Title: Further Analysis of Materials Exposed on MISSE-6 & 7B

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Materials samples were exposed to the low Earth orbit (LEO) environment as part of the MISSE-6 and -7B flight experiments. Optical properties, thickness/mass loss, surface elemental analysis, visual and microscopic analysis for surface change are some of the techniques employed in this investigation. Effects of molecular contamination are discussed. Where possible, the MISSE-6 and -7B results are compared to analyses from other LEO experiments.

Further Analysis of Materials Exposed on MISSE-6 and -7B

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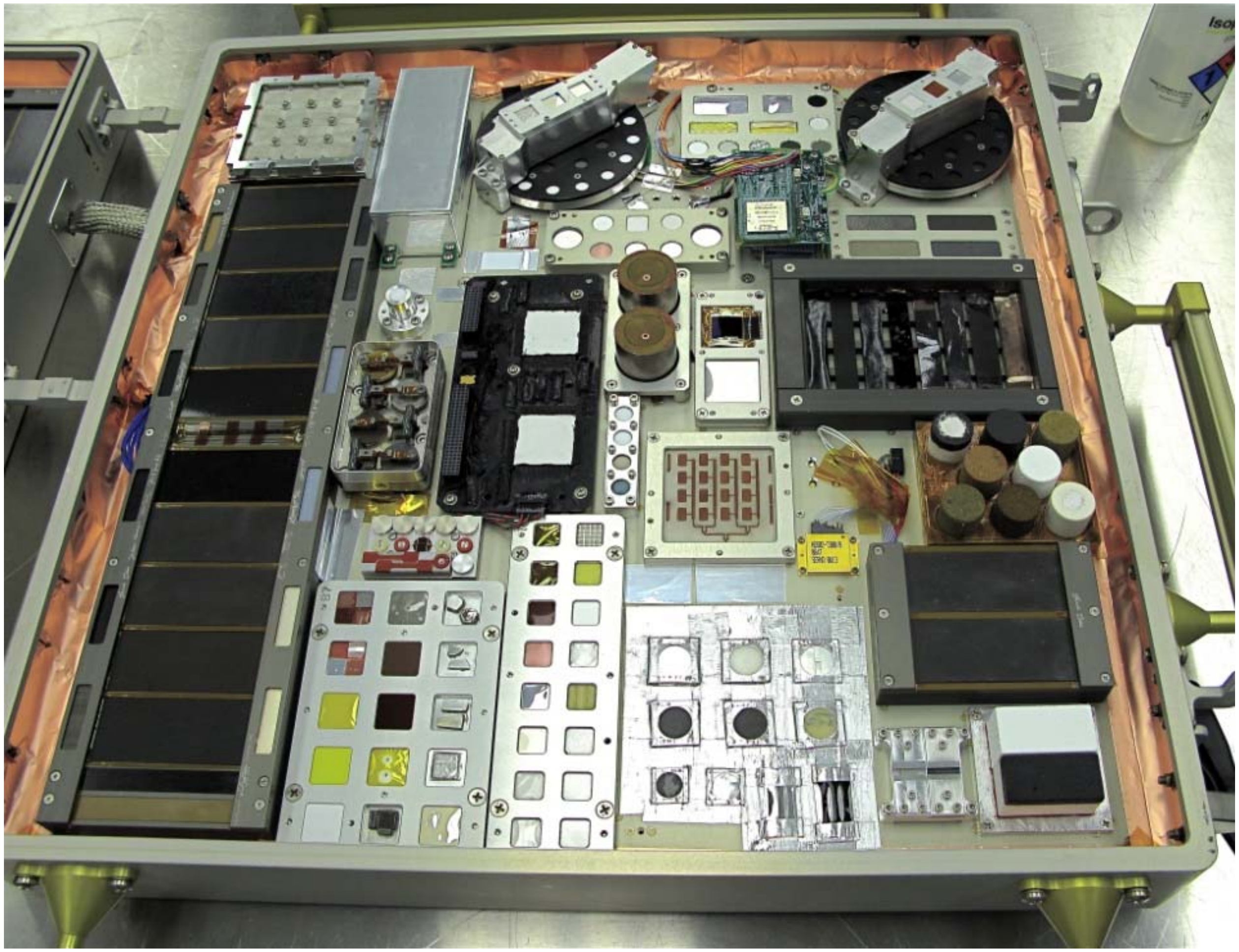
Further Analysis of Materials Exposed on MISSE-6 & -7B

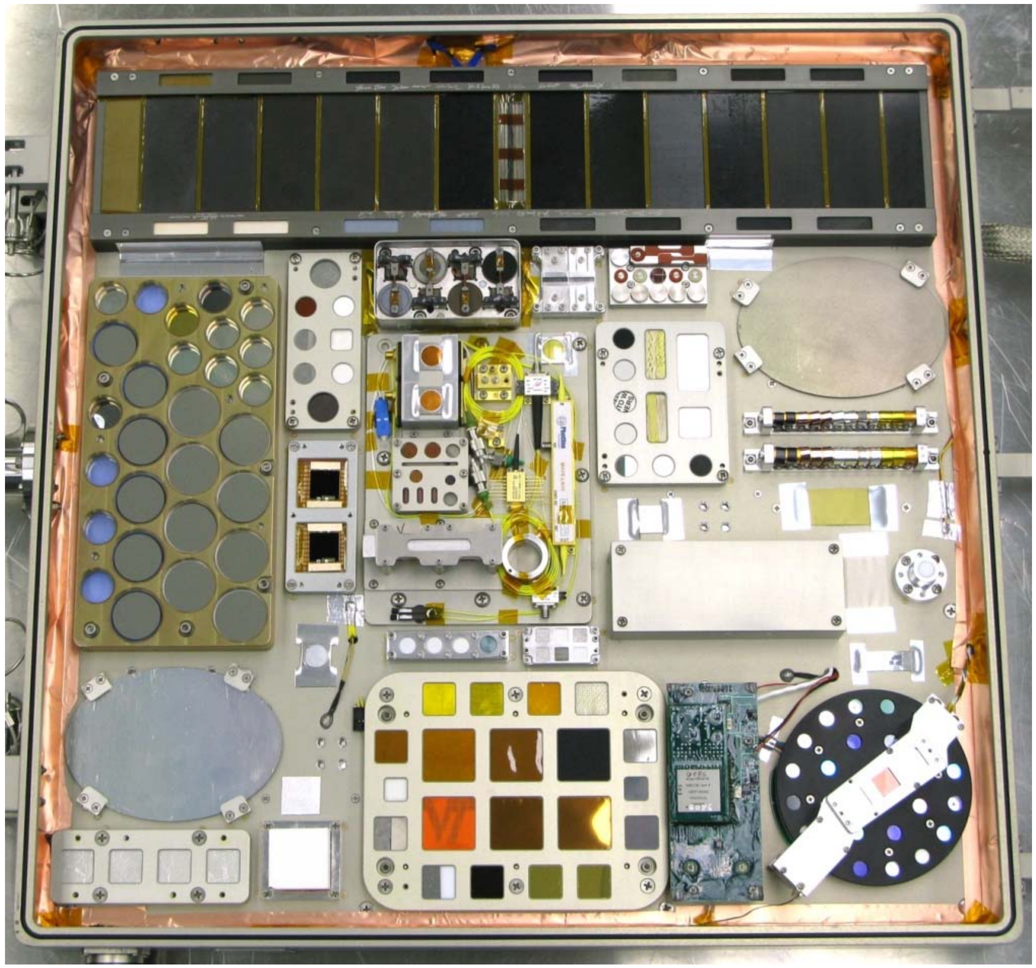
- **Background**
- **Results**
  - **Optical materials on MISSE-7B**
  - **Thermal control coatings on MISSE-7B**
  - **Radiation shielding materials on MISSE-6**
  - **Protective coatings**
- **Summary**

MISSE-7B Ram face - 4.2 +/- 0.1 x 10^{21} atoms/cm^2
Corrected UV dose – 2,400 ESH



Further Analysis of Materials Exposed on MISSE-6 & -7B

MISSE-7B Wake face – 2.9 +/- 0.3 x 10^{20} atoms/cm^2
Corrected UV dose – 2,000 ESH



