

NASA Tech Briefs Webinar

Tuesday, September 22, 2015

Lotus Dust Mitigation Coating

Kenneth O'Connor

Molecular Adsorber Coating

Nithin Abraham

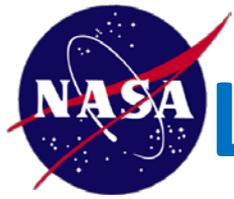


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Lotus Coating

Mitigating Surface Contamination

Kenneth O'Connor
Goddard Space Flight Center
September 22, 2015

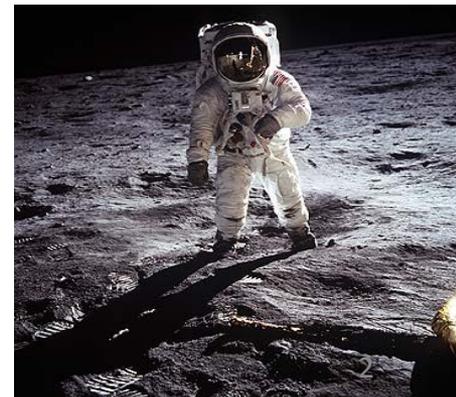


Lotus Technology Description



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- Lotus is a lightweight nano-textured dust mitigation coating originally being developed by NASA Goddard Space Flight Center (GSFC) as a countermeasure for dust accumulation during long-duration human space exploration
- The coating sheds dust particles utilizing anti-contamination and self-cleaning properties that minimize dust accumulation on spacecraft surfaces
- Focus is primarily on the formulation, characterization and environmental testing for space flight application
- Designed to preserve optimal long-term performance of spacecraft and habitation components and systems
- Sheds dust particles utilizing anti-contamination and self-cleaning properties that minimize dust accumulation on spacecraft surfaces
- Presently applied to thermal Control coatings (paint), metal, glass, fused silica, and polymer substrates
- Coating is super hydrophobic and sheds water



Buzz Aldrin on the Moon with footprints in the dust



The Lotus Effect

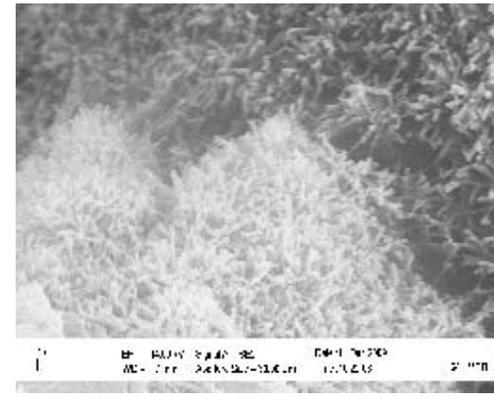
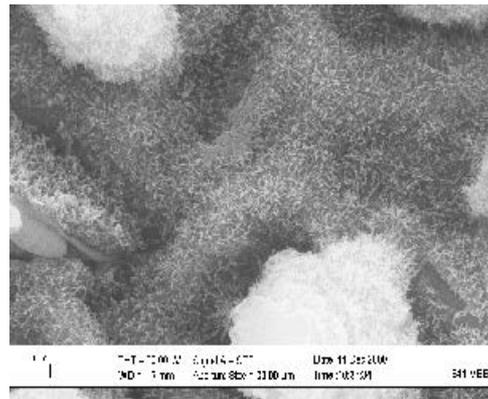
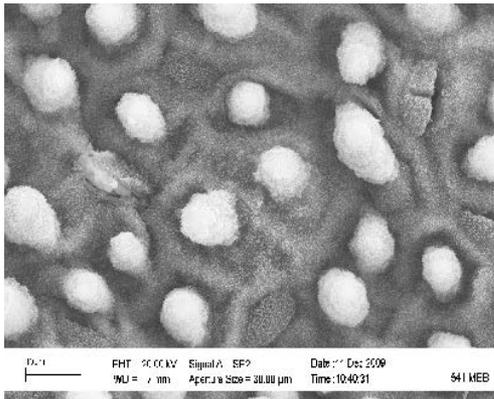


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- Based on the Lotus plant leaf
- Naturally occurring phenomenon
- Found on surface of Lotus leaf
 - Repels water and dirt
 - Hydrophobic
 - Nano-textured surface



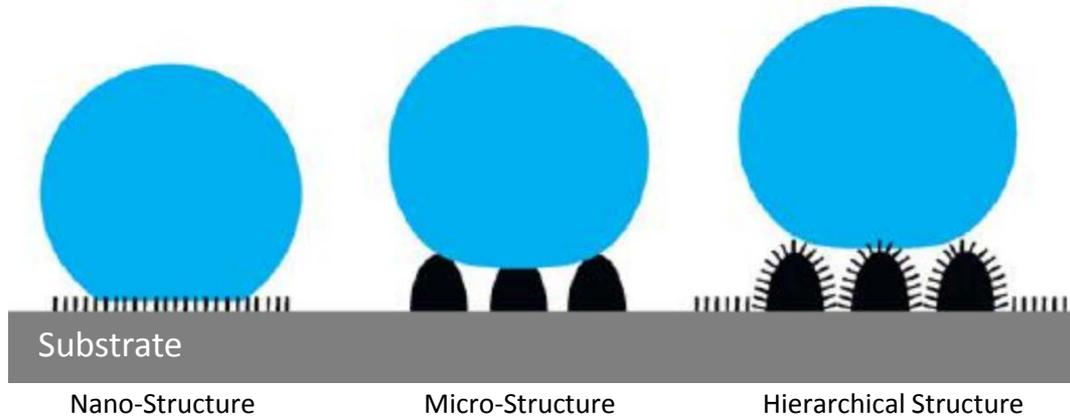
Lotus Leaf Phenomenon



SEM Images of Lotus Leaf



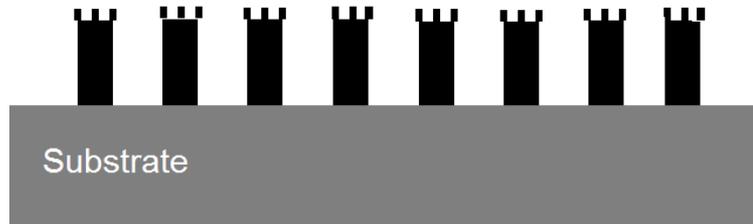
Achieving Hydrophobicity



A hierarchical structure, showing microstructure as well as nano-structure, when coupled with a hydrophobic surface coating, gives the best possible surface contact angle, as seen here.



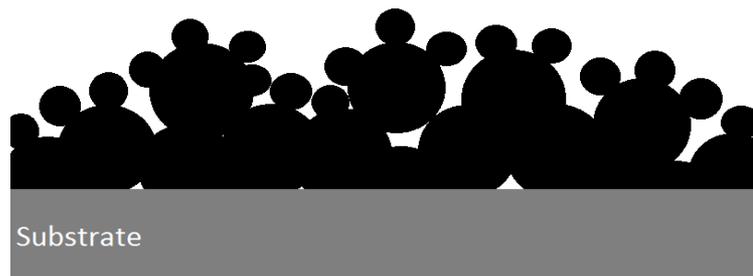
Properties vs Scale-Up



Idealized Structure

Nano-textured micro pillars like these, represent one of the best possible structures.

Only attainable at the laboratory scale. Not viable for manufacturing scale-up.



GSFC Lotus Structure

The GSFC Lotus structure uses different sized nanoparticles. Less ideal for hydrophobicity, due to randomness, but easier to scale up.

