# Enhanced Far Ultra-Violet Optical Properties of Physical Vapor Deposited Aluminum Mirrors through Fluorination

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## INTRODUCTION

Astronomical instrumentation for measurements in the Far Ultra-Violet (FUV, 90-200 nm) typically use aluminum (Al) thin films due to their high reflectance over this wavelength range. However, the native aluminum oxide layer that forms on Al upon exposure to the atmosphere is strongly absorbing in this wavelength range, requiring that the films be protected with a dielectric that inhibits oxidation. Our team at GSFC has developed a new reactive Physical Vapor Deposition (rPVD) process that consists of a fluorination process with $XeF_2$ gas combined with our traditional PVD process. We have found that this new rPVD coating process offers a protected version of Al+LiF with a more environmentally stable and more transparent LiF layer, along with unprecedent reflectivity.

## OBJECTIVES

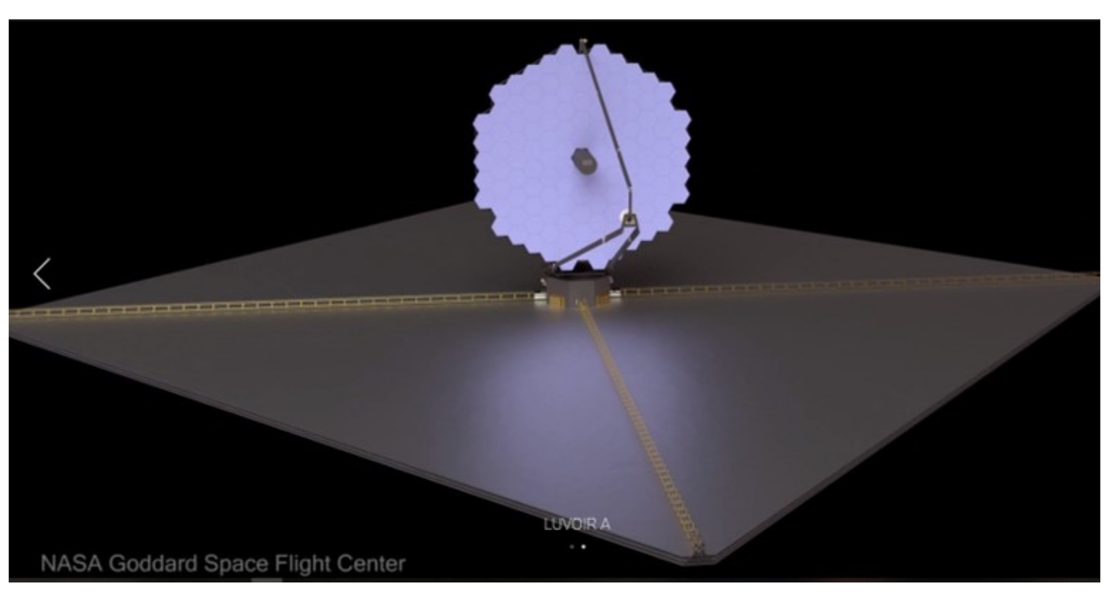
### Task Description

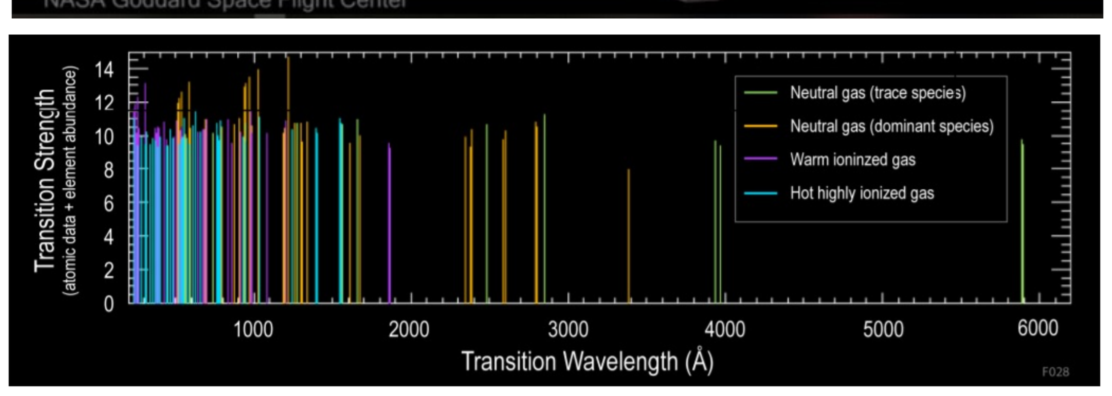
- Deposit high performance optical broadband (FUV -> IR) mirror coatings.

