Emerging Coating Technologies for Realizing High-Reflectance and Stable Mirror Coatings for Observations in the Far Ultra-violet

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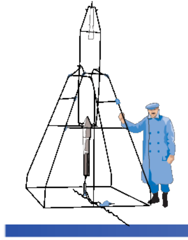
Outline

- Objectives and Goals
- Plasma-based e-Beam Treatment (LAPPS at NRL)
- Reactive PVD/XeF_2 Fluorination (GSFC)
- Broad-Band Reflectance & TRL Comparison
- Conclusions



Broad-band (90 nm – 3 µm) High Reflectance Mirrors for Next Generation Space – Based Telescopes

Task Description

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

- **Fluorination/passivation of Al-based coatings.**
- Atomic Layer Deposition (ALD) layers of AlF_3.
- Ion assisted depositions for low-absorption metal-fluoride to protect Al mirrors.

Driver / Need

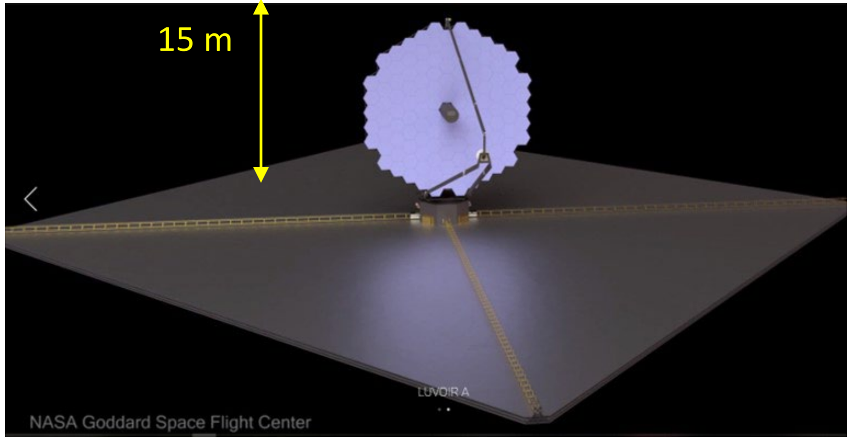
Broadband coatings (90-2,500 nm) have been identified as an "Essential Goal" in the technology needs for a future Large-Aperture Ultraviolet-Optical-Infrared Space Telescope (LUVOIR and HabEx).

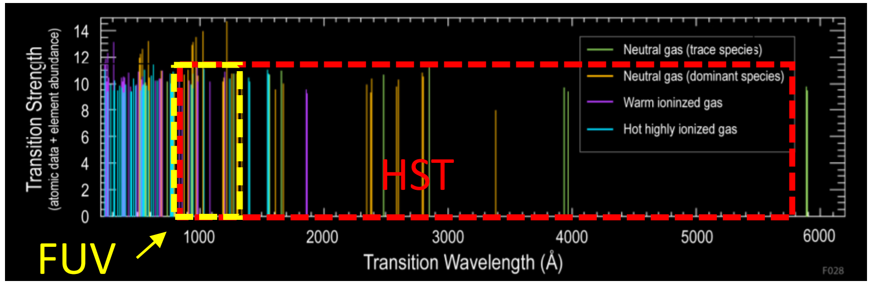
Benefits

High throughput & high signal-to-noise ratio (SNR) over a broad spectral range.

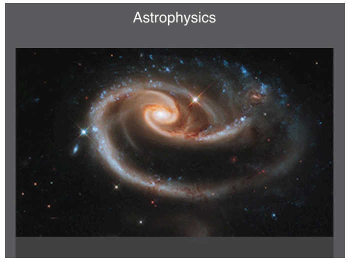
Enabling technology for astrophysics and optical exoplanet sciences (in shared platform).

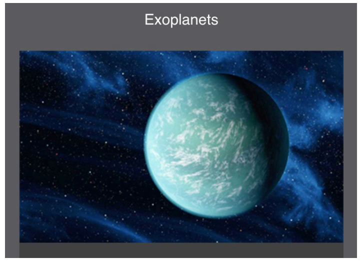
HWO Concept Telescope





(HST = Hubble Space Telescope)