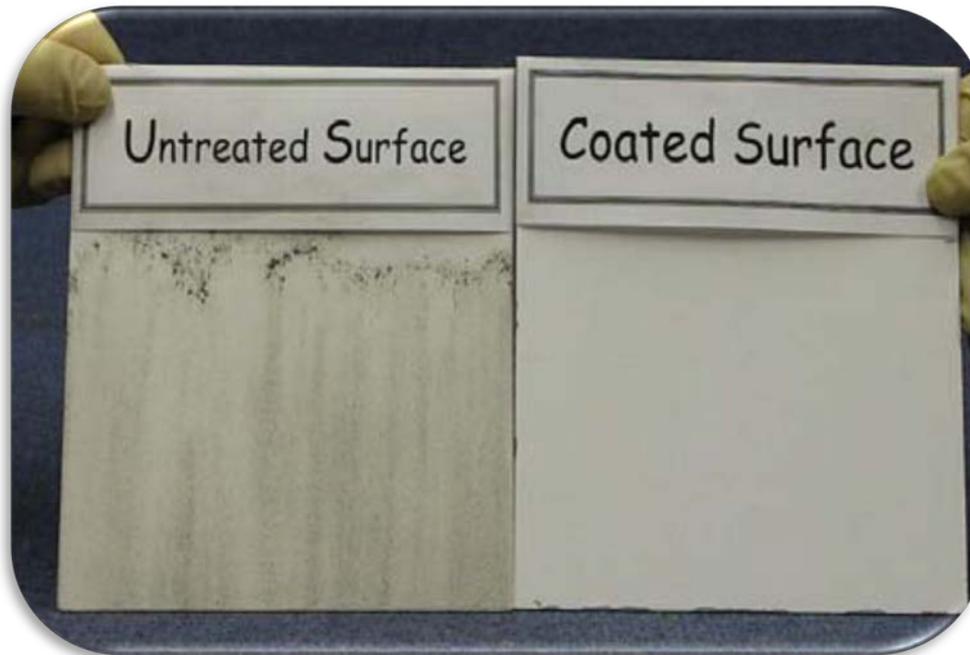


Lotus Coating



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- **Passive Mitigation Technology**
- **Super-hydrophobic coating which repels dust due to its unique surface architecture by reducing surface energy & area that is required for particle adhesion**



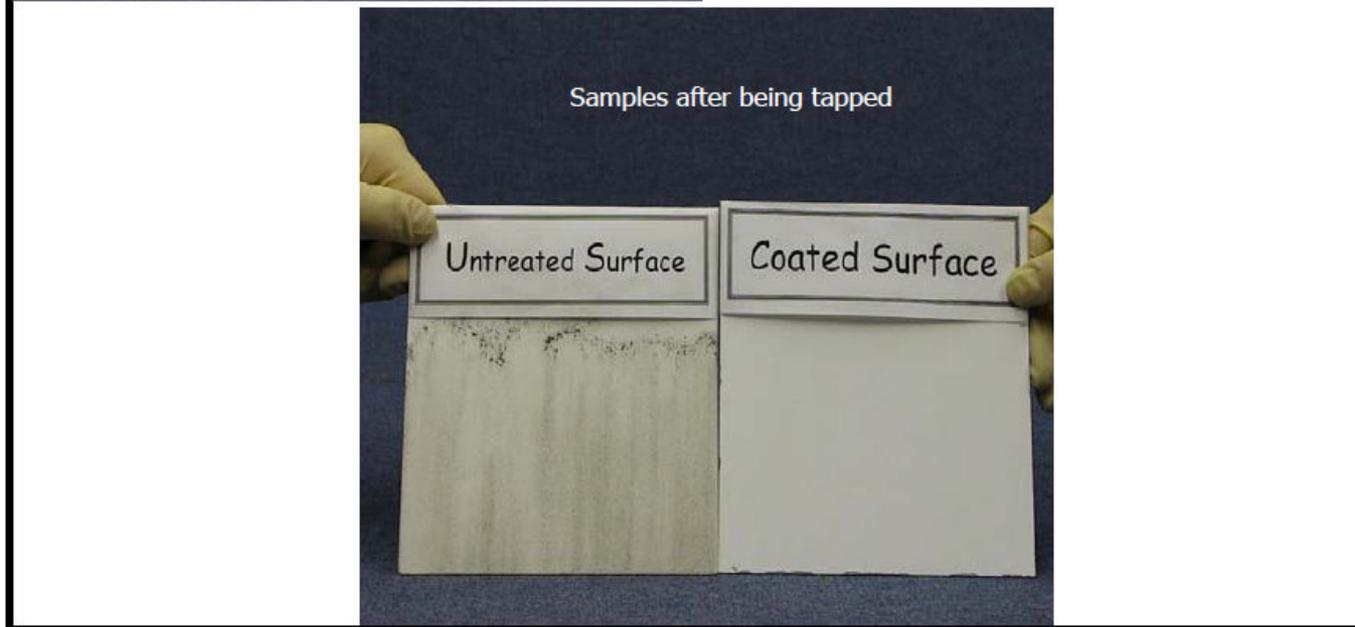
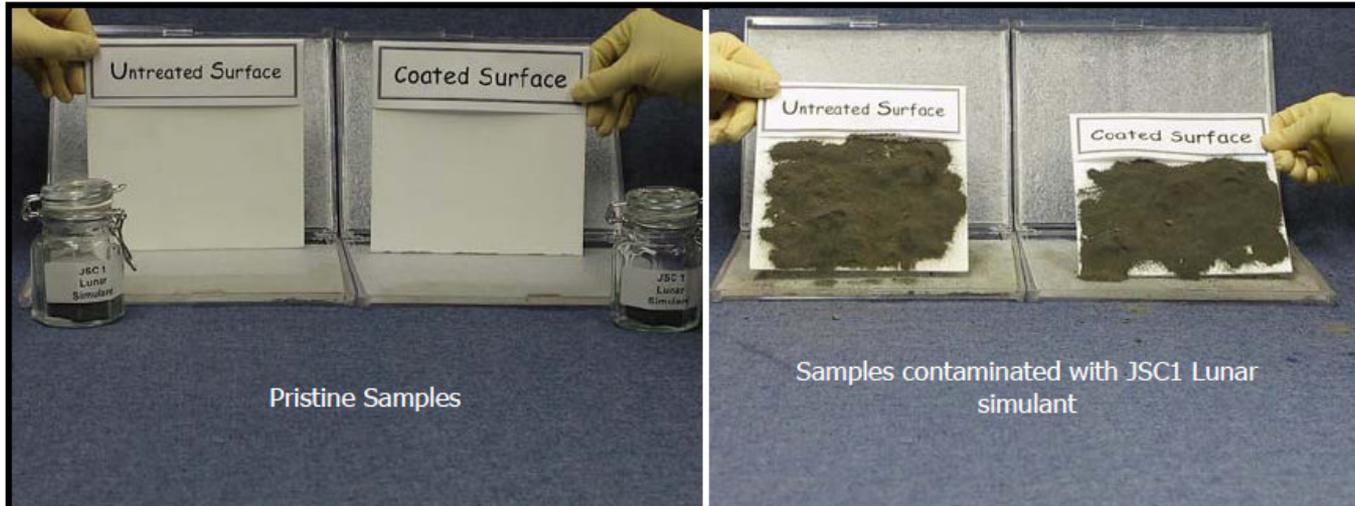
Passive Lotus Coating Technology



Lotus Coating



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Lotus Development



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- **NASA GSFC has developed an in house “wet chemistry” method to modify the Lotus coating to meet NASA’s specific needs**
 - Drivers:
 - Durability of coating
 - Stability in space environments (Vacuum, UV, radiation, etc)
 - Reproducibility
 - Quality control
 - Transmissivity