### Driver / Need

- Broadband coatings (90-2,500 nm) have been identified as an "Essential Goal" in the technology needs for a future Large-Aperture Ultraviolet-Optical-Infrared Space Telescope (Habitable World Observatory).

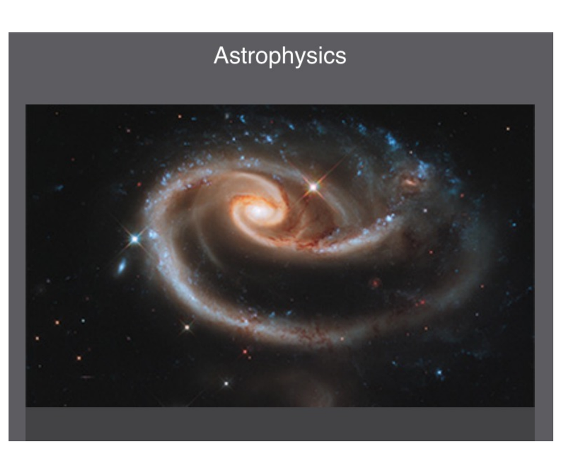
## HWO Concept Telescope

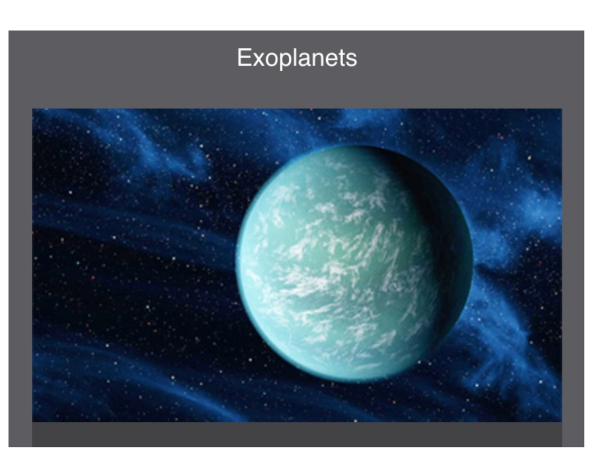



## BENEFITS

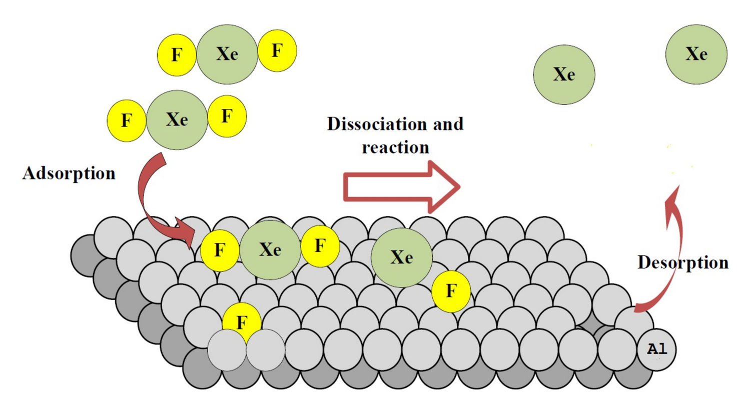
- High throughput & high signal-to-noise ratio (SNR) over a broad spectral range.
- Enabling technology for astrophysics and optical exoplanet sciences (in shared platform).




