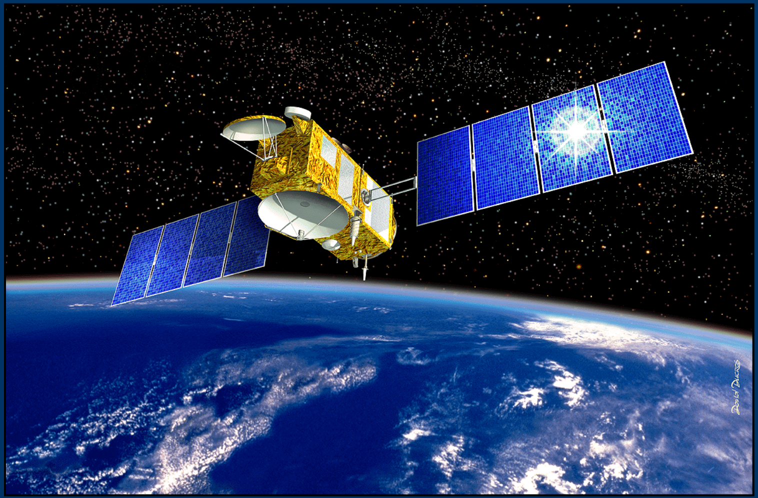
Coatings for Space Flight Composite Reflectors: Reflectance RF Conductivity Thermal Control

July, 2012



SURFACE OPTICS CORPORATION

For more information, or a quote, contact: Mark Wesley, mwesley@surfaceoptics.com / 858-675-7404

Overview

- **COMPANY:** Employee-owned San Diego company with 20 years experience in design, development, and application of precision coatings on critical spaceflight hardware.
- **COATINGS:** Ion Assisted Deposition (IAD) of metallic and dielectric films. Unique coating chambers and configurations to accommodate large substrates. Scalable processes.
- **CHAMBERS:** Four chambers accommodate a variety of applications. Reflectors and optics up to 3 METERS can be coated. Coating processes scalable to meet larger reflector needs.
- **FACILITIES:** 2,000 sq.ft. cleanroom (ISO Class 6) for cleaning, handling, coating. 100's of flight reflectors safely coated. Full design, fab, process capability for accommodating unique hardware.
- **VERIFICATION:** Internationally recognized expertise in measure of reflectance (200nm - 26microns), thermo-optical (α, ε), and surface scatter properties (BRDF).
- **CUSTOMERS:** NASA, AF, MDA, Axsys, Raytheon, L-3, Boeing, NG (Azusa, Baltimore, Xinetics), LM, ATK, Ball.
- **PROGRAMS:** DMSP, W-MAP, TDRS, OSTM, AEHF, Kepler, AMD

1.5m Kepler Primary, Coated w. Protected Ag, for Ball/NASA

SOC Chamber for Parts up to 3 meters

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- *Optical Coatings*
- *Antenna and Spacecraft Coatings*
- *Optical Measurements*
- *Hyper-spectral Sensors*
- *Instruments*
- *Signature/Thermal Control*
- *Small Business in San Diego*
- *Top Secret Facility*
- *DOD and Commercial*

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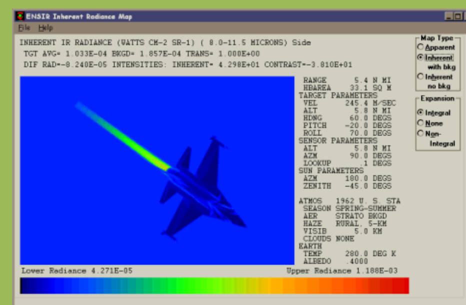
SOC BUSINESS UNITS

Coatings

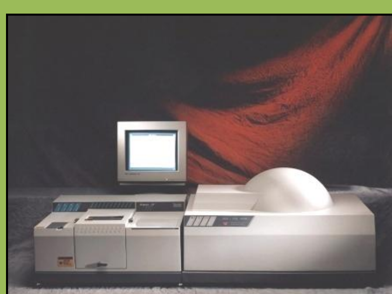
Hyper-spectral Sensors

Analysis



Optical Measurements

Instrumentation



SOC Space Flight Heritage

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Aluminum, Protected Aluminum, & Thermal Control Coatings

