PROTON

THE LEADER IN ON SITE GAS GENERATION.

High Performance, Low Cost Hydrogen Generation from Renewable Energy

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Organization: Proton Energy Systems

Date: May 15, 2013

Project ID #PD071

Overview

Timeline

- Project Start: Oct 2009
- Project End: Sept 2013
- Percent complete: 85%

Budget

- Total project funding
  - DOE share: $3,396,826
  - Contractor share: $849,206
- Funding for FY13
  - DOE share: $181,272

Partners

- Entegris, Inc. (Industry)
- Penn State (Academic)
- Oak Ridge (National Lab)

Barriers

- Barriers addressed

  G: Capital Cost

Table 3.1.5 Technical Targets: Central Water Electrolysis Using Green Electricity [a,b]

Characteristics	Units	2011 Status [c]	2015 Target [d]	2020 Target [e]
Hydrogen Levelized Cost (Plant Gate) [f]	$/kg H_2	4.10	3.00	2.00
Total Capital Investment [b]	$M	68	51	40
System Energy Efficiency [g]	%	67	73	75
	kWh/kg H_2	50	46	44.7
Stack Energy Efficiency [h]	%	74	76	78
	kWh/kg H_2	45	44	43
Electricity Price [i]	$/kWh	From AEO '09	$0.049	$0.031

Table 3.1.4 Source:
DOE Hydrogen, Fuel Cells & Infrastructure Technologies Program Multi-Year Research, Development, and Demonstration Plan, Updated April 2009

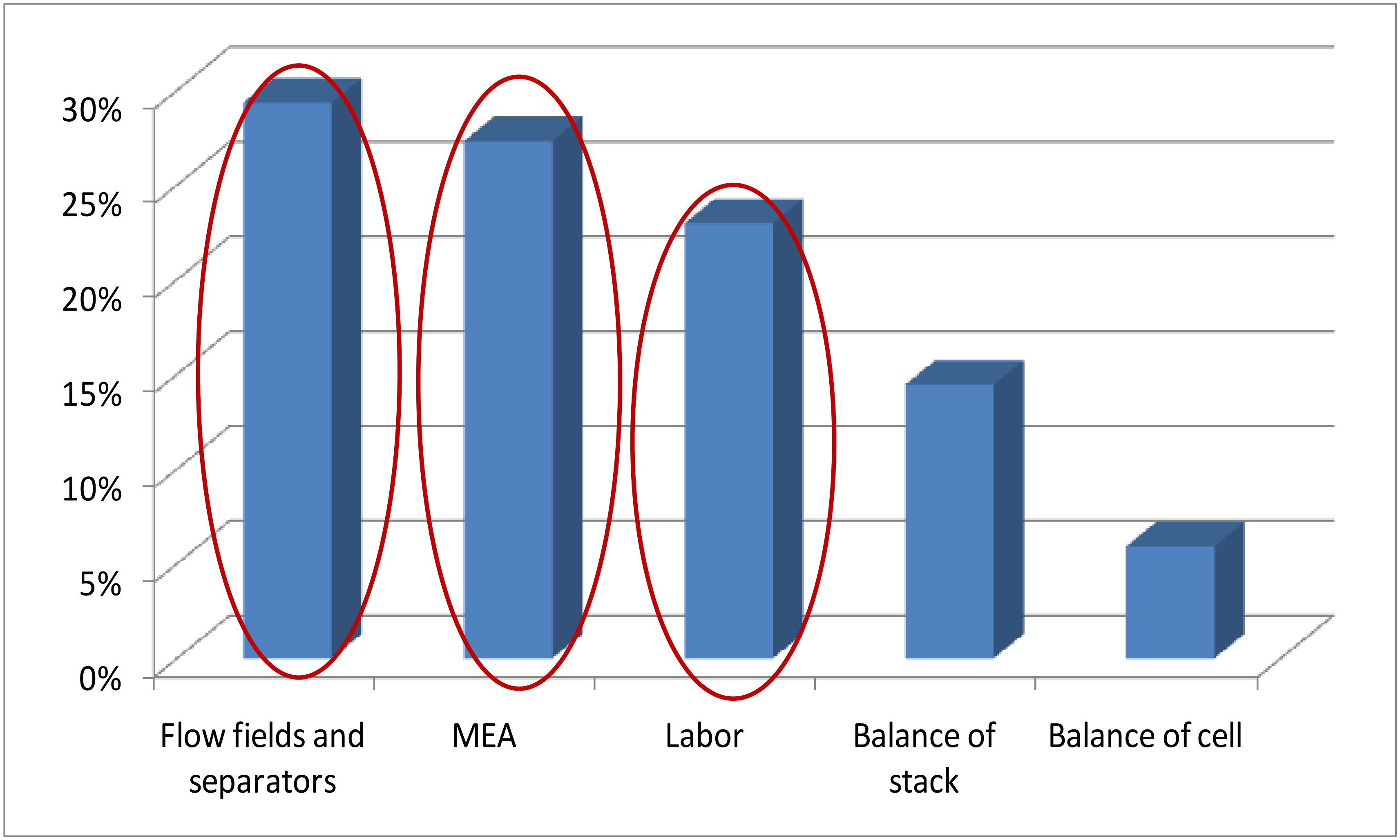
Relevance: Project Objectives

- Reduce cost in electrode fabrication
  - Reduction in precious metal content
- Improve electrolyzer cell stack manufacturability
  - Consolidation of components and reduction in labor
  - Reduction in titanium usage
- Stack active area scale up for MW platform
- Commercialization of technology advances

