Low Cost Coating for PEMFC Metal Bipolar Plates

Presentation at International Workshop of Bipolar Plates for PEM Technology

Conghua "CH" Wang

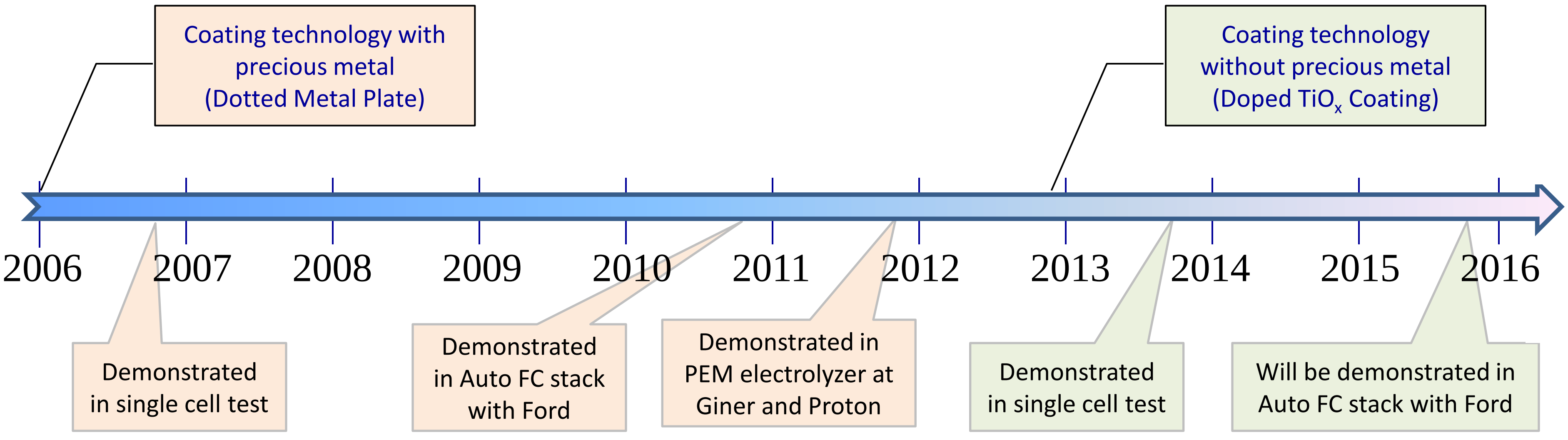
Sattledt, Austria, May 20, 2015

TreadStone Technologies, Inc.

201 Washington Road

Princeton, NJ 08540

Metal Plate Technology Development at TreadStone



Coating with precious metals

- Exceptional stability and electrical conductivity.
- Focus is on precious metal usage reduction and adhesion of coating on substrate.
  - ✓ Reduce the precious metal coating thickness.
  - ✓ Reduce the surface coverage of precious metal on metal substrate.

Coating without precious metals

- Low material cost. Final cost is dominated by the coating processing cost.
- Challenges in long term durability, especially at high potential transit conditions.
  - ✓ Metal nitride is the most investigated coating. The challenge is the stability of the coating at stack transient operation conditions.
  - ✓ Graphite coating is used in some systems. A thick coating is needed to meet the long term (>5,000 hrs) operation requirement. The fabrication cost of the thick coating is an issue.
  - ✓ Conductive metal oxide is the more attractive approach for long term stability.

TreadStone Technologies, Inc.

Challenges to Metal Bipolar Plates

DOE's Performance Requirements for PEM Fuel Cell Bipolar Plates		
Characteristic	Units	2020 Targets
Cost	$ / kW	<3
H2 permeation coefficient	Std $cm^3/(sec.cm^2\ Pa)$	<1.3 x 10–14
Corrosion, anode*	$\mu A / cm^2$	<1
Corrosion, cathode*	$\mu A / cm^2$	<1
Electrical conductivity	S / cm	>100
Areal specific resistance	$Ohm\text{-}cm^2$	0.01
Flexural strength	Mpa	>25
Forming elongation	%	40

Require:

1. Sufficient corrosion resistance in PEM fuel cell stack operation conditions
2. Low surface electrical contact resistance with GDL
3. Low cost.

