Point-Of-Manufacturing Microwave Plasma Jet Material Coatings

"Atmospheric Cold Plasma Jet Coating and Surface Treatment for Improved Adhesive Bonding Performance of Dissimilar Material Joints Subject to Harsh Environmental Exposure"

Control Number: 1465-1578, Emerging Research Award DE-EE0008319
Starfire Industries LLC, General Motors LLC, University of Illinois
24 Months, July 2018-June 2020

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U.S. DOE ADVANCED MANUFACTURING OFFICE
PROGRAM REVIEW MEETING

WASHINGTON, D.C.

JULY 17-19, 2018

Overview

Timeline

- Project Award Notification April 2018
- Anticipated Start July-October 2018
- 24 Month Period Of Performance
- 1 Go/No-Go @ 12 Month
- Project 0% Complete

Barriers

- Miniaturization and integration of microwave delivery system for size, weight and power specifications for in-line robotic manufacturing
- Wide parameter space for harsh-environment coatings with hybrid sputtering and chemical vapor deposition (a.k.a. the too many options problem)

Budget

	FY 17 Costs	FY 18 Costs	FY 19 Costs	Total Planned Funding
DOE Funded	--	$0.4M	$0.4M	$0.8M
Cost Share	--	$0.1M	$0.1M	$0.2M

Partners

Starfire Industries LLC (Prime)
General Motors LLC (Transition)
University of Illinois Center for Plasma-Material Interactions
Applied Research Institute @ University of Illinois

NSF IUCRC Lasers & Plasmas For Advanced Manufacturing
(future transition opportunities)

Objectives

Point of Manufacturing Anti-Corrosion Conversion Coating

- Coat Only Bonding/Joining Surfaces Instead Of Entire Part
- Treat Complex 3D Parts/Surfaces With Extended Plasma Jet

Achieve High-Strength, Long-Life Joints

- Maintain Minimum 80% Lap-Shear Strength For Epoxy Joining
- Resist Corrosion Under Harsh Environment Accelerated Life Conditions

Eliminate Wet Chemistry Steps

- Eliminate Off-Site Transport, Energy Use & Waste Water Effluent
- Reduce Cost By $100-300/Vehicle For Wet Chemistry

Enable Vehicle Lightweighting

- Enable Dissimilar Material Joining (e.g. Al/Mg/CFRP) & New Combinations
- Spillover Energy Reduction Effects For Lighter Weight Vehicles

Technical Innovation I

The conventional approach is to use wet chemical treatments (surface clean, etching, conversion coatings) to achieve a material transformation/deposition to resist corrosion on vehicle parts

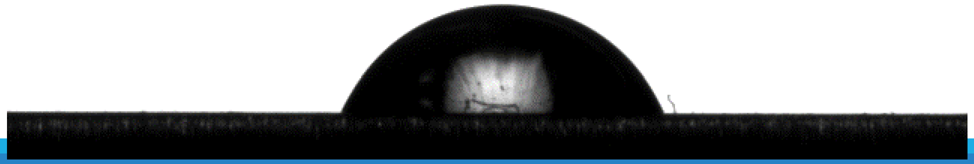
- Parts are totally treated by wet chemistry even though only a few % of the surface area is used for joining
- For epoxy-jointed surfaces of dissimilar materials, the joining surface quality and reliability is paramount

The near-term state of the art is to use laser ablation for aluminum to generate a native, deep surface oxide that resists corrosion and provides excellent surface adhesion for bonding

- Performed immediately prior to joining to limit surface contamination to build on the opposing mating surfaces
- Laser oxide formation is only good for aluminum and is suitable for flat, planar or easily accessible surface parts (not 3D printed, lightweight shapes)

Cost benefit is significant

- Eliminates transport, fuel consumption, bulk chemical use, waste water treatment, and lowers energy/emissions
- 33% reduction in cost compared to near-term laser ablation methods
- Single treatment process for Al, Mg, CFRP @ point of manufacturing; inhibitor for carbon fiber galvanic corrosion



Technical Innovation II

Plasma-based techniques use non-equilibrium chemistry for surface cleaning (e.g. the DC gliding arc & dielectric barrier discharge) prior to adhesive bonding

- The DC gliding arc is limited to downstream chemical precursor injection with a mm-scale plasma zone due to very high gas temperature & turbulent flow
- Dielectric barrier discharges are power density limited and require bulky support hardware
- Industrial scale systems need multiple source heads and treat planar surfaces only

<u>Starfire's Innovation</u>:

- Miniature solid-state power amplifiers using latest high-electron mobility transistors (e.g. GaN) generate microwave energy directly at the coaxial plasma applicator allowing efficiency and small size
- <u>Patent-pending zonal streamline flow enables plasma jet propagation for treatment of complex, 3D parts</u>
- Zonal shield gas, process gas and centerline material delivery enables novel applications using chemical precursors and direct physical sputtering of an electrode at atmospheric pressure
- Simultaneous surface cleaning, radical/etch, material deposition and reactive plasma chemistry with shielded contaminant protection

Technical Approach I

Identify and Resolve Roadblocks for Microwave Plasma Jet Applicator Development

- Demonstrate compact microwave plasma generator with integrated solid-state power amplifier in small form
- Eliminate bulky waveguides, mechanical tuning elements and detractions from using microwave energy
- Demonstrate streamline flow for extended plasma jet and extended reach for material coating for complex parts and 3D surfaces

Design of Experiments on Material Coatings

- Perform surface analysis screening tests for initial recipes, upgrade to tactical wet exposure lap-shear strength evaluations and down-selected strategic corrosion testing analysis on ideal material coating
- Use chemical precursor delivered silane/siloxane chemistries for surface cleaning, coating and sealing
- Evaluate potential for alumina/zirconia thin-film chemistries using hybrid sputtering or chemical precursor delivery

Advanced From Concept To Implementation Readiness

- Demonstrate implementation readiness with field demonstration at General Motors in 2nd Phase
- Leverage University-Industry Collaboration

Technical Approach II

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Tech Mgr: Steve Sikirica
TPO: Gibson Asuquo

TPOC: Dr. Robert Stubbers
APOC: Dr. Brian Jurczyk

starfire industries — Plasma Source, Product

Dr. Robert Stubbers	Microwave Launcher, Plasmas
Dr. Brian Jurczyk	Productization, Coatings
Dr. Darren Alman	COMSOL CFD/EM
Dr. Ivan Shchelkanov	Atmospheric Plasma Testing
Dan Menet	3D CAD/CAM, Systems Design
Martin Litwiller	MW Power Electronics
Paul Browne	Embedded Software
Sena Cooper	Production Manager
Sarah Gossett	Quality Manager

GM — Requirements, Evaluation

Dr. Surender Maddela (lead)
- Dissimilar Material Joining, Coatings

Dr. Blair Carlson
- R&D Group Lead, Vehicle Lightweighting
- Requirements, Costing, Energy Savings

TRANSITION PARTNER

Illinois — Material Depositions

Prof. David Ruzic (lead)
- Plasma-Material Interaction Director

Dr. Eitan Barlaz
- Atmospheric Pressure Plasma Testing
- Microanalysis Materials Analysis

A R I — ILLINOIS APPLIED RESEARCH INSTITUTE — Environmental Testing

Dr. Daniel Krogstad (lead)
- Accelerated Materials Research
- Environmental Testing Lab Manager

3rd Party Evaluation

NSF LPAM

Prof. Mool Gupta (lead) *Transition
- I/UCRC Lasers & Plasmas for Advanced Manufacturing

BROADER MARKET PARTNER

Results & Accomplishments

Project Status

Just getting underway, team in subcontracting

Industrial match provided by General Motors over 24-month period

Leveraging R&D plasma source developed post-NSF IUCRC collaboration

Required Future Work

Parallel plasma source and materials development

De-risking, engineering design, R&D evaluation

Evaluation of native oxide effect

Schedule

	Q1-2	Q3-4	Q5-6	Q7-8
Microwave Plasma Applicator	Requirements Scoping Study EM Design	Compact Plasma Applicator Design	Compact Plasma Applicator Completed	Demo @ GM
Materials DoE	SiOx Coatings	Al/Zr Coatings	Selected Recipe	
Material Eval	Basic Material Screening	Tactical Corrosion Testing	Strategic Corrosion Testing	Demo @ GM
Go/No-Go		>80%Lap Shear 2L, 5kg, 200W		Transition

Transition

Immediate transition plan is for in-line vehicle manufacturing with Partner General Motors

- Interface with robotic arm delivery system

Secondary market opportunities for transition through NSF member companies in I/UCRC Lasers and Plasmas For Advanced Manufacturing

- Trinity Industries (Rail Car, Barge, Wind Towers)
- National Oilwell Varco (Oil & Gas Infrastructure)
- Lockheed Martin (Aerospace Components)

The discussion to transition away from "wet chemistry" to "dry chemistry" is underway in several markets

2+2 Year Strategy	
Year 1	Proof-of-Concept Verification
Year 2	Implementation Readiness Validation
Years 3-4	Beta Pilot Product Transition

Additional IP Filed

License Agreement With Univ. of Illinois Pending