Scope completed in 2011

Relevance

- Project addresses highest cost impact areas



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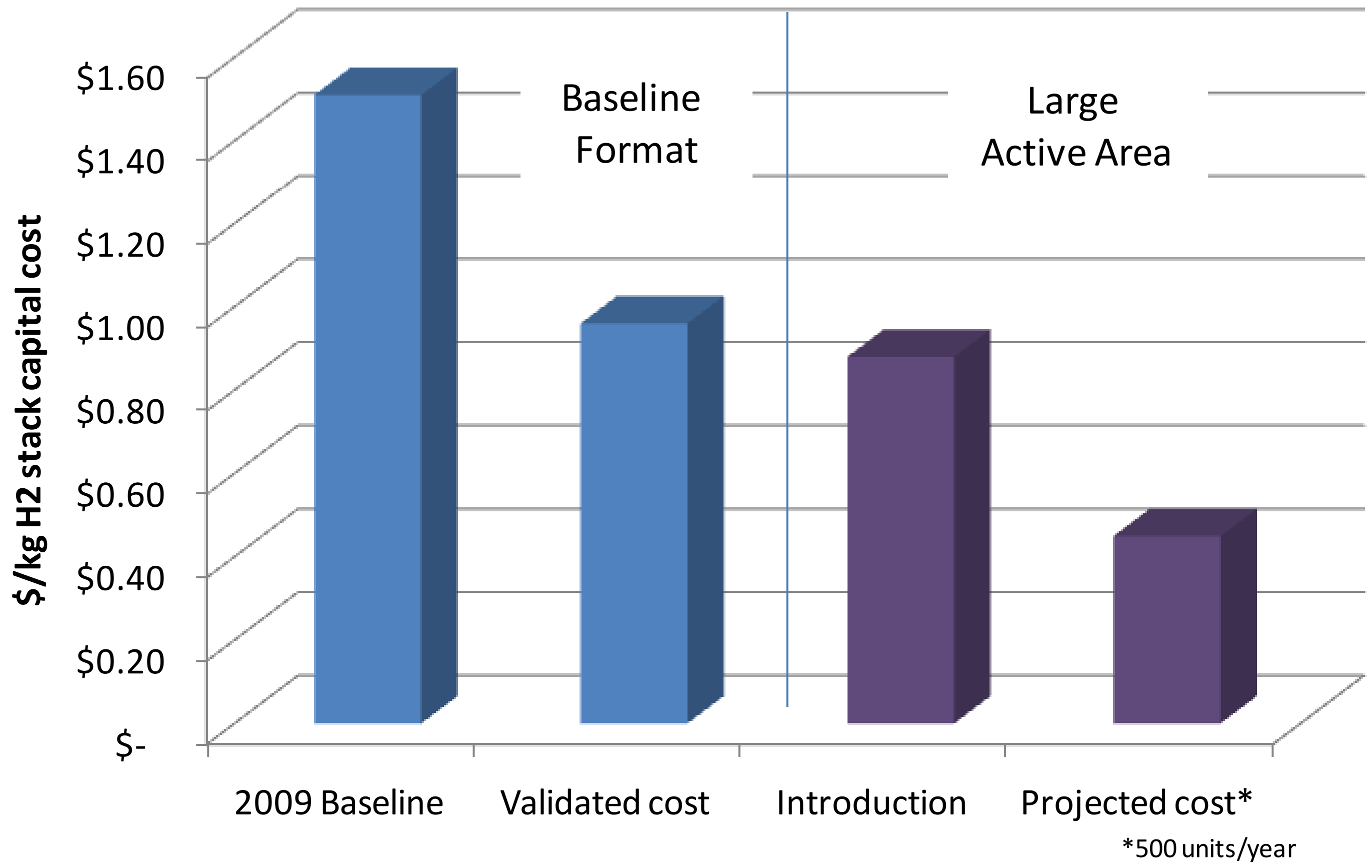
Relevance: Cost Impact

- Combined labor and material advancements result in 40% production cell stack cost reduction
- Additional savings in stack scale up



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Top Level Approach

- Task 1.0: Catalyst Optimization
  - Control catalyst loading
  - Improve application
- Task 2.1: Computational Cell Model
  - Develop full model
  - Flex parameters, observe impact on performance
- Task 2.2: Implement New, Lower Cost Cell Design
  - Design and verify parts
  - Production release
- Task 2.3: Prototype Concepts
  - Test material compatibility
  - Fabricate test parts
- Task 2.4: Composite Bipolar Plates
  - Demonstrate functionality
- Task 3.0*: Low Cost Manufacturing
  - Laminate concepts
  - Alternate processes
- Task 4.0*: Operational Testing and Stack Scale Up
- Task 5.0: Manufacturing Development
- Task 6.0: Manufacturing Qualification
- Task 7.0*: H2A Cost Analysis
  - Input design parameters
  - Assess impact of changes

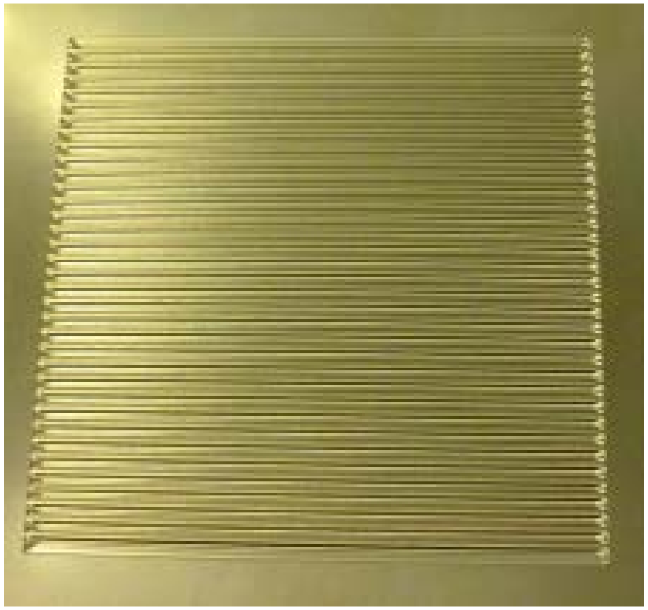
***blue = current review year activities**

Progress on Milestones

Task Number	Project Milestones	Task Completion Date	
		Original Planned	Percent Complete
1	Catalyst Optimization	03/31/10	100%
2.2	Improved Flowfield Implementation	05/30/10	100%
2.1	Electrolyzer Cell Model	01/30/11	100%
2.3	Next Generation Flowfield Prototypes	05/30/10	100%
2.4	Metal-Composite Laminate Plate Fabrication	12/31/10	100%
3.1	Metal-Composite Plate Development	12/30/11	100%
3.2	All-Metal Laminate Plate Development	12/30/11	100%
3.3	Hydrogen Resistant Coating Development	12/30/11	95%
4.1	Sample Operational Tests	12/31/11	100%
4.2	Post Operational Testing Analysis	03/30/12	80%
4.3	Stack Scale Up	09/30/12	100%
5	Bipolar Plate Manufacturing Development	06/30/13	75%
6	Bipolar Plate Manufacturing Qualification	09/30/13	50%
7	H2A Cost Model Analysis	09/30/13	80%
8	Project Management	09/30/13	85%