Lotus Coating Characterization and Test Methods



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- **Preliminary characterization:**
 - Scanning Electron Microscopy (SEM) analysis
 - Contact Angle measurements
 - Durability testing
 - Transmittance
 - Vacuum Compatibility

- **Future Testing:**
 - Thermal Cycling testing in vacuum
 - Ultra Violet Radiation Exposure testing
 - Solar Wind (low energy radiation) testing
 - Contamination assessments

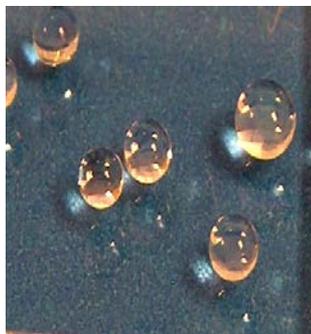


Lotus Coating Characterization and Test Methods



- **Formulations were applied to typical aerospace substrates including:**

- Radiator white thermal control coating/Aluminum substrate
- Bare Aluminum
- Stainless Steel
- Solar Cell Coverglass
- Fused silica
- Kapton
- Plastics



Water droplets on different materials with the Lotus coating From left to right: glass, ceramic, and metal

- **Can be expanded for application to various substrates**
- **Can be customized to meet transmittance requirements at desired wavelengths or for increased durability**
- **Can be spin coated, brushed, or spray coated**
- **Consists of a primer (optional), nanotextured layer, and hydrophobic self assembling monolayer**



Fused Silica Sample

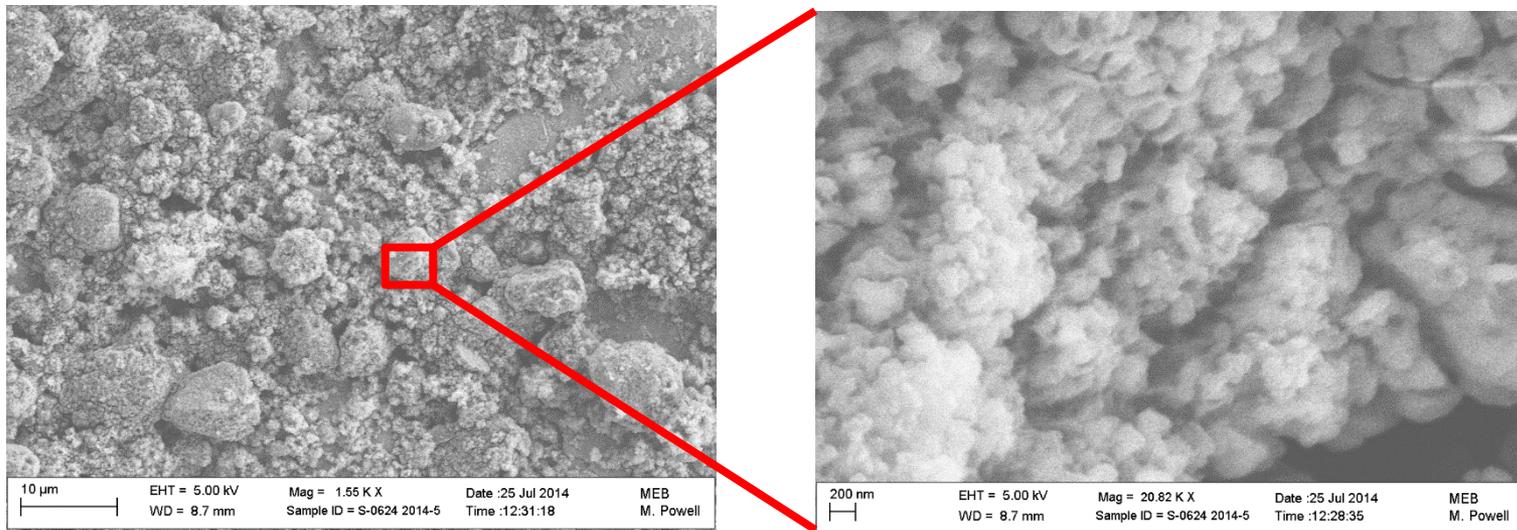


Scanning Electron Microscopy (SEM)



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- SEM was used to show nano structure of coating
- Samples show hierarchical structure, as designed



***SEM micrographs of samples
With Lotus coating***

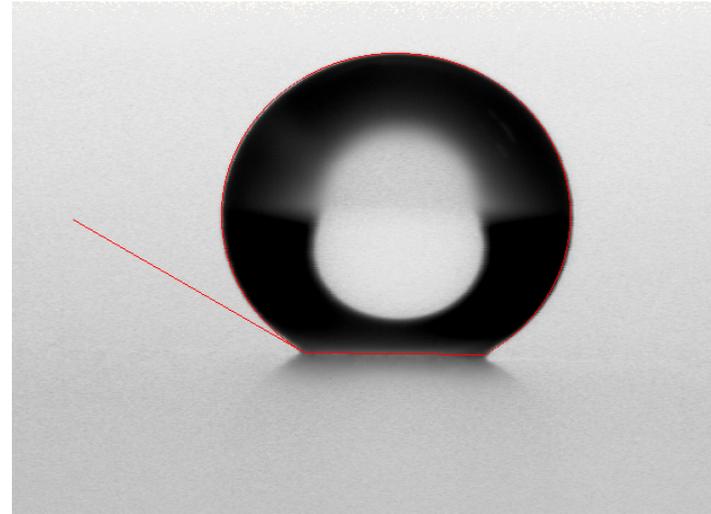
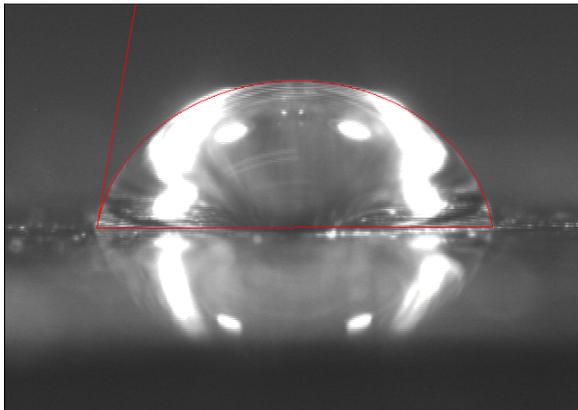


Contact Angle Testing



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- **Goniometer was used to measure contact angle of a water droplet on the surface of both Lotus formulations**
 - Hydrophobic $\geq 90^\circ$
 - Super-hydrophobic $\geq 150^\circ$



Goniometer snapshots of water droplet contact angles

Left: Uncoated sample displaying non-hydrophobic properties (contact angle $< 90^\circ$)

Right: Lotus WC2 coated sample displaying super-hydrophobic properties (contact angle $\geq 150^\circ$)



Durability Testing



- **Durability Testing**
 - **Optical Coatings Hardness Kit**
 - Mil Spec MIL-C-00675 Adherent
 - Contact angle measured after each pass

2lbf Cheesecloth

Pass	Contact Angle
0	153°
1	153°
2	151°
3	150°
4	151°
5	150°
6	150°
7	151°
8	151°

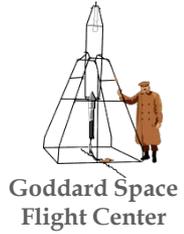
5lbf Eraser

Pass	Contact Angle
0	154°
1	146°
2	151°
3	145°
4	151°
5	151°
6	152°
7	147°
8	145°