Further Analysis of Materials Exposed on MISSE-6 & -7B

- **Optical Materials**
  - **Previous studies indicated approximately 250Å of contaminant on the wake-facing samples.**
  - **Post-flight analysis of spectral data from these samples show:**
    - **Virtually no changes observed in performance of oxide based coatings**
      - **No erosion or addition of material**
    - **Changes observed in ZnSe/ThF4 coatings are consistent with formation of a conversion layer on the surface of ZnO**
      - **Change in top surface layer is clearly evident ZnSe → ZnO + ZnSe**
      - **ZnO has a lower refractive index than ZnSe**
  - **Post-flight investigations hampered by spectrometer change, size of samples, and lack of control samples for each flight sample.**

Further Analysis of Materials Exposed on MISSE-6 & -7B

- **Optical Coatings**

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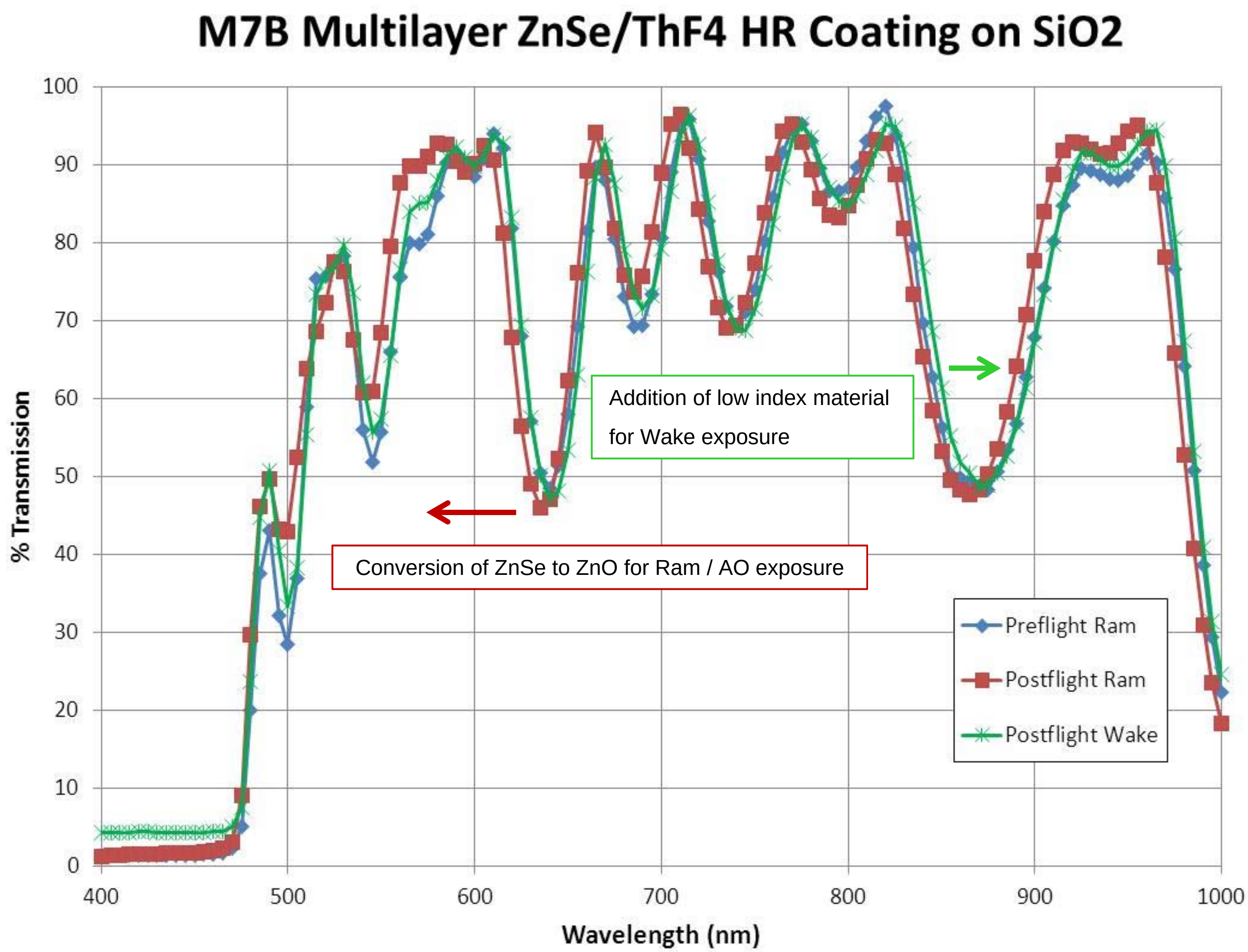


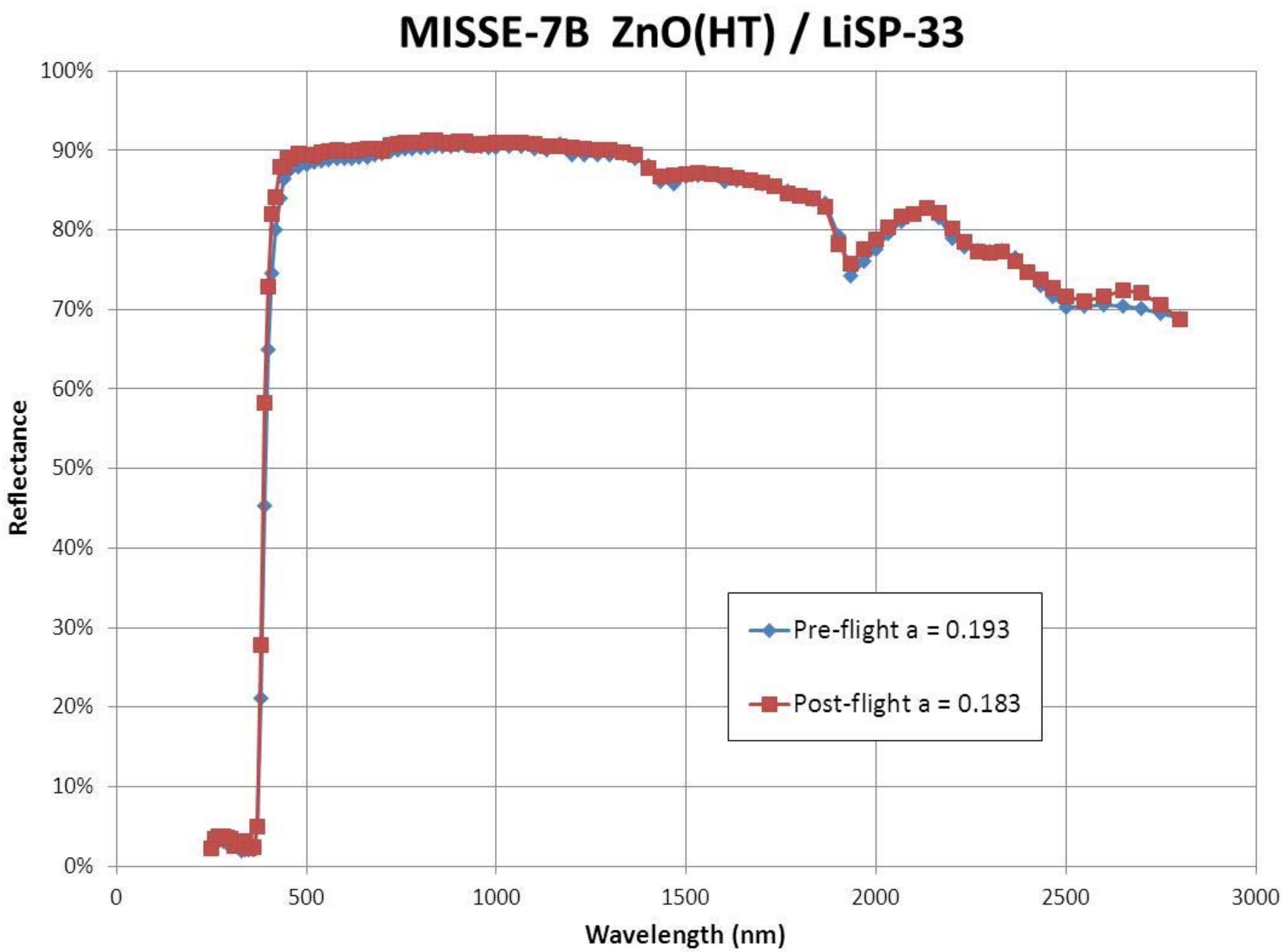
Further Analysis of Materials Exposed on MISSE-6 & -7B