Technical Accomplishments: AMR 2012 Review

- Down-selected manufacturing pathway
  - Designed and validated subscale stack
  - Initiated active area scale up
- Evaluated alternative separator treatments
  - Verified reduced hydrogen uptake

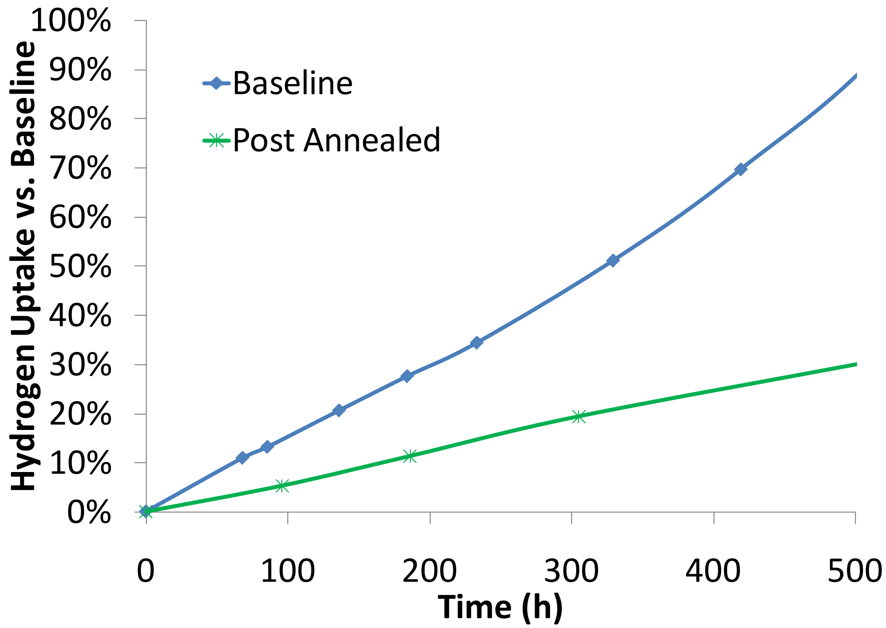


Conceptual part made with new manufacturing process/nitride coating

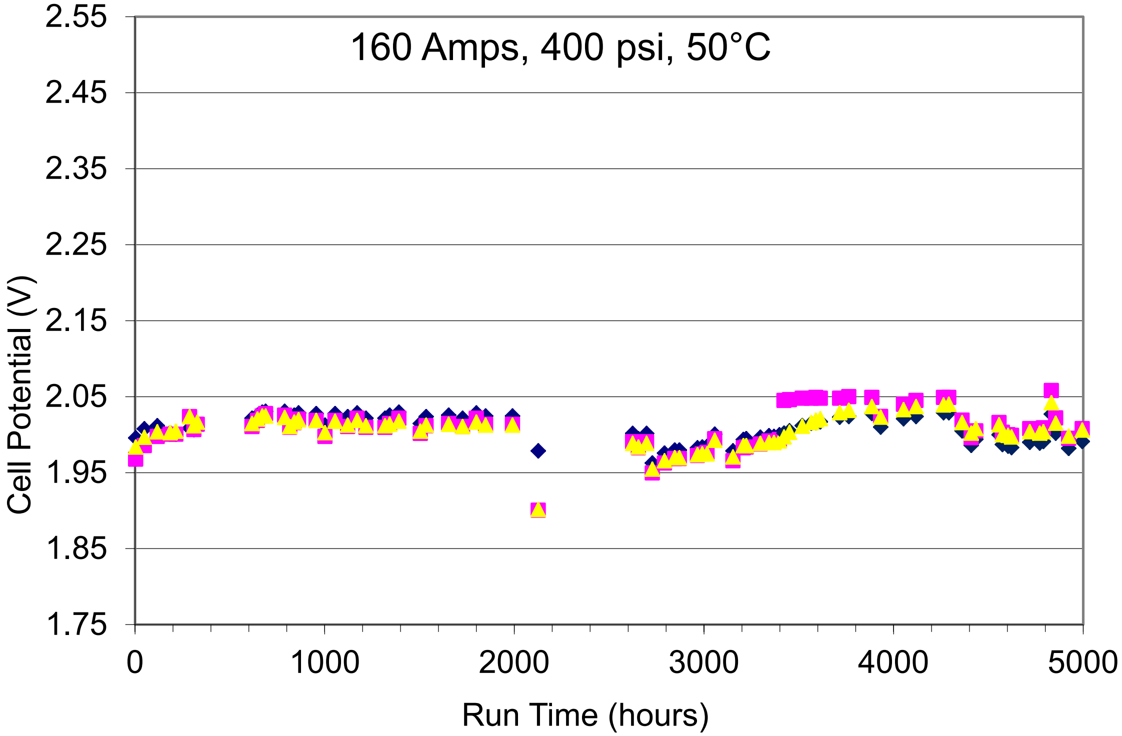
Technical Accomplishments: H_2 Protection

- Long term: alternate coatings for lower cost
- Short term: lessen part stress for lower uptake
  - Process order makes a difference
  - Impact seen on hydrogen uptake
- Implementation review passed March 2013

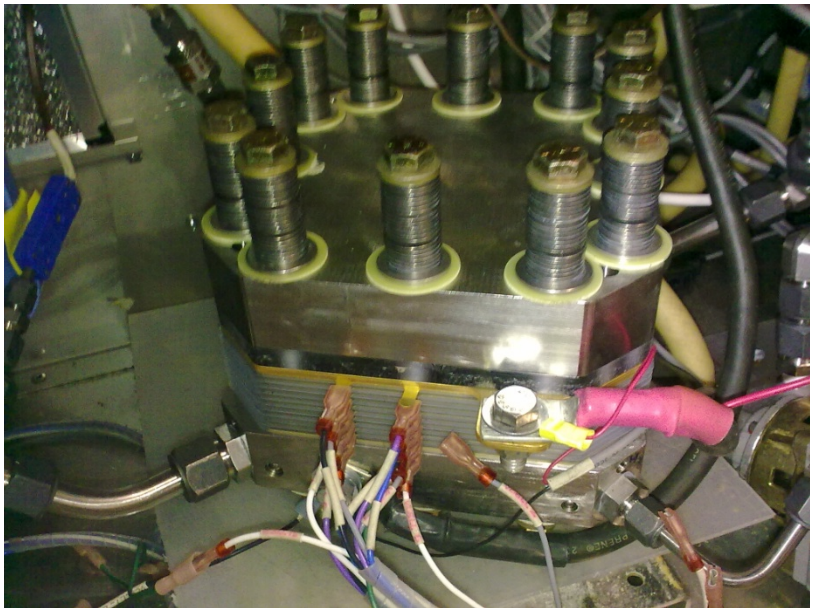
Process Step	Residual Stress (MPa)	Standard Deviation
Unprocessed	-134.2	10.1
Annealed only	15.3	9.1
Baseline process	-386.9	47.2
Annealed – Baseline	-383.7	58.4
Baseline – Annealed	30.3	29.0