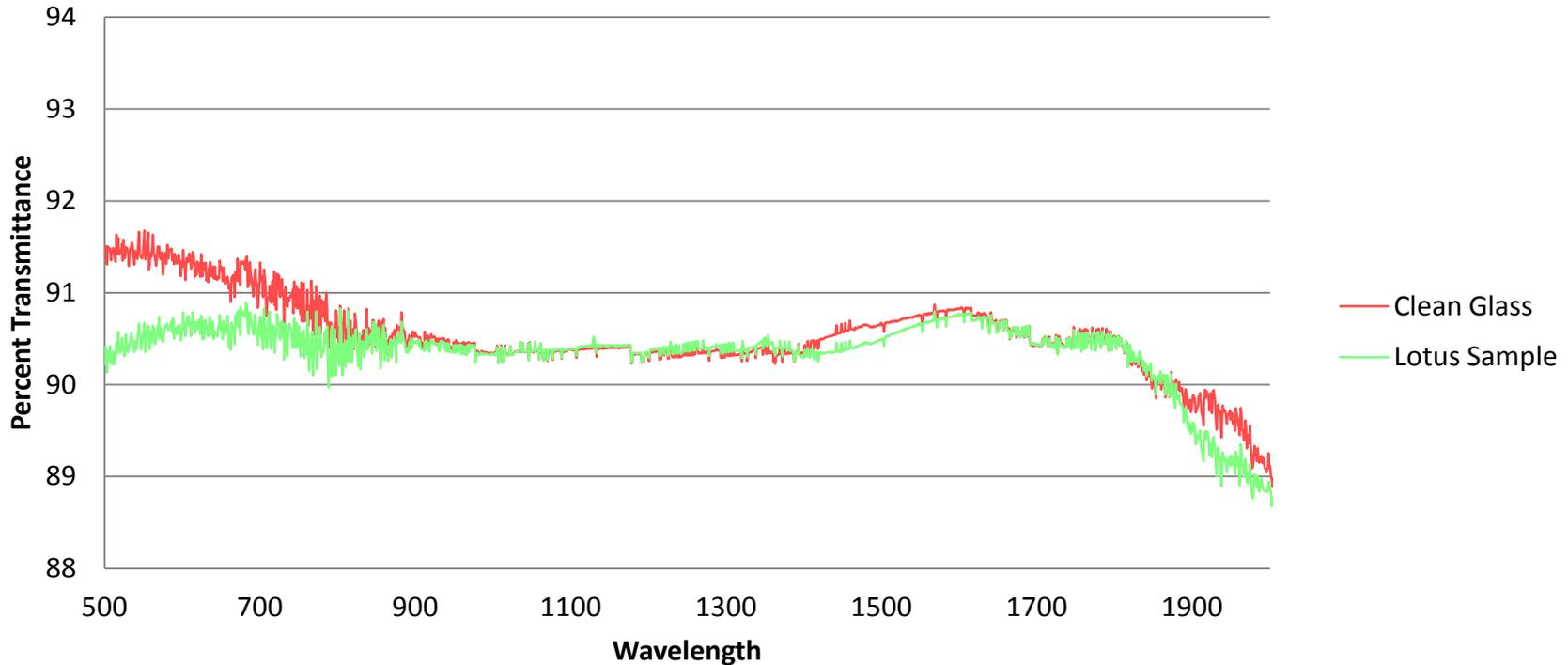
Samples optimized for durability



Transmittance Testing



- **Transmittance Testing**
 - **Cary 5000 Spectrophotometer**
 - Measured Transmittance compared to glass
 - Able to optimize for specific wavelengths



Sample optimized for Transmittance, Contact Angle of 148°



Vacuum Compatibility



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- **Samples exposed to high vacuum**
 - Initial contact angle measured at 153°
 - $\sim 10^{-6}$ torr, Room Temperature
 - 4 week exposure in VEECO chamber
 - Contact angle after exposure was 150°
 - No observable change in appearance





Always Looking to Improve



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- **Looking into new materials and processes:**
 - Replace the current binder system with one that never needs a primer
 - Identified candidates, initial screening is promising
 - Improve both durability and transmittance
 - Pursue one coating that meets all requirements
 - Remove potentially prohibitive processing steps
- **More Testing**
 - Continue vacuum compatibility testing with new materials
 - Thermal stability, in air and vacuum
 - Radiation Testing
 - Ultraviolet Light
 - Solar Wind



Conclusions



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- **Lotus coating demonstrated that it can maintain its anti-contamination and self-cleaning properties when exposed to specific space environments, especially where durability is a concern**
- **Coating demonstrates super-hydrophobic properties in addition to the dust mitigation properties**
- **Future work will focus on improved coating processes and formulations, as well as durability and transmissivity, for customized applications**



Contact Information



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NASA TECH BRIEFS WEBINAR:

Molecular Adsorber Coatings

Mitigating molecular contamination with an innovative NASA coatings technology

Nithin S. Abraham

*NASA Goddard Space Flight Center, Greenbelt, Maryland 20771
Code 546 Contamination and Coatings Engineering Branch
Tuesday, September 22, 2015*



Introduction

- ❖ *What are Molecular Adsorber Coatings?*
- ❖ *Why do we need them for spaceflight applications?*
- ❖ *What are the benefits of using this coating technology?*

Introduction

■ Offgassing

in Ambient Applications

- Most manufactured materials and consumer products release gaseous chemicals that are potentially harmful to human health
- This occurrence, most often referred to as outgassing, *is a part of everyday life!*
- Some everyday examples of offgassing include:
 - That **NEW CAR SMELL** in recently purchased vehicles
 - Film of haze that develops on car windshields or mirrors on hot days
 - Smells that come from household cleaners, plastics, toys, electronics, carpets, flooring, mattresses, furniture, and upholstery



Introduction

■ Outgassing

in Spaceflight Applications

- Significant threat to the spacecraft and the lifetime of NASA missions
- Originates from materials that outgas or release molecules during orbit inside of the spacecraft (in vacuum)
 - **Examples:** *plastics, adhesives, lubricants, silicones, epoxies, tapes, potting compounds, solvents, and other similar sources*
- On-orbit molecular contaminants from outgassed materials can deposit onto hardware and instrument components, and thereby, degrade the performance of highly sensitive surfaces
 - **Examples:** *optics, electronics, laser systems, detectors, baffles, solar arrays, thermal control coatings, and vacuum chambers*



Photo Credit: NASA - https://en.wikipedia.org/wiki/Space_Shuttle#/media/File:STS120LaunchHiRes-edit1.jpg

Introduction



■ Molecular Adsorber Coating (MAC)

- Developed by NASA Goddard Space Flight Center (GSFC) as a practical **low mass** and **cost effective** solution to address on-orbit contamination from molecular outgassing
- Sprayable, patent pending paint technology comprised of **inorganic materials** made from:
 - *Highly permeable, porous zeolite minerals*
 - *Inorganic, colloidal silica based binders*
- Available in both **white** and **black** variations for internal use only
 - *White Molecular Adsorber Coating, GSFC MAC-W*
 - *Black Molecular Adsorber Coating, GSFC MAC-B*
- Successfully demonstrated its technology with development and testing efforts in relevant space environments
- Ready for infusion and application specific advancement efforts for spaceflight projects and commercial markets that need to protect surfaces against the damaging effects of outgassing and/or molecular contamination

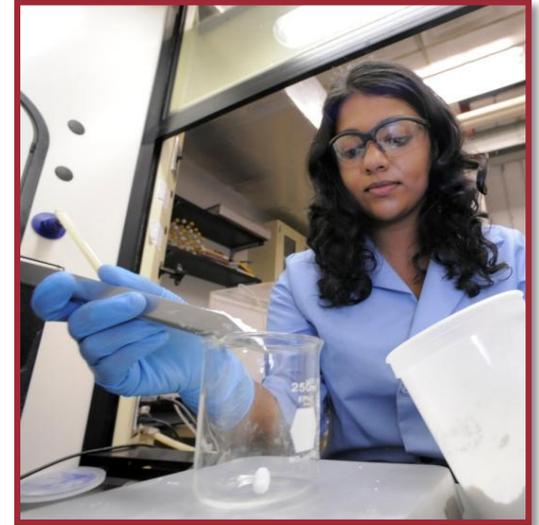


Photo Credit: NASA/Pat Izzo



Introduction

■ Molecular Adsorber Coating (MAC)

