New Materials for LEO, GEO and Planetary Environments: Preliminary Results from MISSE-17 Experiment

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Credit: NASA

Presented at:

A joint ISMSE16/ICPMSE14 conference on
Materials in Space Environment
7 - 11 October 2024, Saint Raphael, France

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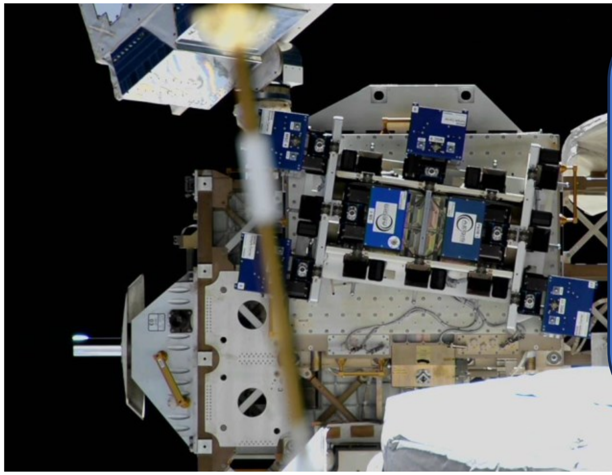
Motivation

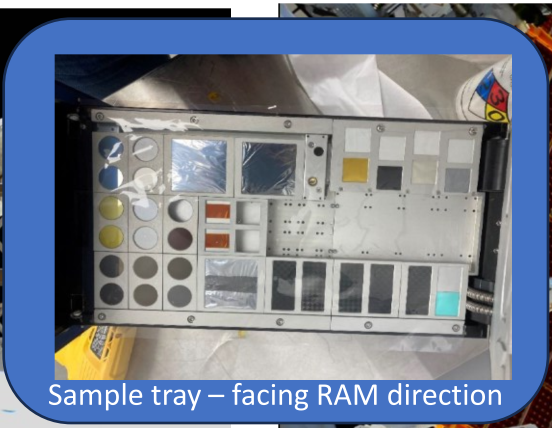
- Activities in space extend from the very low Earth orbit (VLEO) to the low Earth orbit (LEO), Geostationary orbits (GEO) and planetary environments like Lunar and Martian environments.
- The need in materials and coating that will withstand the harsh space conditions in such environments is large and growing.
- New technological solutions (Electric Orbit-Raising (EOR) launches), new orbits and environments (Very Low Earth Orbit launches, Planetary launches) require revision of existing material technologies and command development of new improved technological solutions.
- We are exploring how ITL-developed coatings and surface treatments that include multifunctional coatings with AO-resistant properties and charge-dissipative and dust mitigation properties, can be used, with some modifications, in complimentary applications.

MISSE 17 Mission

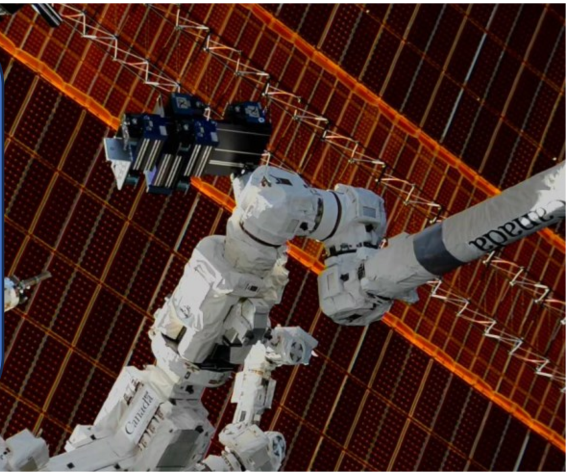
The MISSE-17 Experiment was launched from Kennedy Space Center on March 15, 2023 and returned on SpX-29 flight on December 17, 2023

	Positioning in Flight	
	RAM	WAKE
Fluence of atomic oxygen (at/cm²)	8.0E+20	3.76E+18
Duration	145 days 4 hrs 36 min	157days 4 hrs 22 min
Flux of atomic oxygen (at/cm²/s)	6.38E13	2.77E11