* Standard test condition is in pH 3 H_2SO_4 + 0.1 ppm HF solution at 80°C

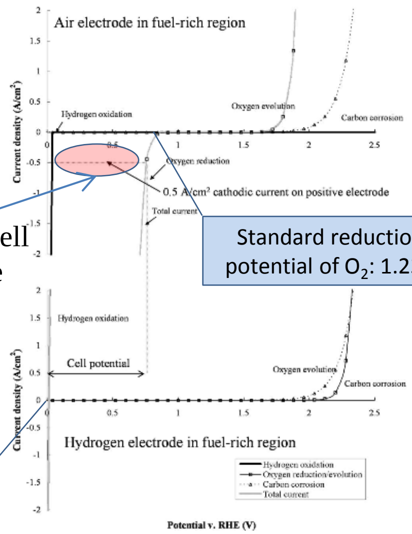
- Potentiostatic test at $0.8V_{NHE}$ for 100 hours.
- Potentiodynamic test at 10 mV/min scan rate.

* The resistance requirement is at the end of life. The resistance at the beginning of the life should be further lower.

* The corrosion test condition at stack transient operation conditions is not defined by DOE. Each OEM has their own testing protocols.

PEM Fuel Cell Operation Environment

Normal Operation Condition



Normal Cell Voltage

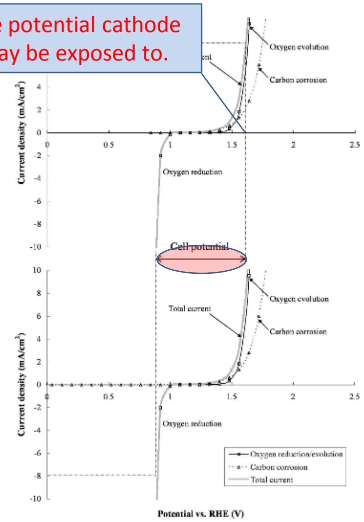
Standard reduction potential of O_2: 1.23V

Standard reduction potential of H_2: 0.00V

Transient Operation Conditions

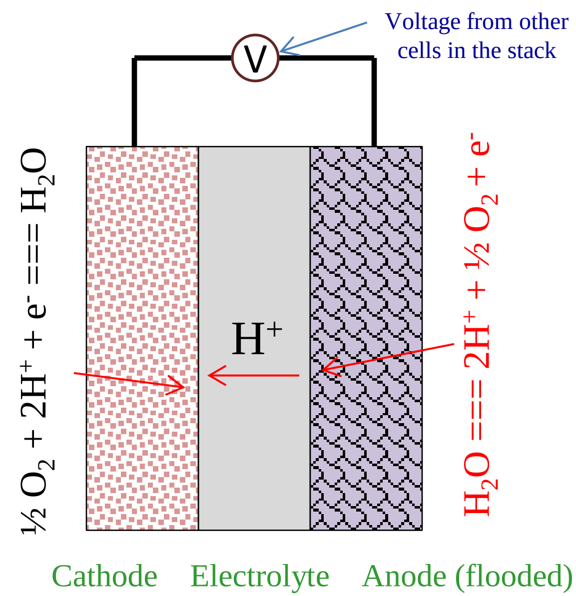
During stack start-up and shut-down

The potential cathode may be exposed to.



- Cathode side may be pushed to the high potential of oxygen evolution

At flooded anode of individual cells in a stack



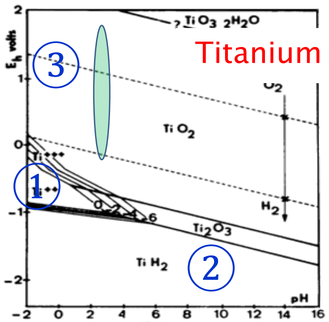
- No hydrogen to generate proton in flooded anode.
- Power from other cells in the stack forces the proton generation by water electrolysis reaction.
- High potential in anode for water electrolysis reactions.

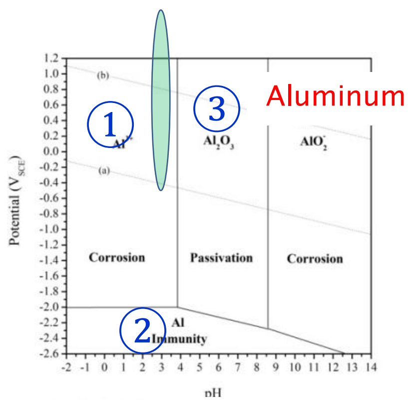
J. P. Meyers, R. M. Darling, JECS., 153, A1432-A1442 (2006)

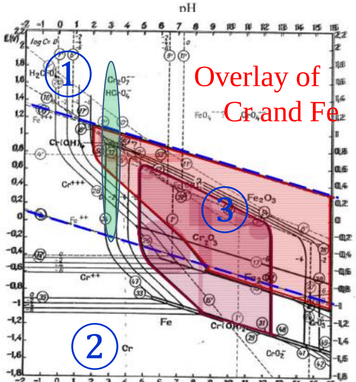
- The corrosion of fuel cell components is more significant at the high potential transient conditions
- Bipolar plates have to have reasonable tolerance to these conditions.
- System design has to minimize these transient conditions. The question is: What is the cost to completely eliminate these transient conditions, if it is possible?