Program	Customer	Year	Reflector Size (m)	Thermal Requirements a/e	Radiometer	RF Conductivity Measured?
MLS	ATK (JPL)	1996	0.8 x 1.6	X		X
SeaWinds	JPL	1996	1.0	X		
Korea SAT		1997	1.0	X		
WMAP	GSFC	1998	1.5	X		
TDRS	BSS	1998	0.5			
BEAST Radio Telescope	ATK (UCSB)	1998	1.0, 2.2			
SSMIS	Aerojet (now NG)	1999	0.6	X	X	X
Jason 1	JPL	2000	0.5	X	X	
CMIS	ATK (Ball)	2000	2.3 x 2.5			
Cloudsat	ATK (JPL)	2002	1.8			X
WindSat	ATK (NRL)	2002	1.8	X	X	
DirectTV	ATK (LM)	2003	1.1			X
OSTM (Jason 2)	ATK (JPL)	2006	0.5	X	X	X
GMI	AASC (Ball)	2009	1.6			
AEHF	NGST	2009 - 2012	0.8 - 1.6			X
AMD	NG-Xinetics	2010 - 2012	1.2			
TDRS	AASC (BSS)	2011	0.5			
Jason 3	ATK (JPL)	2012	0.5	X	X	X

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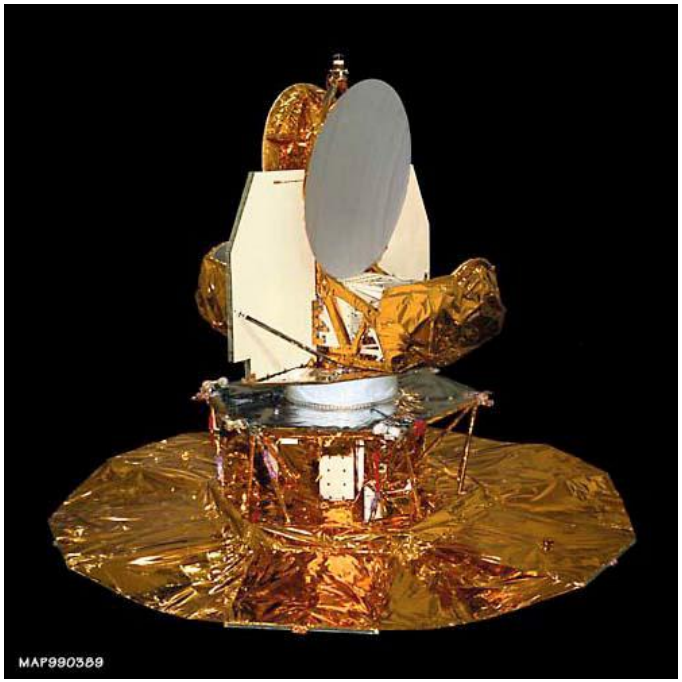
Early Developments