- MAC serves as a dual purpose **contamination control** coating

Type of Coating	WHITE THERMAL CONTROL COATING	WHITE MAC	BLACK MAC	BLACK THERMAL CONTROL COATING
Molecular Contamination Control		✓	✓	
Thermal Control Properties	✓	✓	✓	✓
Optical Stray Light Control			✓	✓

- Provides **thermal control** characteristics for thermal surfaces (*white and black*)
- Provides **optical straylight control** for baffles and optical surfaces (*black*)

- MAC provides several other **advantages** as an innovative coating technology
 - Easily **spray applied** onto most substrates (*with optimal adhesion performance*)
 - Tailored to meet specific adsorption characteristics (*thickness dependent*)
 - Low mass (*adds very little additional mass to the spacecraft*)
 - Low outgassing (*made from all inorganic materials*)
 - Cost effective (*made from low cost materials*)
 - Limited particulation effects (*with cleaning mitigation techniques available*)



Background

- ❖ *What is the chemistry behind the MAC technology?*
- ❖ *What are its coating properties?*

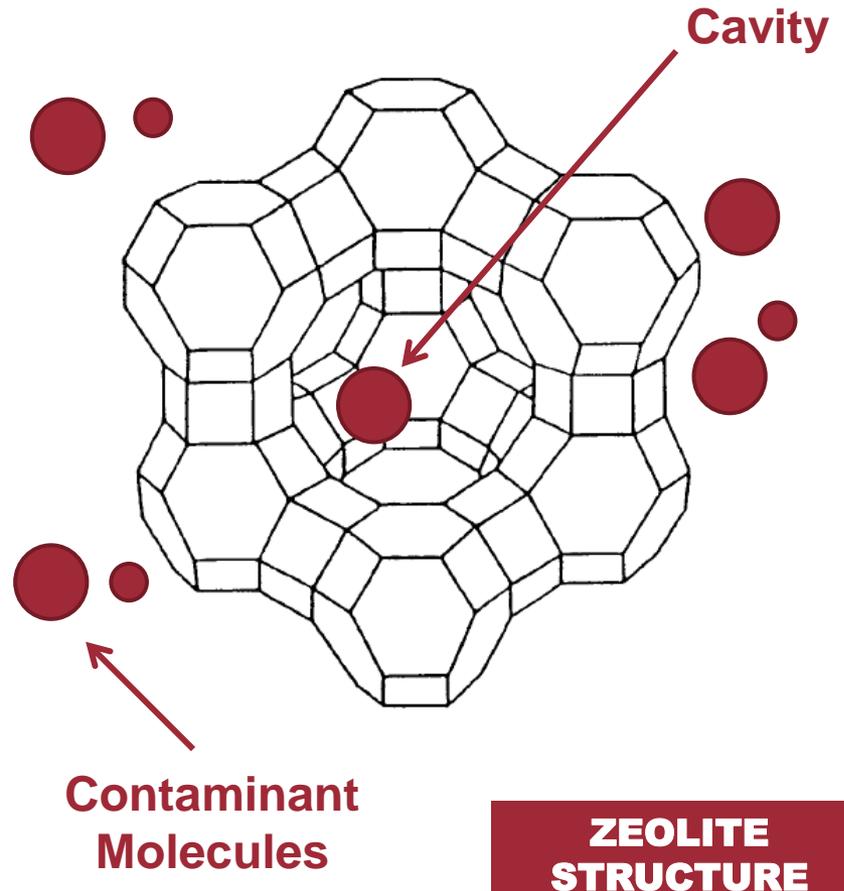
Background

■ Chemistry

- MAC is comprised of two key components: (1) **ZEOLITE** and (2) COLLOIDAL SILICA

ZEOLITE

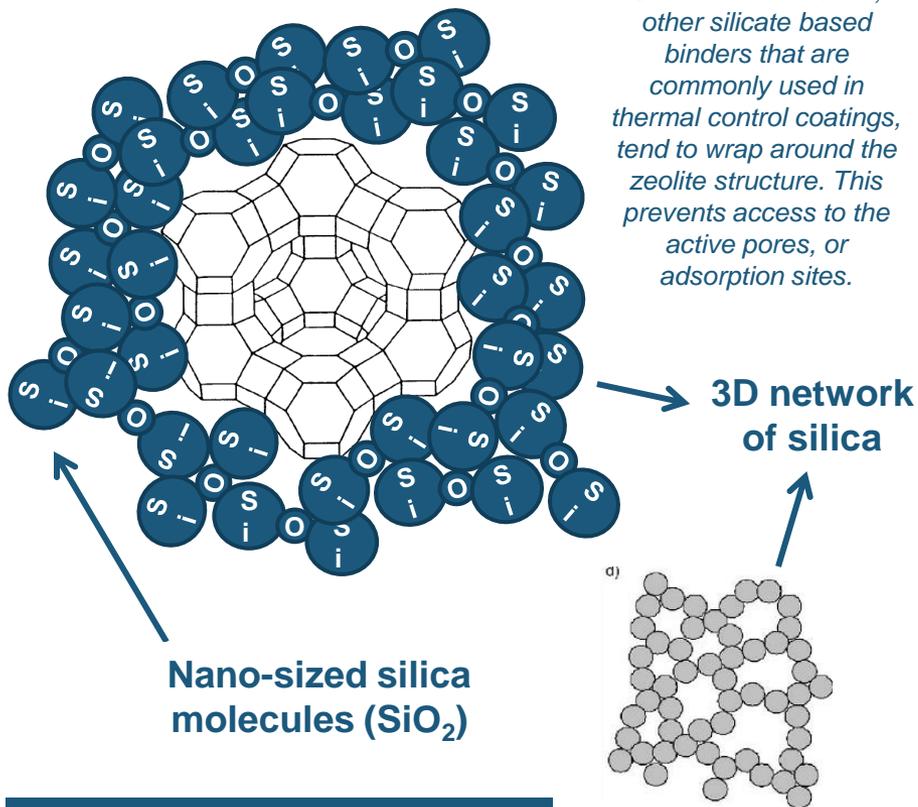
- **Pigment (*Molecular Sieve*)**
 - Acts as the adsorbent material that captures and traps molecules due to its porous structure
- **Desired Characteristics**
 - Large open pores, or cavities, within crystal structure
 - Large surface area to mass ratio that maximizes available trapping efficiency



Background

■ Chemistry

- MAC is comprised of two key components: (1) *ZEOLITE* and (2) *COLLOIDAL SILICA*



BINDER NETWORK SURROUNDING ZEOLITE

COLLOIDAL SILICA

- **Binder (*Suspensions of Colloidal Silica in Liquid Phase*)**
 - Acts as the glue that holds the coating together and provides adhesion between substrate layers
- **Desired Characteristics**
 - Nano-sized silica molecules are not large enough to clog pores or prevent access to the adsorption sites on the zeolite structure. Instead, a 3-dimensional network of silica gels around the zeolite structure.

