Improved Satellite Robustness through Application of Erosion Resistance and High Emissivity Coatings

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Background

- Spacecraft can experience charging throughout operation due to high flux of incident electrons (ex. during geomagnetic substorm). As a result, different materials/components may experience a range of potentials which may lead to plasma-induced arcs, damaging spacecraft components.
- 54% of spacecraft failures are due to enhancement of radiation belt particles and magnetospheric plasma that cause charging/discharging
- Current space charge mitigation technologies:
  - Metallic coatings
  - System chassis ground leads to as many surfaces possible
  - Not effective in severe sub-storm conditions and do not enable local application of coating

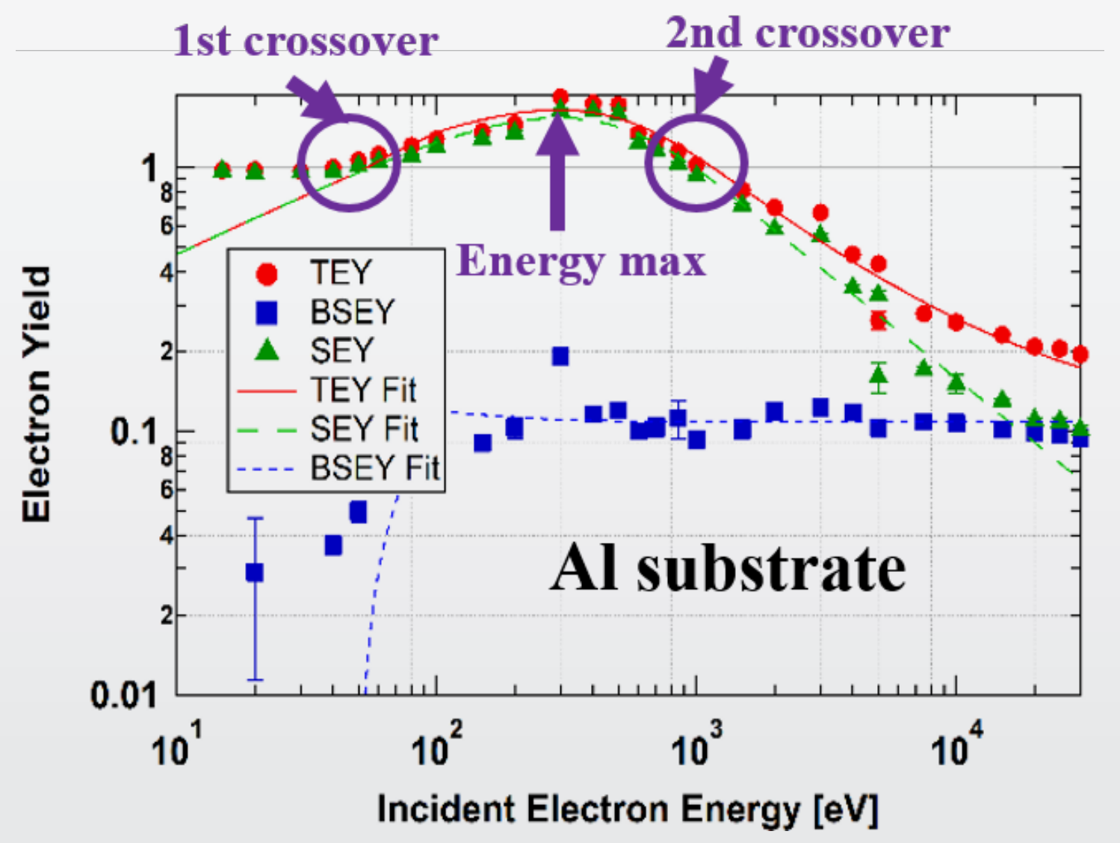
Space Environment Impacts on Space Systems

Anomaly Diagnostics	Number	%
ESD-Internal, Surface and Uncategorized	**162**	**54.1**
SEU (GCR, SPE, SAA, etc.)	85	28.4
Radiation Dose	16	5.4
Meteoroids, Orbital Debris	10	3.3
Atomic Oxygen	1	0.3
Atmospheric Drag	1	0.3
Other	24	8.0
Total	**299**	**100.0%**

Objective

To develop and deploy a robust space charge mitigation technology to protect spacecraft components failure from space weather by enabling:

- High passive electron emission properties (anticipated to be >300% over bare Al substrate)
- Improved durability and lifetimes in low-earth (LEO) and geosynchronous(GEO) orbits.