Sample tray – facing RAM direction

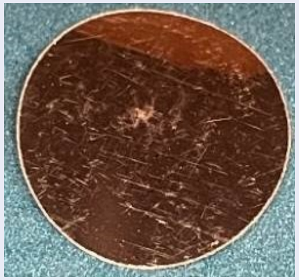


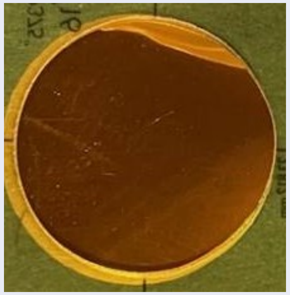
Credit: NASA ~ MISSE 17 on 5 Apr 23

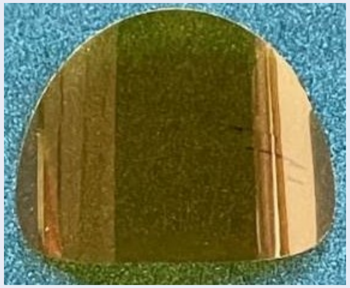
Credit: NASA ~ MISSE 17 on the MTT and MISSE Flight Facility (the blue boxes)

Samples Prepared for MISSE-17 Mission


CK


CT Ag


CK Al


WFM CK

Position on MISSE	Sample ID		Surface resistance (SR) [Ω/ם]
WAKE	C T Ag	N-doped DLC on Teflon FEP/Ag/Inconel	$1\cdot10^{8}$
WAKE	C K Al	N-doped DLC/Kapton/Al	$7.5\cdot10^{7}$
WAKE	WFM C K	(Si+O)-DLC/Kapton /Al	$1\cdot10^{10}$
RAM	WFM C K	(Si+O)-DLC/Kapton /Al	$1\cdot10^{9}$
RAM	C K Al	Si-doped DLC/Kapton/Al	$2\cdot10^{8}$
RAM	CK	Si-doped DLC/Kapton	$2\cdot10^{8}$

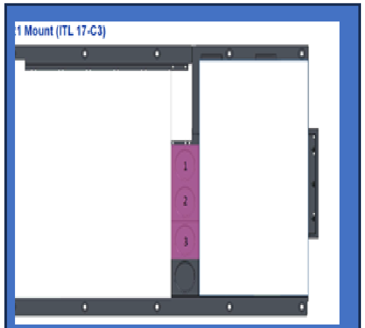
The flown samples represent three novel materials that serve as:

- charge -dissipating coatings for use in GEO and planetary environments,
- thermal protection materials to maintain the thermal optical properties of structures exposed to the sun radiation and
- coatings with work function matching the lunar dust work function to mitigate the dust accumulation on the surfaces.

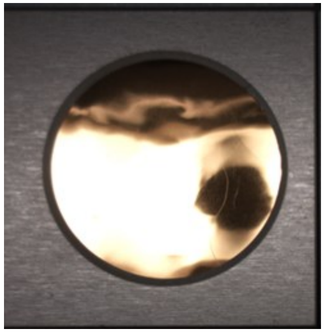
Images of Samples Flown in RAM Direction

Upper row: preflight picture; Lower row: after 5 months in flight

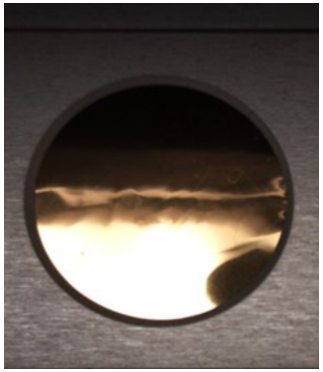
CK -RAM



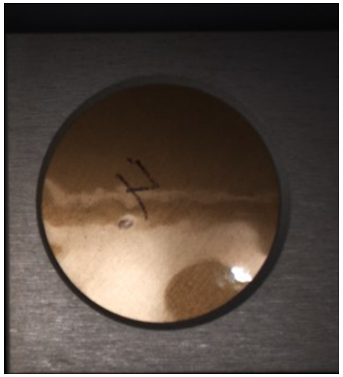
ITL 17-C1	
1	CK
2	CK Al
3	WFM CK



CK Al -RAM



WFM CK -RAM



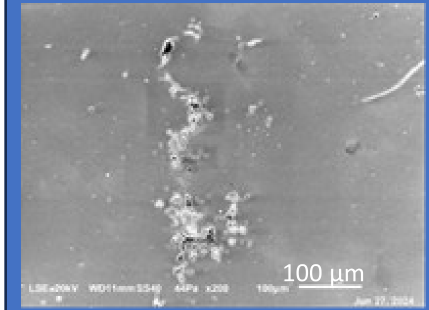
Bottom row: after removal from orbit and return to ITL

