Experimental Study of the Effects of Xenon Plasma Erosion on Spacecraft Thermal Control Surfaces

Evan Racine-GRC

Presented By
Evan Racine

Thermal & Fluids Analysis Workshop
TFAWS 2018
August 20-24, 2018
NASA Johnson Space Center
Houston, TX

Outline

- Background
- Purpose
- Test Setup
- Results
- Future Work

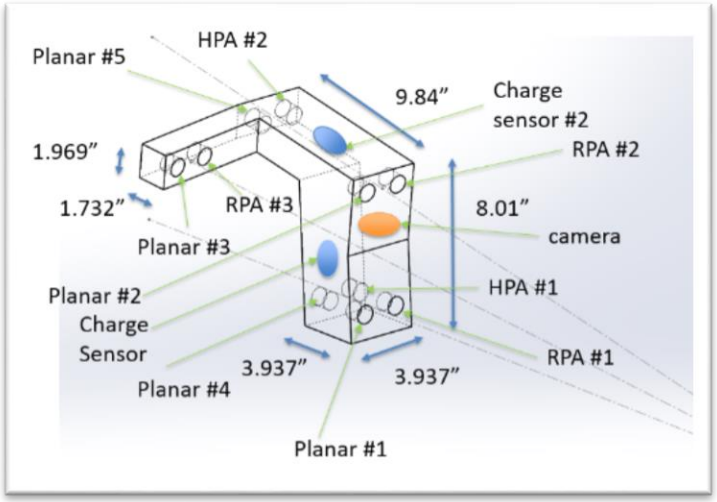
Background - Gateway and the PPE

Gateway and the PPE (Power and Propulsion Element)

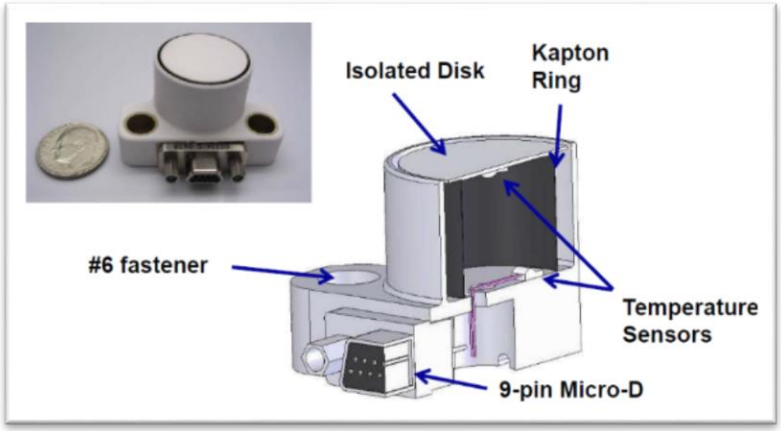
The Gateway is a manned cis-lunar orbiting space station under development. The station will be assembled in multiple stages, while in orbit, starting in 2022. The first stage is the Power and Propulsion Element. It will be responsible for providing power generation and propulsion for the station. It will utilize up to 40kW of electrostatic propulsion capability.

Background – Electric Propulsion and PDP

- The ion plume created by Electrostatic thrusters can have a detrimental effect on spacecraft materials.
- The plume behaves differently on-orbit then in a ground vacuum facility.
- On orbit performance data needs to be captured in order to study the EP system, plum and plume effects.
- The Plasma Diagnostic Package (PDP) is being developed to study the plume for PPE.
- Among the many sensors, Radiometers will be flown to measure changes on absorptivity/emissivity of spacecraft materials



PDP Probe Package Concept

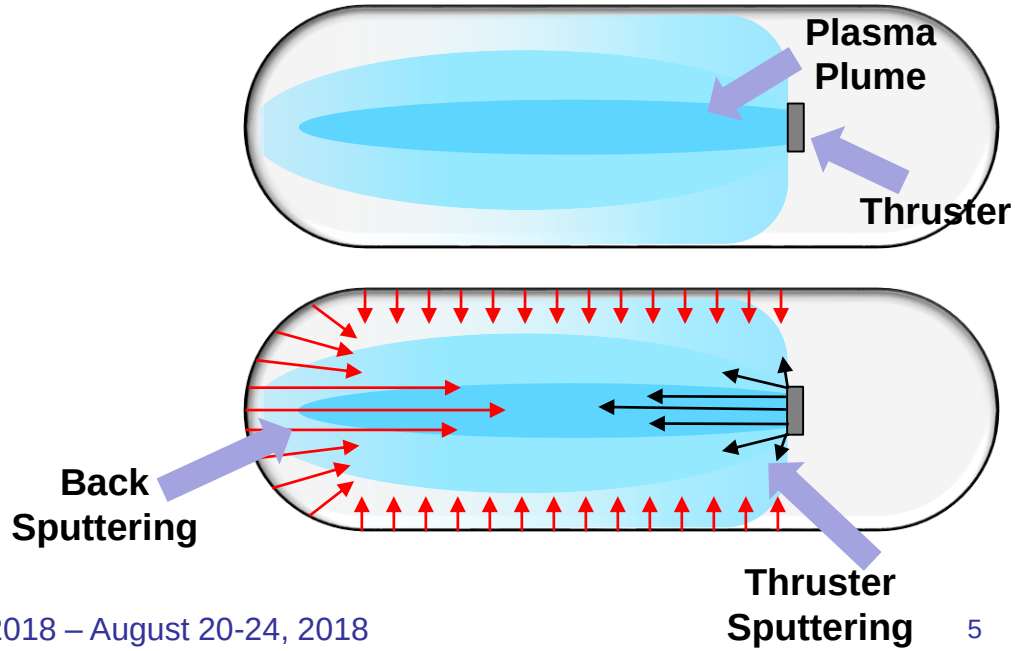


Radiometer

Background – Plasma Plume

- Contamination to spacecraft surfaces from the EP thrusters is caused through several means.
- Testing in a vacuum chamber has more sources of contamination then on orbit

- Erosion
  - Xenon Ion Plasma Plume (smaller in VC)
- Deposition
  - Thruster Sputter (about equal on orbit vs in VC)
  - Back Sputter (significantly less on orbit)



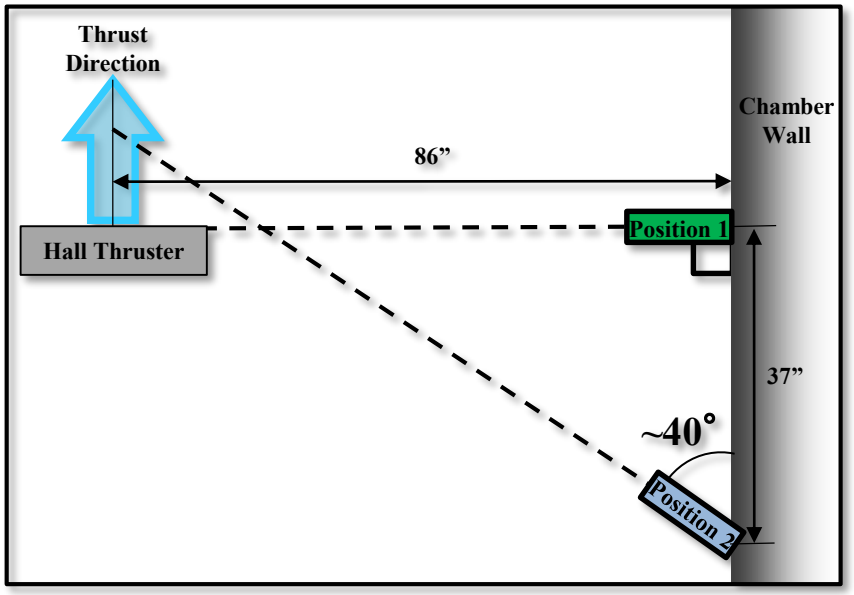
Purpose of Experiment

1. To study how the optical properties of various thermal coatings are changing due to the exposure of xenon plasma erosion.

2. To develop criteria for selecting a radiometer coating that will produce the best on-orbit data for the PDP.
   1. Provide deterministic results. i.e. allow for a correlation between exposure and measured results.
   2. Produce results representative of how the spacecraft is changing during flight exposure. i.e. coatings similar to what the spacecraft will fly with.
   3. Maximize the life of the sensor. i.e. tolerance to erosion

Test Summary

- A total of 10 different materials were selected for long duration exposure testing to the thrust plume of the TDU-3 hall effect thruster.
- Two locations were chosen to represent realistic exposure to an actual spacecraft (90° & 115° from the thrust axis)
- The samples were mounted in collimators to remove other sources of contamination within the chamber, such as back sputter.
- The emissivity and absorptivity were measured before, during, and after the test.

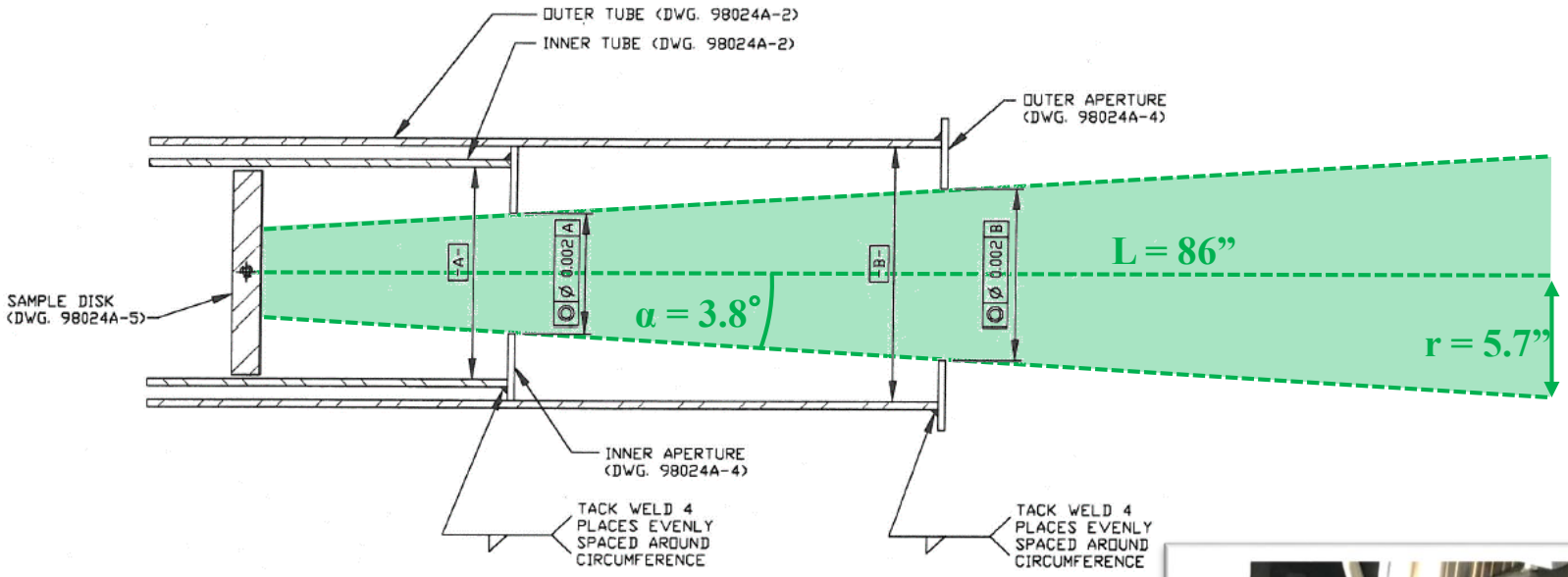


Collimator Positioning (Top-Down)