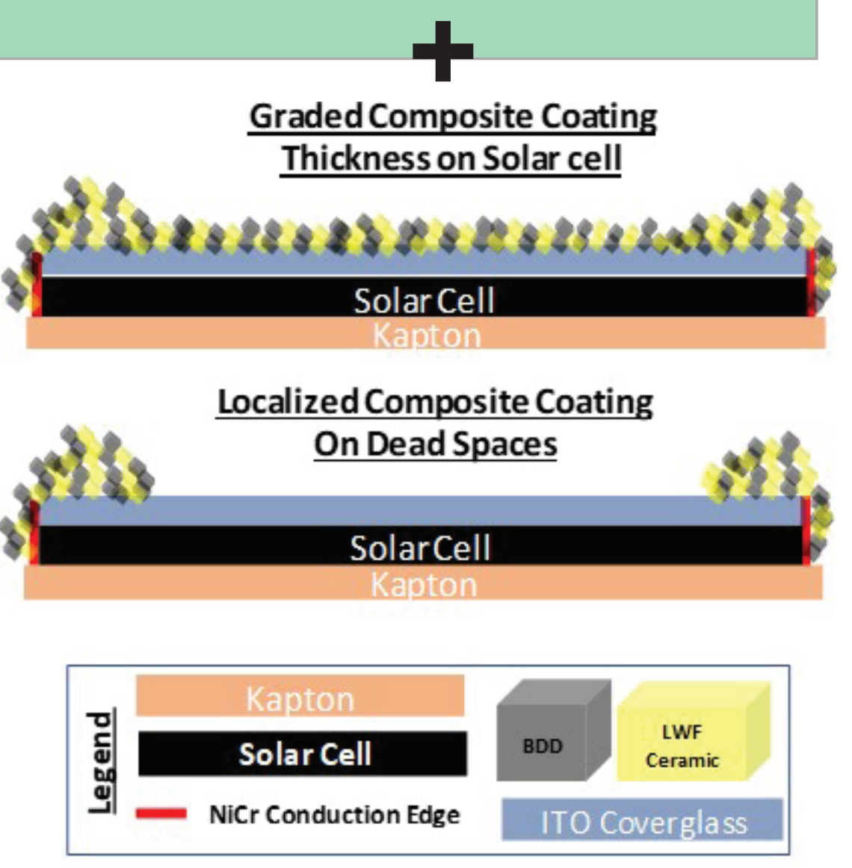
Baseline – Total electron emission yield ~1.5 for Bare Al Substrate

Technical Approach

Tunable Composite Coating for Robust Charge Mitigation:

- **Hard material** - provides resistance to erosion in severe substorm conditions
- **Conductive material** - provides conductivity to distribute the negative charge across the spacecraft components
- **Low work function (LWF) material** - provides enhanced electron emission properties
- **Electrophoretic deposition method** - Scalable, low-cost, works for complex geometries, and enables tuning of the composite structure

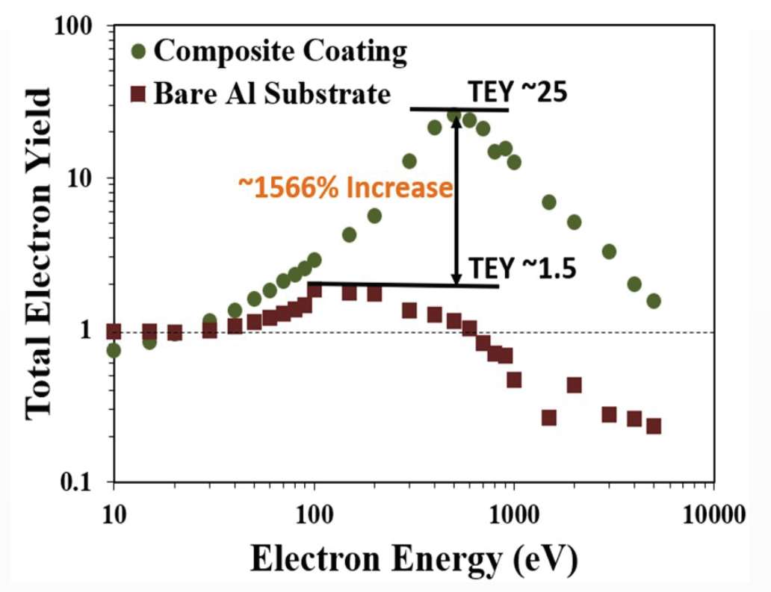
A tunable composite coating based on passively emitting, lightweight, erosion resistant materials is deposited using a scalable/economic electrochemical method. The coating can be locally applied onto a specific spacecraft component for robust space charge mitigation for NASA and/or other commercial end users (Patent application #: 63/231,923 ; Filing date Aug 11, 2021).