## EXPERIMENTAL DETAILS

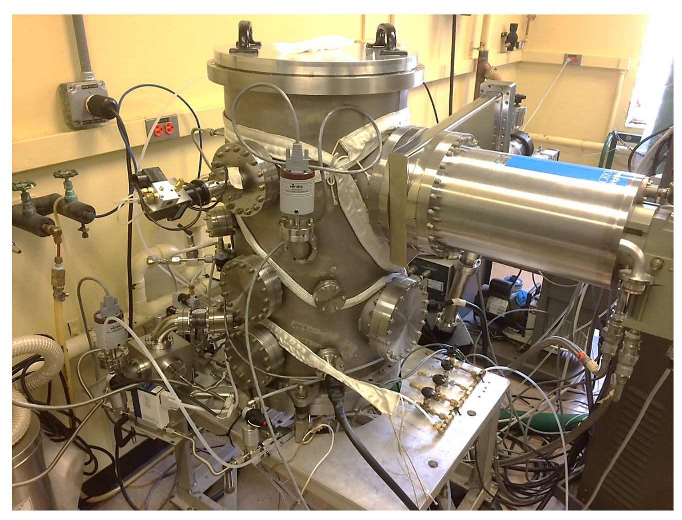
### Hybrid PVD Passivation/Fluorination



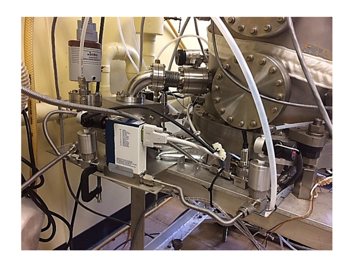

Reactive fluorine compound with low bond energy used (e.g., $XeF_2$ with 133.9 kJ/Mole).

Heating of the $XeF_2$ may also be used if compound is not sufficiently reactive for increased selectivity.

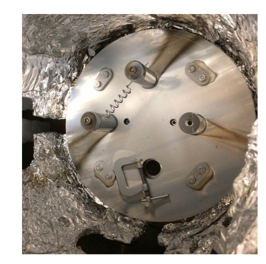
### GSFC Research Coating Chamber



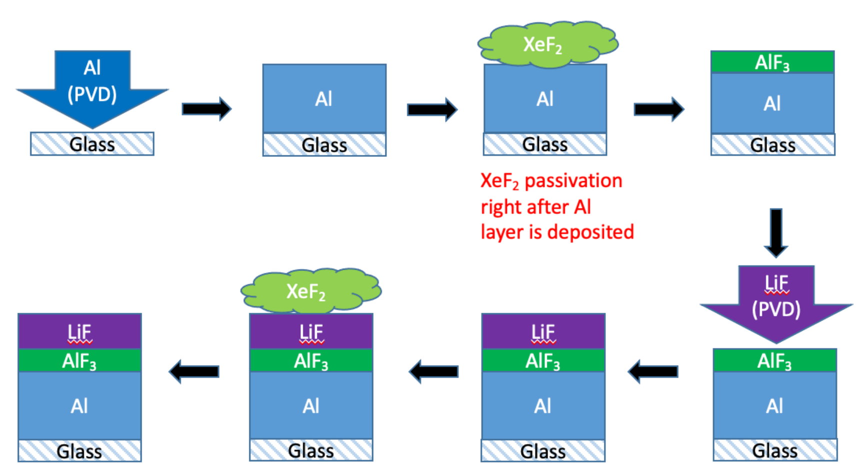
UHV Research Chamber capable of thin film physical vapor deposition (PVD).



$XeF_2$ Gas feed components capable of continuous flow or pulsed flow.