Sample Material Information

Nomenclature	Material	Source	PN	Hemispherical Emittance (ƐH)	Solar Absorptance (α)	1st Material	1st Thick	2nd Material	2nd Thick	3rd Material	3rd Thick
ALK	Aluminum Kapton MLI, 1st Surface Mirror	Sheldahl	146448-005	≤ 0.035	≤ 0.14	Aluminum	1000 Å	Polyimide	2.0 mil		
ALT	Aluminum Tape, 0.5 mil			≤ 0.035	≤ 0.14	Aluminum	0.5 mil				
ALF	Aluminum Foil			*≤ 0.035**	*≤ 0.14**	Aluminum					
ST	Silver Teflon Tape, 2nd Surface Mirror	Sheldahl	146411-005	≥ 0.40	≤ 0.09	FEP (Teflon)	0.5 mil	Silver/Inconel	1500Å/275 Å	acrylic 966 adhesive	2.3 mil
Z93	White Paint Z-93	AZ Tech	AZ-93	0.91 ± 0.02	0.15 ± 0.02	Pigment/Silicate Binder	5.0 ± 1.5 mils				
GK	Germanium MLI (1500 Au) x 2.0 mil Kapton	Sheldahl	160759-009	≥ 0.72*	≤ 0.45*	Germanium	1500 Å	Polyimide	2.0 mil		
ITO	ITO MLI (1600 ohm/sq)x 2.0 mil Kapton x Al	Sheldahl	146633-001	≥ 0.71*	≤ 0.49*	Indium Tin Oxide	1600 ohm/sq	Polyimide	2.0 mil	Aluminum	1000 Å
BKT	Kapton Black tape			0.88	0.92	Polyimide (Black)					
GF	Graphite Foil	CERA Materials	2010A	0.35	0.65	Graphite High Purity (99.7%)	0.040"				
SW	Solar White			0.52	< 0.025	BaF_2 Powder	3.0 mm				

Collimators

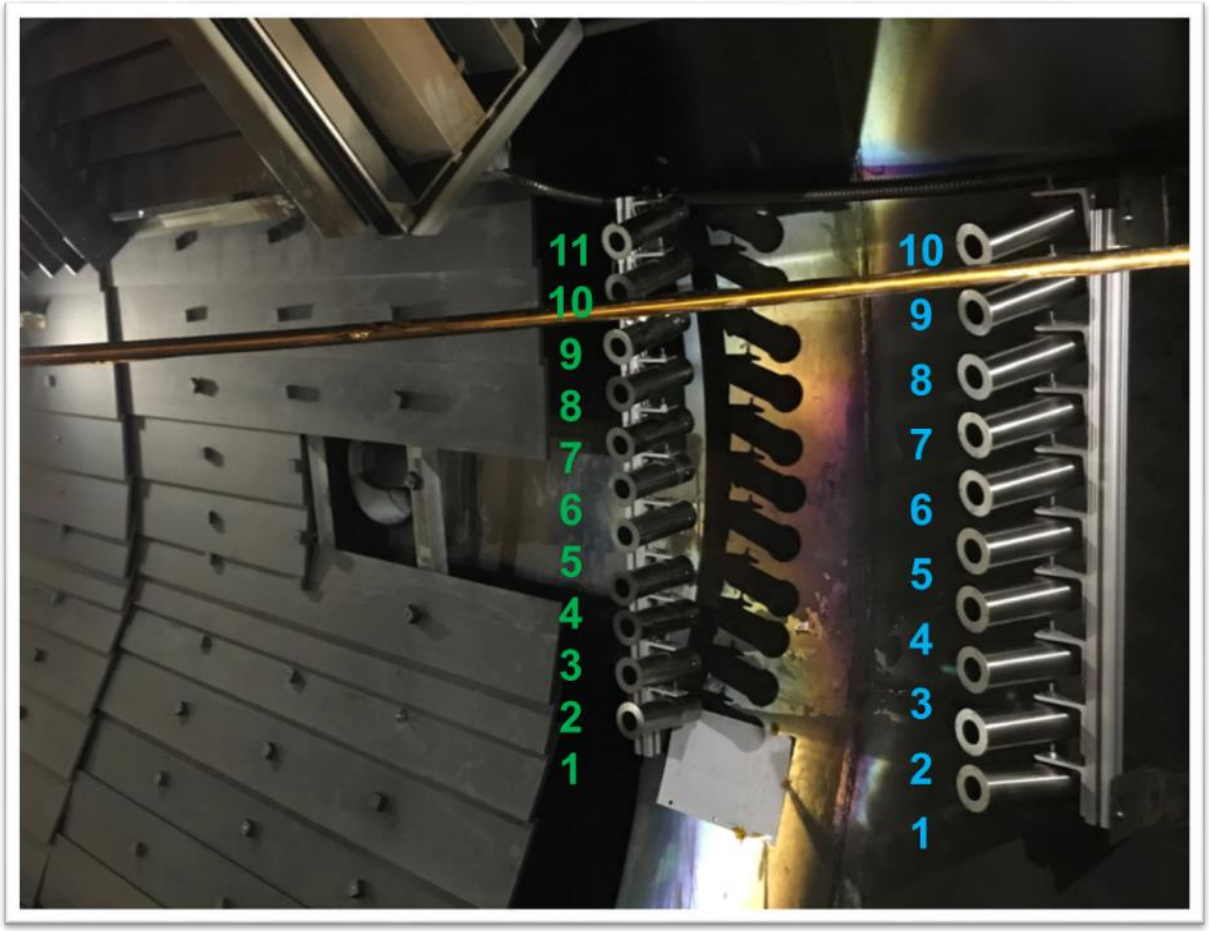


- **Field of view half angle: α = 3.8°**
- **Focal length: L = 86 in**
- **View area at focal length: 100.3 in^2**

Collimator mounted in vacuum chamber

Test Setup

No.	Nomenclature	Material
Position 1		
1	AlK-1	Aluminum x 2.0mil Kapton, 1st Surface Mirror
2	AlT-1	Aluminum Tape 0.5 mil
3	AlF-1	Aluminum Foil
4	ST-1	Silver Teflon 2nd Surface Mirror
5	STE-1	Silver Teflon 2nd Surface Mirror (Exposed, 240hr)
6	Z93-1	White Paint Z-93
7	GK-1	Germanium (1500 Au) x 2.0 mil Kapton
8	ITO-1	ITO (1600 ohm/sq)x 2.0 mil Kapton x Al
9	BKT-1	Kapton Black tape
10	GF-1	Graphite Foil
11	SW-1	Solar White
Position 2		
1	AlK-2	Aluminum x 2.0mil Kapton, 1st Surface Mirror
2	AlT-2	Aluminum Tape 0.5 mil
3	AlF-2	Aluminum Foil
4	ST-2	Silver Teflon 2nd Surface Mirror
5	Z93-2	White Paint Z-93
6	GK-2	Germanium (1500 Au) x 2.0 mil Kapton
7	ITO-2	ITO (1600 ohm/sq)x 2.0 mil Kapton x Al
8	BKT-2	Kapton Black tape
9	GF-2	Graphite Foil
10	SW-2	Solar White