- **Thermal Control Coatings**
  - **AMSENG developed low-cost thermal control coatings under SBIR.**
  - **These were flown in one of the carousels on the ram-facing side of MISSE-7B.**
  - **ZnO(HT) is pigment annealed at high temperatures to remove Zn interstitials. These and the nanoparticle version N-ZnO(HT) showed the most durability in the space environment.**
  - **ZnO(FC) is pigment flash calcined for reduced grain resistivity.**
  - **BN coating is boron nitride in a mix of nanomesh and nanotubes, which was tailored for reflectance and secondary emission.**

Further Analysis of Materials Exposed on MISSE-6 & -7B

- **Thermal Control Coatings**
  - **Lithium silicate, lithium-potassium silicate, and lithium-sodium silicate with and without dopant binders were used. Mass loss for these samples was noted.**
  - **AMSENG experimented with these various combinations for optimum optical properties, conductivity, durability, and cost.**
  - **Additional samples of P2-1 and P4-1 coatings were flown. These are low-pH, single step encapsulated pigmants in AMSENG processed low-cost, low-outgassing, flexible silicone binder. These coatings are similar in performance to the S13G series but much cheaper (as much as 50% lower cost) to process.**

- **Thermal Control Coatings**



Further Analysis of Materials Exposed on MISSE-6 & -7B

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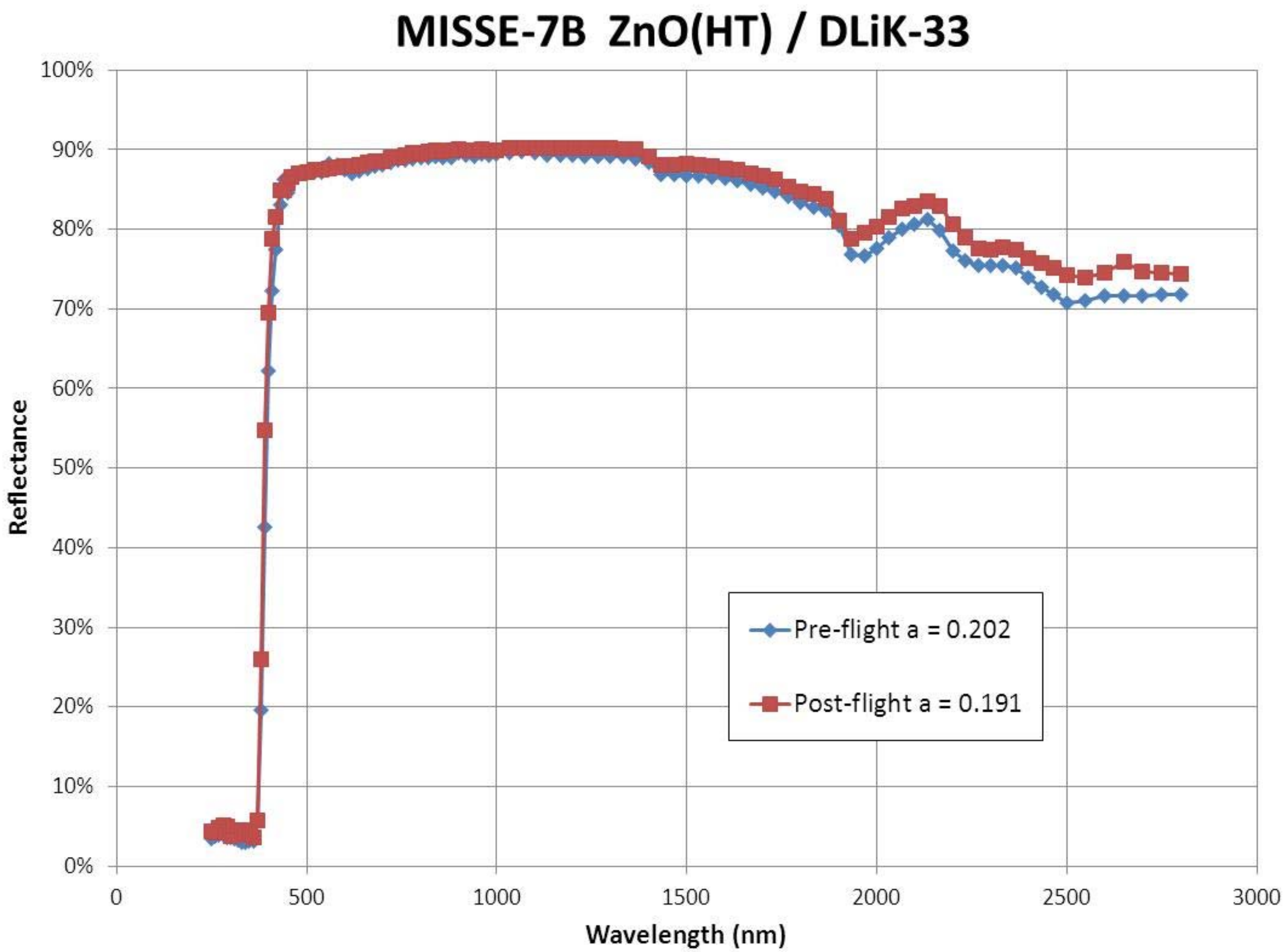

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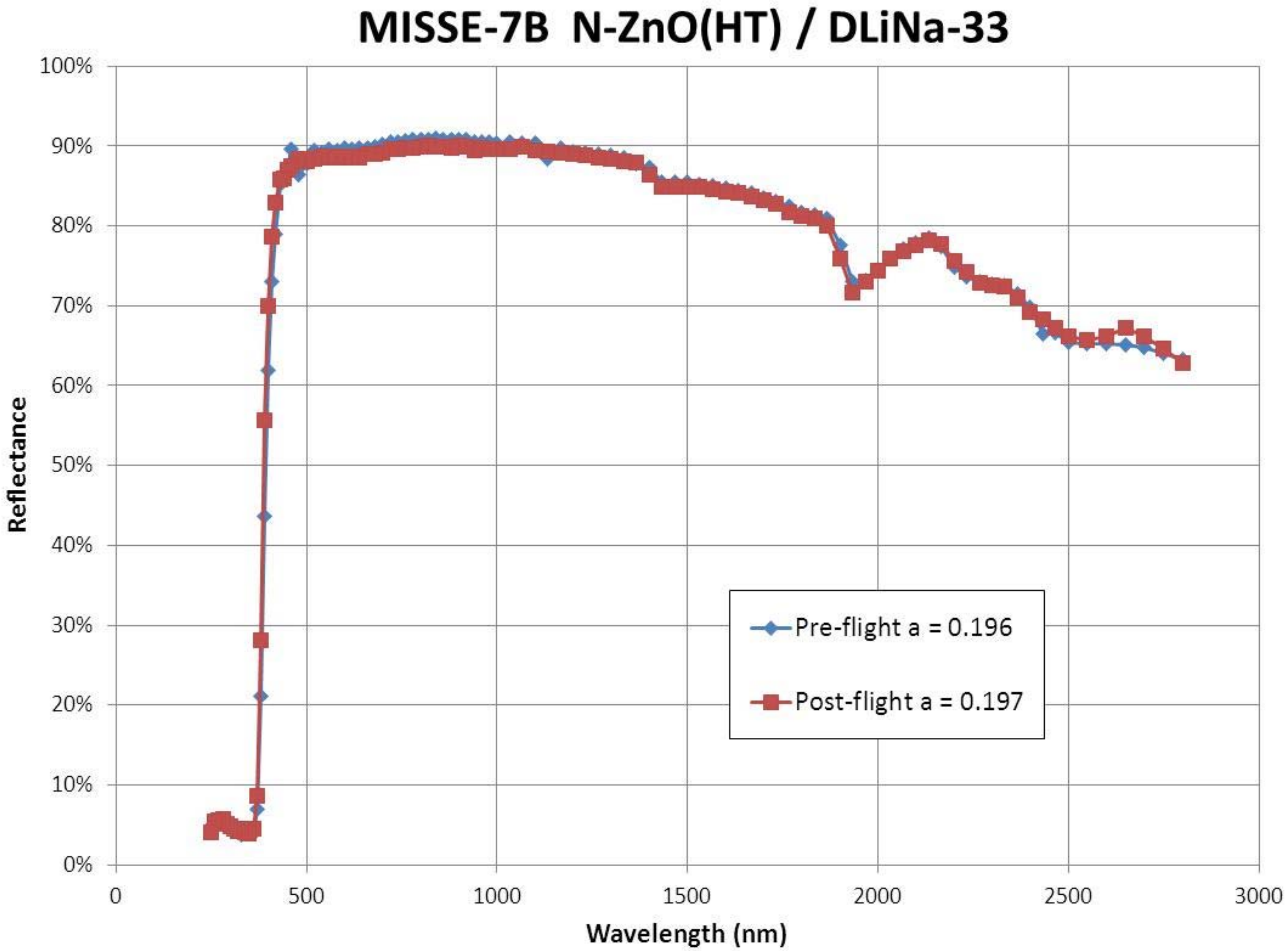