Technical Accomplishments: Coatings



- 5000 hour validation achieved with no change in voltage
- 10-cell stack still on test with over 6000 hours



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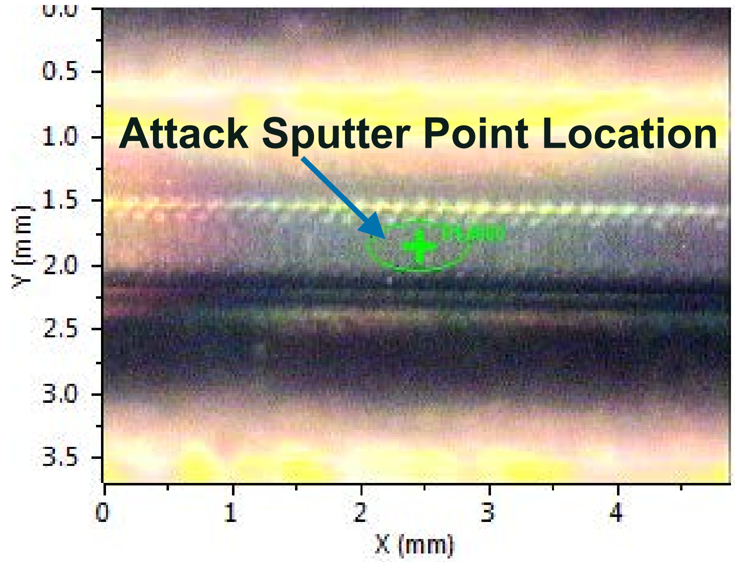
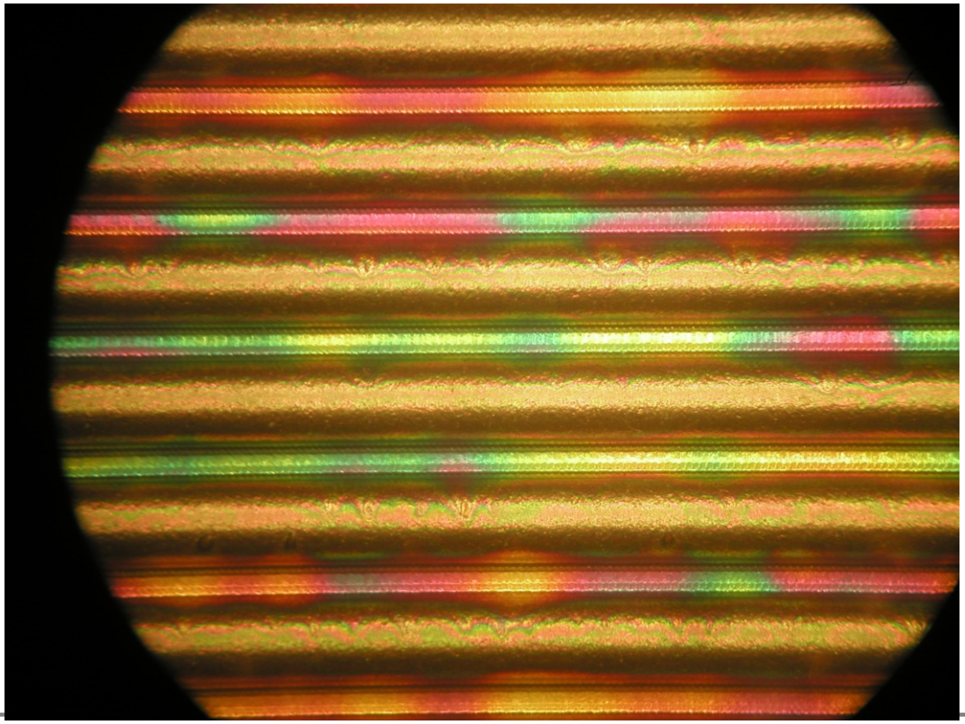
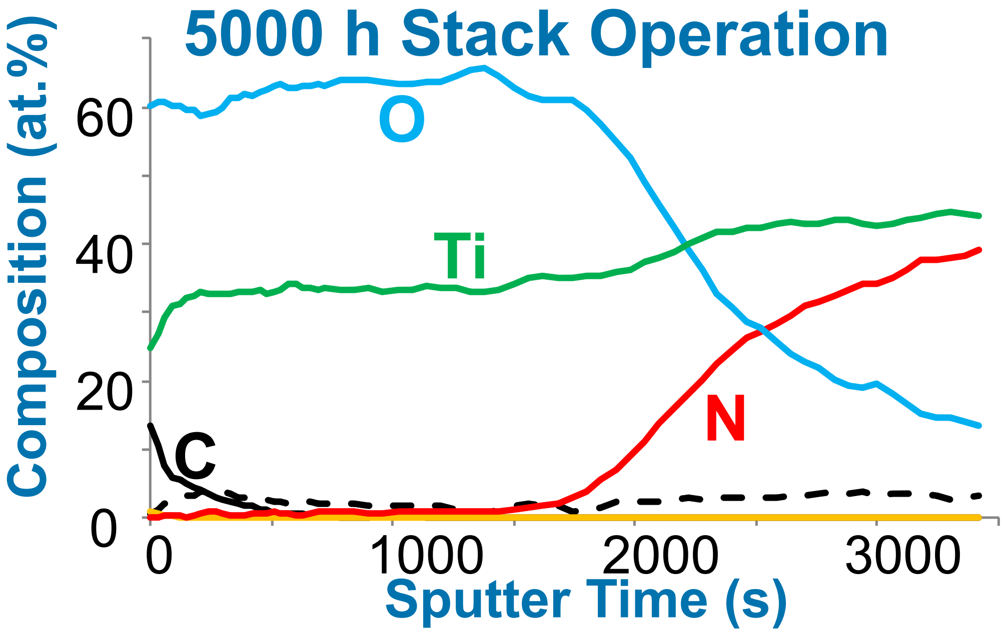
Technical Accomplishments: Coatings