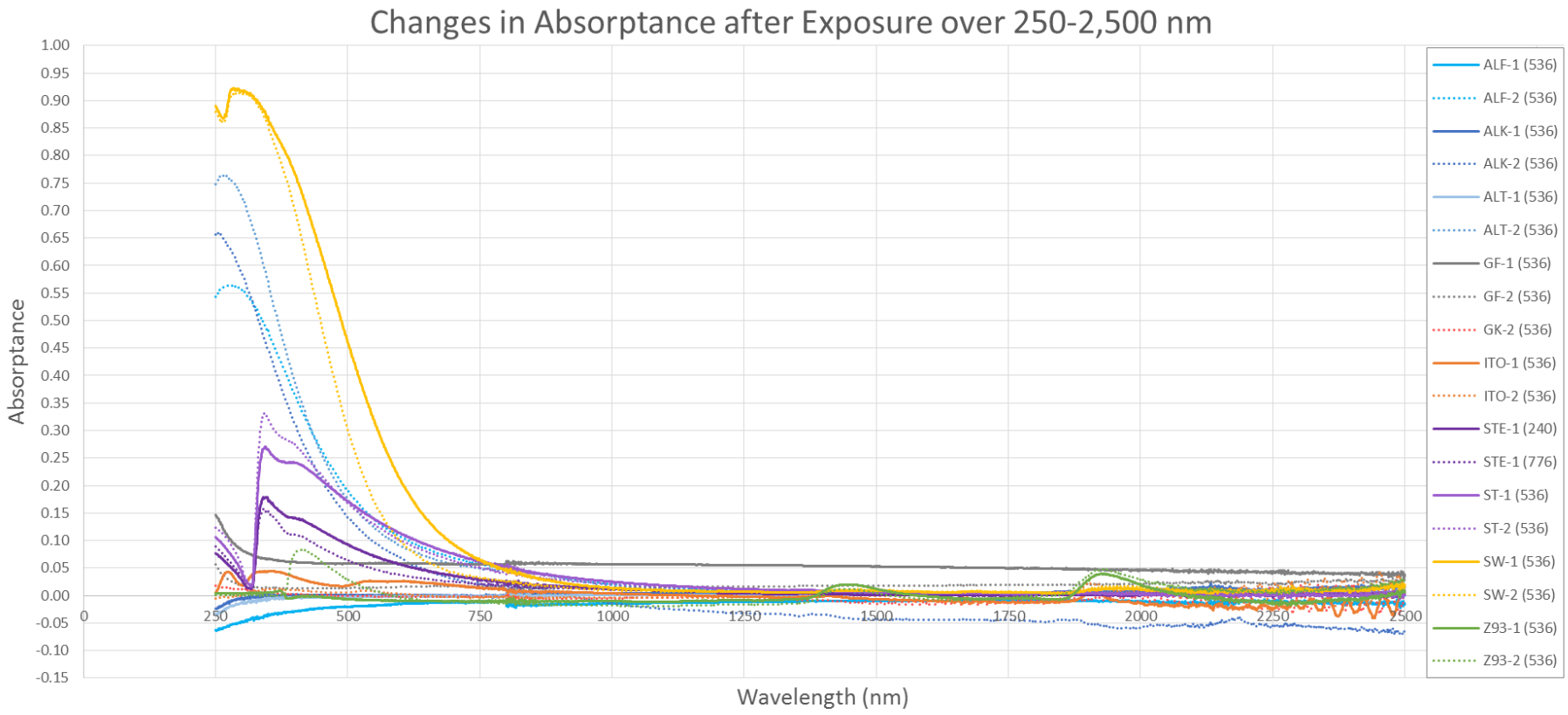
Test samples mounted in VF-5

Results after 536 Hours of Exposure

			Baseline Measurements		Test Measurements			Dates: 5/7/18 - 6/11/18	Hours:	536.36
Nomenclature	**Material**	**Location**	**Hemispherical Emittance (ε_H)**	**Solar Absorptance (α)**	**Hemispherical Emittance (ε_H)**	**Change**	**% Change**	**Solar Absorptance (α)**	**Change**	**% Change**
AlK-1	Aluminum Kapton	E90°	0.021	0.094	0.021	0.001	2.4%	0.096	0.002	1.8%
AlT-1	Aluminum Tape 0.5 mil	E90°	0.029	0.097	0.022	-0.007	-24.1%	0.096	-0.001	-1.4%
AlF-1	Aluminum Foil	E90°	0.030	0.141	0.029	-0.001	-3.3%	0.123	-0.018	-12.4%
ST-1	Silver Teflon	E90°	0.404	0.083	0.422	0.018	4.5%	0.173	0.091	110.1%
STE-1	Silver Teflon (+240hr)	E90°	0.404	0.079	0.411	0.007	1.7%	0.117	0.038	47.4%
Z93-1	White Paint Z-93	E90°	0.814	0.161	0.771	-0.043	-5.3%	0.155	-0.006	-3.7%
GK-1	Germanium Kapton	E90°	0.391	0.498	N/A			N/A		
ITO-1	ITO Kapton, x Al	E90°	0.499	0.394	0.465	-0.034	-6.8%	0.408	0.013	3.4%
GF-1	Graphite Foil	E90°	0.486	0.722	0.520	0.034	7.0%	0.780	0.058	8.0%
SW-1	Solar White	E90°	0.653	0.025	0.533	-0.120	-18.4%	0.263	0.238	948.6%
AlK-2	Aluminum Kapton	E-30°	0.021	0.134	0.018	-0.003	-12.2%	0.217	0.083	62.1%
AlT-2	Aluminum Tape 0.5 mil	E-30°	0.030	0.099	0.022	-0.008	-26.7%	0.224	0.126	127.8%
AlF-2	Aluminum Foil	E-30°	0.030	0.211	0.030	0.000	0.0%	0.334	0.123	58.3%
ST-2	Silver Teflon	E-30°	0.404	0.082	0.407	0.003	0.7%	0.172	0.091	111.1%
Z93-2	White Paint Z-93	E-30°	0.814	0.167	0.766	-0.048	-5.9%	0.172	0.005	2.7%
GK-2	Germanium Kapton	E-30°	0.391	0.523	0.370	-0.021	-5.4%	0.520	-0.002	-0.5%
ITO-2	ITO Kapton, x Al	E-30°	0.499	0.397	0.513	0.014	2.8%	0.398	0.002	0.4%
GF-2	Graphite Foil	E-30°	0.486	0.714	0.483	-0.003	-0.6%	0.730	0.016	2.2%
SW-2	Solar White	E-30°	0.653	0.026	0.637	-0.016	-2.5%	0.211	0.185	708.5%

- **Most samples showed a decrease in Hemispherical Emittance and an increase in Solar Absorptance**

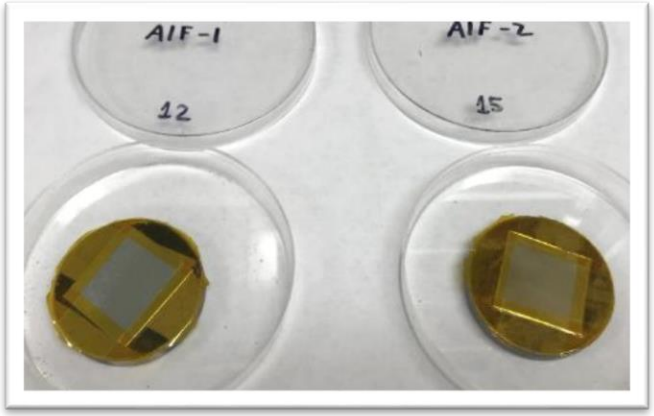
Results after 536 Hours of Exposure



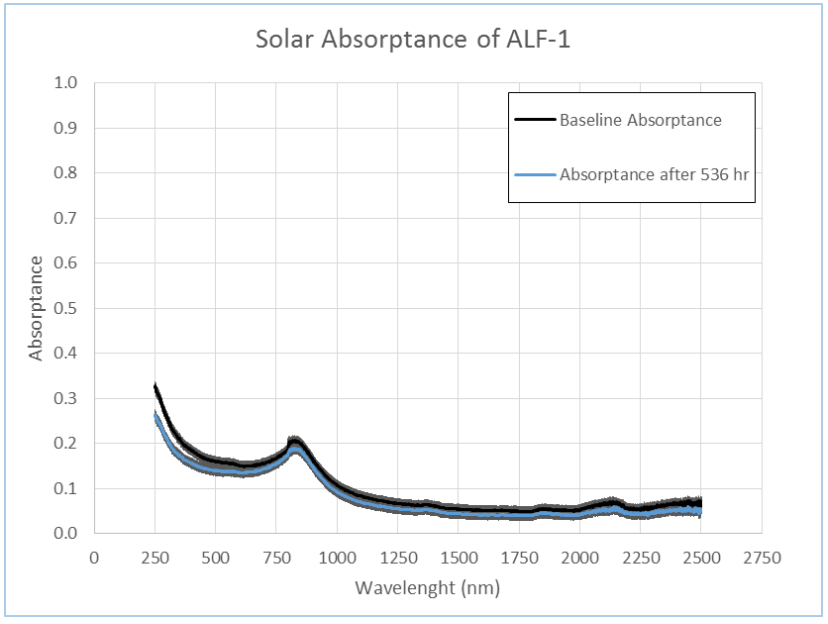
- Chart shows the change in measured solar absorptance over the range of wavelength for all samples tested
- Overall, most of the samples showed an increase in absorptance with the largest increase in the 250-750nm range

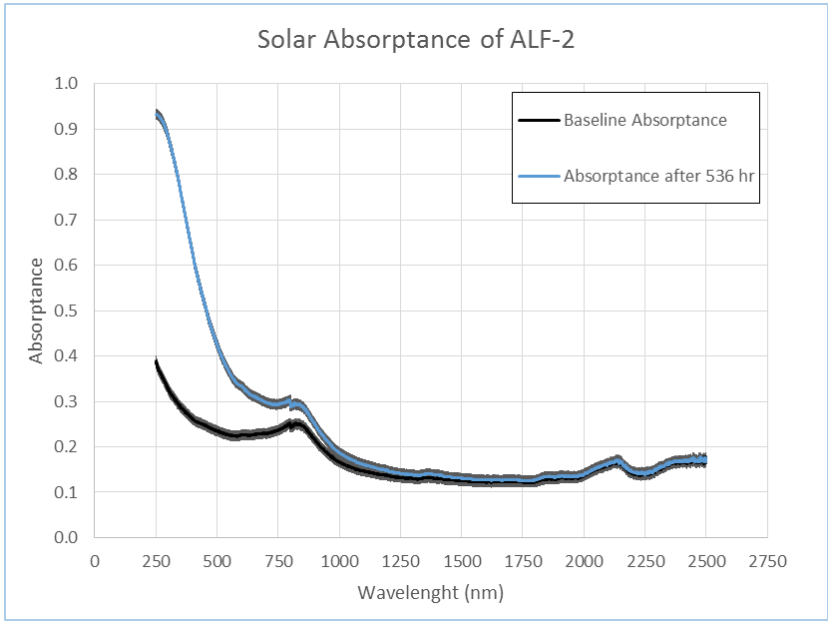
Aluminum Foil Results

			Baseline Measurements		Test Measurements		Dates:	5/7/18 6/11/18	Hours:	536.36
Nom	**Material**	**Location**	**ε_H**	**α**	**ε_H**	**Delta**	**% Change**	**α**	**Delta**	**% Change**
AlF-1	Aluminum Foil	E90°	0.030	0.141	0.029	-0.001	-3.3%	0.123	-0.018	-12.4%
AlF-2	Aluminum Foil	E-30°	0.030	0.211	0.030	0	0.00%	0.334	0.123	58.3%