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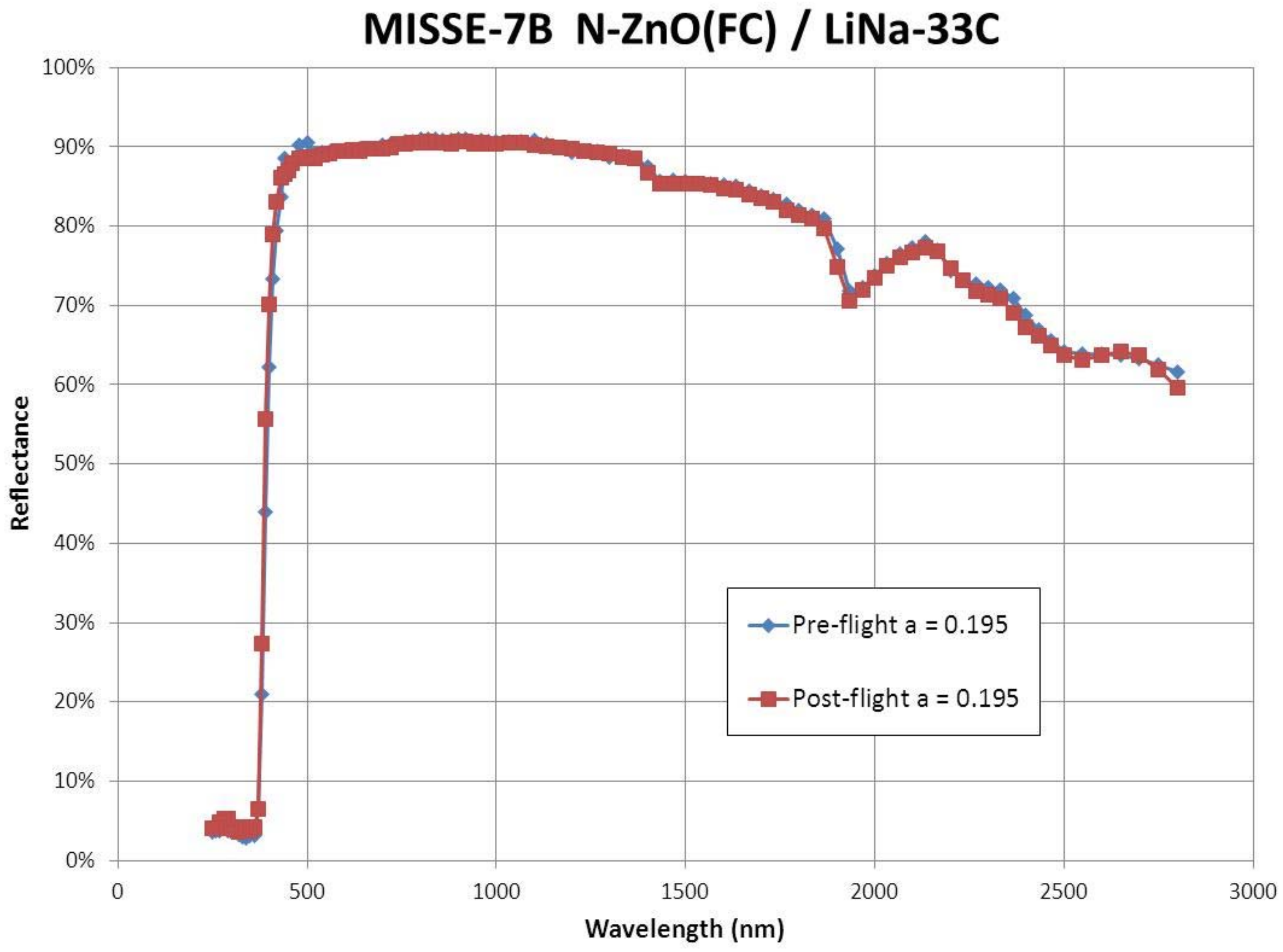

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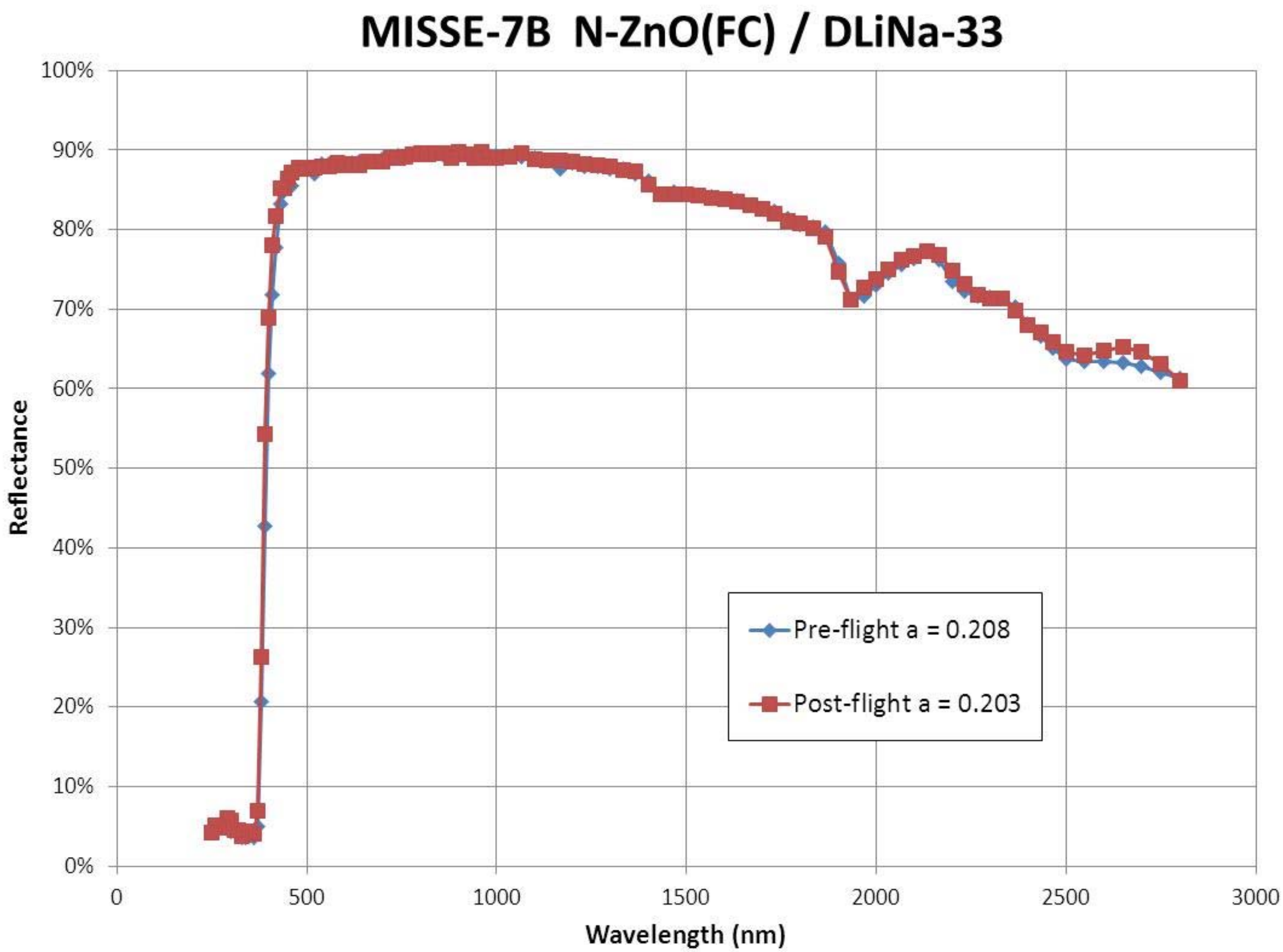

