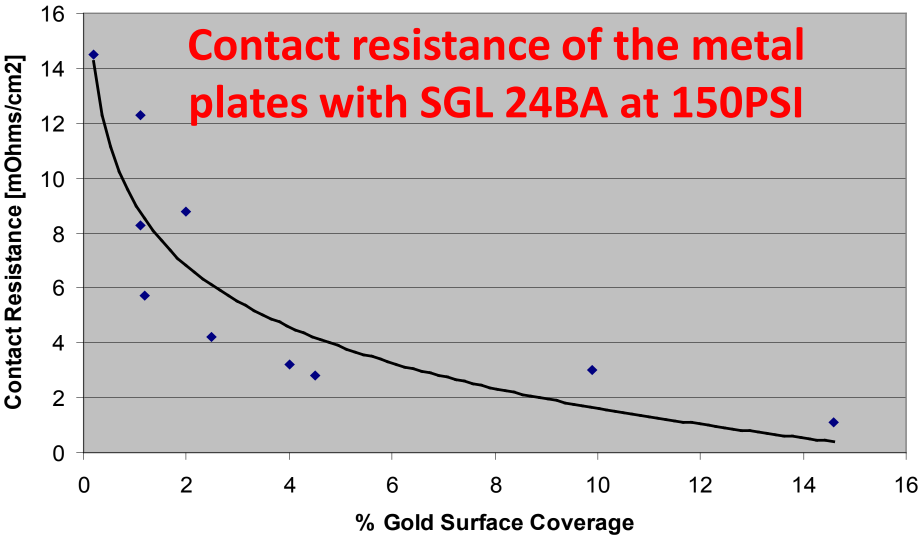
Technical Approach

TreadStone's Metal Plate Design

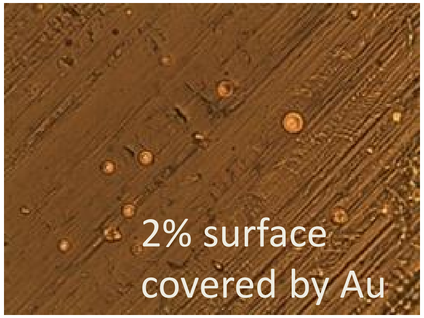
TreadStone's Plate Design

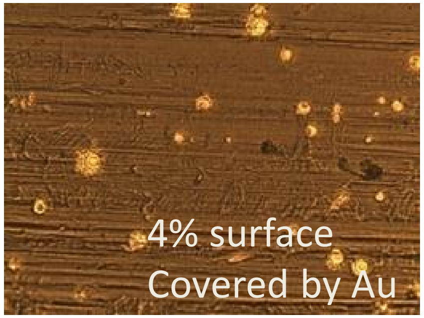


US 7,309,540, Dec. 18, 2007



- 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





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Approach

Work Plan and Milestones (Task 3)

Milestones	Month/Year	% Comp.
Task 3. Fuel Cell Stack Application Demonstration		
3.5 Metal Plate Evaluation for Automobile Applications		
3.5.1 Metal Coupon Preparation and Evaluation.	09/11	100%
3.5.2 Short Stack Metal Plate Preparation.	09/11	100%
3.5.3 Stack Assembly and Testing.	07/12	100%
3.5.4 Stack Lifetime Test in Client's Lab.	02/13	75%*

- Stack durability test was delayed because of the testing station scheduling and maintenance. The 2000 hours test is expected to be finished in April 2013.
- After achieve the 2000 hours durability test milestone, we plan to further extend the durability to 4000 hours at our own cost.

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Technical Accomplishments

TreadStone Au-Dots Technology Ex-situ Test

Attribute	Metric	Unit	2015 DOE Target	Ford Data on Au-Dots
Corrosion anode	**Current density at active peak in CV**	μA/cm^2	<1	No active peak
Corrosion cathode	**Current density at 0.8 V_{NHE} in potentiostatic expt.**	μA/cm^2	<1	~0.1
Area Specific Resistance	**ASR (measured through plane) at 6 bar contact pressure** (includes both side surface; doesn't include carbon paper contribution)	mOhm.cm^2	<20	8.70 (as-recd flat samples)
Electrical Conductivity	**In-plane electrical conductivity (4-point probe)**	S/cm	>100	34 kS/cm
Formability	**% elongation (ASTM E8M-01)**	%	>40%	53(∥ to RD*)/ 64 (⊥ to RD)
Weight	**Weight per unit net power** (80 kWnet system)	Kg/kW	<0.4	<0.30