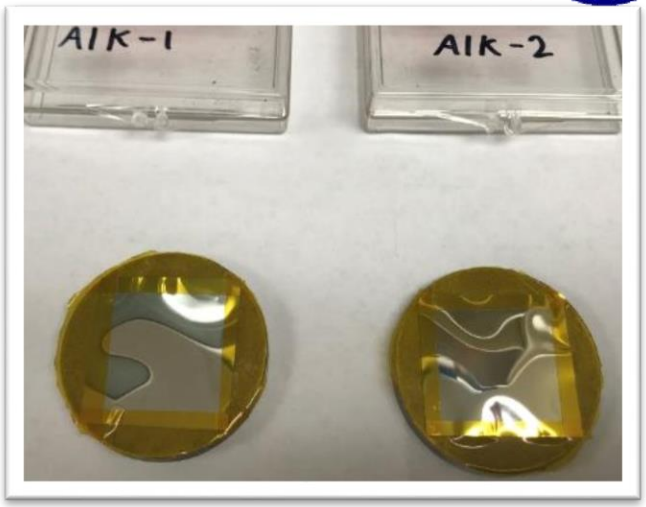
After 536hr Exposure



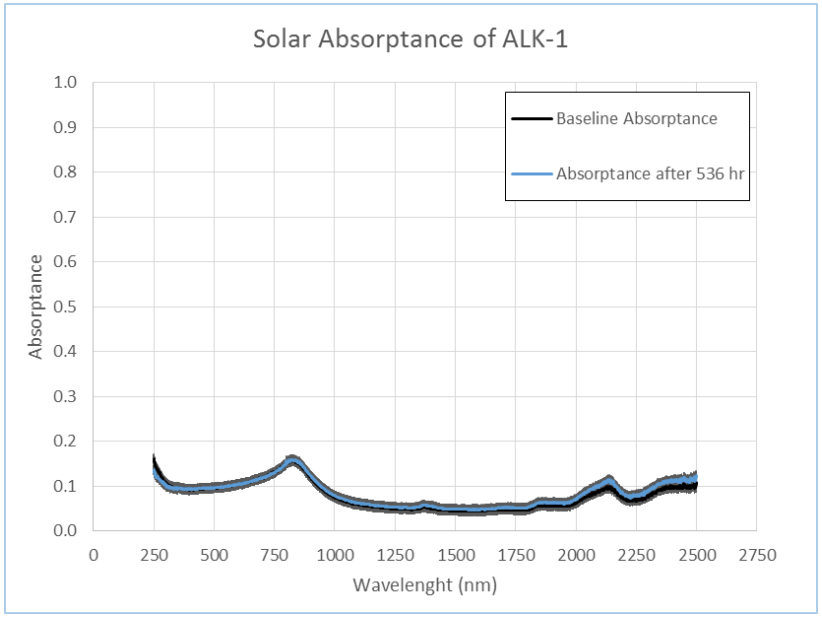


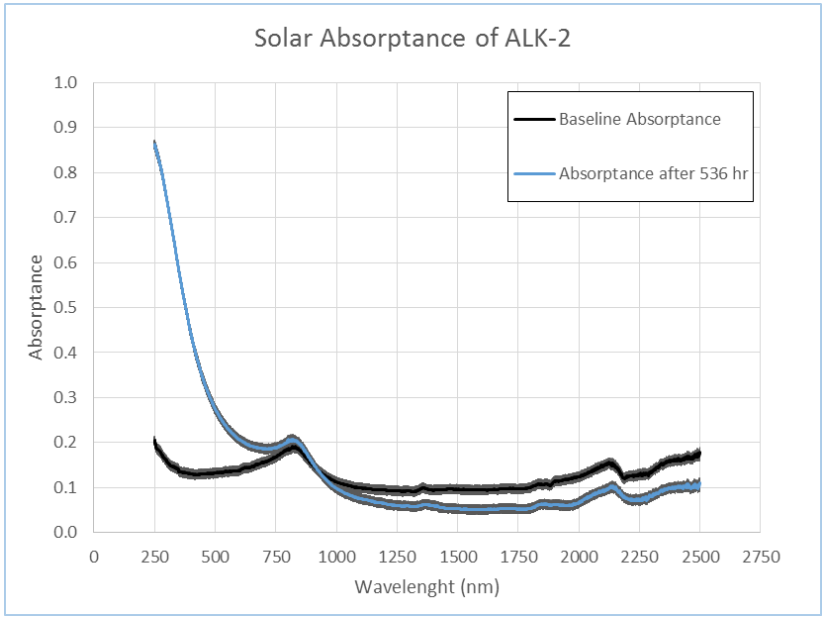
Aluminum Kapton Results

			Baseline Measurements		Test Measurements			Dates:	5/7/18 6/11/18	Hours:	536.36
Nom	**Material**	**Location**	**ε_H**	**α**	**ε_H**	**Delta**	**% Change**	**α**	**Delta**	**% Change**
AlK-1	Aluminum Kapton	E90°	0.021	0.094	0.021	0.001	2.40%	0.096	0.002	1.80%
AlK-2	Aluminum Kapton	E-30°	0.021	0.134	0.018	-0.003	-12.20%	0.217	0.083	62.10%



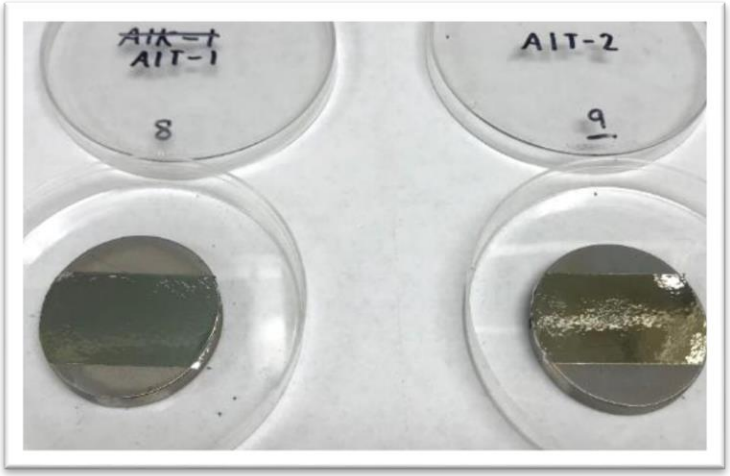
After 536hr Exposure



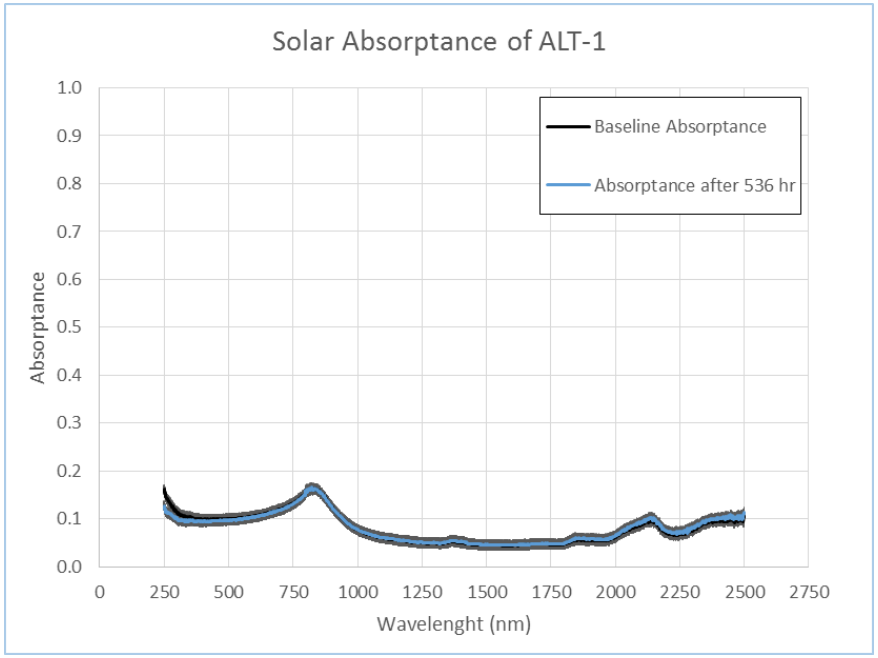


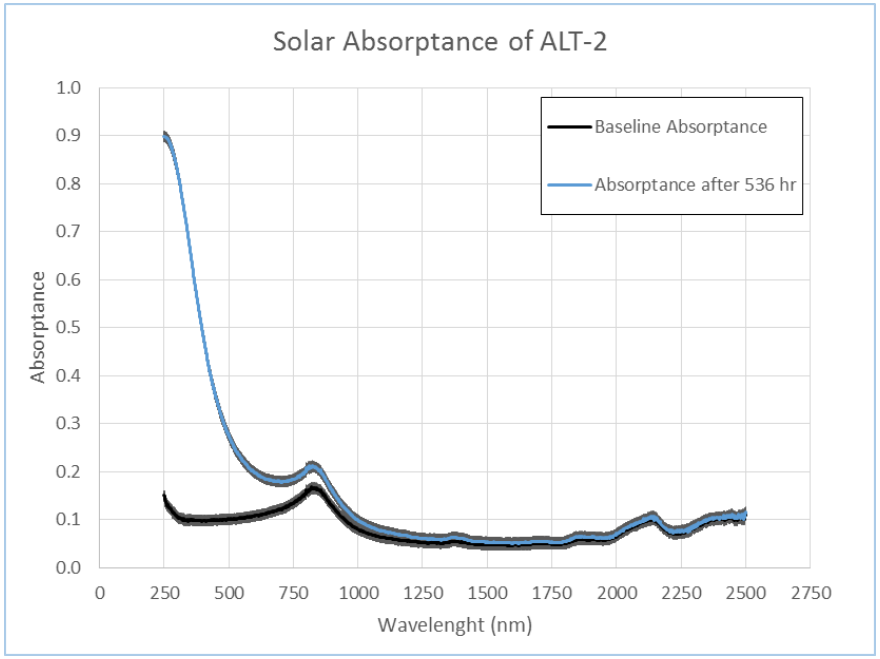
Aluminum Tape Results

			Baseline Measurements		Test Measurements		Dates:	5/7/18 6/11/18	Hours:	536.36
Nom	**Material**	**Location**	**ε_H**	**α**	**ε_H**	**Delta**	**% Change**	**α**	**Delta**	**% Change**
AlT-1	Aluminum Tape 0.5 mil	E90°	0.029	0.097	0.022	-0.007	-24.10%	0.096	-0.001	-1.40%
AlT-2	Aluminum Tape 0.5 mil	E-30°	0.03	0.099	0.022	-0.008	-26.70%	0.224	0.126	127.80%