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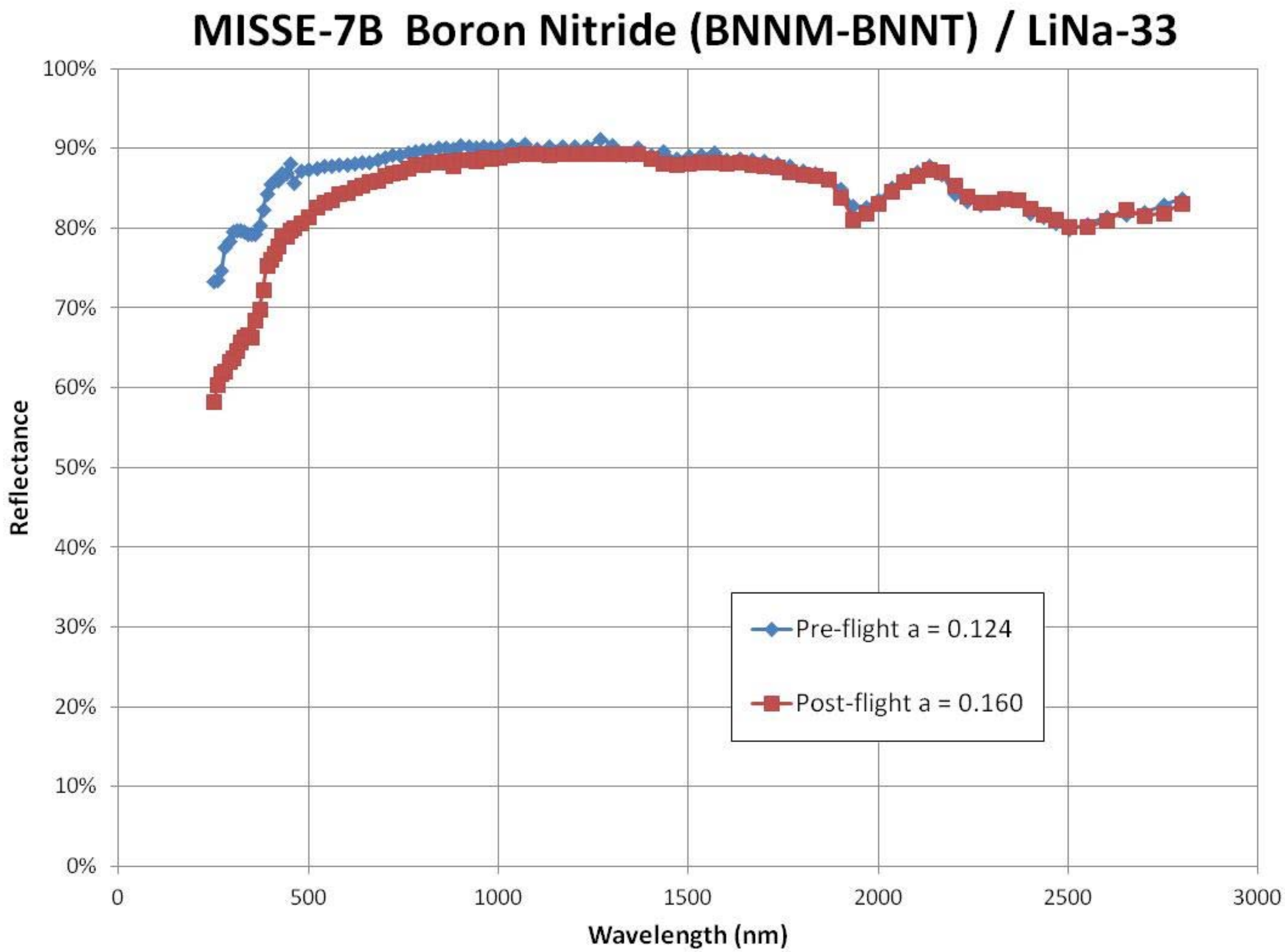

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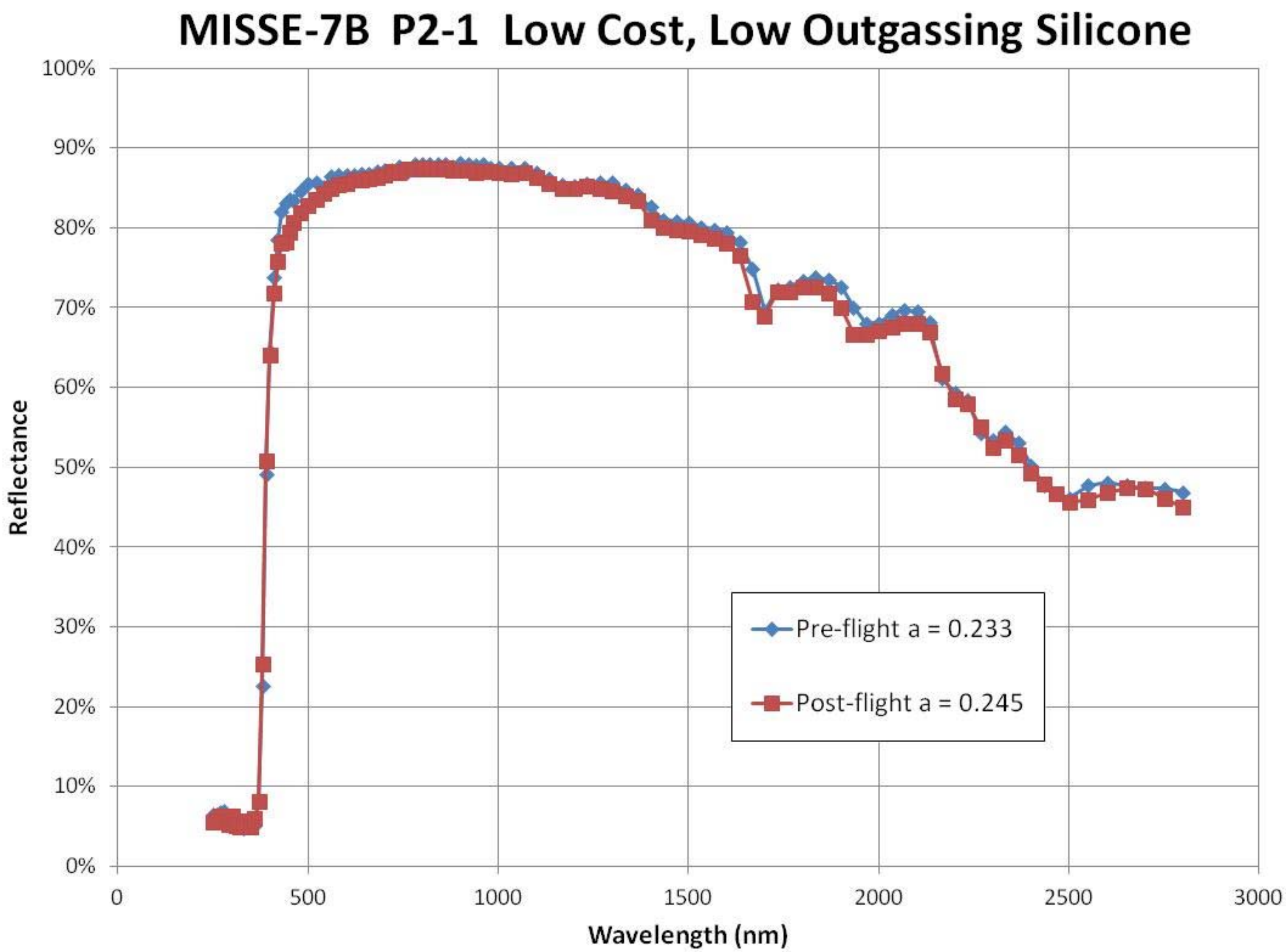