*RD: Rolling Direction

Technical Accomplishments

First 10-cell Stack Test at Ford

- 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

Post Test Evaluation of Plates in the First 10-cell Stack

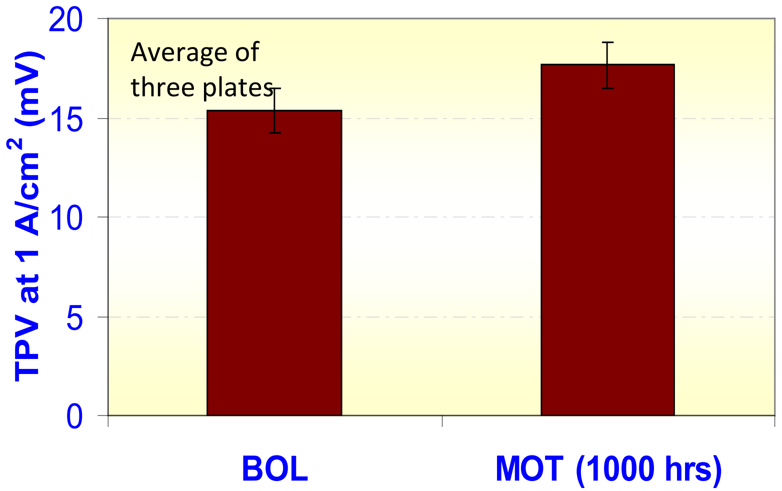

Plate TPV at BOL and EOT (1000 hrs)

BOL: Beginning of life
EOT: End of the test

- 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).

- Repeat the test using a 20-cell stack for 2000 hrs
- Check plate properties periodically through the test

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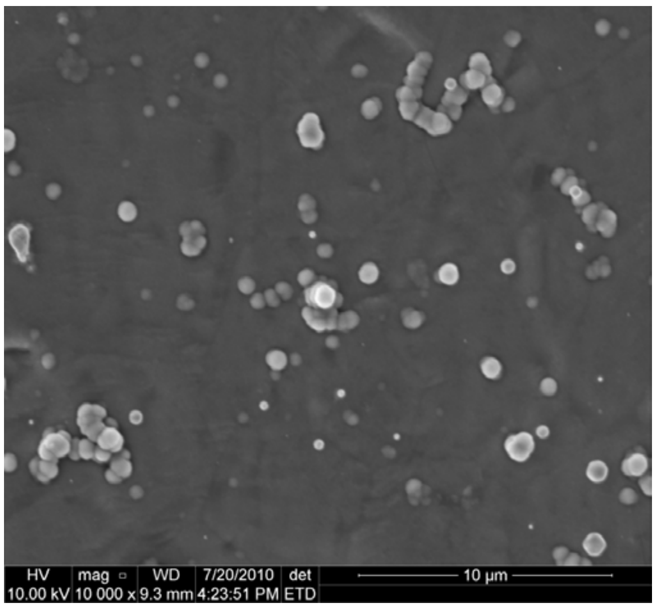
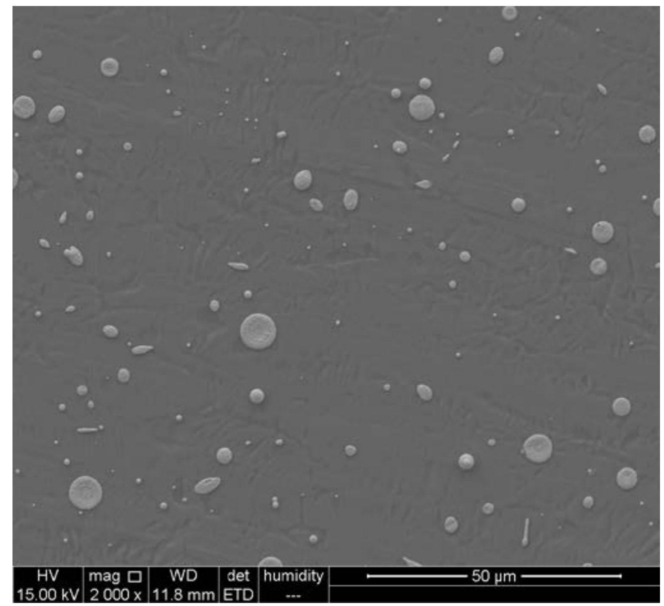
Technical Accomplishments

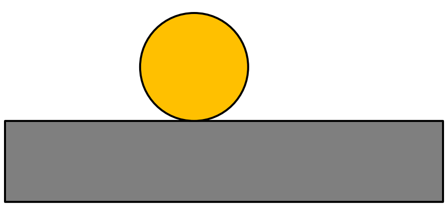
Processing Optimization

Original Process
(first 10-cell stack)