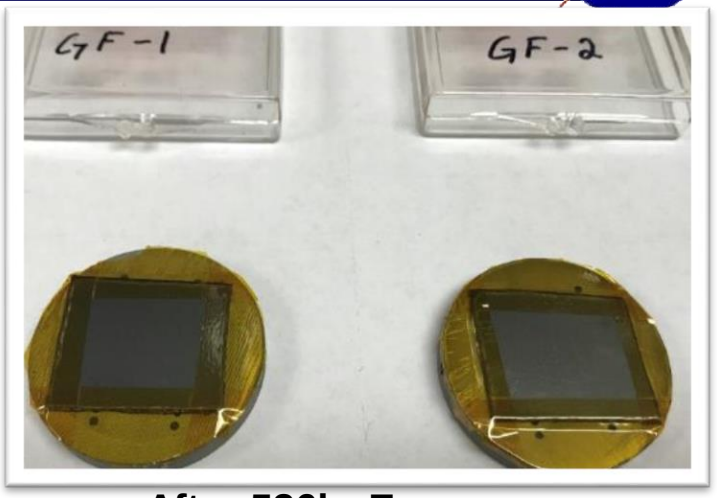
After 536hr Exposure



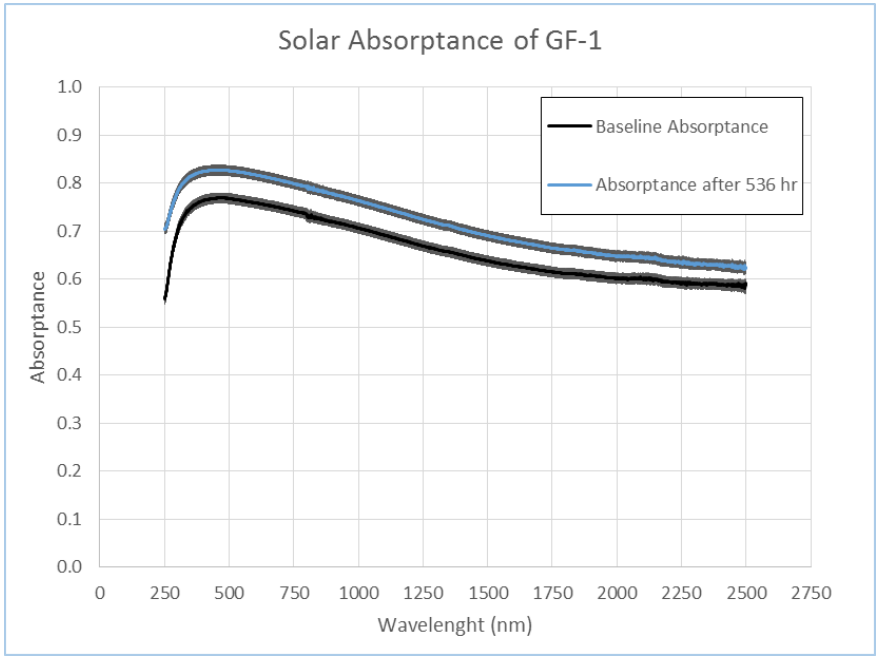


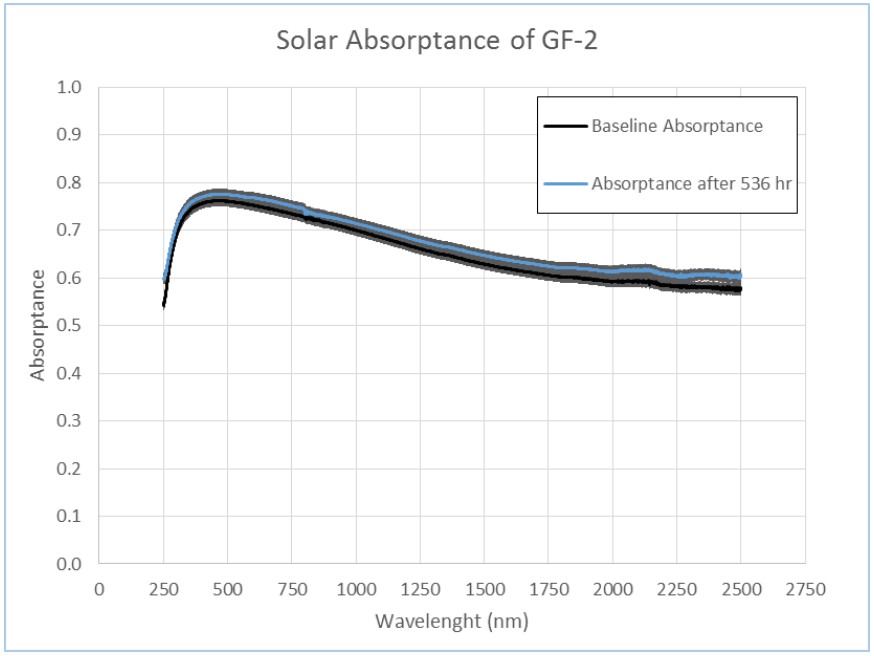
Graphite Foil Results

			Baseline Measurements		Test Measurements		Dates:	5/7/18 6/11/18	Hours:	536.36
Nom	**Material**	**Location**	**ε_H**	**α**	**ε_H**	**Delta**	**% Change**	**α**	**Delta**	**% Change**
GF-1	Graphite Foil	E90°	0.486	0.722	0.52	0.034	7.00%	0.78	0.058	8.00%
GF-2	Graphite Foil	E-30°	0.486	0.714	0.483	-0.003	-0.60%	0.73	0.016	2.20%



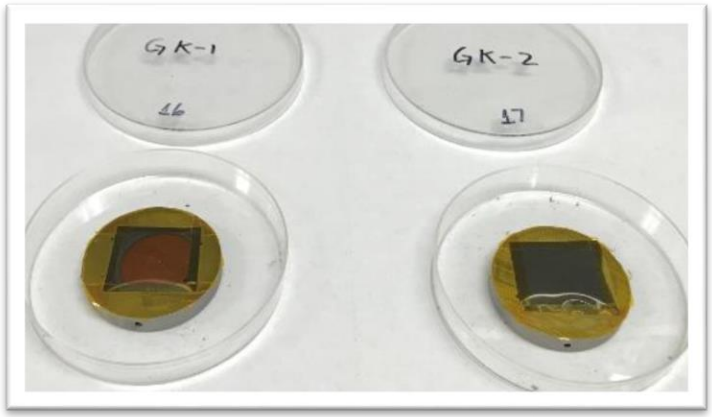
After 536hr Exposure



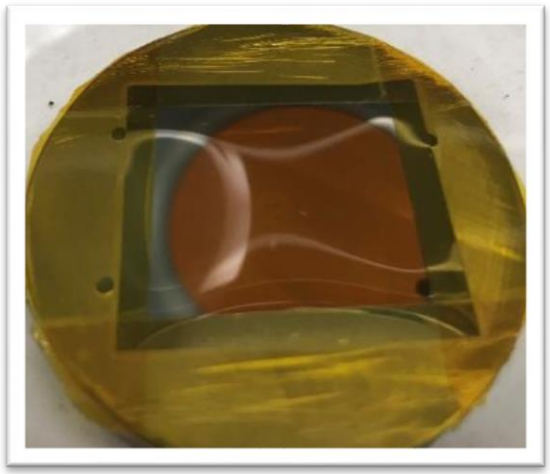


Germanium Kapton Results

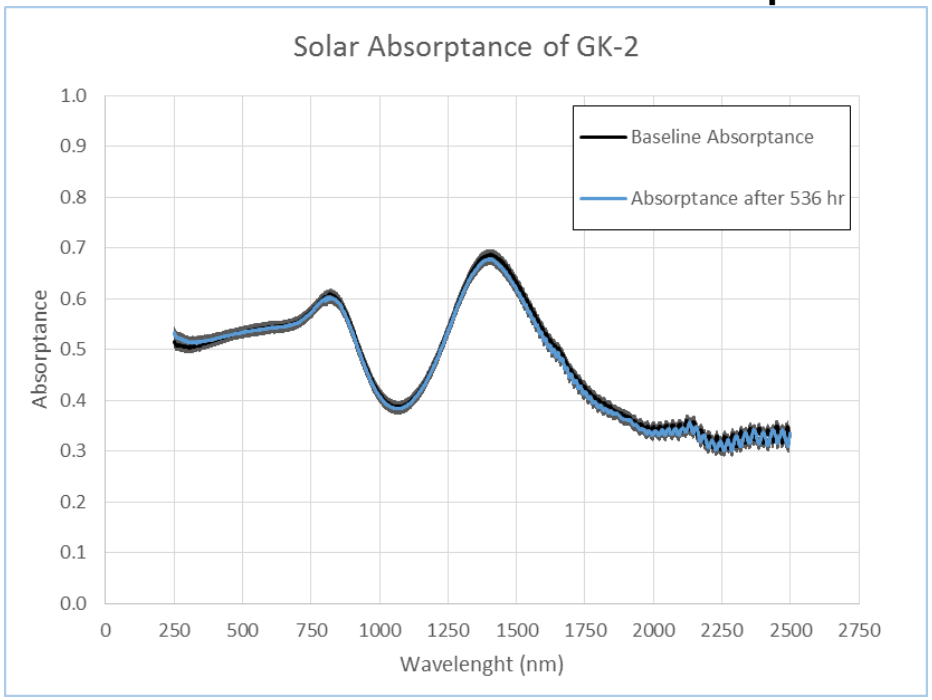
			Baseline Measurements		Test Measurements		Dates:	5/7/18 6/11/18	Hours:	536.36
Nom	**Material**	**Location**	**ε_H**	**α**	**ε_H**	**Delta**	**% Change**	**α**	**Delta**	**% Change**
GK-1	Germanium Kapton	E90°	0.391	0.498	N/A		0.00%	N/A		0.00%
GK-2	Germanium Kapton	E-30°	0.391	0.523	0.37	-0.021	-5.40%	0.52	-0.002	-0.50%