- Operated parts showing some oxidation
  - Not impacting cell voltage
  - Appears limited to channels







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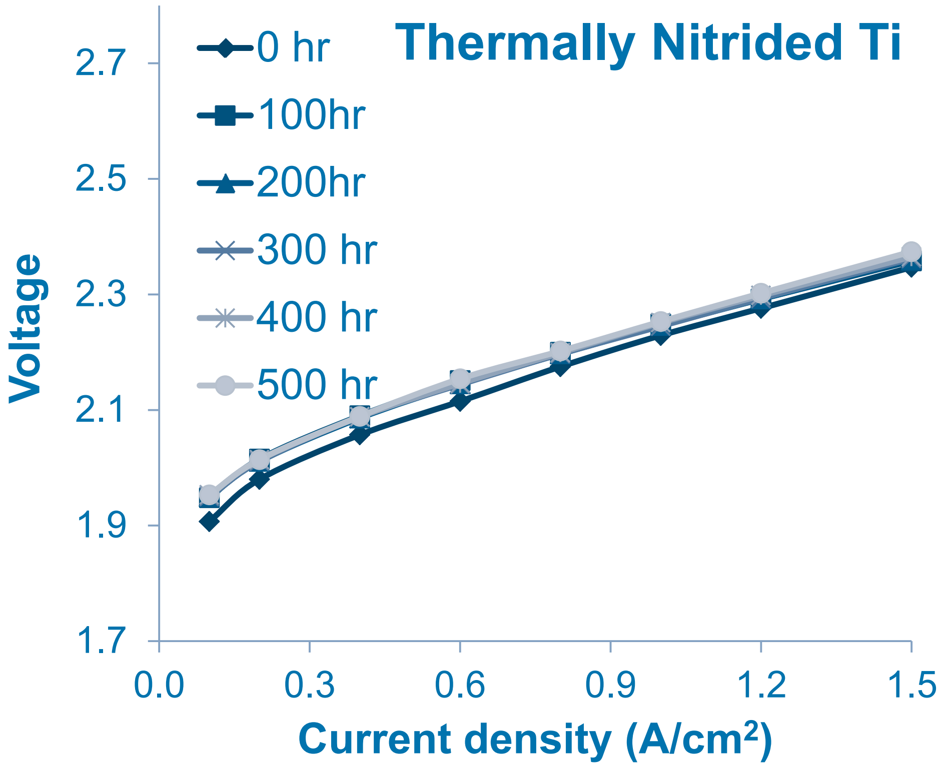
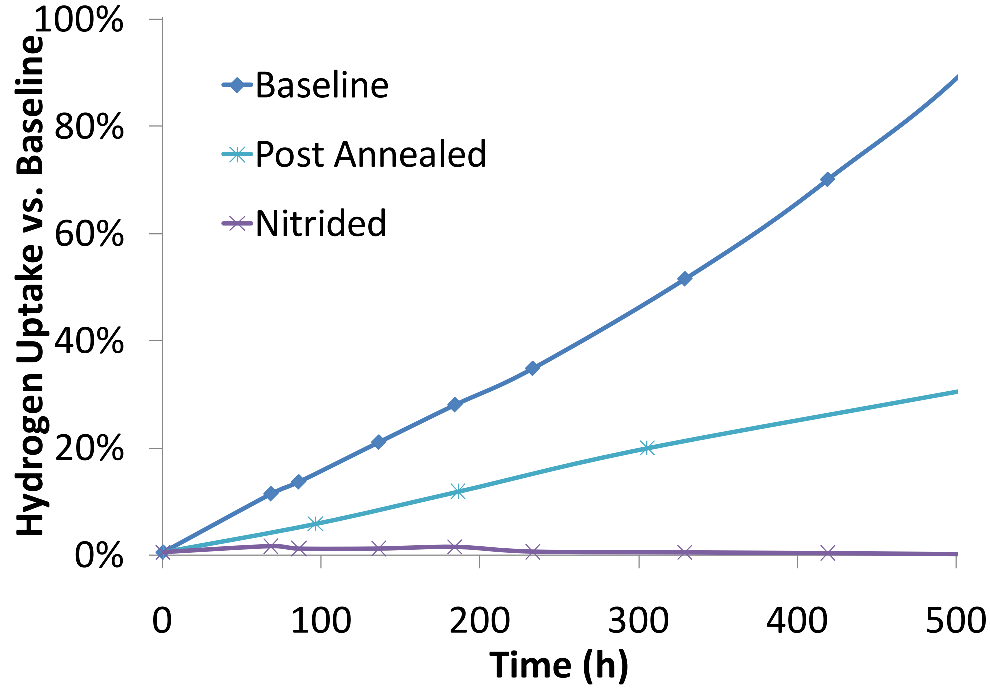
Technical Accomplishments: Coatings

- Alternate methods of nitriding and alloys examined for manufacturability
  - Degree of TiN/Ti_2N varies
  - All show low uptake; some oxidation but no voltage impact