Results - Autonomous Emission

To date, the composite coating was tuned to demonstrate autonomous space charge mitigation with:

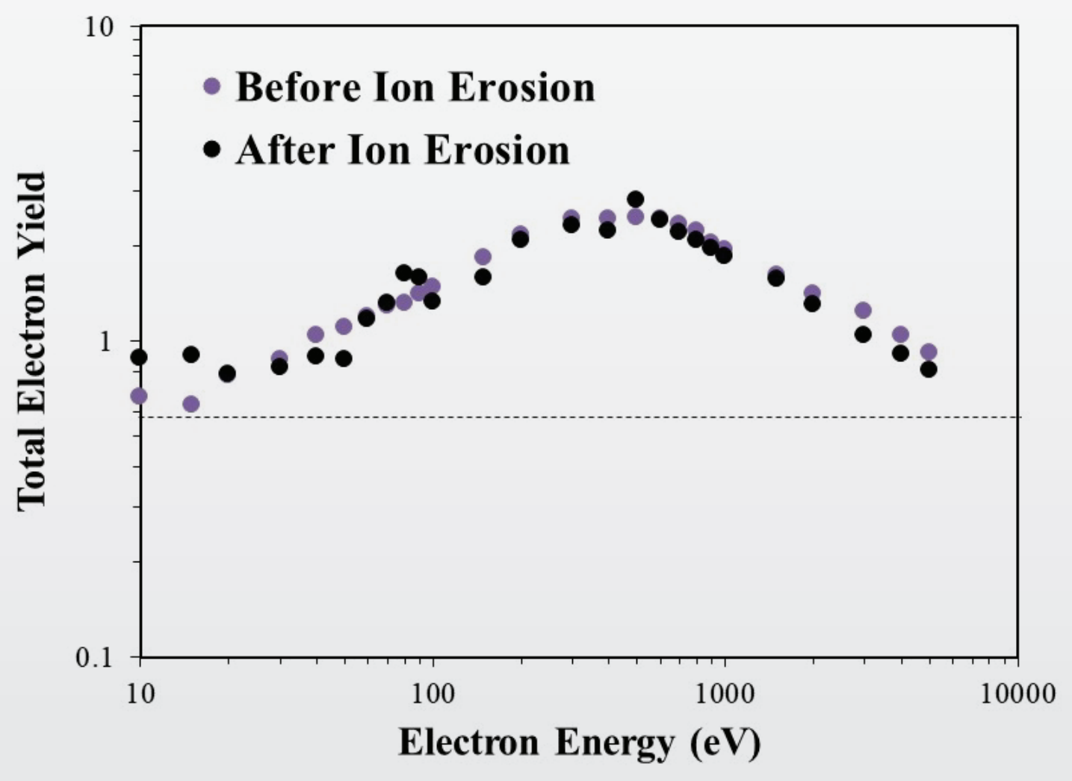
- Total Electron Yield (TEY) ~ 25 compared to 1.5 for Bare Al substrate
- Extending the range of electron yields between crossover energies above 1 by ~4x



	Total Electron Yield (TEY)			
Sample ID (condition)	σ_{max}	E_{max} (keV)	E_1 (keV)	E_2 (keV)
HOPG	1.5±0.1	215±15	42±2	755±25
Al 6061 substrate	1.8±0.1	300±10	43±2	1050±50
Grit Blasted Al 6061 Substrate	1.5±0.1	320±20	26±4	1500±50
Composite Coating Mixture 1	3.2±0.2	370±20	45±5	3300±50
Composite Coating Mixture 2	3.6±0.2	520±30	31±5	6000±50
Composite Coating Mixture 3	25 ± 5	525±20	35±5	7000±50

Results - Ion Erosion Resistance

- Durability of the composite coating was demonstrated through exposure to ion erosion of modeled ISS plasma erosion conditions.
- No change in Total electron yield was observed before and after ion erosion exposure.