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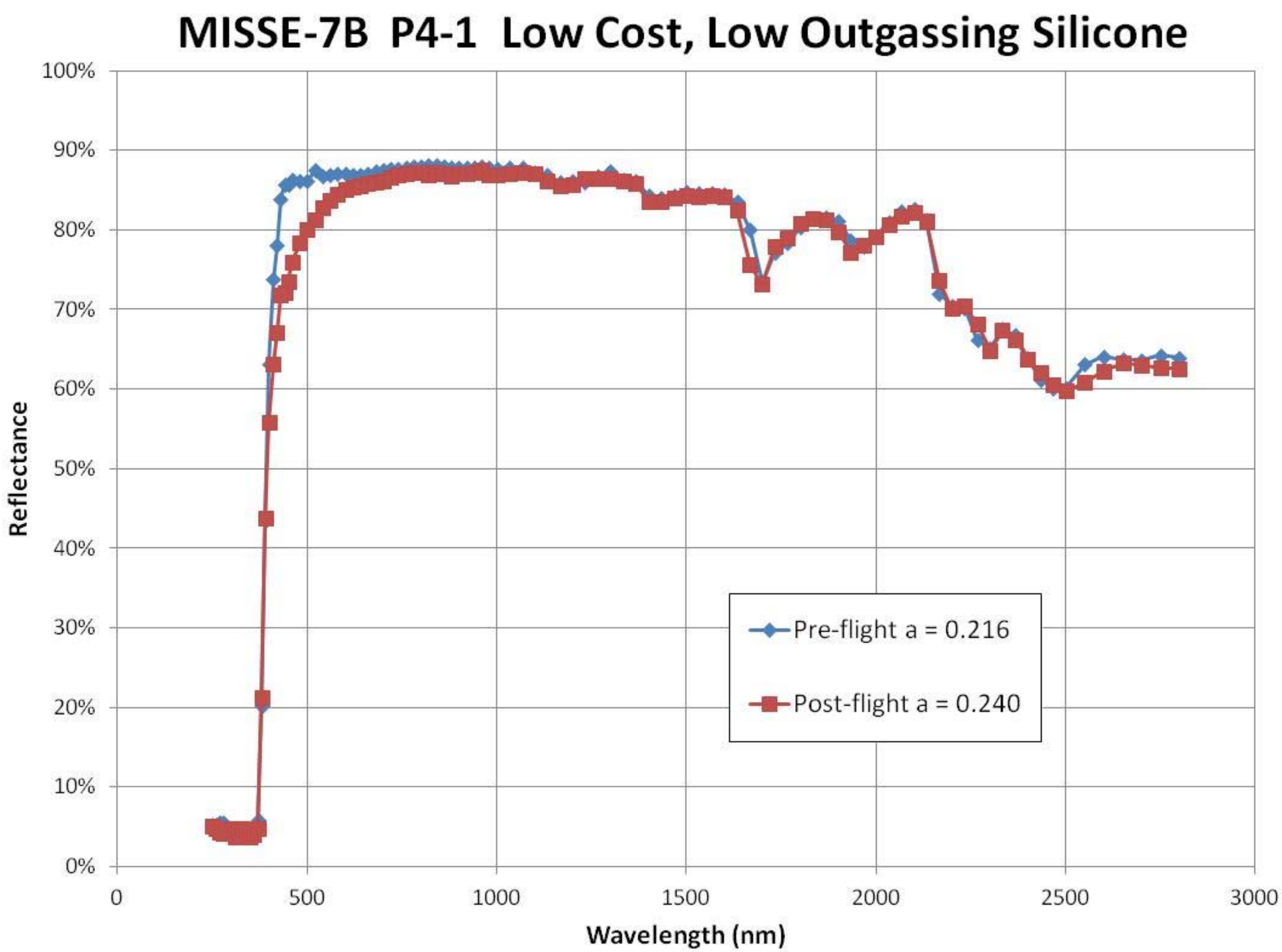
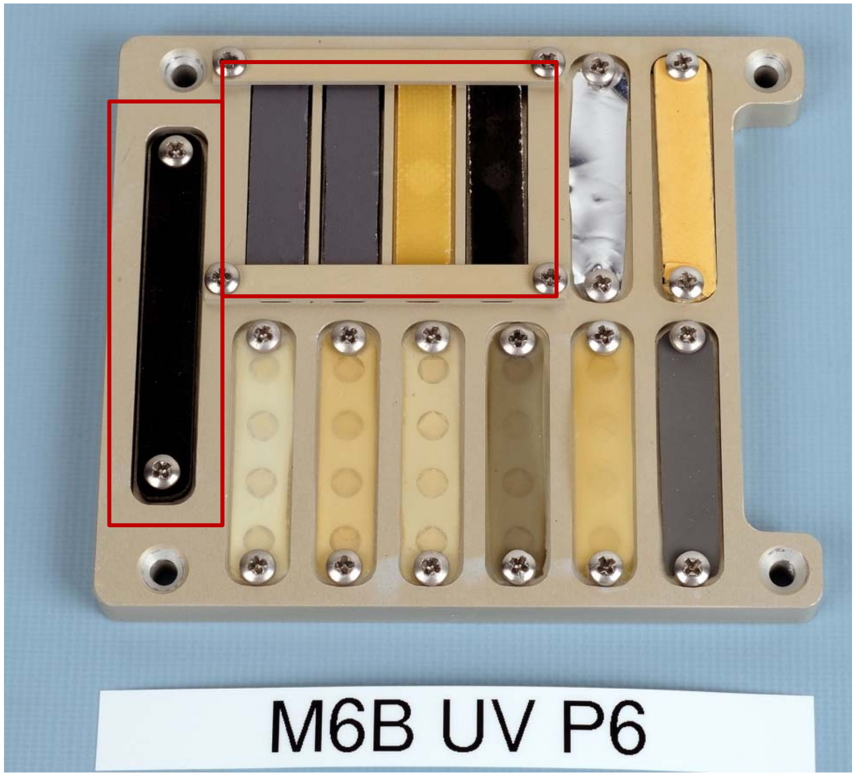


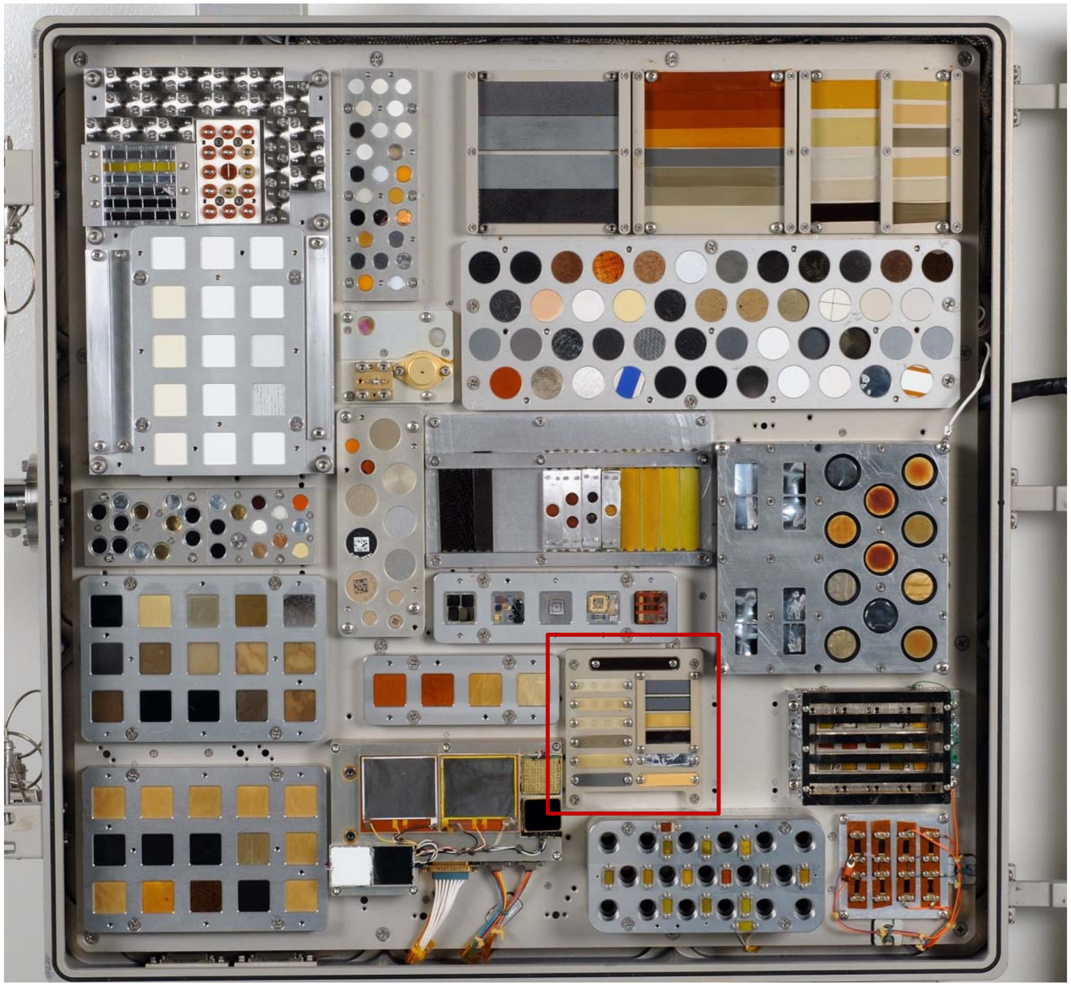
Further Analysis of Materials Exposed on MISSE-6 & -7B