Properties of Metals

Pourbaix diagrams







Note: ① corrosion region.
② immunity region.
③ passivation region.

In PEM fuel cell operation environment

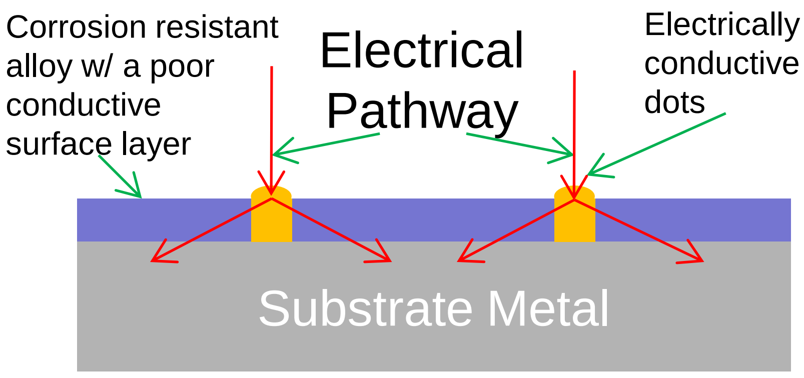
(including high potential during stack transient operation conditions)

- Ti is very stable
  - too expansive.
  - Difficult to form desired flow channels.
- Al has aggressive corrosion.
  - Need defect-free coating for protection.
- Stainless steel has reasonable corrosion resistance, formability and cost. It is the most favorable substrate material for auto PEMFC. Challenges remain in:
  - Slow Ion leaching may poison MEA.
  - High surface electrical contact resistance.
  - Corrosion
    - High potential during start-up shut-down process and anode flooding conditions.
    - Reducing of oxide surface layer on anode side.
  - Corrosion resistant coating is needed.
    - Reduce ion leaching
    - Reduce surface electrical contact resistance with GDL

At low cost!

TreadStone's Coating with Precious Metals

--- Dotted Metal Plate Technologies



Design Feature:

1. Using a small amount of electrically conductive and corrosion resistant material to cover a small portion of the substrate surface in the form of isolated vias (dots).
   - Low cost
2. Using non-conductive (or poor conductive) material to cover the rest of the substrate surface and separate conductive vias.
   - Eliminate galvanic corrosion
   - Easy processing

Electrical Resistivity

Graphite: 1375 μΩ.cm

Gold: 2.2 μΩ.cm

Highly conductive small dots can ensure the sufficient low electrical contact resistance of the metal plates for electrochemical applications

Actual Contact between GDL and Metal Plate

In micro scale, the GDL only in contact with metal plates at high points, of the rough surface of plates.

GDL Fiber

Gold Coated SS Surface

Majority of gold coated surface are not in contact with GDL.

On plates with gold dots on the surface: dots can standout out of the rough surface SS plate that have more chances to be contact with GDL.