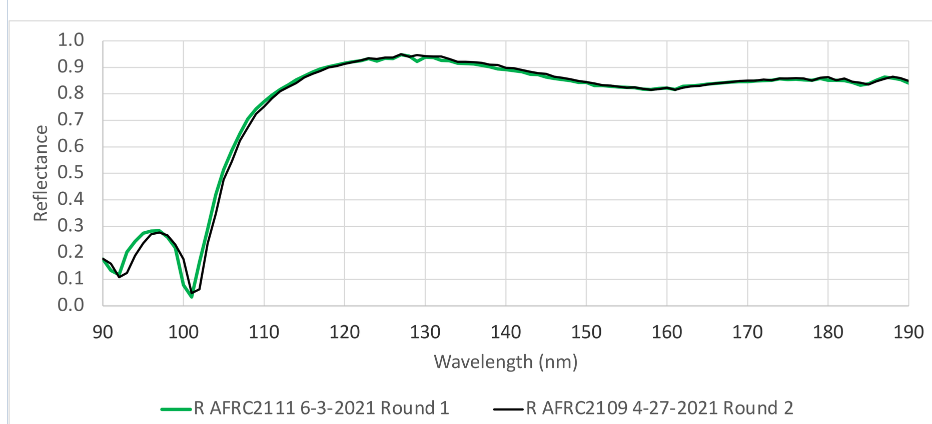


Inside of chamber PVD components.

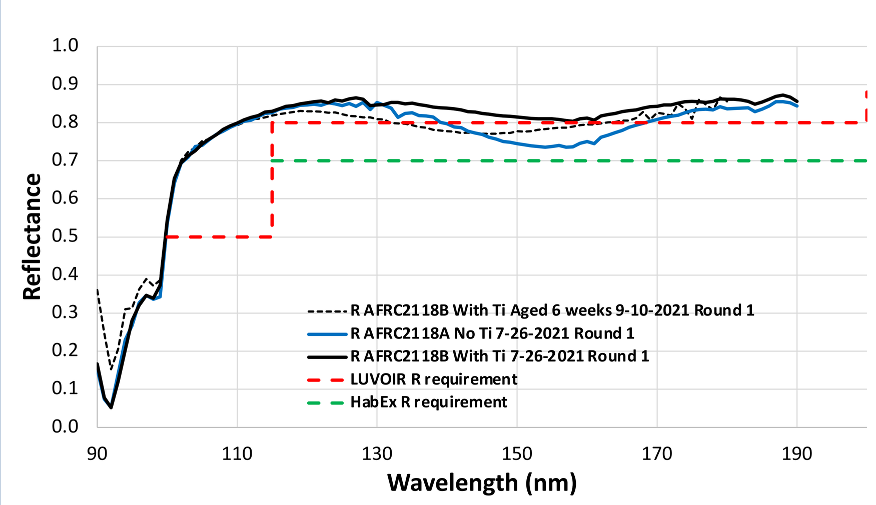



Steps for the reactive Physical Vapor Deposition (rPVD).

### FUV Reflectance Results: Al+LiF



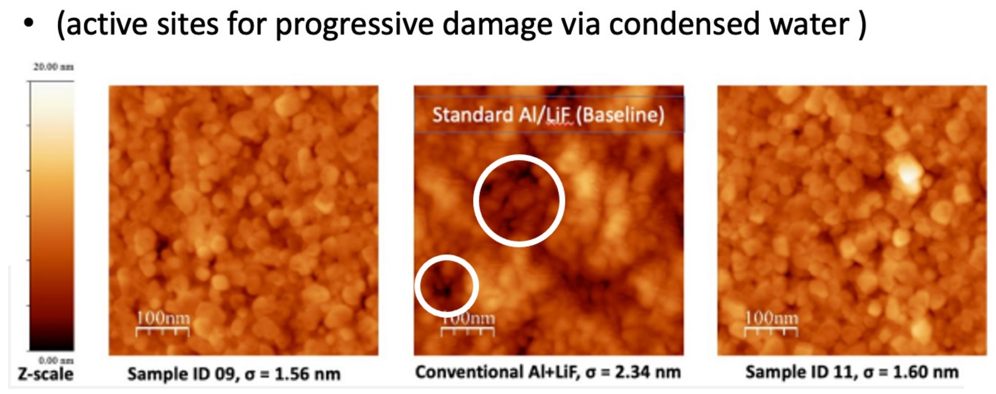

Highest %R at H Lyman-alpha ever reported for Al+LiF!