Simulated ISS Plasma Environment

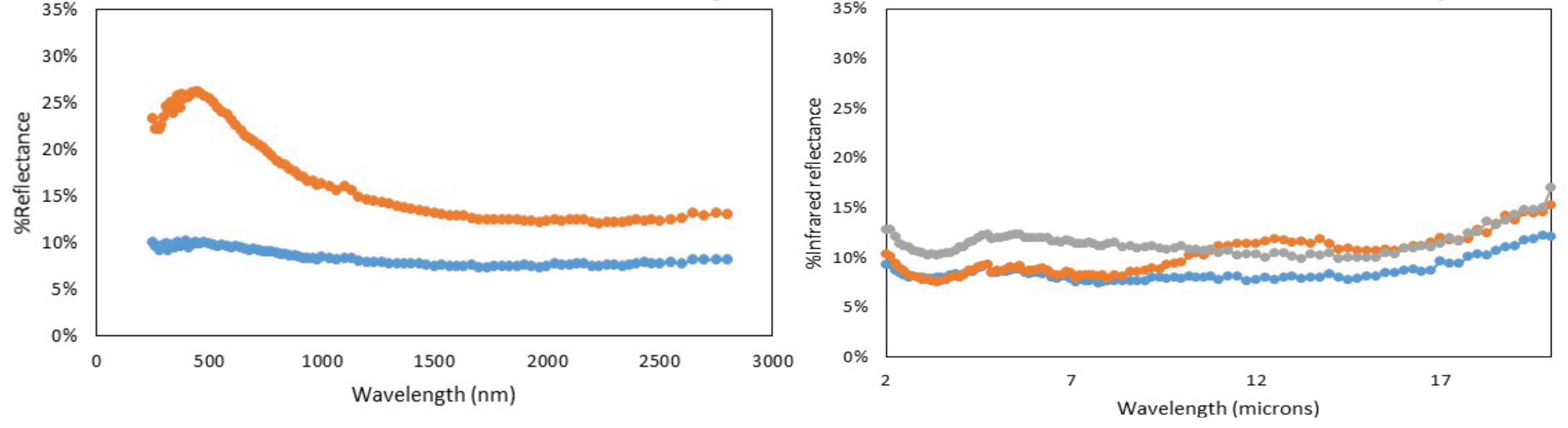
Plasma at

- 106/cm3 density
- ≤1-eVelectron temperature
- ~60±1 min with an approximate 30% duty cycle.

Tunable Optical Properties of Composite Coating

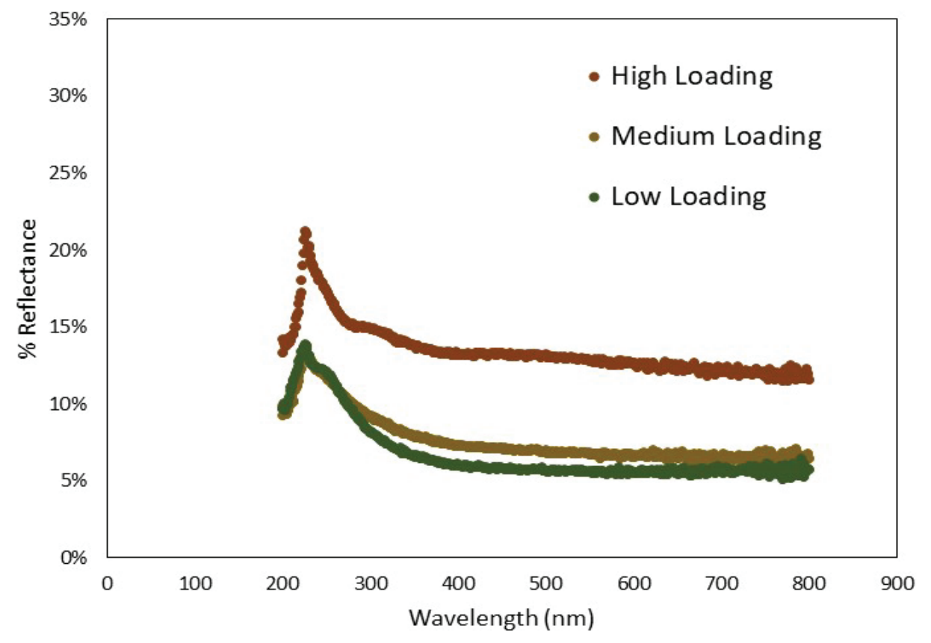
Controlling the composition and thickness of the composite coating enables variable reflectance properties across wide wavelength spectrum for specific spacecraft component of interest.