- **Radiation shielding materials**
  - **Multi-layer radiation shielding samples provided by Plasma Processes**
  - **Loaded with lithium fluoride thermoluminescent dosimeters**



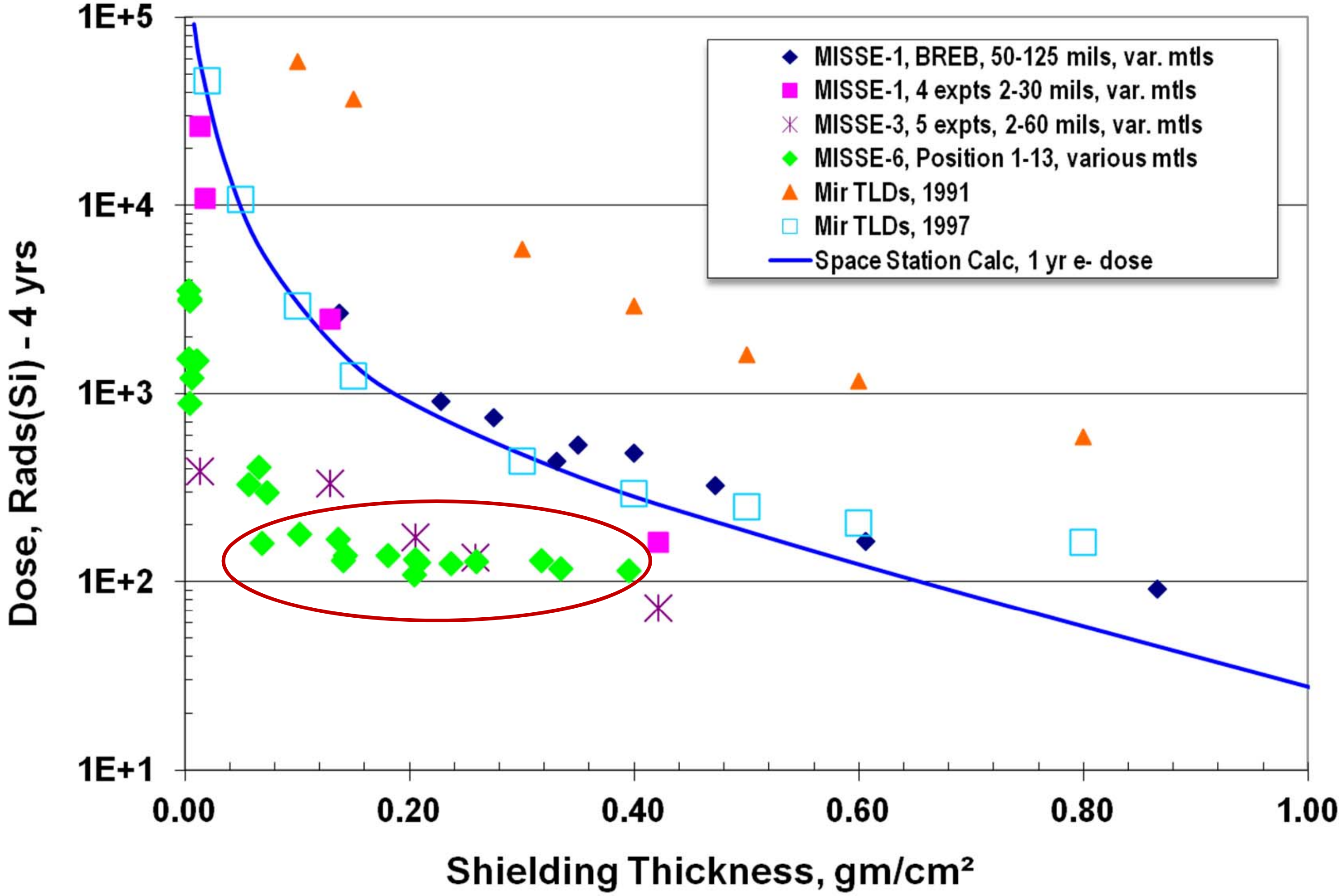
Further Analysis of Materials Exposed on MISSE-6 & -7B

- **Radiation shielding materials**
- **MISSE-6B Wake AO fluence -1.21 x 10^{20}atoms/cm^2, UV dose – 1,950 ESH**



Further Analysis of Materials Exposed on MISSE-6 & -7B

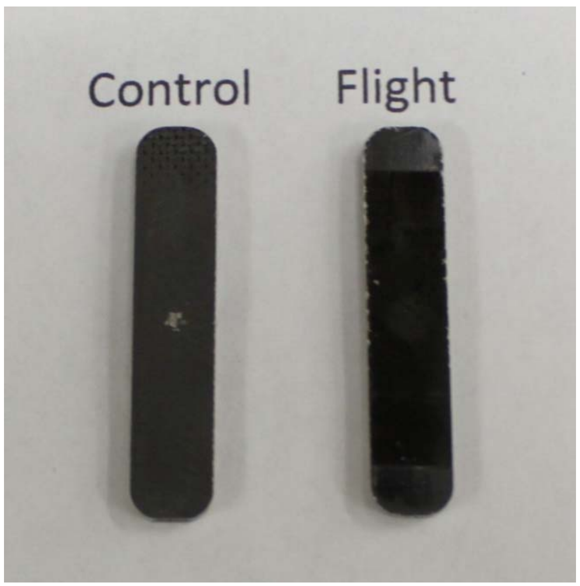
- **Radiation shielding materials**



Eugene Normand, George A. Perry, Gary Pippin, Jerry Wert, and Elizabeth Schofield,
"Passive Radiation Measurements on MISSE-1, -2, -3, and -6 Using TLDs", NSMMS 2009

Further Analysis of Materials Exposed on MISSE-6 & -7B

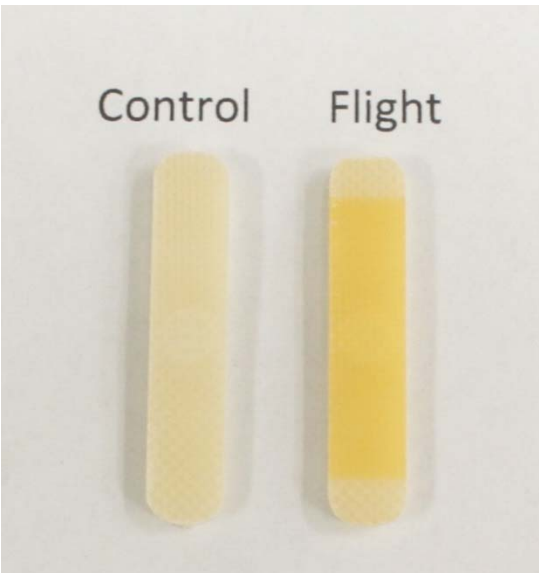
- **Radiation shielding materials**
  - **Epoxy composite samples with boron and polyethylene eroded where exposed to AO**
  - **This is also apparent in the optical properties, with the flight samples having a velvety texture.**



		Control	Flight	Δ
Epoxy composite A M6B Wake	α	0.91	0.95	+0.04
	ε	0.91	0.92	+0.01
Epoxy composite E M6B Wake	α	0.93	0.96	+0.03
	ε	0.90	0.92	+0.01