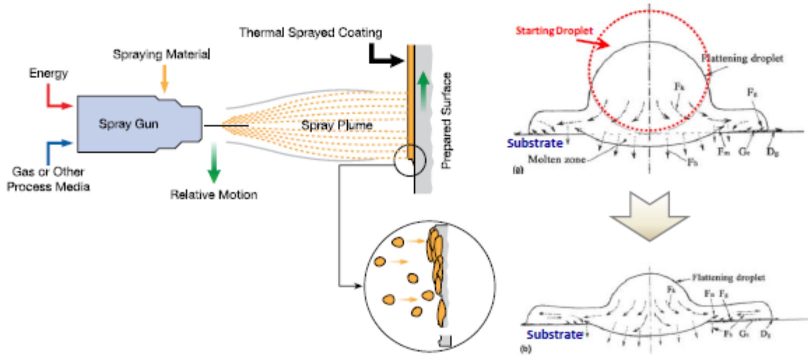
GDL Fiber

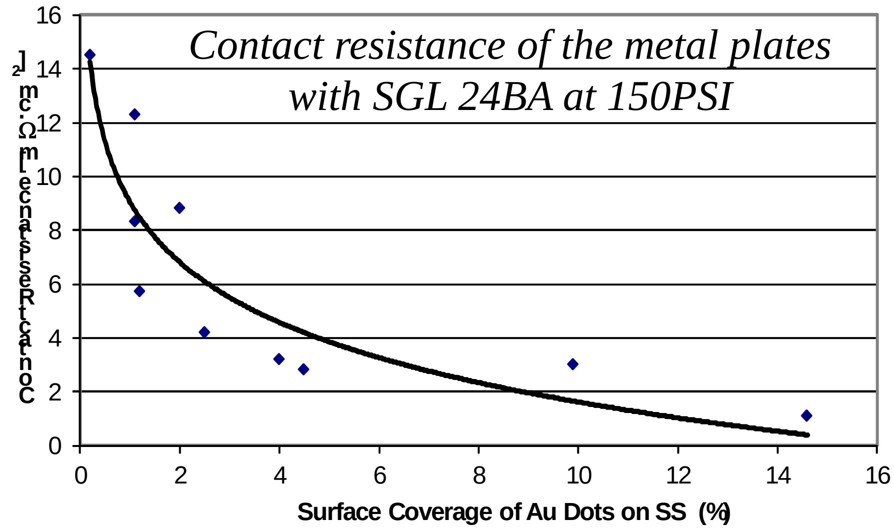
Gold Dots on SS Surface

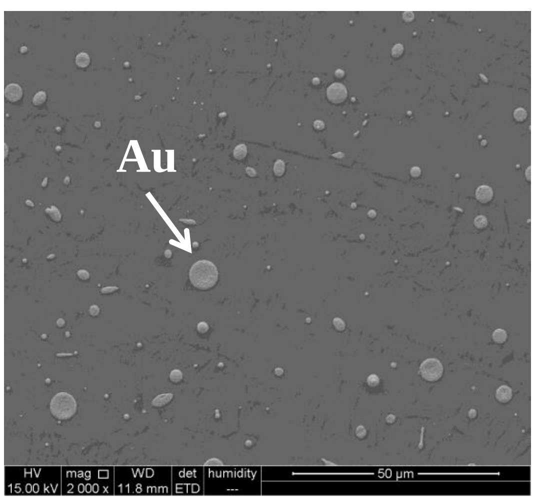
Large amount of small gold dots can maintain sufficient contact points for low contact resistance.

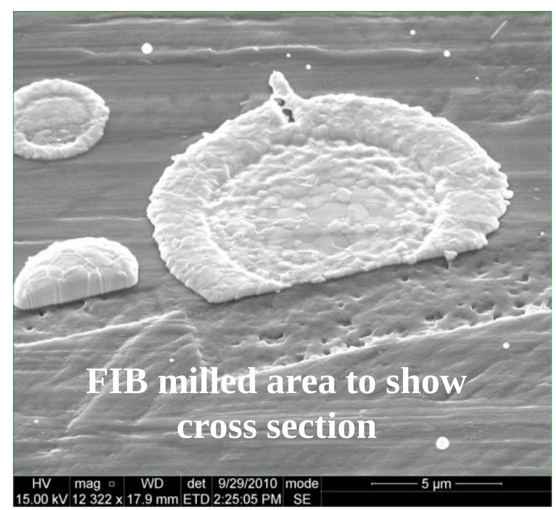
Electrical Contact Resistance vs Gold Coverage