1.0 m Jason-1 Radiometer, NASA/JPL



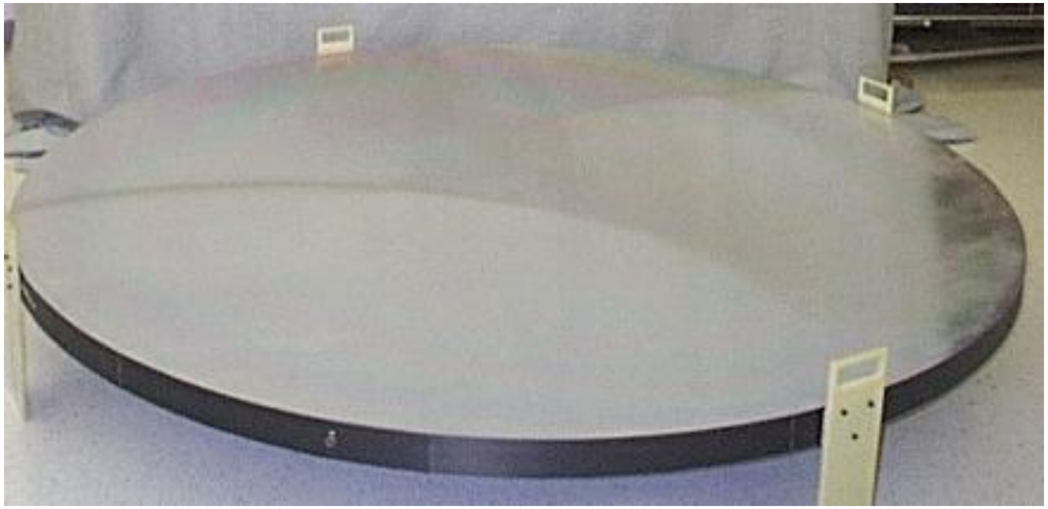
1.5 m WMAP Reflectors, GSFC

2.2 m BEAST Telescope, UCSB

Large Apertures

1.8 m CloudSat Reflector, NASA/JPL

1.8 m WindSat Reflector, NRL



2.5 m CMIS Reflector, Ball

1.6 m AEHF Reflector, NGST

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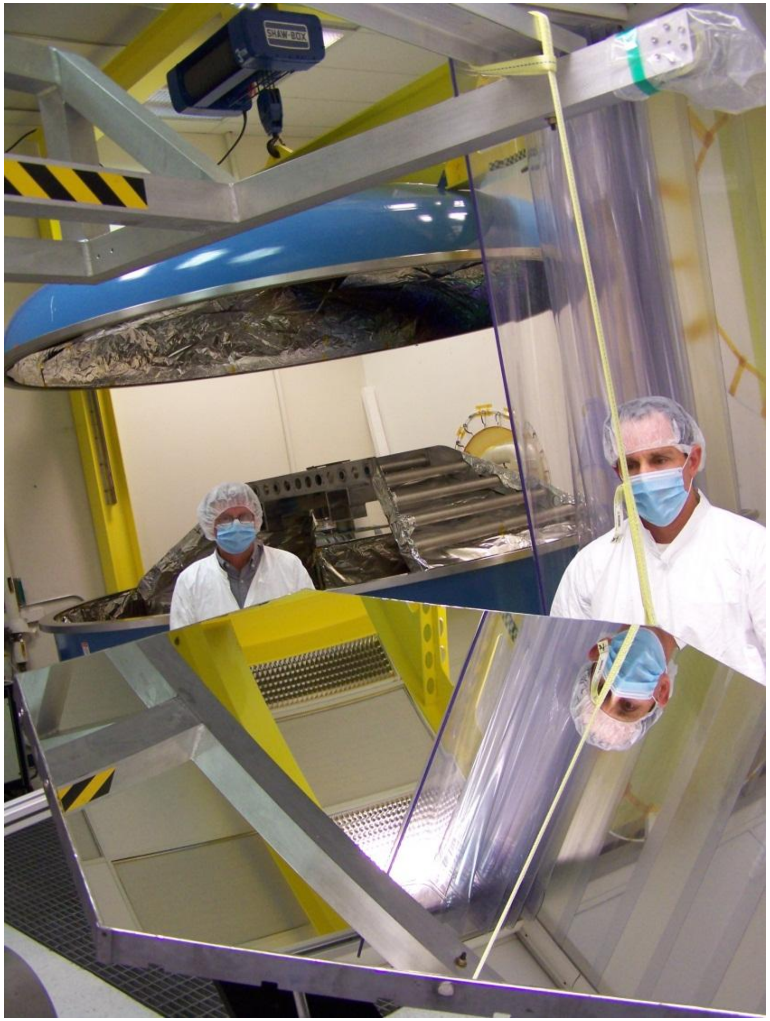
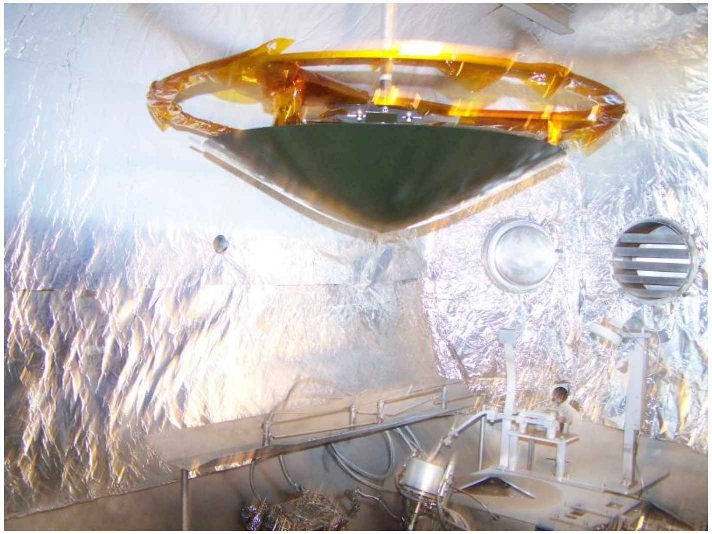
Recent Projects