Reflectance in NUV-IR Region — Reflectance in IR Region



121A–Coating with mixture of composite materials
122A–Coating with ceramic matrix
124A–Coating with Layers of composite materials

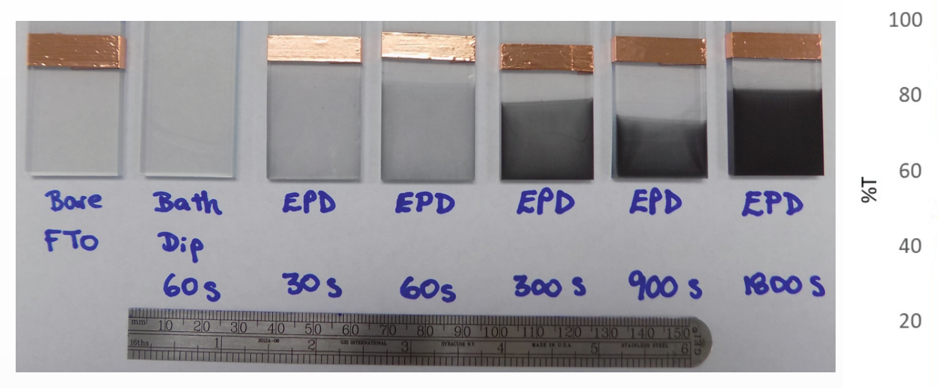
Reflectance in UV-Vis Region



Composite Coating with various loading of hard material into conductive matrix

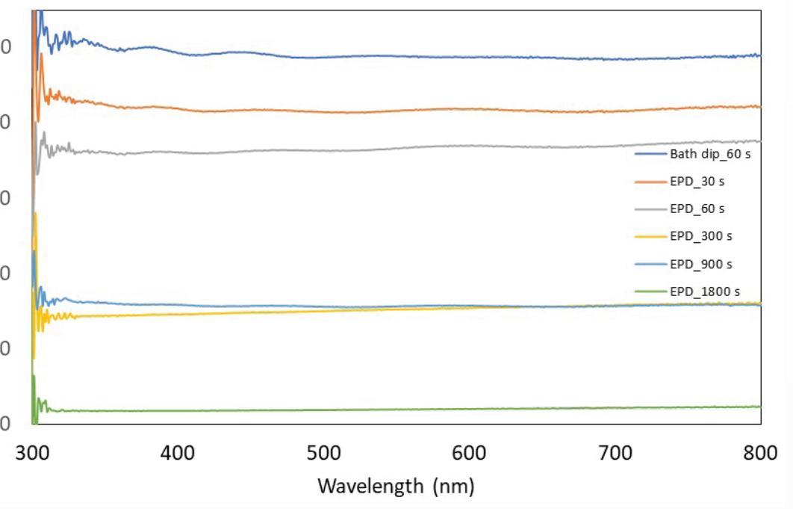
Tunable composite coating thickness for optimum space charge mitigation without significantly affecting the transmission property of component of interest (e.g., solar cell)