Schematic Drawing of Thermal Spray
and the Solidification Process









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

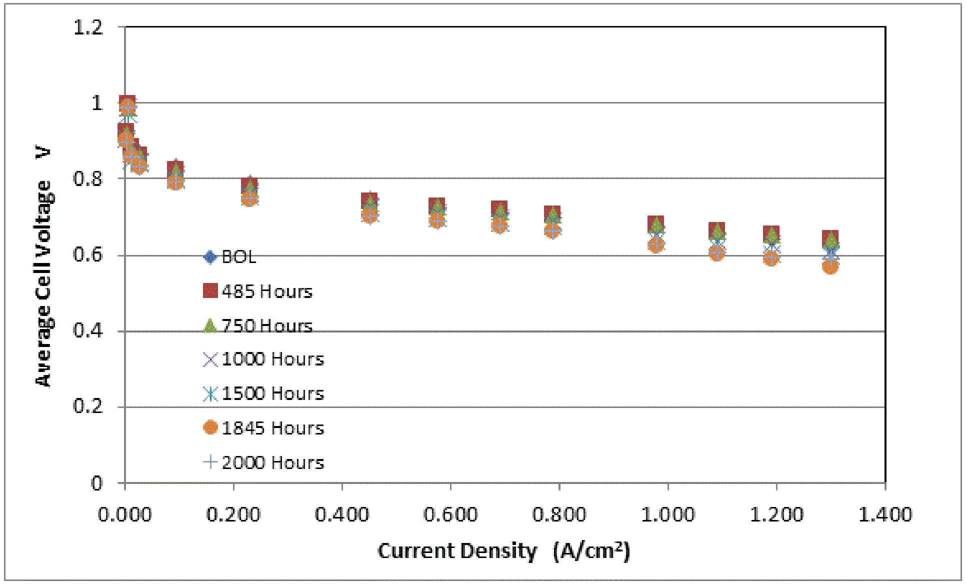
Short Stack in-situ Testing at Ford

- *TreadStone SS plates w/ Au dots were tested in-situ for durability at Ford Motor Company.*
- *Ford designed metallic bipolar plate w/SS316L as base substrate,*
  - *300 cm^2 active area, with TreadStone's coating*
  - *A 20-cell 5kW short stack was tested.*
- *Durability Cycle:*
  - *The stacks were tested for durability utilizing durability cycle (which includes FTP cycle along with others) mimicking real world driving conditions.*
- *Results*
  - *The 20-cell stack demonstrated stable operation in 2000 hrs. durability test.*

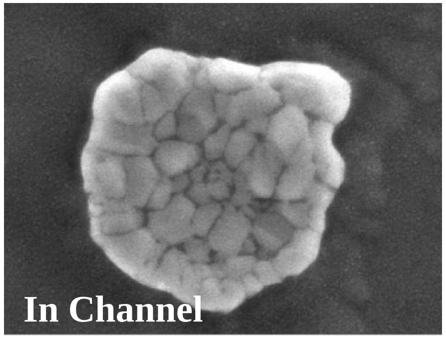
Ford short stack with TreadStone metal bipolar plates

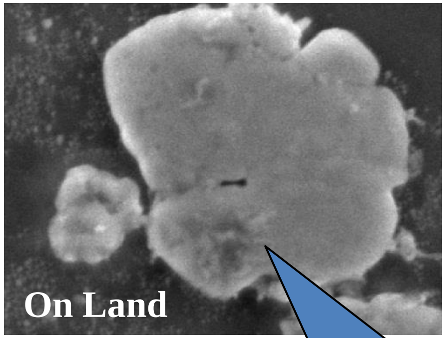
20-cell Stack Test at Ford

TreadStone Au-dot Plate Durability Test on 316L MP3 MBPP



Au splats on 1000 hrs. tested plate





Au splat pressed flatter in the stack, lead to the lower contact resistance.

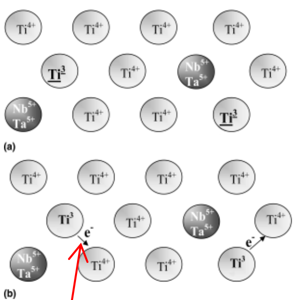
Contact Resistance [$m\Omega.cm^2$]

Plate #		#18	#19	#17	#16	Average of all plates
Testing Time (hrs.)		500	1000	1500	2000	500-2000
TPV (mV)	BOL	9.09	8.49	7.42	8.12	8.41
	MOL	5.90	7.21	5.93	5.67	6.40

TreadStone's Coating without Precious Metals

--- Doped TiO_x Coating

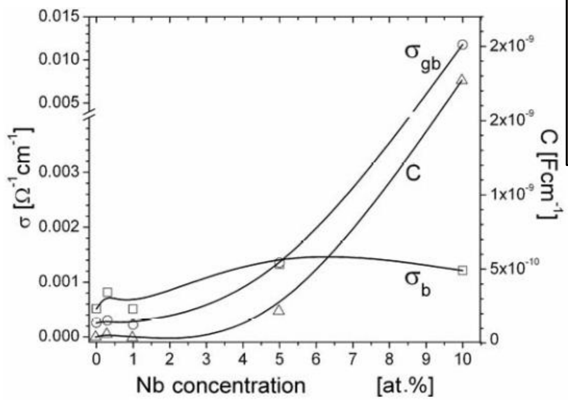
Doping TiO_2 with +5 valence elements will enforce the formation of Ti^{+3} in TiO_2 lattice structure, and result in higher electronic conductivities.