Background

■ Surface Morphology

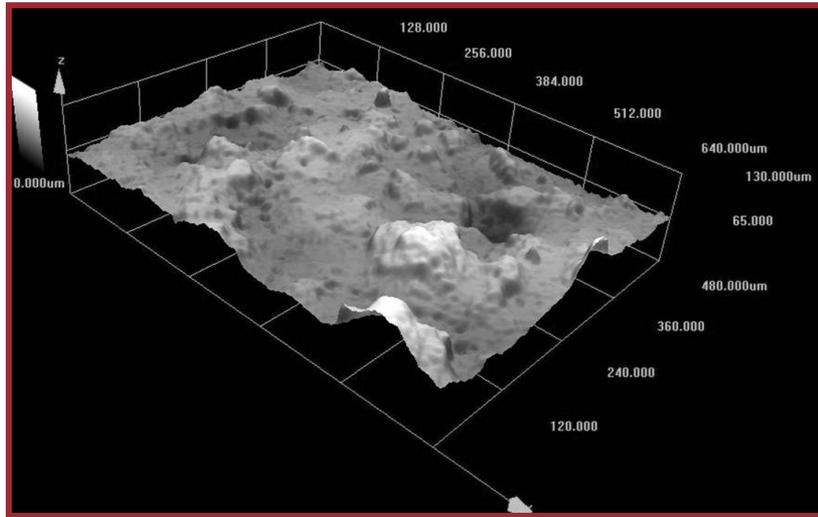


Photo Credit: NASA/Code 546

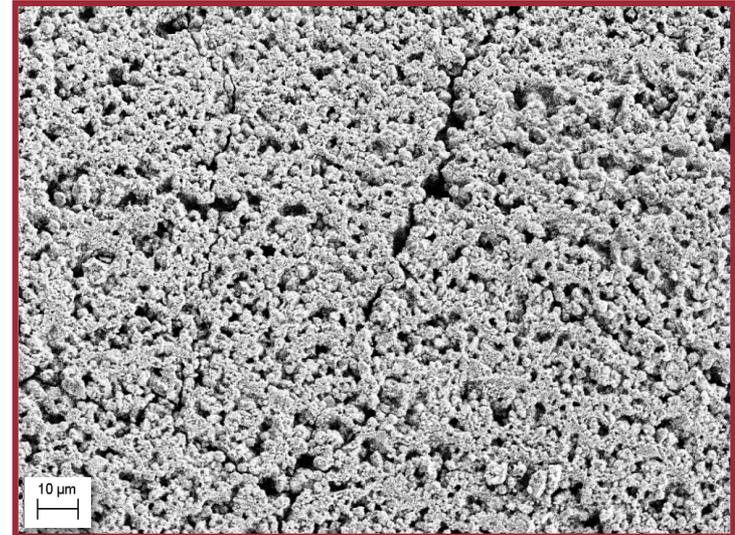


Photo Credit: NASA (SEM Analysis performed by Mollie Grossman/NASA GSFC Code 541)

Confocal Imaging Microscope (CIM)

CIM Parameters	CIM Analysis
Olympus LEXT confocal laser scanning microscope producing 3D imaging of coating surface at 20X magnification	Image above illustrates high surface area and surface roughness of the coating

Scanning Electron Microscope (SEM)

SEM Parameters	SEM Analysis
Electron scanning microscope under 5 kilovolts (kV) at 636X magnification	Image above illustrates highly porous structure of zeolite materials in the coating



Background

■ Thermal & Optical Properties

Solar Absorptance (α_s)	Normal Emittance (ϵ_N)
<p>The measure of the proportion of solar radiation the coating absorbs</p> <p>AZ Technology LPSR-300 Spectral Reflectometer</p> <p><i>Instrument measures reflectance from 0.25 to 2.8 microns at a 15° angle of incidence (ASTM E903-82)</i></p>	<p>The measure of the relative ability of the coating to radiate absorbed radiation</p> <p>Gier-Dünkle DB-100 Infrared Reflectometer</p> <p><i>Instrument measures reflectance from 5 to 40 microns at room temperature (ASTM E408-71)</i></p>

COATING TYPE	COATING DESCRIPTION	COATING THICKNESS	SOLAR ABSORPTANCE	NORMAL EMITTANCE
White Silicate	Alion Z-93P	4.0-5.0 mils	0.16	0.92
White Silicate	Alion Z-93C55	4.0-5.0 mils	0.13	0.92
White MAC	GSFC MAC-W	4.0-5.0 mils	0.30	0.93
Black MAC	GSFC MAC-B	2.5-8.5 mils	0.97	0.92
Black Polyurethane	Aeroglaze® Z306	2.0-3.0 mils	0.96	0.91
Black Polyurethane	Aeroglaze® Z307	2.0-3.0 mils	0.97	0.88

Background

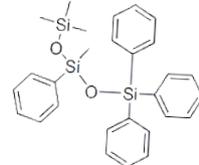
■ Adsorption Characteristics

- **Molecular capacitance** is the measure of the coating's ability to adsorb or entrap outgassed materials
- Adsorption characteristics are dependent on:
 - *Coating Thickness*
 - *Surface Area Coverage*
 - *Type of Contaminant*
 - *Duration of Exposure*
- Main contaminant sources used for vacuum molecular capacitance testing have been **complex chemical constituents**, which are representative of the commonly outgassed materials in spaceflight applications
 - *Long Chain Hydrocarbons*
 - Example: **Stearyl Alcohol**
(This specific compound is commonly found in cosmetic products, such as shampoos and lotions)
 - *Silicone Based Compounds*
 - Example: **DC704 Diffusion Pump Oil**



Photo Credit: NASA/Pat Izzo

Background

Long Chain Hydrocarbon	Type of Contaminant	Silicone Based Compound
<p>Stearyl Alcohol</p>  <p><i>Stearyl Alcohol</i>, comprised of volatile condensable materials that have a constant vapor pressure, provides a <u>constant source rate</u> for testing purposes.</p>	<p><i>Contaminant Source</i></p>	<p>Dow Corning® DC704 Diffusion Pump Oil</p>  <p><i>DC704 Diffusion Pump Oil</i>, comprised of complex materials that have varying vapor pressures, <u>does not</u> provide a constant source rate for testing purposes.</p>
1-octadecanol	<i>Chemical Name</i>	tetramethyl tetraphenyl trisiloxane
$C_{18}H_{38}O$	<i>Chemical Formula</i>	$C_{28}H_{32}O_2Si_3$
2.3 mg/cm²*	<i>Molecular Capacitance</i>	1.2 mg/cm²**
6.0 mils	<i>Coating Thickness</i>	6.0 mils
~88 hrs	<i>Exposure Time</i>	~115 hrs
45 °C	<i>Source Temperature</i>	70 °C