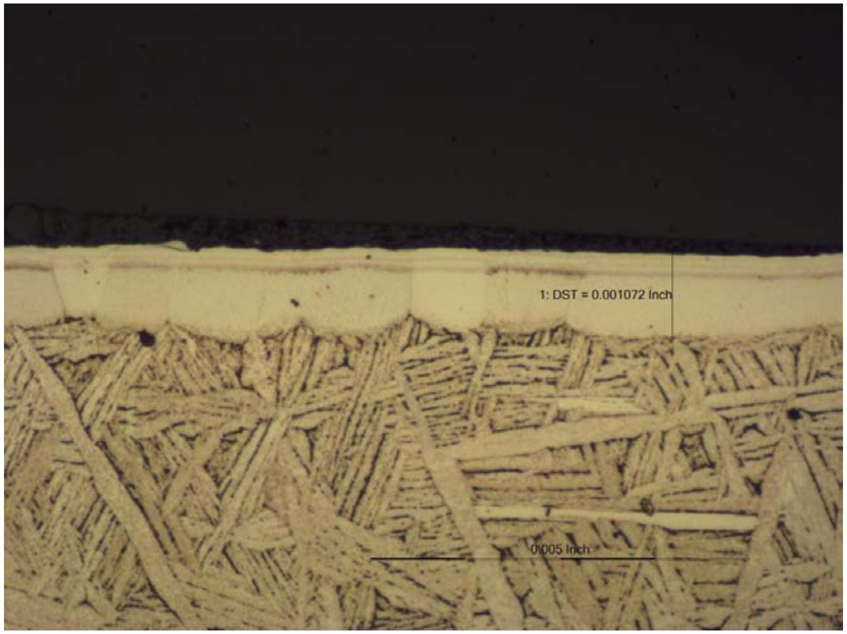




Technical Accomplishments: Coatings

- Surveyed manufacturing methods for nitride coatings
  - Deposition methods are line of sight limited; batch size limited at large active area
  - Thermal methods provide more flexibility but can result in unwanted compositions
    - Preference for TiN vs. Ti_2N for higher corrosion potential
  - Worked to tune parameters with multiple suppliers

Thermal Gas
25 um thick
Deposition
0.3-1.2 um thick

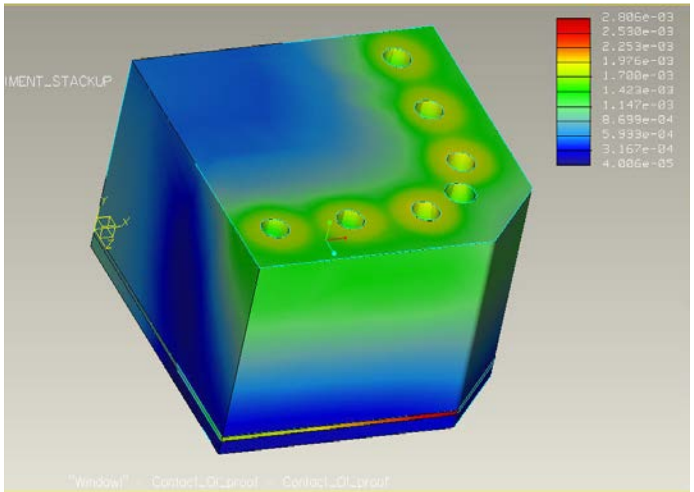


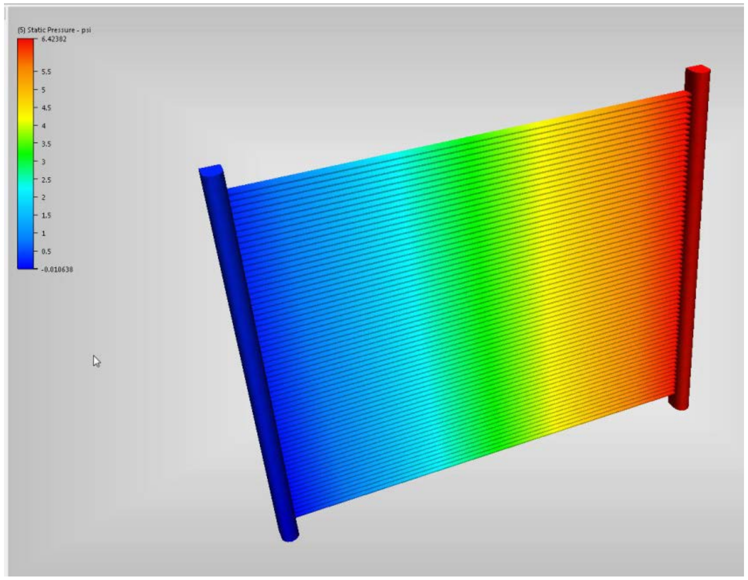
Technical Accomplishments: Scale Up

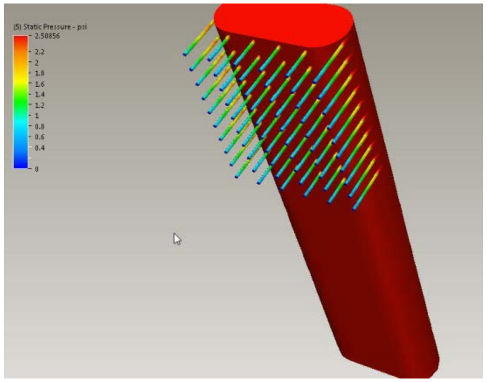
- Large active area format required re-design of flow features
  - Traditional channels would result in “oil-canning” during manufacture
- Investigated alternate flow geometries
- Developed novel solution with exceptional flow distribution while providing tortuosity to avoid long straight runs

Technical Accomplishments: Scale Up

- Design refinement of large active area stack
  - FEA of critical components: flow fields, frames, endplates
  - CFD of individual cells
    - Sensitivity analysis to flow rate variations
  - CFD of entire stack
    - Understand cell count impact on individual cell flow rate







Technical Accomplishments: Scale Up

- Design for manufacturability
  - Frame orientation for error-proofing
  - GDL registration features for alignment
- GDL and separator load testing completed
  - No deformation observed
- Frame testing completed with successful hydrostatic test to proof pressure of >700 psi

Technical Accomplishments: Manufacturing Development

- Proof of concept parts made by supplier
- Tooling initiated
- Material in house for production run