Electron hopping between Ti^{+3} & Ti^{+4} sites

Electrical conductance of Nb_2O_5 doped TiO_x

A. Trenczek-Zajac, M. Rekas, Materials Science-Poland, Vol. 24, No. 1, 2006



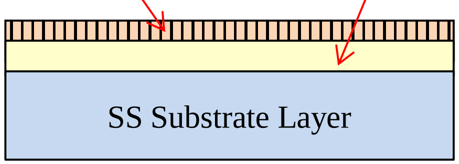
Challenges to use doped TiO_x coating:

1. Doped TiO_x is semi-conductive. The electrical conductivity is not high enough.
2. How to obtain reliable bonding of doped TiO_x on metal substrate surface.

TreadStone's Coating Structure

Doped TiO_x semi-conductive surface layer

Ti alloy bonding layer



TreadStone's approach:

- To coat stainless steel substrate with Ti-Nb or Ti-Ta alloy. Then, grow the doped TiO_x surface layer on the Ti alloy coating layer.

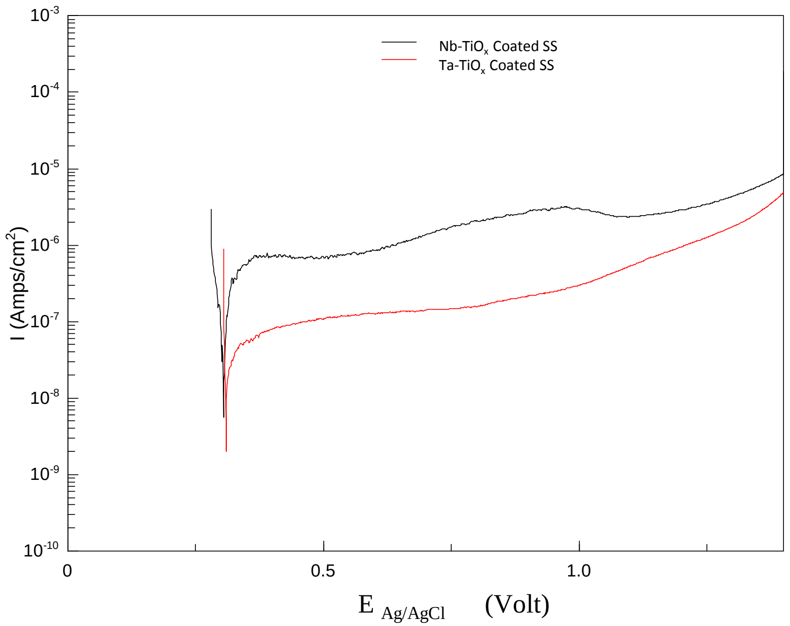
1. The doped TiO_x on Ti alloy surface is thin and reliable.
2. Ti alloy bonding layer has excellent adhesion on metal substrate.

TreadStone Technologies, Inc.

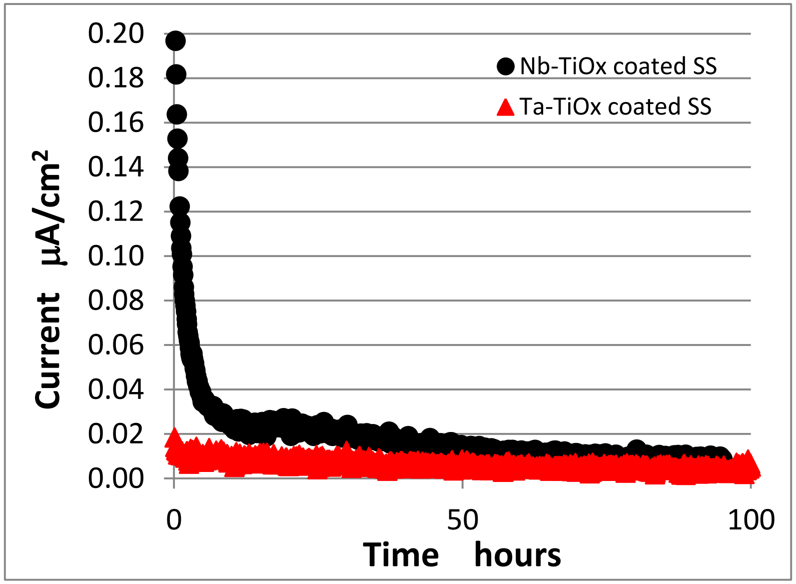
ex-situ Tests of Doped TiO_x coated SS

in pH 3 H_2SO_4 + 0.1 ppm HF at 80ºC

Potentiodynamic Test (@10 mV/min)



Potentiostatic Test (@0.8V_{NHE})