1.0 m Jason-3 Radiometer, JPL



1.2 m AMD Mirror, NG-Xinetics



0.5 m TDRS Reflectors, Boeing

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Chambers & Capabilities

- **3.3 meter (motion controlled e-beam IAD)**
- **1.8 meter (motion controlled e-beam IAD)**
- **1.2 meter (planetary)**
- **Small R&D chamber (up to 2 runs per day)**

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Key Coating Technologies

DESCRIPTION	APPLICATIONS	Technology Status
Ion Assisted E-beam Evaporation	Reflective & Transmissive coatings: optical, IR, RF	Industry standard
Moving Source Coating Platform	Enables coating of parts as large as chamber	Proprietary (SBIR data rights)
Aluminum coating w/ tailored thermal control properties	RF coating for composite spaceflight reflectors	Designated supplier in NG and BSS Specs
Low temperature coating of polymer substrates	Plastic lens, Nano-laminate Structures	Proprietary (SBIR data rights)

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Substrate Handling Background

- SOC has safely processed hundreds of flight reflectors through our Coating facility.
- We have a full capability to address unique hardware
  - mechanical design
  - Fabrication
  - proof-loading
  - complete handling plans.
- Examples of some of our most complex Programs: Kepler, AMD, NIF, WMAP, Chandra, NuStar

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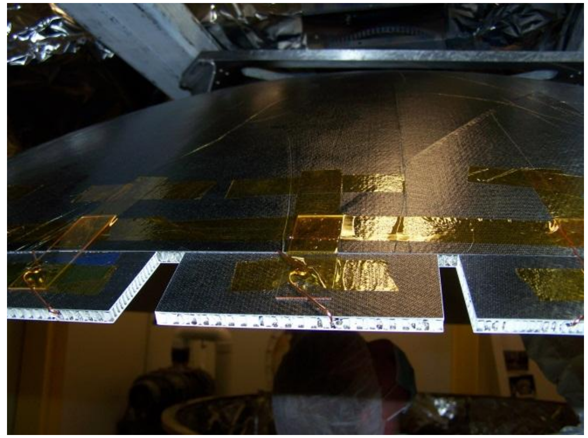
AEHF 1.6m Composite Reflector

Unpacking and inspection



Edge coupons installed

Final inspection

Reflector installed in chamber, ready for coating

Surface Optics Quality System

Surface Optics quality system has been fully documented and implemented and is maintained as needed to meet the requirements of our Company vision and governing policies. Surface Optics has adopted a process-oriented method of management. This approach emphasizes the importance of continuous improvement and understanding, meeting and integrating customer requirements:


nqa global assurance

Certificate of Registration

This is to certify that the Quality Management System of:

Surface Optics Corporation
11555 Rancho Bernardo Road
San Diego, CA 92127

applicable to:

Coating of optics and reflectometers

has been assessed and approved by
National Quality Assurance, U.S.A., against the provisions of:

ISO 9001:2008 and AS 9100:2009

and in accordance with the requirements of AS9104A.