After 536hr Exposure

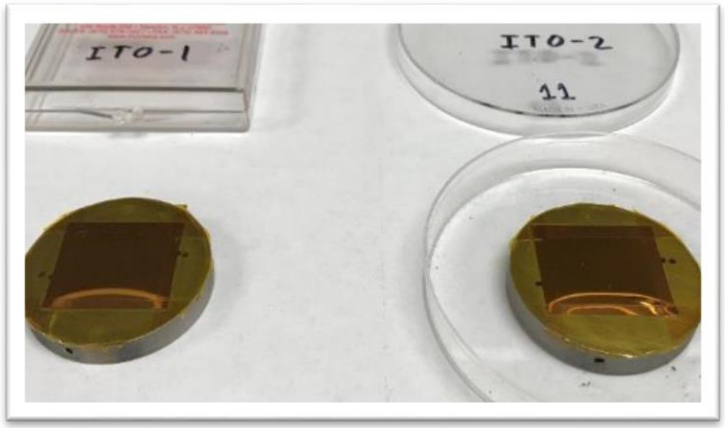


Gk-1 After 536hr Exposure

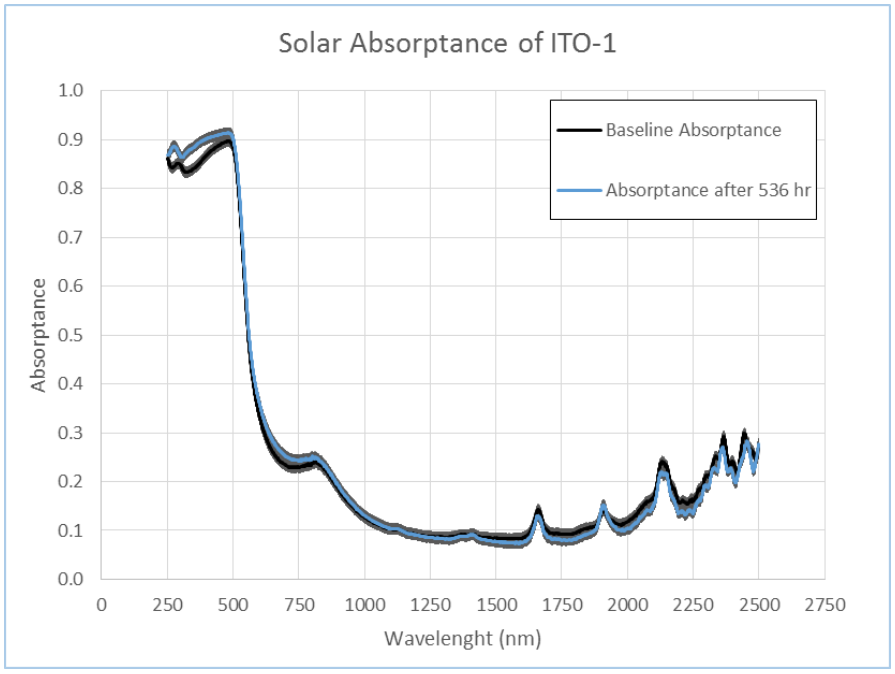


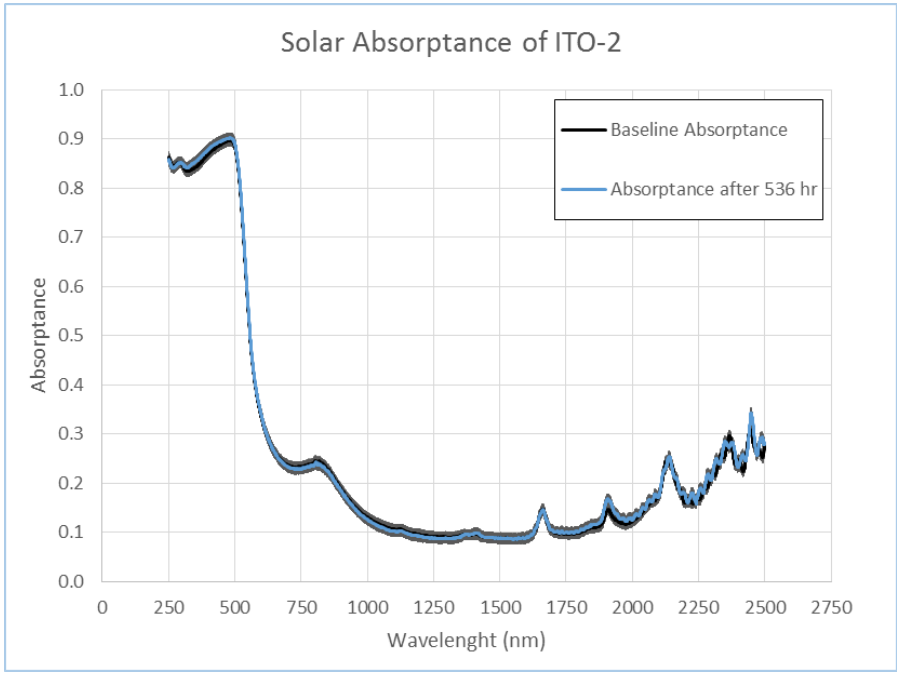
ITO Results

			Baseline Measurements		Test Measurements		Dates:	5/7/18 6/11/18	Hours:	536.36
Nom	**Material**	**Location**	**ε_H**	**α**	**ε_H**	**Delta**	**% Change**	**α**	**Delta**	**% Change**
ITO-1	ITO Kapton, x Al	E90°	0.499	0.394	0.465	-0.034	-6.80%	0.408	0.013	3.40%
ITO-2	ITO Kapton, x Al	E-30°	0.499	0.397	0.513	0.014	2.80%	0.398	0.002	0.40%



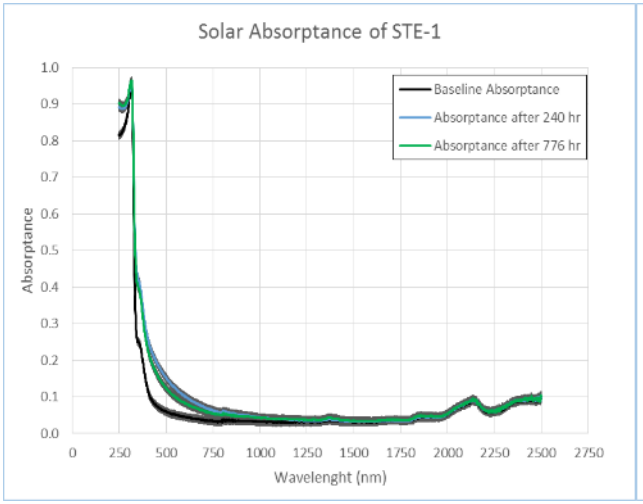
After 536hr Exposure

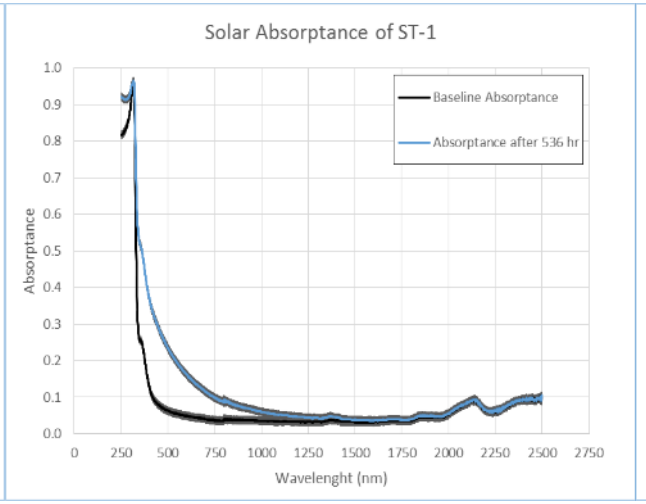


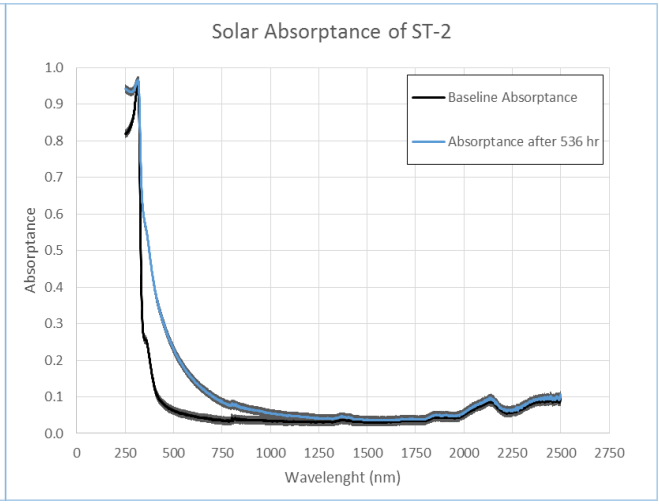


Silver Teflon Results

			Book Values		Baseline Measurements		Test Measurements			Dates:	5/7/18 - 6/11/18	Hours:	536.36
Nom	**Material**	**Location**	**(ƐH)**	**(α)**	**(ƐH)**	**(α)**	**(ƐH)**	**Change**	**% Change**	**(α)**	**Change**	**% Change**
ST-1	Silver Teflon	E90°	≥ 0.40	≤ 0.09	0.404	0.083	0.422	0.018	4.5%	0.173	0.091	110.1%
STE-1	Silver Teflon (Exposed, 240hr)	E90°	≥ 0.40	≤ 0.09	0.404	0.079	0.411	0.007	1.7%	0.117	0.038	47.4%
ST-2	Silver Teflon	E-30°	≥ 0.40	≤ 0.09	0.404	0.082	0.407	0.003	0.7%	0.172	0.091	111.1%

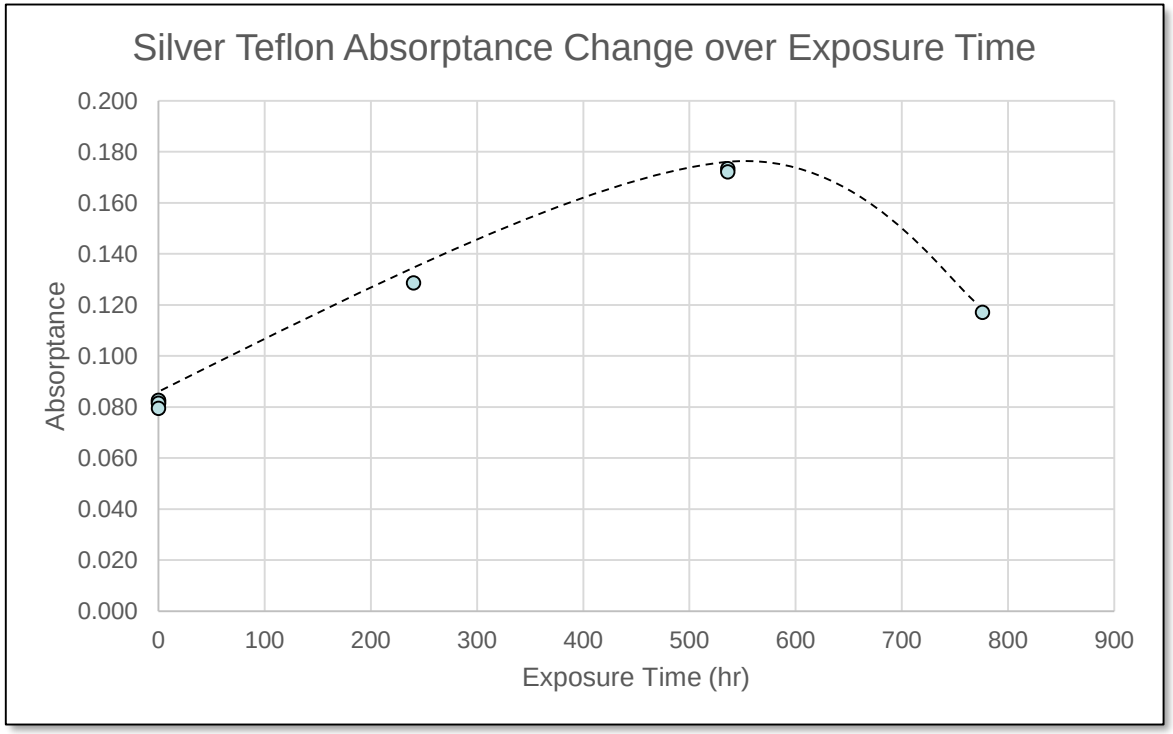






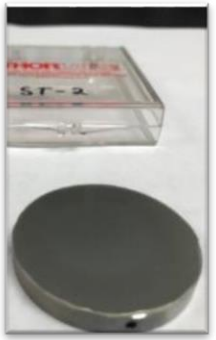
Silver Teflon Results

			Book Values		Baseline Measurements		Test Measurements			Dates:	5/7/18 - 6/11/18	Hours:	536.36
Nom	**Material**	**Location**	**(ƐH)**	**(α)**	**(ƐH)**	**(α)**	**(ƐH)**	**Change**	**% Change**	**(α)**	**Change**	**% Change**
ST-1	Silver Teflon	E90°	≥ 0.40	≤ 0.09	0.404	0.083	0.422	0.018	4.5%	0.173	0.091	110.1%
STE-1	Silver Teflon (Exposed, 240hr)	E90°	≥ 0.40	≤ 0.09	0.404	0.079	0.411	0.007	1.7%	0.117	0.038	47.4%
ST-2	Silver Teflon	E-30°	≥ 0.40	≤ 0.09	0.404	0.082	0.407	0.003	0.7%	0.172	0.091	111.1%