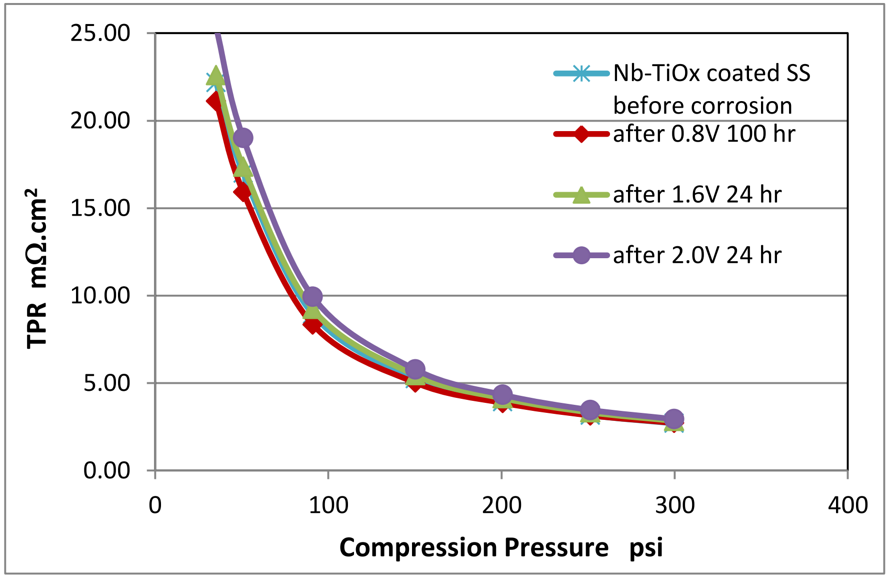
- Both Nb and Ta doped TiO_x coated SS can meet the corrosion current target (<1 μA/cm²)
- Ta-TiO_x coated SS has lower corrosion current than that of Nb-TiO_x

TreadStone Technologies, Inc.

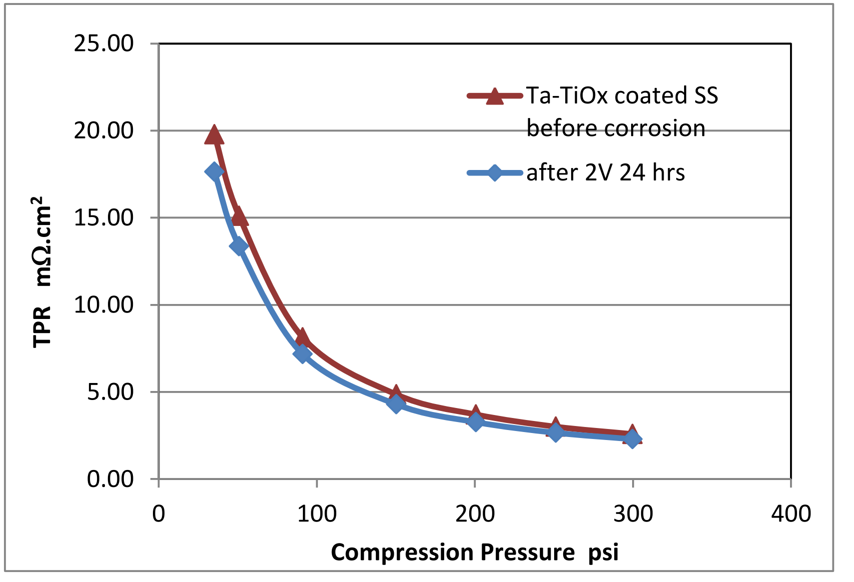
Doped TiO_x Coating Stability Test in Extreme Conditions