For and on behalf
of NQA, USA, Acton, MA 01720

Certificate Number: 13575
EAC Code: 19
First Issued: December 2, 2010
Valid Until: December 2, 2013
Reissued: February 1, 2012

ANAB ACCREDITED

Page 1 of 1

This approval is subject to the company maintaining its system to the required standard, which will be monitored by NQA, USA, an accredited organization under the Aerospace Registrar Management Program.

nqa. ISO 9001 Registered | ANAB ACCREDITED | nqa. AS9100 Registered

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SOC Laboratory Measurement Expertise

BRDF
Emittance
Coating Thickness
Directional Reflectance
Hyper-spectral Discrimination
Surface Contamination
Optical Density
Coating Stress
Resistivity
Adhesion

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RF Conductivity

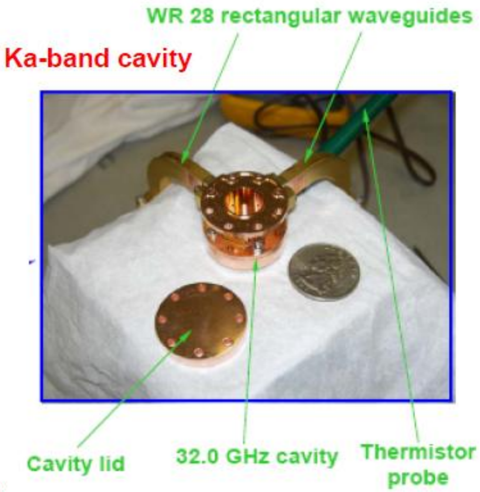
- Method developed by Aluizio Prata (USC) and JPL for 32GHz measurements.
- SOC now contracts directly with Aluizio Prata (California Electromagnetic Works) for these measurements.

Resonant Cavity Technique

- Resonant cavity technique yields effective conductivity of flat or gently curved surfaces
- Conductivity of cavity walls and lids first calibrated by measuring cavity Q at two resonant frequencies
- Top lid is replaced by material under test and Q at lower resonant frequency used to measure its effective conductivity, σ_E

$$|\Gamma_H|^2 \cong \left| \frac{\cos\theta_i - \frac{\eta_1}{\eta_2}}{\cos\theta_i + \frac{\eta_1}{\eta_2}} \right|^2, \quad |\Gamma_V|^2 \cong \left| \frac{-\cos\theta_i + \frac{\eta_2}{\eta_1}}{\cos\theta_i + \frac{\eta_2}{\eta_1}} \right|^2,$$

$$\frac{\eta_1}{\eta_2} \cong \sqrt{\frac{\sigma_E}{j2\pi f \varepsilon_0}}.$$



Brown et al. MicroR

Thermal Control Coating Basics

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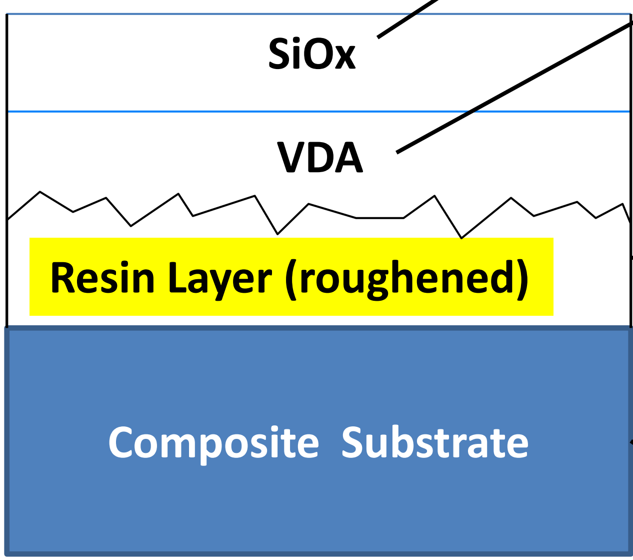
The design and application of a thermal control coating requires the balance of several competing requirements. Both Substrate and Coating are important.