776hr @ 90˚

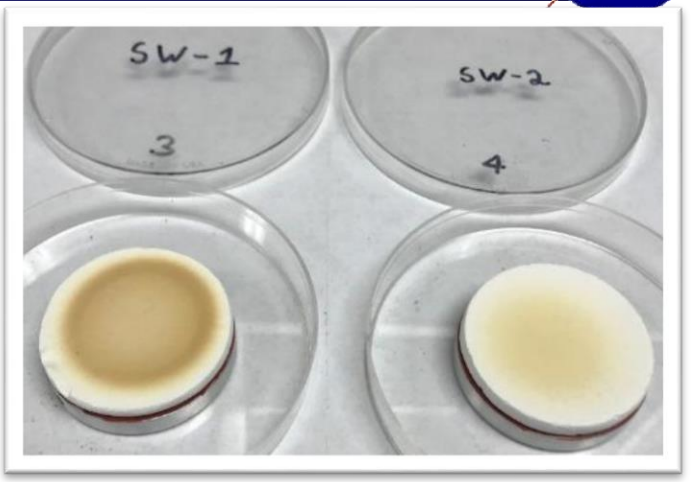
536hr @ 90˚



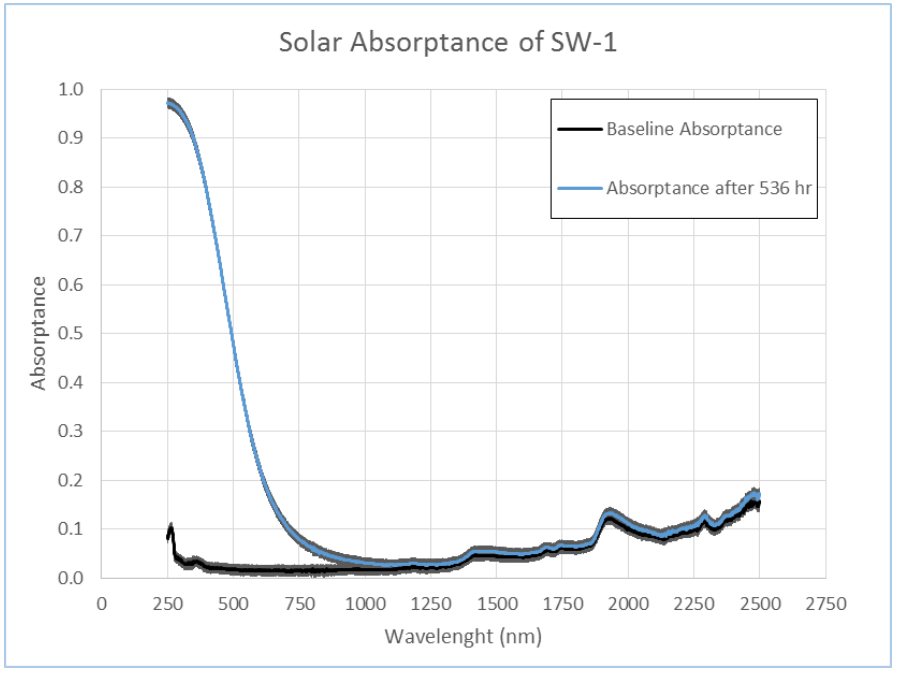
536hr @ 115˚

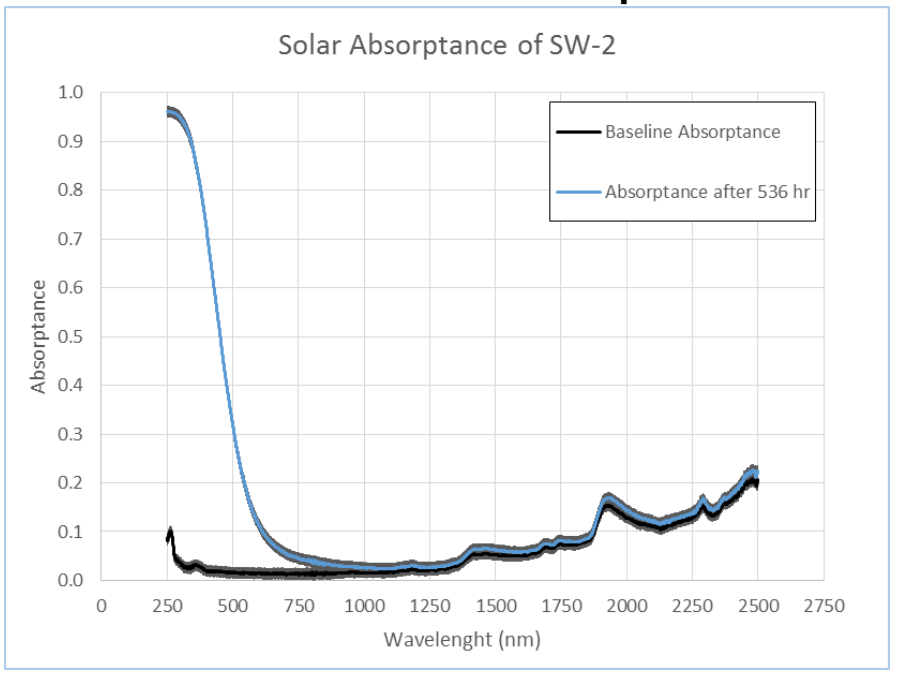
Solar White Results

			Baseline Measurements		Test Measurements		Dates:	5/7/18 6/11/18	Hours:	536.36
Nom	**Material**	**Location**	**ε_H**	**α**	**ε_H**	**Delta**	**% Change**	**α**	**Delta**	**% Change**
SW-1	Solar White	E90°	0.653	0.025	0.533	-0.12	-18.40%	0.263	0.238	948.60%
SW-2	Solar White	E-30°	0.653	0.026	0.637	-0.016	-2.50%	0.211	0.185	708.50%



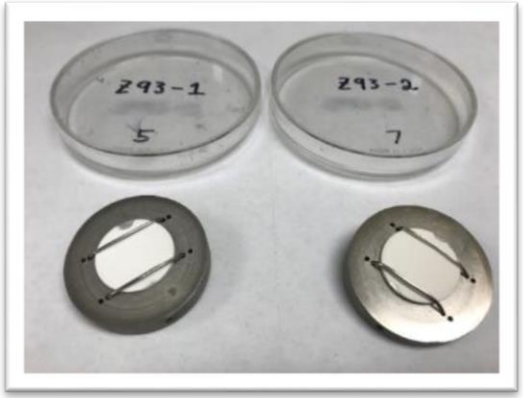
After 536hr Exposure



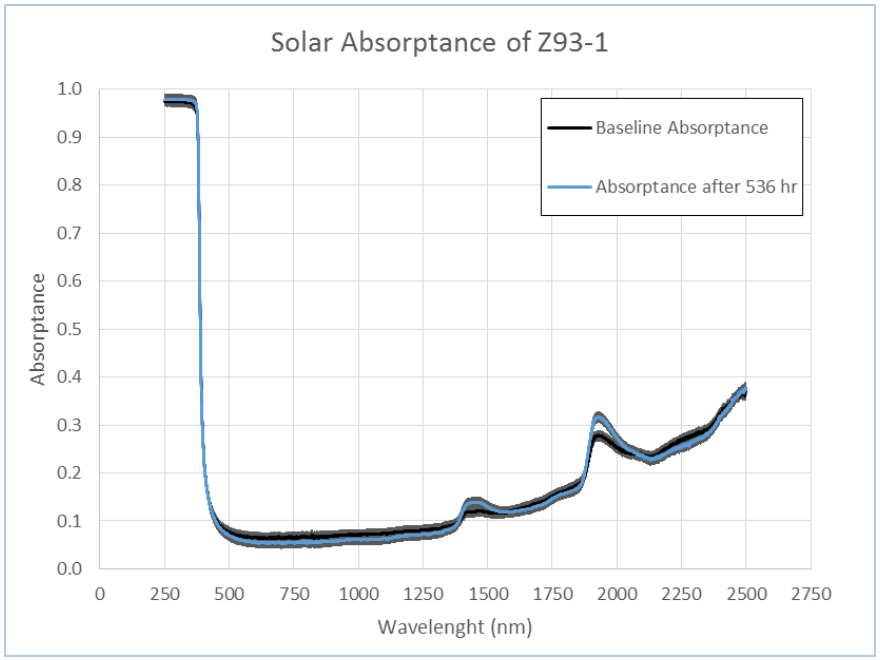


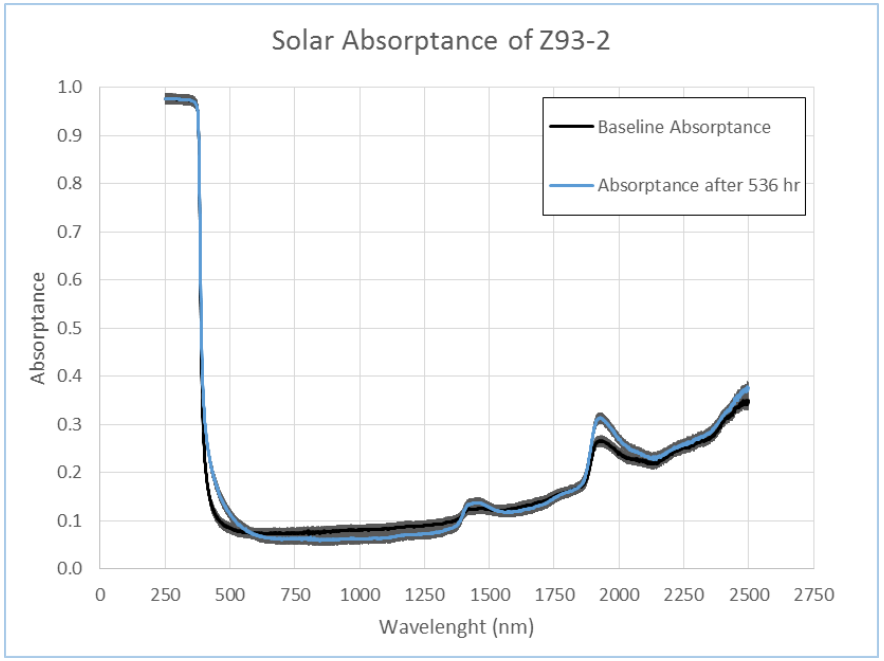
White Paint AZ-93 Results

			Baseline Measurements		Test Measurements		Dates:	5/7/18 - 6/11/18	Hours:	536.36
Nom	**Material**	**Location**	**ε_H**	**α**	**ε_H**	**Delta**	**% Change**	**α**	**Delta**	**% Change**
Z93-1	White Paint Z-93	E90°	0.814	0.161	0.771	-0.043	-5.3%	0.155	-0.006	-3.7%
Z93-2	White Paint Z-93	E-30°	0.814	0.167	0.766	-0.048	-5.9%	0.172	0.005	2.7%