Weight Changes of the MISSE-17 Samples

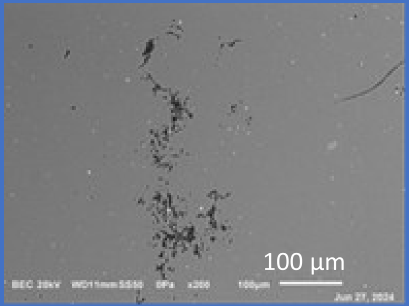
Sample ID	**Position on the ISS**	**Weight (g)**				**Comments**
		Before Flight (g)	After Flight (g)	Weight Change (µg)	Weight Change (%)	
C T Ag	WAKE	0.140000	0.139901	-99.0	-0.07	N-DLC Teflon FEP/Al/Inconel
C K Al	WAKE	0.017750	0.017730	-20.3	-0.11	N-DLC/Kapton/Al
WFM C K	WAKE	0.017230	0.017211	-19.3	-0.11	(Si+O)-DLC/Kapton HN
WFM C K	RAM	0.017190	0.017715	-85.5	-0.48	(Si+O) -doped DLC/Kapton HN
C K Al	RAM	0.017800	0.017033	-156.7	-0.91	Si-DLC/Kapton/Al
C K	RAM	0.017260	0.017092	-168.0	-0.97	Si-DLC/Kapton

SEM Analysis of Sample RAM-CK Al and RAM-CK

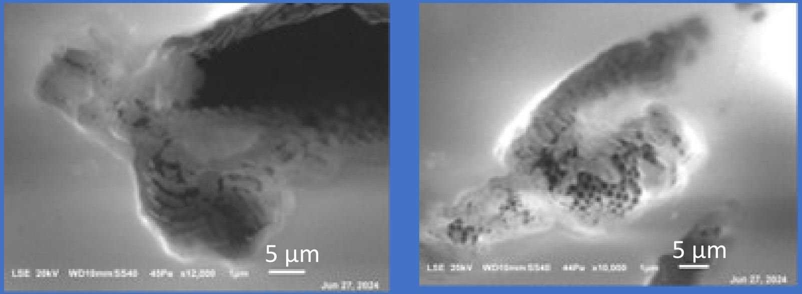
RAM-CK Al (N-doped DLC/Kapton/Al back)



Secondary SEM image

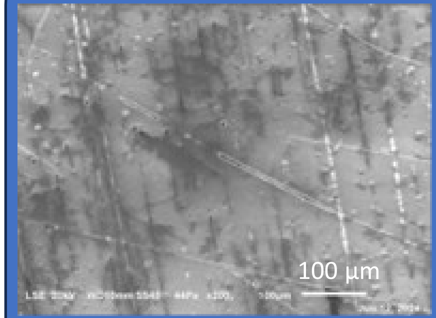


Backscattered SEM image

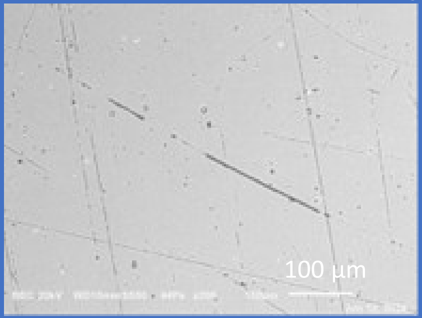


Secondary electron SEM images

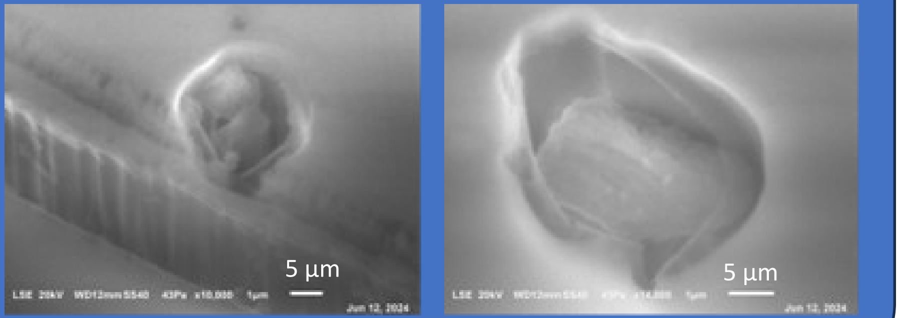
RAM-CK (Si-doped DLC/Kapton)