- Thermal emittance (function of thickness)

- Solar absorptance
- RF Conductivity
- Specularity (VDA structure an important factor)

- Provides electrical isolation between VDA and graphite composite (galvanic corrosion possible otherwise)
- Must be roughened "enough" to create diffuse surface that will meet Specularity requirement
- If "too" rough can lead to discontinuities in VDA layer, negatively impacting RF Conductivity

- Rigid, stable foundation
- Meets all thermo-mechanical requirements
- Parabolic surface of required accuracy

Thermal Control Coating Steps

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- Composite substrate preparation is important to meet Specularity requirement, and mitigate galvanic potential with Aluminum
  - Epoxy resin washcoat, thermally condition, Gritblast
  - OR, apply primer in thin layers with matte finish (BR127 typical)
  - Measure resin surface prior to coating:
    - Measure Specularity on reflector surface using SOC handheld spectrometer
    - Measure DC resistivity to ensure electrical isolation
- Apply vapor deposited aluminum (VDA) with low solar absorptivity (α), in correct thickness for lowest op. frequency
- Apply overcoat (SiOx or SiO2) in correct thickness to yield desired value of emissivity (ε)
- Measure RF Conductivity, α, ε, and Specularity on both witness coupons, <u>and</u> coated reflector (if desired)

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Typical VDA Requirements

- Reflective Coating
  - Aluminum Minimum Thickness
  - Reflectance
  - Adhesion
- Advanced Reflector Coating
  - DC Conductivity
  - RF Conductivity
  - Thermal Cycle
- Thermal Control Coating
  - Solar Absorptance (α)
  - IR Emittance (ε)
  - α/ε Ratio
  - Specularity (Solar Concentration)

Importance of VDA Process Parameters

- VDA process parameters determine aluminum microstructure.
- Microstructure influences competing coating performance properties:
  - Alpha
  - RF Conductivity
  - Specularity
  - Terrestrial stability (i.e. ground storage)
- Significant investment at SOC over last 10 years to understand, control, and document correct VDA processes

Radiometer Coating Programs Sample Summary

Project	Customer	Year	Size	Freq (GHz)	VDA	Overcoat	a/e	Diffusivity	Thermal Cycle	32 GHz RF Conductivity (MS/m)	Status
MAP	NASA	1998	0.6m	22 - 90	2.5 µ	2.4 µ SiOx	<<1	<5% , 10° cone			12 years on-orbit operation
WindSat	NRL	2002	1.8m	6 - 37							9 years on-orbit operation
MLS	ATK (COI)	2004	1.5m	63 - 205	1.2 µ	1.5 µ SiOx	1 - 2	<2% , 5° cone			8 years on-orbit operation
CloudSat	NASA/JPL	2005	2.5m	94	1.2 µ	1.1 µ SiOx	1 - 2	<5% , 10° cone			6 years on-orbit operation
OSTM	NASA/JPL	2008	1m	1 - 100	1.2 µ	1.1 µ SiOx	1 - 2	<25% , 10° cone	-120C / +135C		4 years on-orbit operation
GMI	NASA/ GSFC	2009	1.2m	10 - 183	1.7 µ	1.2 µ SiO2	< 1	< 0.4% , 1° cone	-100C / +150C		Flight article coated at JDSU. Thermal cycle reduced to +130C.
Jason 3	NASA / JPL	2012	1m	18 - 34	1.6 µ	1.1 µ SiOx	1 - 2	<25% , 10° cone	-120C / +135C		To Be Launched 2013