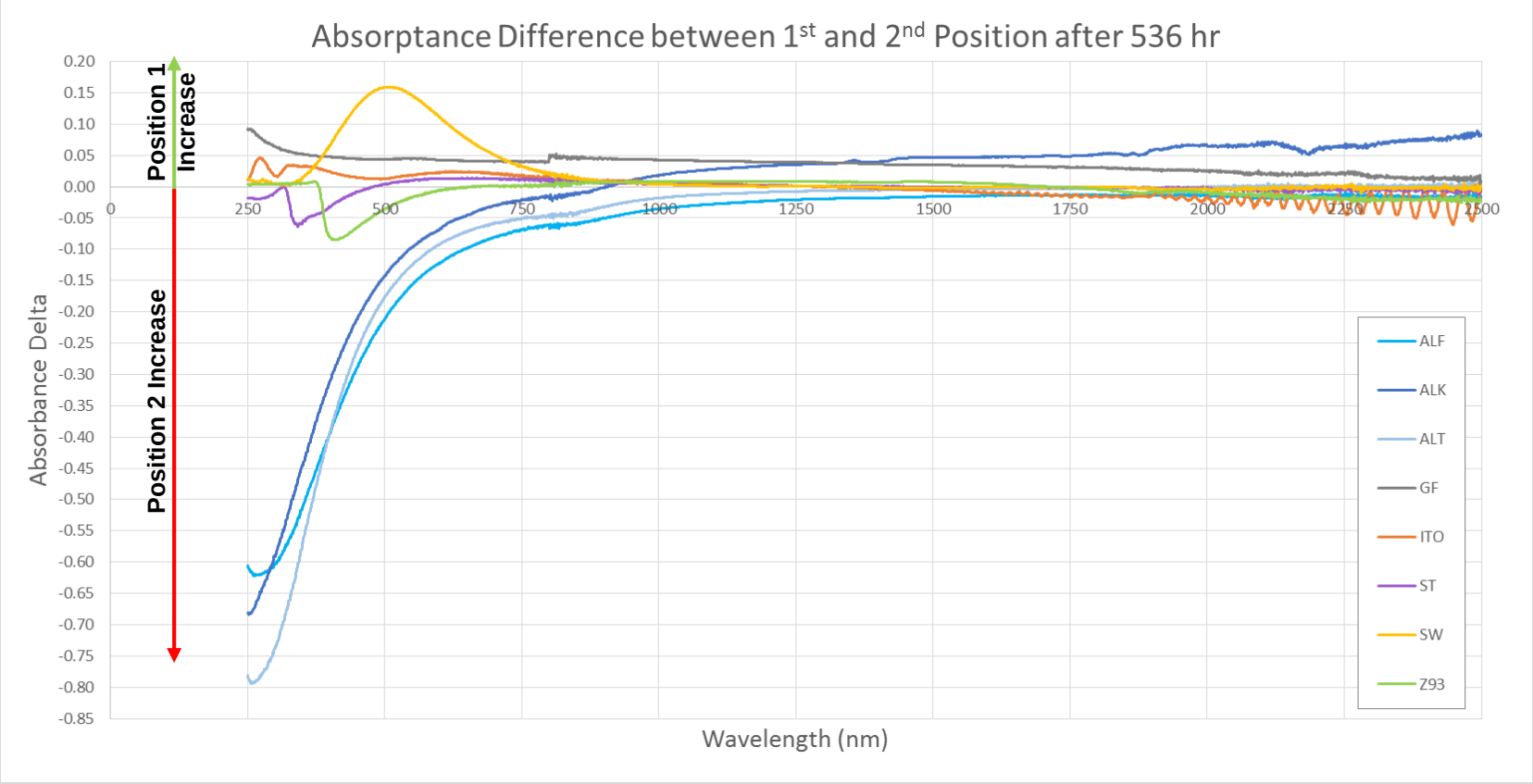


After 536hr Exposure





Absorptance Delta for Positon 1 vs 2



- A comparison of the difference in absorptivity between the 1st and 2nd position after 536 hr.
  - This comparison was made to see if there is a significant difference in the changes to the samples based on their position.
  - The difference between the 1st position was subtracted from the 2nd, for the 536 hr results
  - The difference between the Pre results was subtracted, to effectively remove any difference in the 2 samples
- Generally the 1st positions saw decreases in absorptivity, with the greatest increase being seen in the 250 to 750 nm range.

Summary of Key Findings

- Most samples showed a decrease in Hemispherical Emittance and an increase in Solar Absorptance.
- Overall, most of the samples showed an increase in absorptance with the largest increase in the 250-750nm range
- Position 2 showed higher increases in Absorptance for the 250-750nm range.

Future Work

1. Complete Testing on current samples
   - Currently at 1000+ hours of exposure
   - Quantify effects of back sputter
     - EDAX Analysis

2. Begin phase 2 of testing
   - 7 more sample materials will be added
   - Adding a collimated RPA Probe, to record ion exposure

3. Comparison to related work

Acknowledgements

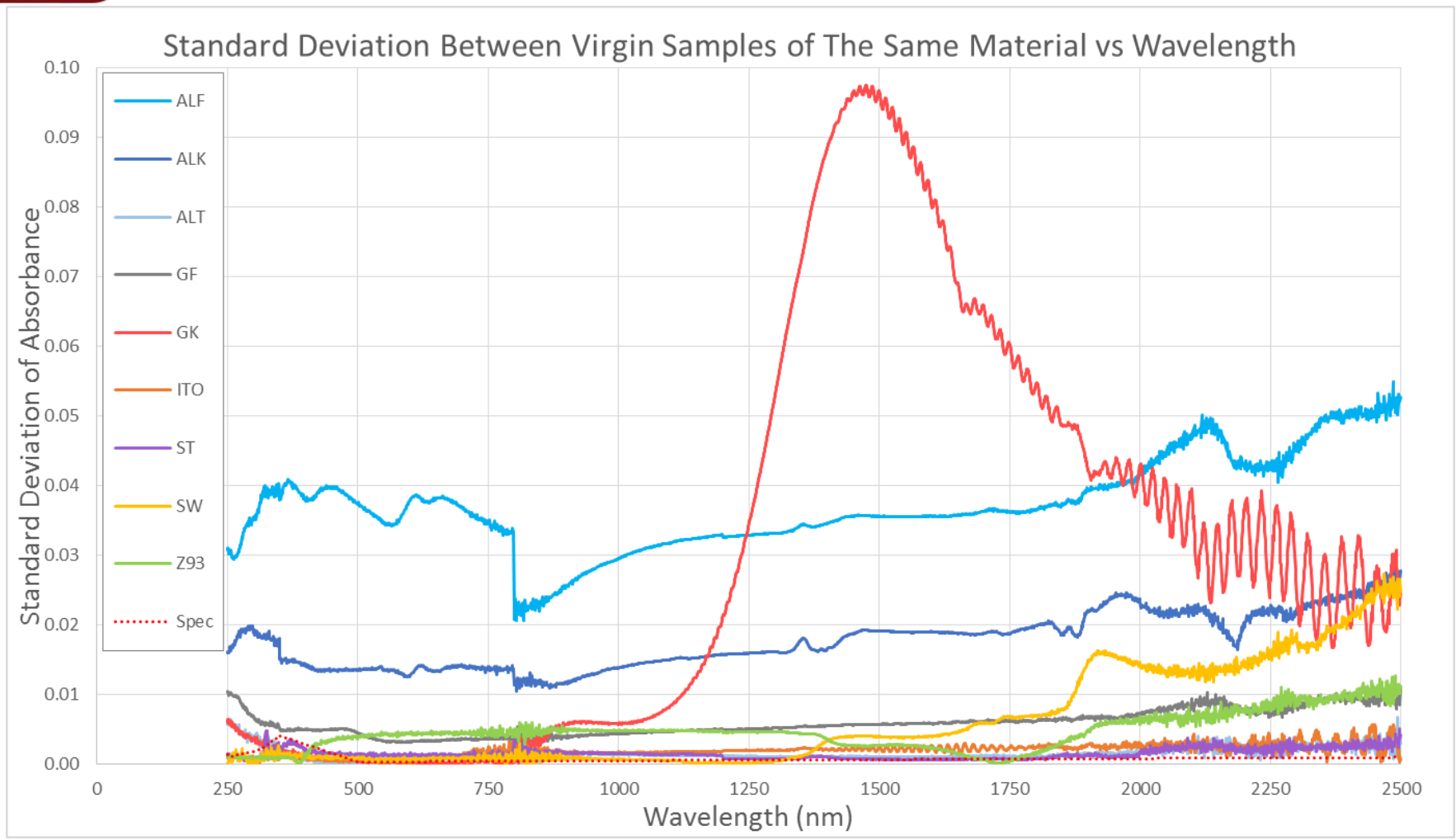
- Glenda Yee – NASA, GRC
  - PDP Project Manager
- Sharon Miller – NASA, GRC
  - Absorptivity Measurements
  - Materials Expert
- Wesley Johnson – NASA, GRC
  - Providing materials samples
- Jim Myers – NASA, GRC
  - Emissivity Measurements
- Wensheng Huang & John Yim – NASA, GRC
  - EP Technical Experts
- Miria Finckeror & Brian O'Connor – NASA, MSFC
  - Providing materials samples
- Robert Youngquist & Tracy Gibson – NASA, KSC
  - Providing materials samples

Thank You

Questions?

Back Up Slides

Absorbance Measurement Error for Virgin Samples



Material	ALF	ALK	ALT	GF	GK	ITO	ST	SW	Z93
Population Size	2	4	2	4	2	2	5	2	2
Average σ	0.0372	0.0176	0.0014	0.0058	0.0309	0.0019	0.0014	0.0060	0.0046

Measurement Instrumentation

Solar Absorptance (α)

Cary 5000 UV-Vis-NIR

(with Diffuse Reflectance Accessory DRA-2500)

Photometric accuracy of internal DRAs in the UV-Vis region (200nm to 800nm):

- 0.004 error @ 350nm
- 0.002 error @ 313nm
- 0.001 error @ 257nm
- 0.002 error @ 235nm

Photometric accuracy of the Agilent DRA in the NIR region (500nm to 1500nm):

- 0.00026 error @ 500nm
- 0.00058 error @ 1,500nm

- Measurements done at 900C

Measurement Instrumentation

Hemispherical Emittance

ET-100 Thermal Handheld Emissometer

- Error for hemispherical emittance is ±0.001
- Measurements done at 20C