Further Analysis of Materials Exposed on MISSE-6 & -7B

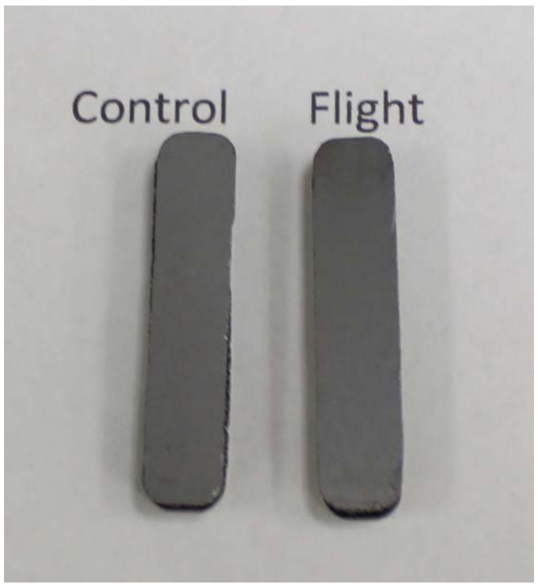
- **Radiation shielding materials**
  - **Epoxy composite samples with polyethylene fabric was darkened by UV radiation and eroded where exposed to AO**



		Control	Flight	Δ
Epoxy composite B M6B Wake	α	0.72	0.79	+0.07
	ε	0.91	0.92	+0.01

Further Analysis of Materials Exposed on MISSE-6 & -7B

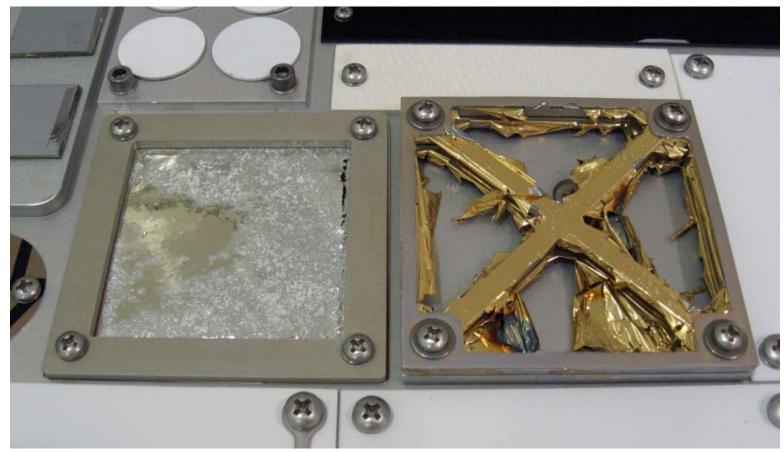
- **Radiation shielding materials**
  - **Samples with boron carbide faceplate had no visible reaction to space environment.**
  - **Confirmed by negligible changes in optical properties**

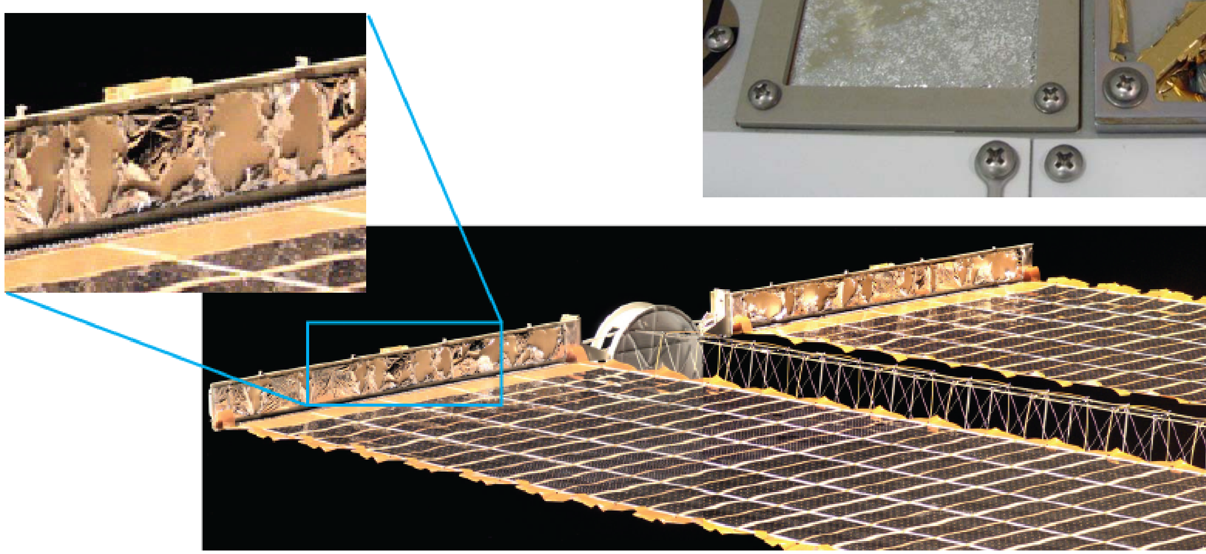


		Control	Flight	Δ
Epoxy composite C M6B Wake	α	0.85	0.84	-0.01
	ε	0.78	0.79	+0.01
Epoxy composite D M6B Wake	α	0.85	0.84	-0.01
	ε	0.79	0.78	-0.01

Further Analysis of Materials Exposed on MISSE-6 & -7B

- **Protective coatings**
  - **Past experience indicates that metallization is insufficient protection for polymers from AO erosion, whether due to pinholes, undercutting, or CTE mismatch during thermal cycling.**

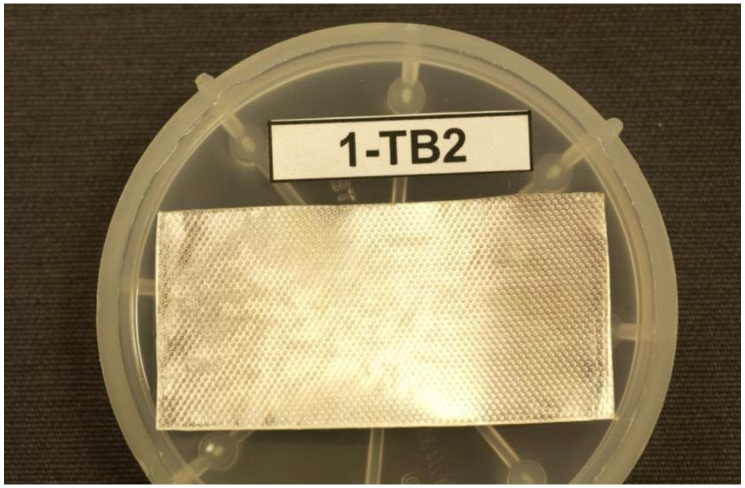




B.A.Banks, K. K. de Groh, and S. K. Miller. "Low Earth Orbital Atomic Oxygen Interactions with Spacecraft Materials." NASA/TM-2004-213400 (Nov. 2004).

Silicon Oxide (SiO_2 or SiO_x)

- Flown on multiple silver/Teflon samples on MISSE
- If applied correctly, very durable in the space environment
- Some SiOx coatings crack due to CTE mismatch



		Control	Flight	Δ
5.5 mil silver/Teflon with SiOx MISSE-2 Ram	α	0.08	0.08	-
	ε	0.80	0.80	-
5.5 mil silver/Teflon with SiOx MISSE-2 Wake	α	0.08	0.08	-
	ε	0.80	0.80	-

Indium Tin Oxide

- Two different resistivities on aluminized Kapton flown on MISSE-7B wake side
- Negligible mass change for both samples
- Negligible conductivity change for sample with thicker ITO coating
- Also used on silver/Teflon flown on MISSE-4 ram and wake sides
- Negligible mass change for both samples
- Ram-facing sample measured 1.2 – 1.6 x 10^7 ohms/square
    - Pre-flight measurements not available
- Wake-facing sample measured 4.2 – 5.0 x 10^5 ohms/square

- **Summary**
  - **Less contamination on ram-facing optical samples than wake-facing**
  - **Some peak shifts with atomic oxygen exposure**
  - **Low-cost innovative thermal control coatings lost weight, otherwise performed well**
    - **Low-cost, low-outgassing silicone thermal control coatings indicated same performance in the space environment as S13G coatings**
  - **Boron carbide performed the best out of five different radiation shielding samples**
  - **SiOx and ITO shown to protect polymeric materials**

- **Acknowledgements**
  - **Special thanks to:**
    - **Dr. John Alred, system manager for ISS M&P**
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    - **Phil Jenkins, Rob Walters, John Vasquez, and others at the Naval Research Laboratory, Craig Lamb and Richard A. Caldwell, DoD Space Test Program, Human Spaceflight Payloads Office, and Dr. Gary Pippin and others at Boeing Research & Technology, for getting MISSE-7B off the ground.**
    - **Tim McKechnie of Plasma Processes and Elizabeth Schofield formerly of Plasma Processes for providing the radiation shielding samples**
    - **Curtis Bahr for lab support**