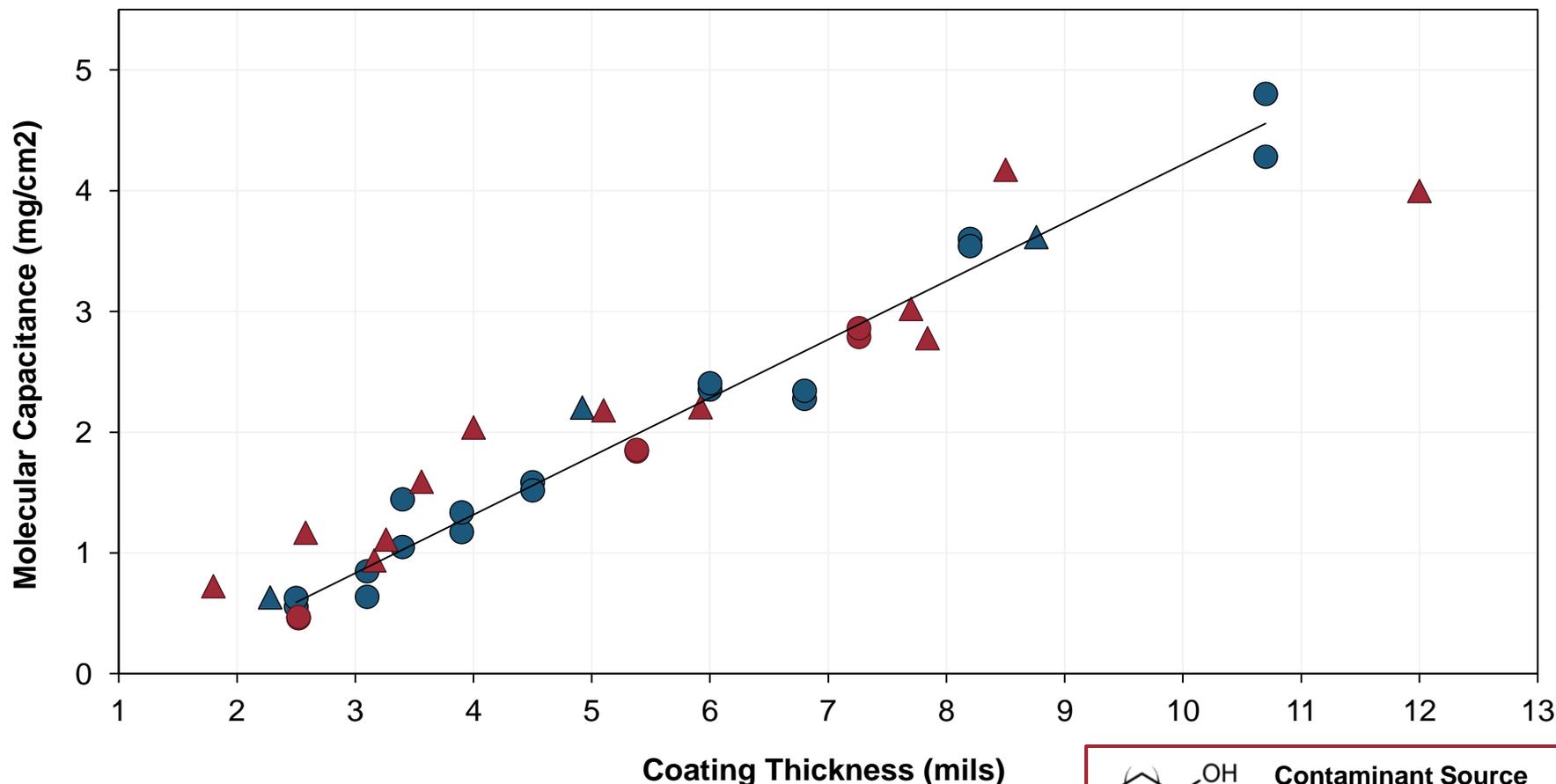
* Stearyl alcohol adsorption data is based on samples that have reached saturation at the coating thickness.

** Diffusion pump oil adsorption data is based on samples that have not reached saturation. The value listed is adsorption at a minimum at the coating thickness.

Background

Effect of Coating Thickness on MAC Adsorption Capabilities

Molecular capacitance is a function of coating thickness. Ex: white MAC at 6 mils is projected to have a molecular capacitance three times greater than a 3 mil sample.



- WHITE MAC (Formula B-TRL6) at 88 hr exposure
- ▲ WHITE MAC (Formula B-TRL6) at 160 hr exposure
- ▲ BLACK MAC (Formula 2-ML-H75) at 160 hr exposure
- BLACK MAC (Formula 2-ML-H75) at 155 hr exposure

Contaminant Source
Stearyl Alcohol at 45 °C

Adsorption varies from 0.5 to 5.0 mg/cm² at thicknesses between 2 to 11 mils

Background

■ Structural Integrity

- Performed vacuum thermal cycle tests at temperature extremes similar to those expected during spaceflight conditions to evaluate the **thermal survivability** and **vacuum stability** of the coating
 - MAC is anticipated to operate at temperatures that are representative of electronics boxes and other sensitive internal surfaces, which typically reach temperatures between **-10 °C to 40 °C**
- Coating **structural integrity** was evaluated on its **adhesion performance** before and after exposure to vacuum thermal cycle test conditions
 - Favorable coating adhesion performance results were achieved

Thermal Cycle Parameters	Expected Survivability Conditions	White MAC Test Conditions	Black MAC Test Conditions
<i>Vacuum Duration</i>		50 cycles	100 cycles
<i>Cold Temperature Limit</i>	- 10 °C	- 40 °C	- 60 °C
<i>Hot Temperature Limit</i>	40 °C	70 °C	90 °C
<i>Test Margin</i>		30 degrees	50 degrees



Photo Credit: NASA/Code 546



Applications

- ❖ *What are the NASA Applications of MAC?*
- ❖ *What is its scope for other applications?*

NASA Applications



- MAC has been proposed to be integrated as an innovative **contamination mitigation tool** on several NASA applications in the recent year(s).
- Current examples of these implementation efforts include:



Photo Credit: NASA <<http://www.nasa.gov/content/goddard-implementation-plan-in-response-to-the-2014-nasa-strategic-plan>>

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- Within **vacuum chamber environments** to protect test equipment from outgassed contaminants
 - **JWST:** Chamber A
- Inside small, sensitive **instrument cavities** to reduce effects of on-orbit material outgassing
 - **ICON:** Far Ultraviolet Instrument
 - **GEDI:** Laser Components
- For **hardware bake-outs** to reduce effects of vacuum material outgassing
 - **MMS:** Navigator Box

NASA Applications



Project

James Webb Space Telescope (JWST)

- Successor to NASA's Hubble Space Telescope
- Most powerful infrared space telescope ever built with a 6.5 meter primary mirror and a tennis court sized five layer sunshield
- Expected launch date is 2018



Photo Credit: NASA/ Chris Gunn < <http://www.nasa.gov/content/space-simulation-chamber-prepared-for-testing-webb-telescope>>



Photo Credit: NASA/Chris Gunn <https://www.nasa.gov/multimedia/imagegallery/image_feature_2467.html>

Application

Chamber A at NASA Johnson Space Center (JSC) in Houston, Texas

- MAC was used to capture ***vacuum chamber contamination*** originating from persistent outgassing sources within Chamber A, such as silicone pump oil residue (and other hydrocarbons)
- MAC is expected to lower the contamination risk cost effectively and prevent harmful outgassed components within the chamber environment from migrating and depositing onto JWST's highly sensitive ***optical ground support equipment*** surfaces during testing

NASA Applications



Problem

Chamber A's Contamination

- Chamber A is a **55 ft diameter** cryogenic optical vacuum chamber that has been upgraded to test JWST in a space stimulation environment
- Prior to its upgrade, Chamber A was originally used for testing space capsules for **NASA's Apollo missions**
- Due to its history, **DC704 oil residue** (among other hydrocarbons) still remained within the chamber
 - Silicone based contaminants are known to outgas and spread easily, even at ambient temperatures, and are extremely difficult to remove. Its outgassing effects can harm test equipment.*

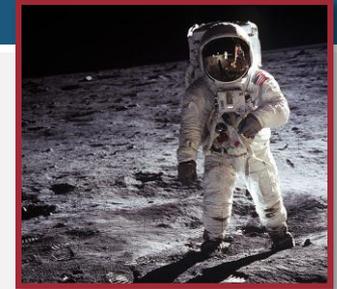


Photo Credit: NASA. <http://grin.hq.nasa.gov/ABSTRACTS/GPN-2001-000013.html>

Solution

MAC Test Panels

- Much effort has been performed to remove these persistent contaminants
 - Among one of the innovative contamination mitigation tools is through the use of MAC*
- MAC technology was tested during JWST's **Chamber A Commissioning Test** in October 2014 for **proof of concept** prior to its first large scale vacuum chamber application in May 2015