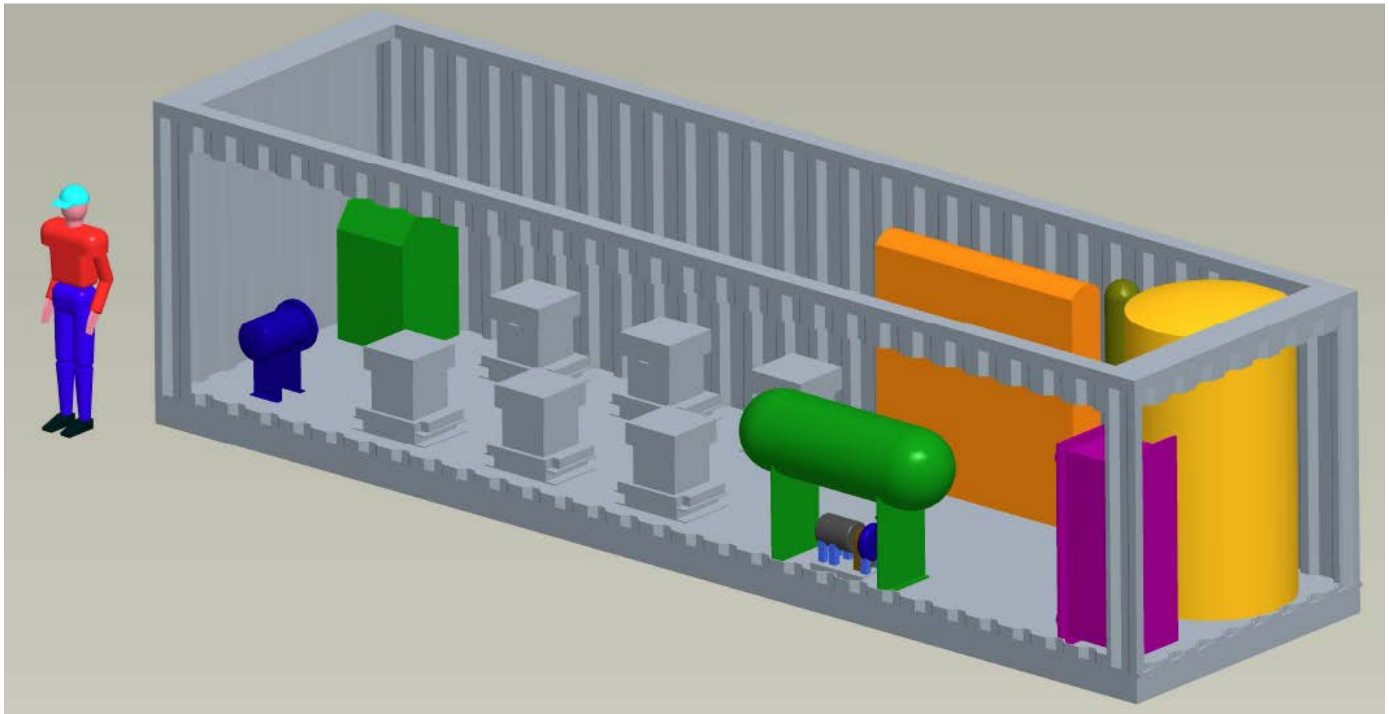
Existing large format stack; new design scaling to >50-cell design point, 20% increase in active area

Future Work

- Task 3.0 Continued characterization of coating stability with operational time and location
- Task 4.0 Complete design scale up and prototyping
  - First operational stack expected May 2013
- Task 5.0 Manufacturing process development
  - Qualifying large active area components
- Task 6.0 Manufacturing qualification
  - Production run to follow prototype parts
- Task 7.0 Perform H2A analysis for end design

Support of Overall Electrolysis Pathways

- Program forms basis of MW development effort
  - Needed for energy storage applications
- Part of overall technology roadmap
  - Synergistic with other programs



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Summary

- Relevance: Cost savings at the electrolyzer cell level directly impacts hydrogen production costs
- Approach: Reduce cost of largest contributors first
- Technical Accomplishments:
  - Flowfield: Phase 1B design passed technical review, prototype on test; project 40% stack cost savings
- Collaborations:
  - Cell Model: Leveraging learnings for scale up
  - Entegris: Concepts show good durability, incorporated into design
  - ORNL: Providing detailed materials understanding for predictability of long term stability
- Proposed Future Work:
  - Scale up and manufacturing development

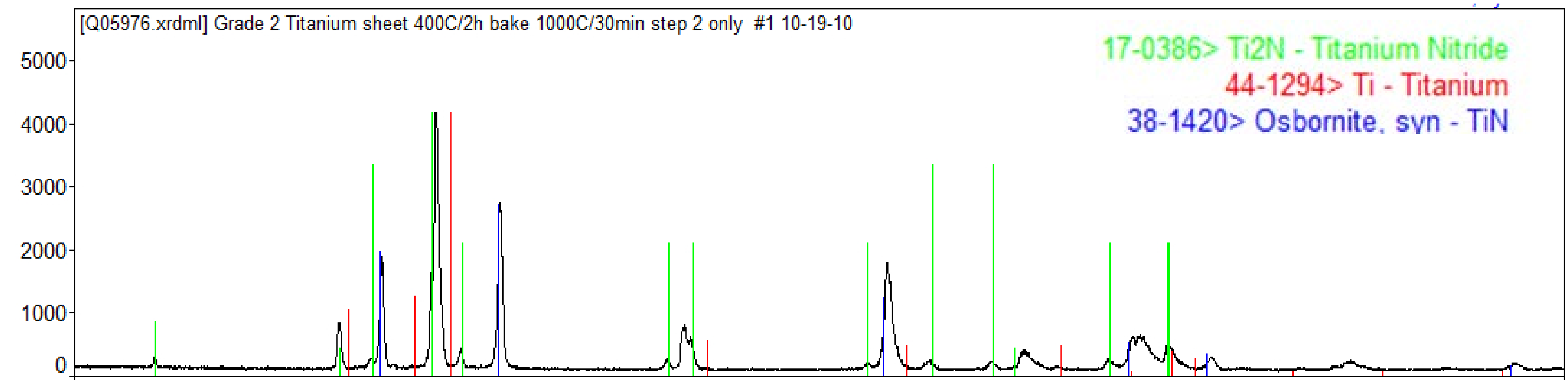
Team

- Blake Carter
- Luke Dalton
- Rachel Wax
- Andy Roemer
- Mike Niedzwiecki
- Tom Mancino (Entegris)
- Mike Brady (ORNL)
- Todd Toops (ORNL)