in pH 3 H_2SO_4 + 0.1 ppm HF at 80°C

316L SS with Nb-TiO_x coating before and after corrosion tests

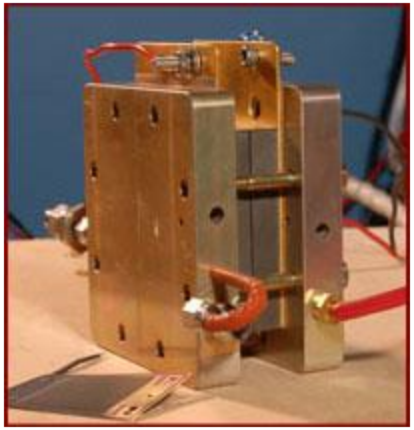


316L SS with Ta-TiO_x coating before and after corrosion tests



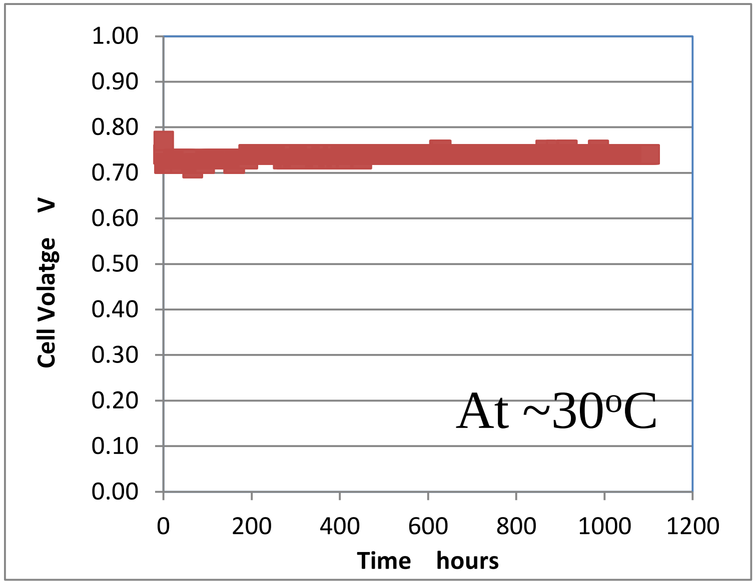
- Doped TiO_x coated SS has low surface electrical contact resistance.
- The coated SS has superior corrosion resistance for PEM fuel cell applications.
- The extreme corrosion condition (@ 1.6V_{NHE} or 2 V_{NHE}) *ex-situ* tests are not included in regular standard, but it is very attractive to OEMs because of the concerns of stack transient operation conditions.

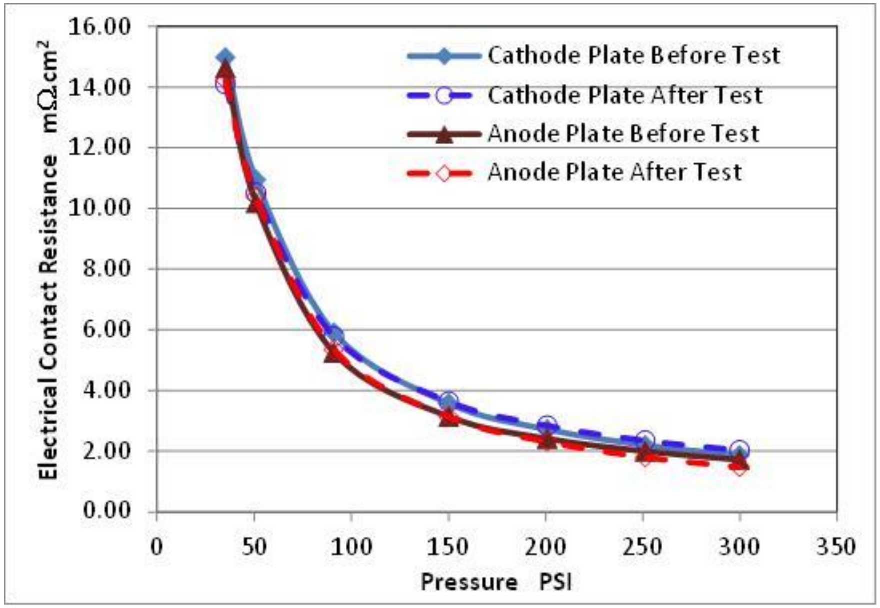
Single Cell Test with Nb Doped TiO_x Coated SS Plates



16 cm^2 active area cell using Fuel Cell Technology hardware

Contact Resistance with GDL before and after 1,100 hrs. single cell test





TreadStone Technologies, Inc.

Summary

- TreadStone has developed low cost coating technologies for PEM fuel cell and electrolyzer applications.
- The coating technology using precious metal has a unique design and processing technique for cost reduction, while meet metal plate's technical requirements.
  - The technology has been demonstrated in 2,000 hours stable operation in automobile PEM FC operation conditions.
  - The technology has also been demonstrated for PEM electrolyzers and redox batteries for energy storage applications.
- The coating technology without using precious metal (doped titanium oxide coating) has demonstrated the feasibility for PEM fuel cell applications
  - Demonstrated superior corrosion resistance and performance stability in ex-situ corrosion tests and single fuel cell test.
  - The demonstration in automobile fuel cell stack is planned in July 2015.
  - The doped titanium oxide coating has the potential for PEM electrolyzer applications due to is superior stability at high potential.
- TreadStone is actively looking for production partners to scale up and commercialize these technologies.