Secondary SEM image



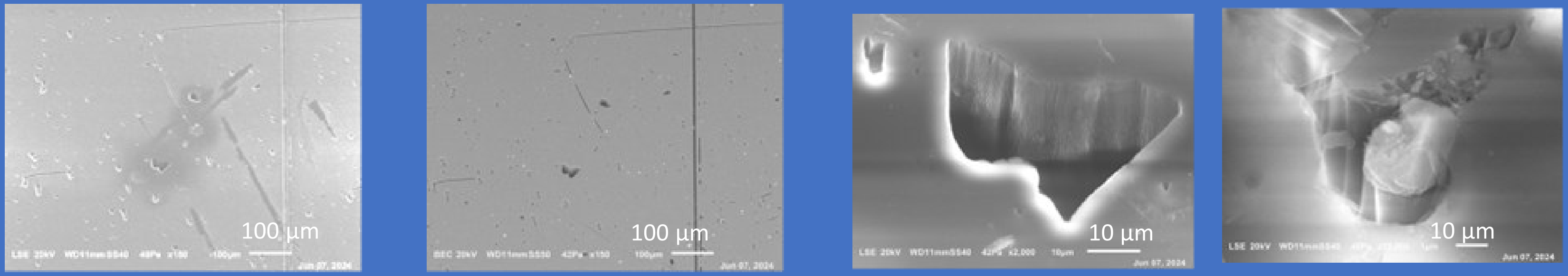
Backscattered SEM image



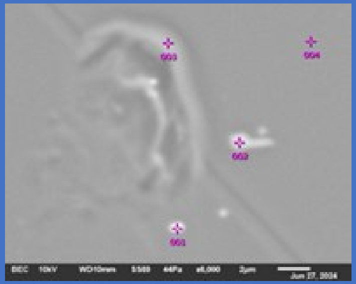
Secondary electron SEM images

SEM Analysis of Sample RAM- WFM C K

RAM- WFM C K ((Si+O) -doped DLC/Kapton HN)

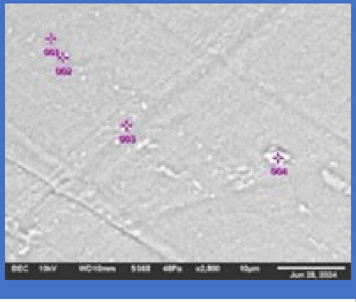


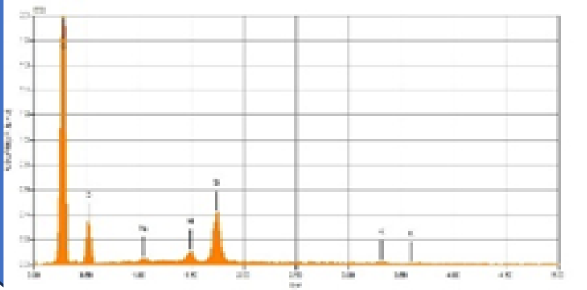
WAKE-C K Al (N-doped DLC/Kapton/Al back)

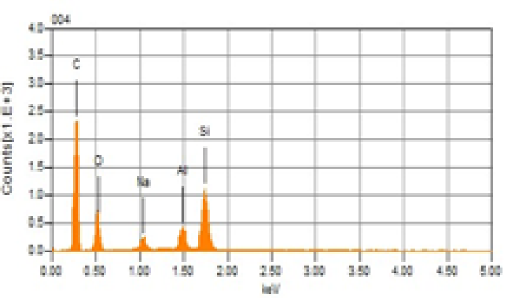


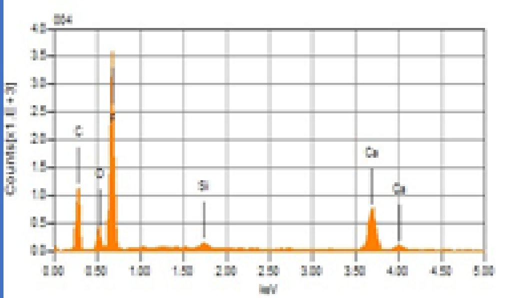
WAKE-WFM C K ((Si+O)-DLC/Kapton HN)

WAKE-C K Ag (N-doped DLC on Teflon FEP/Al/Inconel)









Summary of Observations

- The samples flown in RAM direction while remaining shiny and without major observable defects in the pictures from the flight, demonstrated some surface changes in images taken upon their return.
- All flown samples, positioned in RAM and WAKE directions, experienced very small mass losses, demonstrating erosion yields of the order of 10^{-28} at/cm^3 in the RAM and 10^{-29} at/cm^3 in the WAKE directions.
- The samples in the RAM direction had shown a ~ 0.5% - 1.0% weight loss
- Surfaces of all three samples in ram direction remained smooth and not etched, demonstrating good AO erosion protection.
- Selectively etched regions were seen on all three samples, with small, but distinct pits developed.
- All sample positioned in the WAKE direction exhibited negligible ~ 0.1% weight loss, with the surfaces showing practically no erosion features.
- The EDS analysis indicated that some contamination/cross-contamination with Na, K, Ca, F and Si happened in the WAKE samples.