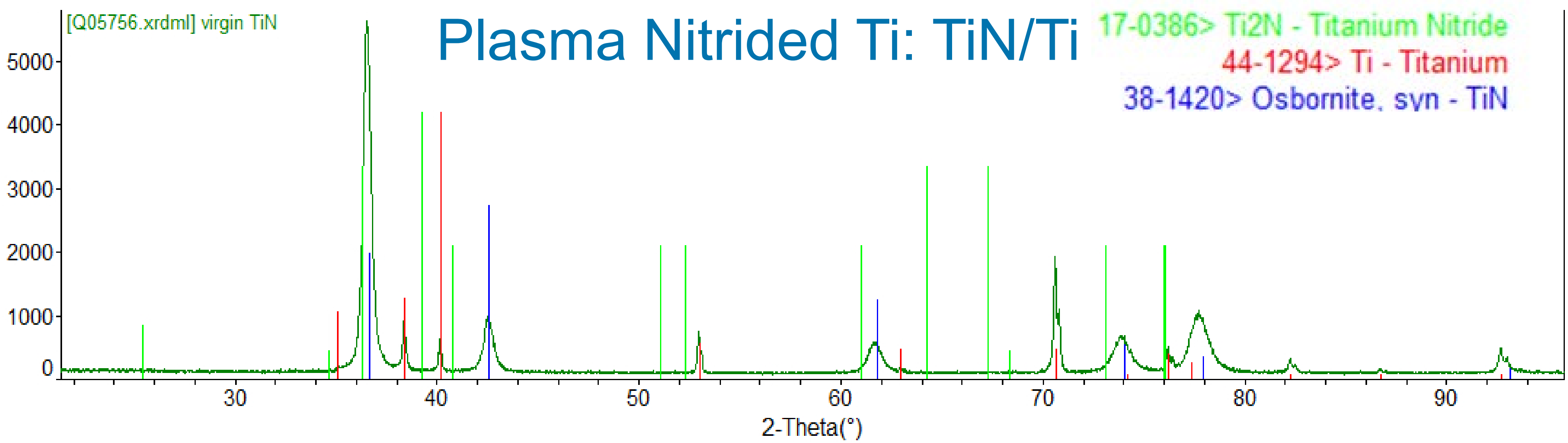
Supplemental Slides

XRD Indicates Thicker, More Exclusive TiN on Plasma Nitrided Matrial

ORNL Gas Nitrided Ti: TiN/Ti_2N/Ti



Plasma Nitrided Ti: TiN/Ti

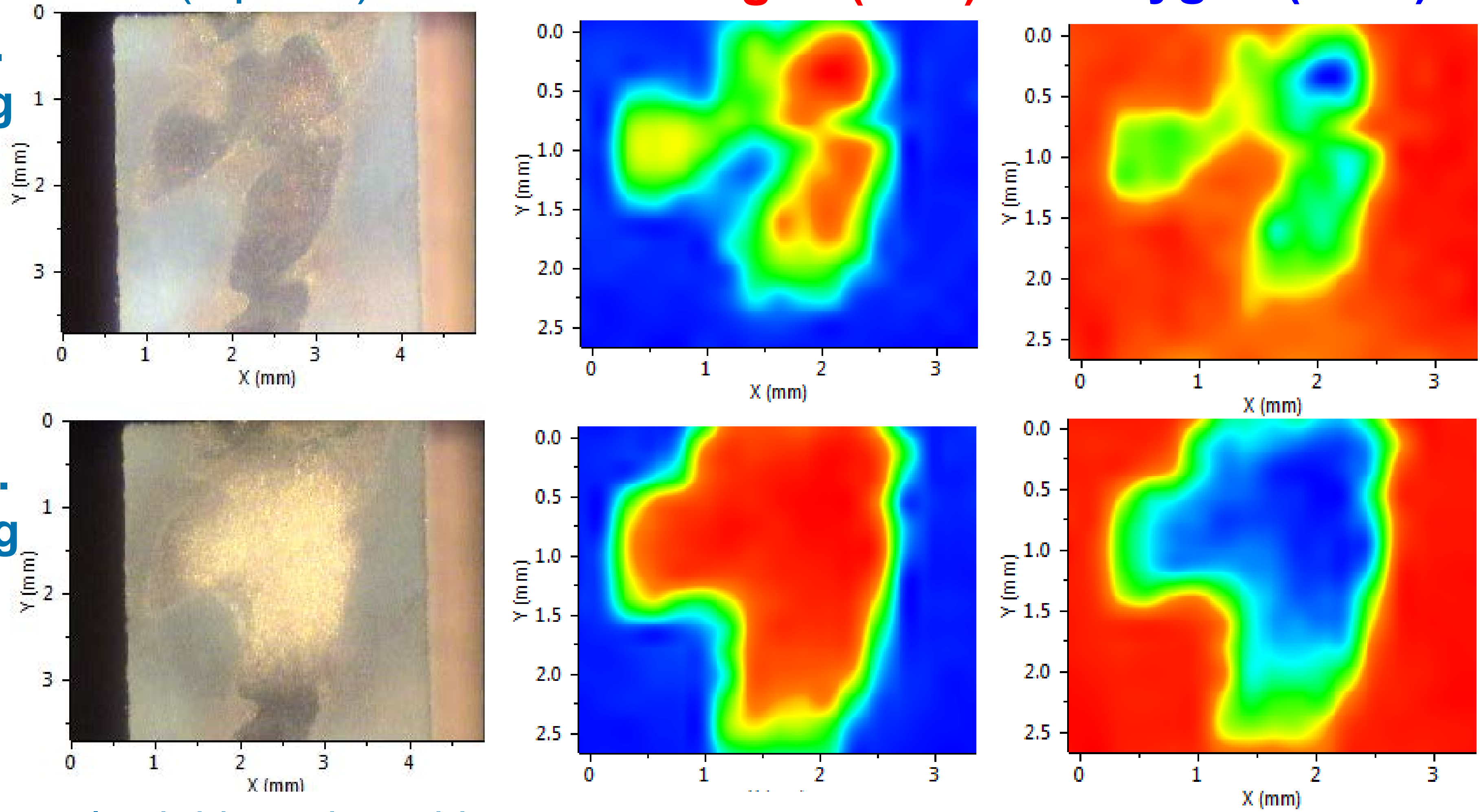


XPS Analysis of 500 h ORNL Gas Nitrided Ti Plate Shows Attack is Oxidation of Ti_xN

Flow Field Attack (Optical) | **XPS <u>Increased</u> Nitrogen (Red)** | **XPS <u>Decreased</u> Oxygen (Blue)**

10 min. etching

38 min. etching



Etching reveals nitride under oxide

Oxidation resulted in only minor effect on plate performance

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