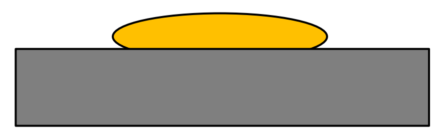


Modified Process
(Second 20-cell stack)





Optimize the thermal spray parameters to deposit flat splats for better adhesion of splats on SS substrate



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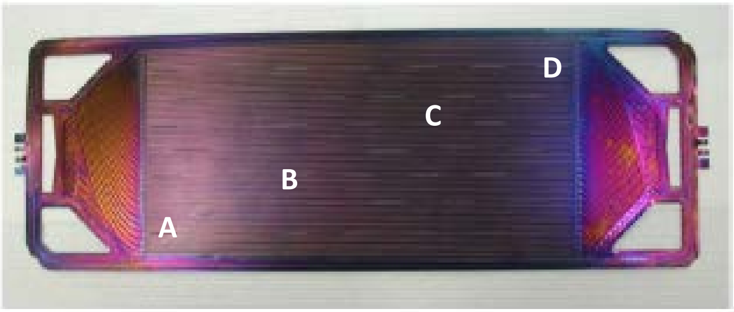
Technical Accomplishments

Plate Properties Consistency



As presented by Ford Motor Company at 2011 Fuel Cell Seminar, Orlando, FL . Nov. 1 2011

Processed 5 plates and measured TPV at 4 locations on each plate

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

The process has met Ford's requirements

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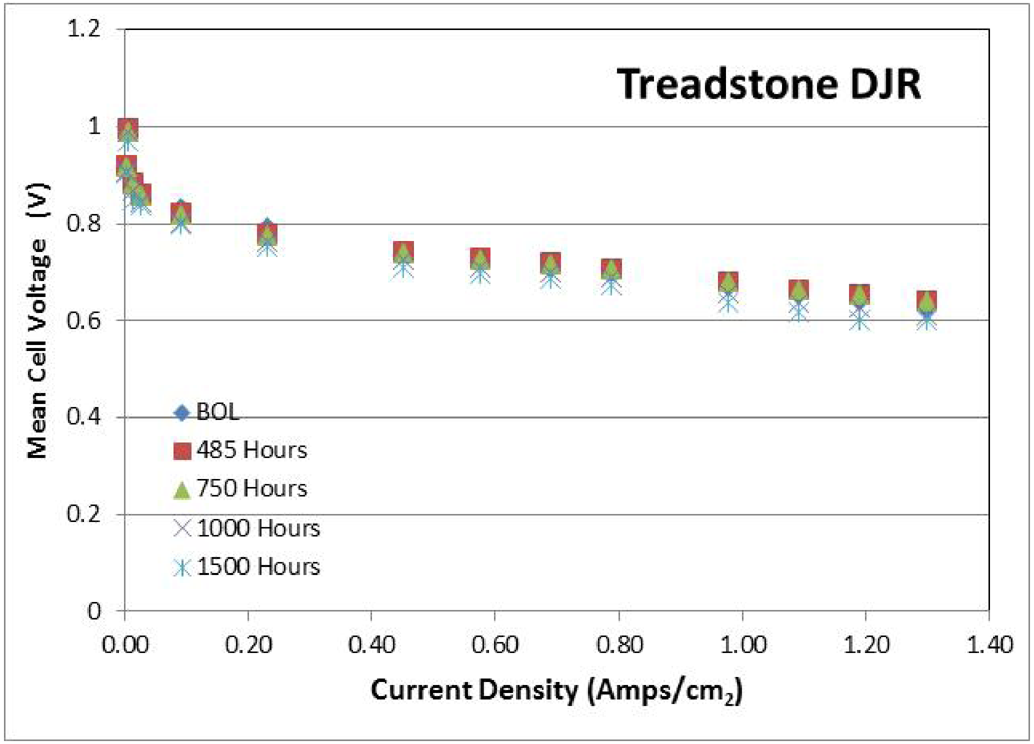
Technical Accomplishments

20-cell Stack Test using DJR Testing Protocol at Ford



Stack performance is the consistent with the Ford's standard based on this baseline flow field design.