State-of-the-art reflectance performance of Al+LiF mirror coatings in the FUV spectral region.

### Atomic Force Microscopic

- Exceptionally smooth surfaces → few pores
- Capillary theory- pores pull in condensable vapors.
- (active sites for progressive damage via condensed water )




## RESULTS: $XeF_2$-passivated Al

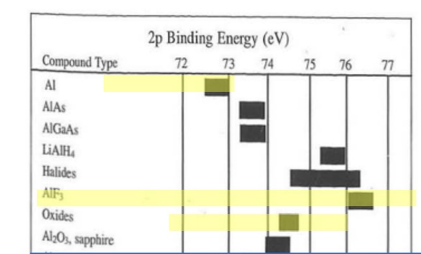
### Approach:

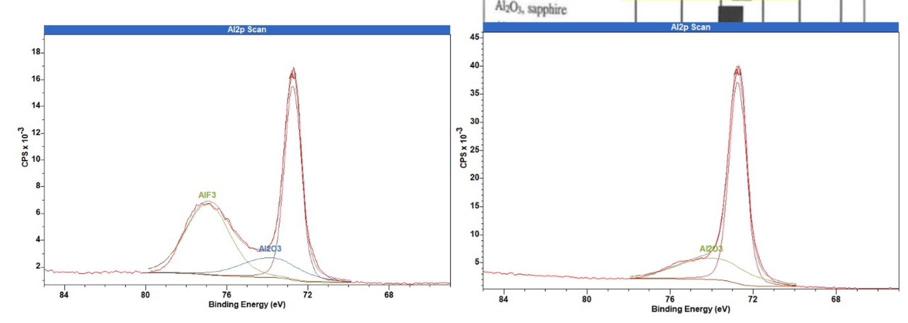
- A series of samples ($XeF_2$-passivated bare Al) were prepared (using the smaller 0.5 m research chamber at GSFC)
- Stored in various conditions
  - Ultradry (0 by hygrometer) and lab conditions)
  - Film is thin and likely unstable
- Focus on surface changes
  - AFM
  - XPS
  - Spectroscopic ellipsometry
  - SEM

| Temperature | Relative Humidity |
|---|---|
| 60°C | 0% |
| 3°C | 26% |
| 20°C | 0% |
| 20°C | 30% |

### XPS

- $Al_2O_3$ forms within probe depth of $AlF_3$ surface
- Next, sputter off the $AlF_3$ layer
- $Al_2O_3$ is present on/in Al



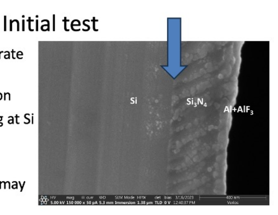

### $XeF_2$-Etching of Si

- **$XeF_2$ is a known etchant of Si**
- **1-2 μm/min for isotropic etching**
- **GSFC rPVD process has 6 min $XeF_2$ exposure**
- **Why is this Important?**
  - Si diffraction gratings (made with e-beam lithography)

SEM Images

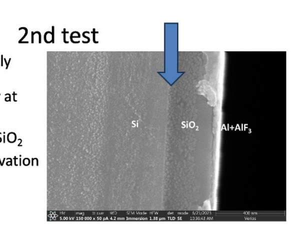
Initial test

- CVD $Si_3N_4$ layer for separate tests
- 3-minute $XeF_2$ passivation
- Looking for undercutting at Si interface
- None observed
- Conclusion: Native $SiO_2$ may sufficiently protect