Composite coating with various thickness on FTO/Float Glass

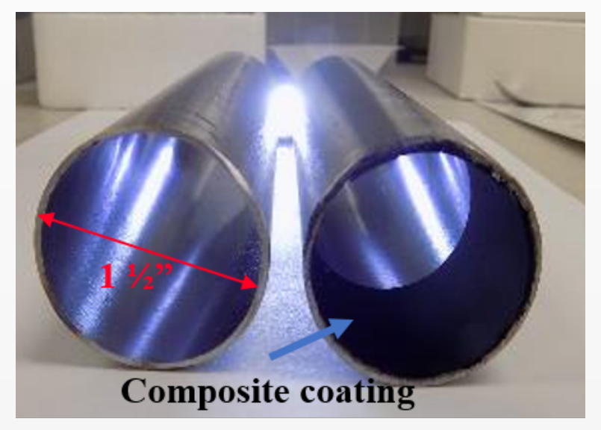


Increase in composite coating thickness

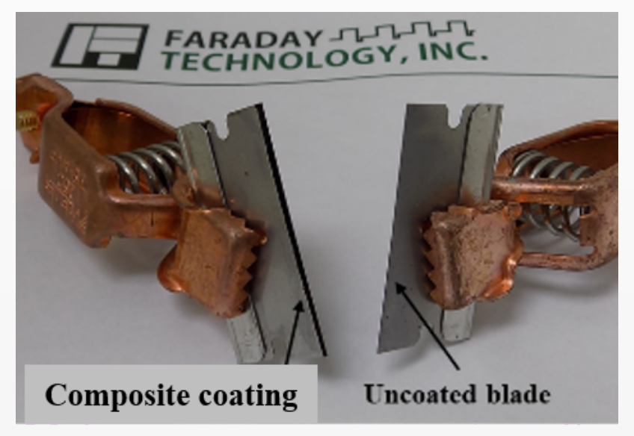
Transmission in UV-Vis Region



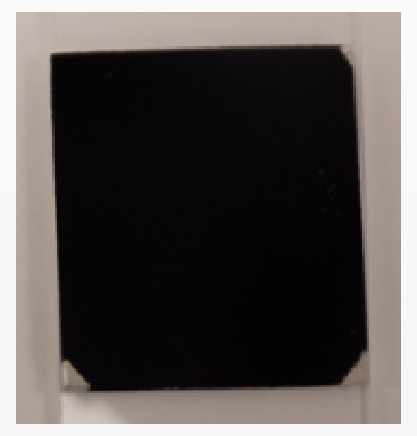
Composite Coating on a Variety of Geometries



Curved Surface



Sharp Edge



Flat Substrate

Internal and External Surfaces of Square Tubes

Electrochemical method enables uniform deposition of composite coatings on a variety of geometries: flat coupons, curved surfaces, sharp edges, and internal and external surface of square tubes

Validated in MISSE-16 Mission

- Faraday's composite coating was tested on exterior of ISS on MISSE-16 program from August 2022 to March 2023
- Faraday's composite coating maintained its durability when exposed to Ram, Wake and Zenith directions

Before Exposure to ISS

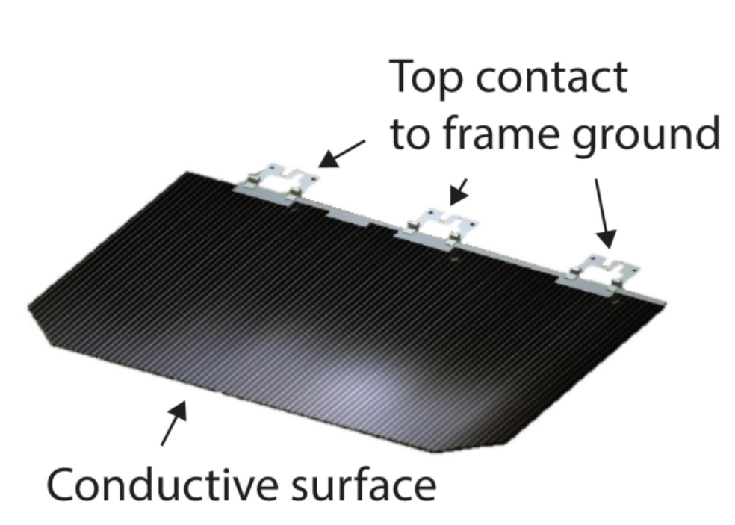
After Exposure to ISS for ~6 months

Summary/Next Steps

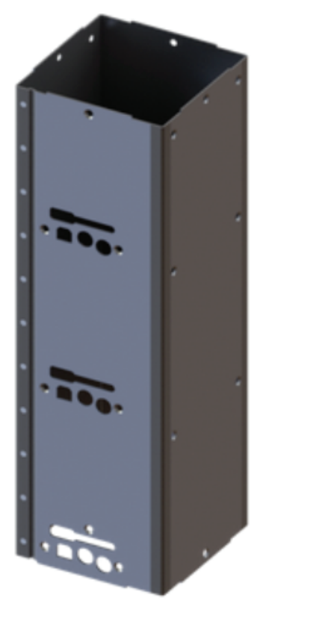
The robust and autonomous space charge mitigating composite coating to protect spacecraft component failures from space weather:

- Achieved ~1500% increase in autonomous electron emission over the bare Al substrate
- Extended the range of electron yields above 1 by ~4 times
- Survived on the exterior of International Space Station on MISSE-16
- Exhibited durability and charge/dust mitigation properties for space applications
- Filed the US patent application, Application #: 63/231,923 ; Filing date Aug 11, 2021

Potential Target Integration



Solar Cell Conductive Edges



Chassis

Next Steps

Scale/transition the technology onto spacecraft components (ex., spacecraft chassis, solar cell) for commercialization

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