TPV [mΩ.cm^2] (BOL < 10 mΩ.cm^2, EOL <20 mΩ.cm^2)

BOL Plate #3	500 hrs Plate #18	1000 hrs Plate #19	1500 hrs Plate #20
8.52	5.90	7.21	5.90

No TPV increase after 1500 hrs. test

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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

Future Work

-- *DOE FY12 SBIR I Project*

Novel Structured Metal Bipolar Plates for Low Cost Manufacturing

Budget:	$149,831
Project Start:	Nov. 15, 2012
Project End:	Aug. 15, 2013

- Overall Objective: Develop lower cost metal bipolar plates to meet performance target and 2020 cost target (<$3/kW)
  - Identify the electrical conductive and corrosion resistive coating for metal bipolar plate fabrication
  - Eliminate Au usage.
  - Develop the fabrication process based on roll-by-roll physical vapor deposition process
  - Demonstrate the technology in coupons and small cells in Phase I, and full size short stack test at Ford in Phase II of the project .

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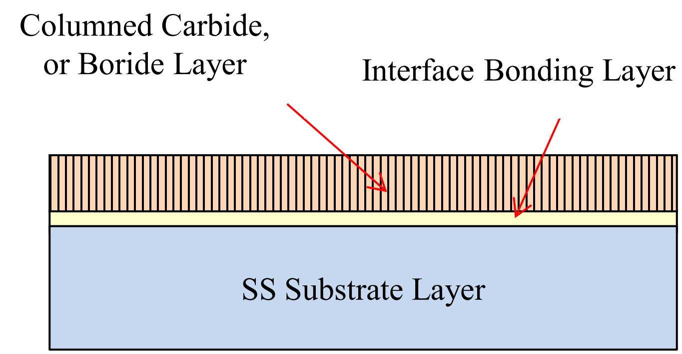
SBIR Project Technical Approaches

- Based on industrial available roll-by-roll sputtering technology for the coating materials deposition.
  - Ready for high volume production
- Identify the electrical conductive and corrosion resistive carbides and borides as the coating materials.
  - Low cost materials.
- Focused on the deposition and post coating treatment conditions to obtained the desired structure of the surface coating.
  - Proper interface bonding layer
  - Post deposition treatment for the right phase structure of the coating layer.



Applied Materials SmartWeb®
roll-by-roll cating system

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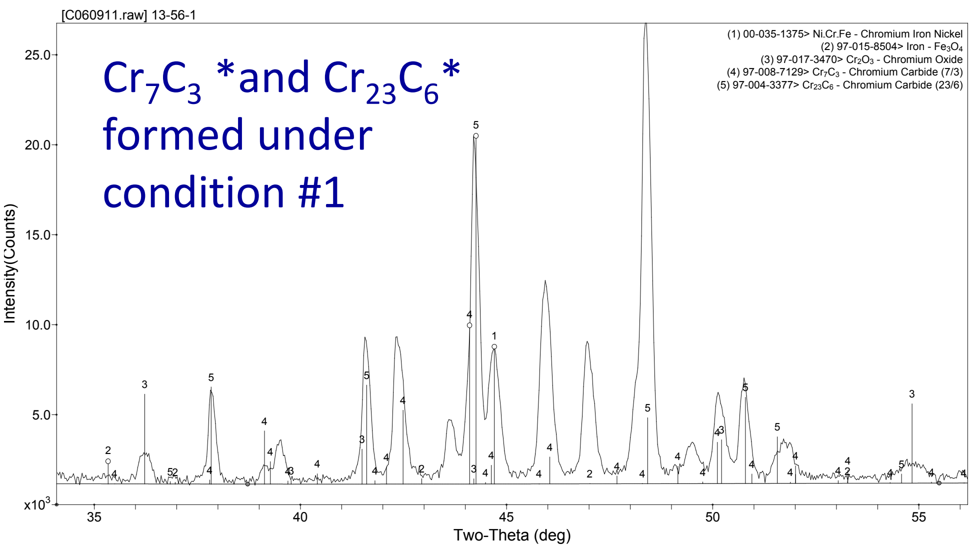
SBIR Project Initial Results --- Thin Film Coating Process