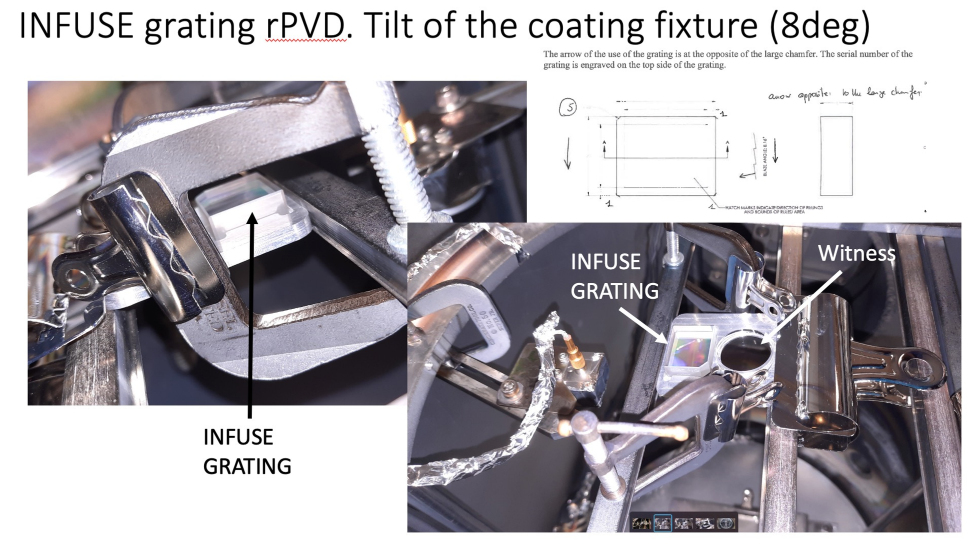


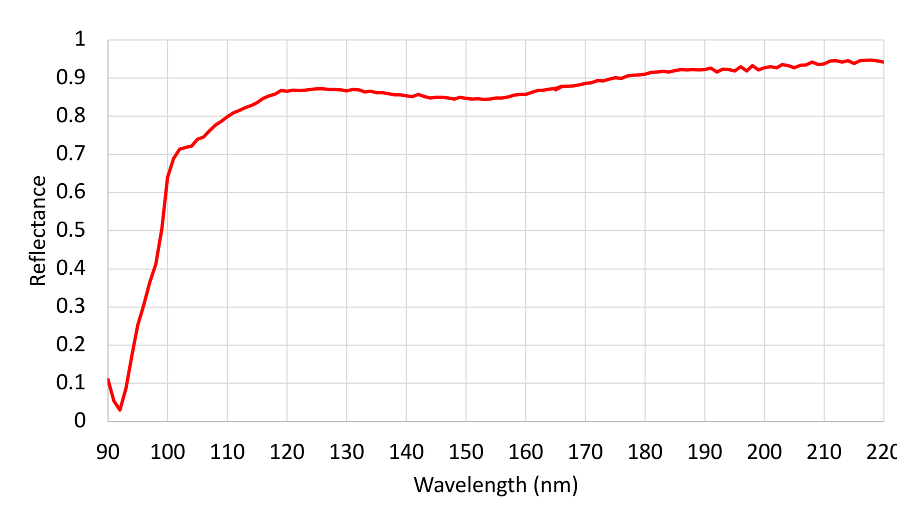

2nd test

- Wafer cleaved directly before mounting in deposition chamber at GSFC.
- Minimal amount of $SiO_2$
- Full 6 min $XeF_2$ passivation




INFUSE grating rPVD. Tilt of the coating fixture (8deg)




The FUV reflectance curve for a test witness (shown in the picture above) after the application of the Al+LiF by using the rPVD coating process.

## Conclusions

- Passivated layer of $Al+AlF_3$ is very smooth (~0.8 nm RMS)
- Smoothness in $AlF_3$ is advantage will not translate to additional layers
- No significant change after 5 months
  - When samples were exposed to moderate Relative levels
- The application of the rPVD coating on the grating for the INFUSE sounding rocket program (PI: Brian Fleming U. of CO) would permit TRL advancement of this emerging coating technology

## Acknowledgement

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