Chamber A Commissioning Test: MAC Proof of Concept Nonvolatile Residue (NVR) Materials Chemical Analysis Sample Size: 700 cm ²	Pristine Sample 01	Contaminated Sample 04 (Loc 1, BD)	Contaminated Sample 05 (Loc 2, PL)
NVR Adsorption	5.7 E-03 mg/cm ²	1.7 E-01 mg/cm ²	1.3 E-01 mg/cm ²
Hydrocarbons	4.0 mg (>99 %)	103.1 mg (88%)	82.4 mg (89%)
DC704 Diffusion Pump Oil	0 mg	0.7 mg (0.6%)	4.0 mg (4%)
Methyl Based Silicones	0 mg	0.5 mg (0.4%)	1.4 mg (1%)
Other Contaminants	0 mg	12.4 mg (11%)	5.3 mg (6%)

Fourier Transform Infrared Spectroscopy (FTIR) and Gas Chromatography/Mass Spectrometry (GC/MS)
Materials Chemical Analysis performed by Aparna Boddapati NASA/GSFC Code 541

NASA Applications



Description of Task

MAC was deployed for JWST's first Optical Ground Support Equipment (OGSE-1) test effort in May 2015

- Several MAC panels were custom designed, fabricated, and installed in very strategic locations within Chamber A to capture vacuum chamber contamination and prevent them from entering the test environment where the OGSE is housed.



All Photo Credits: NASA/Chris Gunn

NASA Applications



Project

Ionospheric Connection Explorer (ICON)

- NASA explorer program, led by University of California-Berkeley (UCB), designed to study the boundary between Earth and space and to understand its physical connection
- Expected launch date is 2017



Photo Credit: NASA/UC Berkeley <<http://icon.ssl.berkeley.edu/>>

Application

ICON's Far Ultraviolet (FUV) Imaging Spectrograph Instrument

- MAC is proposed to be used internally within the FUV *instrument cavity* to address on-orbit material outgassing concerns and to meet molecular contamination requirements
- This implementation will be MAC's *first flight mission application*

Description of Task

Custom Fabricated MAC Plates

- UCB supplied hardware will be spray applied with MAC and installed in strategic locations within the instrument cavity of the spectrograph and imager

NASA Applications



Project

Global Ecosystem Dynamics Investigation Lidar (GEDI)

- NASA science program designed to characterize the effects of changing climate and land use on ecosystems, and to understand Earth's carbon cycle and biodiversity
- Expected launch date is 2018



Photo Credit: NASA <<http://science.nasa.gov/missions/gedi/>>



Photo Credit: NASA <https://www.nasa.gov/sites/default/files/paquettes_device_0.jpg>

Application

GEDI's Laser Electronics Components

- MAC is proposed to be used on the interior cover of a **laser q-switch board** to address on-orbit material outgassing from electronics cards and its conformal coatings, and to meet molecular contamination requirements

Description of Task

- MAC will be spray applied directly onto the laser cover hardware surface

NASA Applications

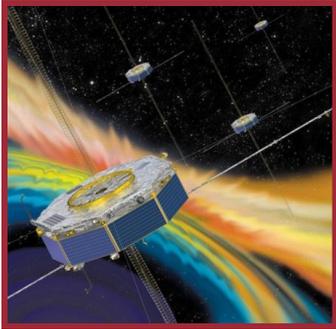


Photo Credit: NASA <<http://mms.gsfc.nasa.gov/index.html>>

Project

Magnetospheric Multiscale Mission (MMS)

- NASA mission comprised of four identical satellites flying in a tetrahedral formation designed to investigate how the magnetic fields of the Sun and Earth connect and disconnect
- Launched on March 2015



Photo Credit: NASA <<http://mms.gsfc.nasa.gov/index.html>>

Application

Vacuum Bake-out of MMS's Navigator Box Components

- MAC was used during a Navigator (NAV) box thermal vacuum test to reduce the effects of vacuum material outgassing from pre-baked components, such as electronic wires and harnesses

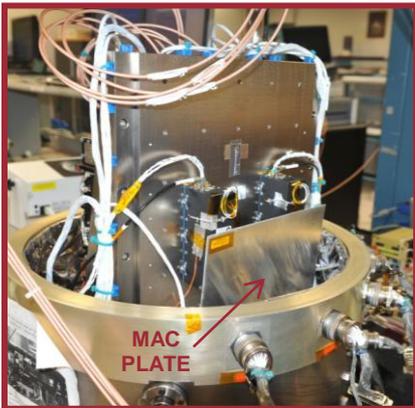


Photo Credit: NASA/MMS

Description of Task

Custom Fabricated MAC Plates

- MAC coated plates were placed along side the NAV box components during thermal vacuum test runs
- Quartz Crystal Microbalance (QCM) outgassing rates showed a significant reduction with the use of MAC
- Post analysis of MAC samples verified the adsorption of hydrocarbons, silicones, phenyls, and plasticizers from the NAV vacuum test environment

QCM OUTGASSING RATES

Empty Chamber	No MAC ~575 Hz/hr
Chamber with NAV Box and pre-baked Components	No MAC >~6000 Hz/hr
	With MAC Plate, TR1 ~300 Hz/hr
	With MAC Plate, TR2 ~675 Hz/hr

QCM Analysis performed by
Glenn Rosecrans SGT/Code 546

Commercial Applications



■ NASA GSFC Innovative Technology and Partnerships Office (ITPO)

- We coordinate with ITPO for technology transfer licensing opportunities

- ITPO facilitates creative collaborations between NASA Goddard technology researchers and external parties for mutual benefit. For more information, please visit <http://itpo.gsfc.nasa.gov> or contact our Technology Manager, Dennis Small at dennis.a.small@nasa.gov



- Commercial applications for MAC may include industries that require general gas adsorption, collection and containment of outgassed and/or offgassed contaminants and volatiles. Some of these potential applications may include but are not limited to:

- Aerospace
- Vacuum Systems
- Laser
- Optics
- Electronics
- Semiconductor
- Manufacturing
- Pharmaceutical
- Medical
- Food Industry
- Chemical Processing



Conclusions



Conclusions

■ Summary

- MAC is an **innovative solution** for molecular contamination control
 - Captures contaminants that otherwise can cause harm by depositing onto sensitive hardware
 - Helps meet mission molecular contamination requirements for hardware with outgassing components
 - Lowers pressures in vacuum chambers
 - Reduces outgassing rates during thermal bake-out times
 - Limits the use of cryogenic panels (i.e. liquid nitrogen scavenger cold plates) in vacuum chambers
 - Ideal within instrument cavities or hardware with electronics, optics, mirrors, telescopes, cameras, laser systems, detectors, baffles, solar arrays, etc

■ Future Plans

- Continue with the **advancement** of the existing MAC technology with further qualification efforts and seek **infusion opportunities**

Acknowledgements



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- Keeseey, L. “*Infusion Success: Technology Helps Prevent Outgassing Problems During Webb Observatory Testing*”, Cutting Edge Magazine. Goddard’s Emerging Technologies, Volume 11, Issue 4, Summer 2014; pg 16.

NASA SPACEFLIGHT MISSIONS

- James Webb Space Telescope (JWST), <<http://www.jwst.nasa.gov/>>
- Ionospheric Connection Explorer (ICON), <<http://icon.ssl.berkeley.edu/>>
- Global Ecosystem Dynamics Investigation Lidar (GEDI), <<http://science.nasa.gov/missions/gedi/>>
- Magnetospheric Multiscale (MMS), <<http://mms.gsfc.nasa.gov/>>



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