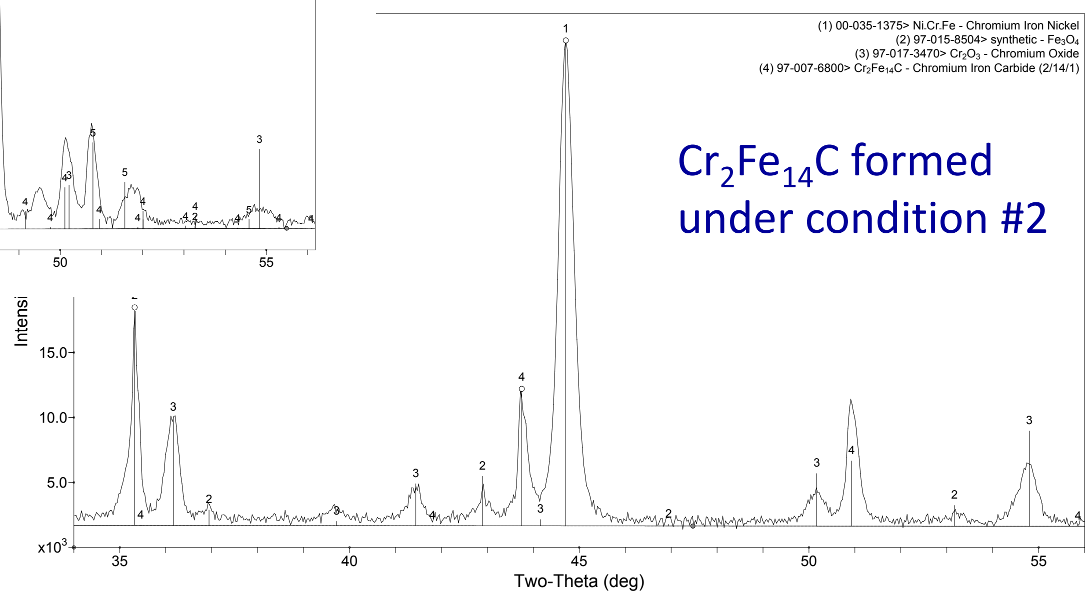
Deposit the CrCx layer (20-30 nm) on 316L SS

- The phase structure of CrCx is related with the processing condition
- Some phases are more stable than others in PEM fuel cell conditions.

Cr_7C_3 *and $Cr_{23}C_6$* formed under condition #1



$Cr_2Fe_{14}C$ formed under condition #2



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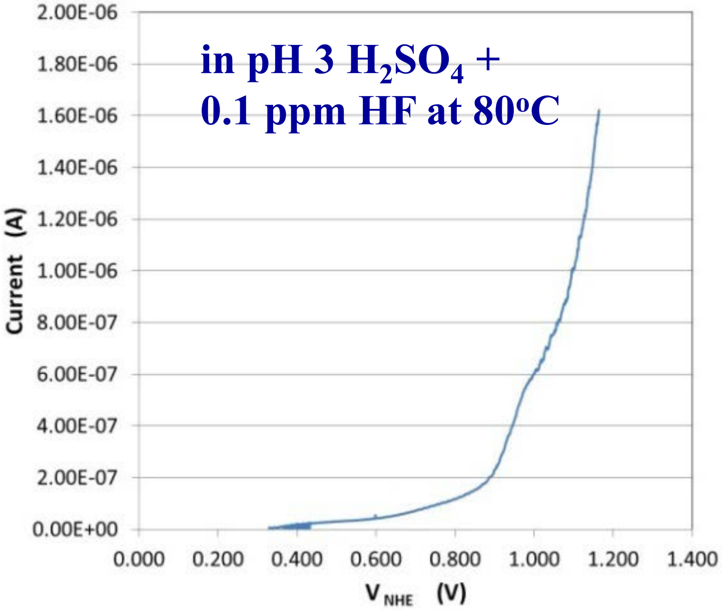
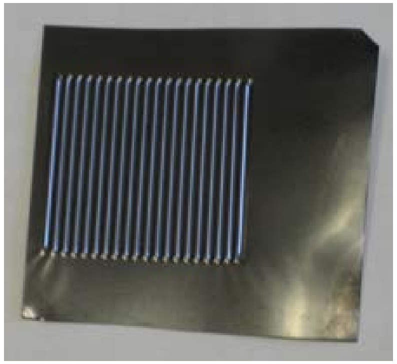
SBIR Project Initial Results --- Stability of CrCx Thin Film on SS



Stamped CrC_x coated 316L SS plate



Contact Resistance of SS with CrC_x coating before and after 100 hour, 0.8 V_{NHE} corrosion in pH 3 H_2SO_4 + 0.1 ppm HF solution at 80°C

Coated 316 SS		Coated Flat Foil	Post Coating Stamped
Corrosion Current mA/cm²		0.01	0.03
Contact Resistance mΩ.cm²	Before Corrosion	3.5	7.0
	After Corrosion	4.8	7.1

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Summary

- ***Relevance:*** Reducing the metal bipolar plate cost to meet FY20 requirements.
- ***Approach:*** Using conductive dots on metal plates surface for fuel cell applications..
- ***Accomplishment:***
  - Demonstrated 2000 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.
  - Partnership with Ford Motor Company for automobile application demonstration.
- ***Future Work:***
  - Continue the stack durability test to 4,000 hrs.
  - Scale-up the metal plate production process.