Thermal Optical Properties

Thermal optical properties were measured using portable and stationary spectrophotometers

UV-VIS-NIR spectrometers

SOLA-02 SOLA-4B

Carry 500-5000

Gier-Dunkle
DB-100

Portable infrared
spectrometer
TOEM-002

Thermal Optical Properties' Changes

Sample ID	Position on the ISS	Thermal Optical Before Flight			Thermal Optical After Flight			Comments
		α	ε	α/ε	α	ε	α/ε	
C T Ag	WAKE	0.233	0.811	0.29	0.263	0.808	0.33	N-DLC Teflon FEP/Al/Inconel
C K Al	WAKE	0.443	0.654	0.68	0.465	0.637	0.73	N-DLC/Kapton/Al
WFM C K	WAKE	0.373	0.647	0.58	0.419	0.632	0.66	(Si+O)-DLC/Kapton HN
WFM C K	RAM	0.370	0.649	0.65	0.367	0.637	0.56	(Si+O) -doped DLC/Kapton HN
C K Al	RAM	0.350	0.646	0.57	0.355	0.633	0.58	Si-DLC/Kapton/Al
C K	RAM	0.423	0.654	0.54	0.384	0.639	0.60	Si-DLC/Kapton

- The solar absorptance, in most samples, either remained unchanged or increased slightly, with only exception being samples CK (Si-doped DLC on Kapton)
- The thermal emittance of all samples in RAM and WAKE positions decreased slightly.
- The α/ε ratio increased slightly, with only exception being the WFM CK in RAM direction sample.

XPS Analysis of Sample Surfaces

Before Flight

Peaks	Si2p	C1s	N1s	O1s	F1s	
Position	Rel.At.%	Rel.At.%	Rel.At.%	Rel.At.%	Rel.At.%	Comments
C T Ag -WAKE	0.5	77.5	7.2	10.3	4.5	N-DLC Teflon FEP/Al/Inconel
C K Al -WAKE	0.3	85.7	6.0	7.7	0.3	N-DLC/Kapton/Al
WFM C K -WAKE	11.8	62.3	2.1	23.6	0.2	(Si+O)-DLC/Kapton HN
WFM C K -RAM	13.43	53.28	2.97	30.01	0.21	(Si+O) -doped DLC/KaptonHN
C K Al -RAM	27.0	42.9	1.7	28.4	0.1	Si-DLC/Kapton/Al
CK -RAM	8.4	75.7	1.8	14.0	0.0	Si-DLC/Kapton

After Flight

Peaks	Si2p	C1s	N1s	O1s	F1s	
Position	Rel.At.%	Rel.At.%	Rel.At.%	Rel.At.%	Rel.At.%	Comments
C T Ag -WAKE	15.8	28.8	1.5	36.4	17.4	N-DLC Teflon FEP/Al/Inconel
C K Al -WAKE	9.3	51.8	2.0	33.2	3.7	N-DLC/Kapton/Al
WFM C K -WAKE	9.1	49.9	2.1	34.2	4.8	(Si+O)-DLC/Kapton HN
WFM C K -RAM	29.1	11.1	0.5	59.2	0.0	(Si+O) -doped DLC/Kapton HN
C K Al -RAM	29.7	9.7	0.6	60.0	0	Si-DLC/Kapton/Al
CK -RAM	29.6	8.92	0.42	61.1	0.0	Si-DLC/Kapton

All wake-positioned samples were contaminated with Si and F.

Summary

- Six samples representing different functional solutions developed at ITL for use in various space environments like VLEO, LEO, GEO and planetary were flown on MISSE-17 mission for a period of 6 months and returned to ITL.
- Initial analysis of the flown samples indicated that they retained all basic functional properties, with very small changes in weight and thermal optical properties.
- Cross-contamination with Si and F of samples flown in the WAKE direction was observed

Acknowledgements

We acknowledge the financial support of Canadian Space Agency (CSA) [20STDPO07].
The help from Aegis Corporation in providing the information on the MISSE-17 flight details is acknowledged with thanks.

Thank you for the attention

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Photo credit NASA