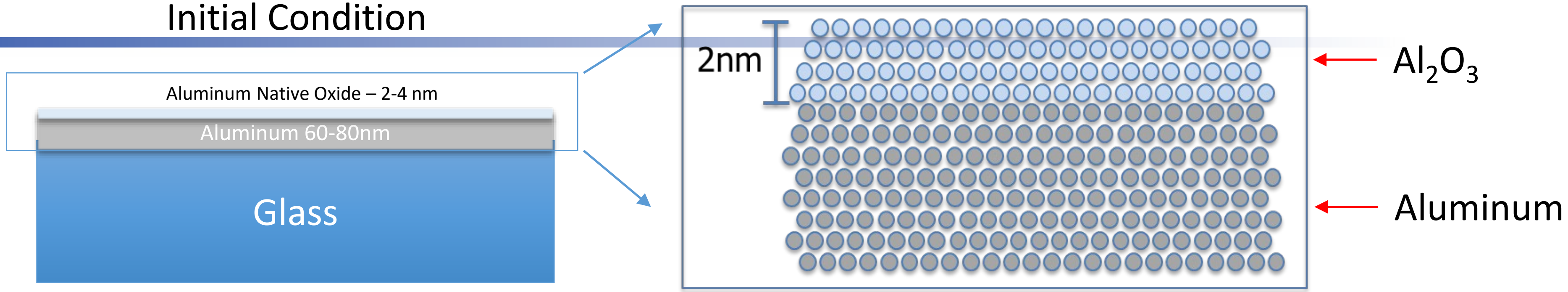




The LUVOIR Final Report (https://asd.gsfc.nasa.gov/luvoir/reports/LUVOIR_FinalReport_2019-08-26.pdf)

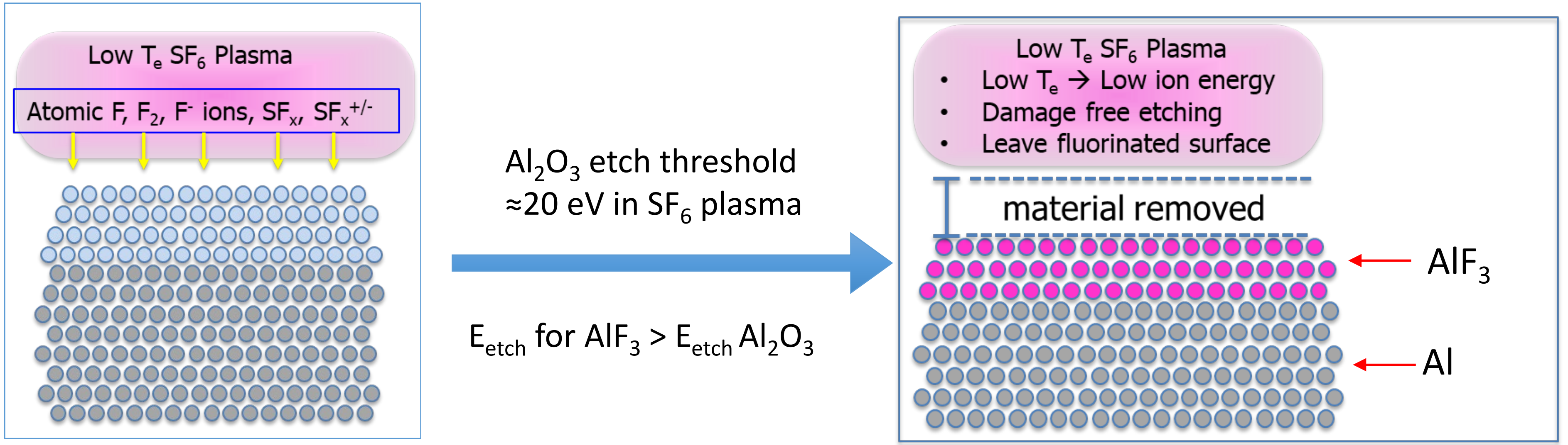
Approach: Using Low T_e Plasmas to Remove Oxide and Passivate Al surface with Fluorine

Initial Condition



Plasma Treatment

Final Condition



- Low T_e → Low ion energy
- Damage free etching
- Leave fluorinated surface

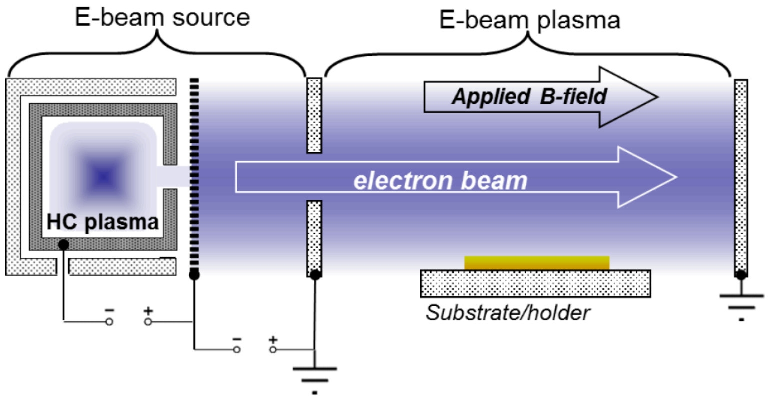
Al_2O_3 etch threshold ≈20 eV in SF_6 plasma

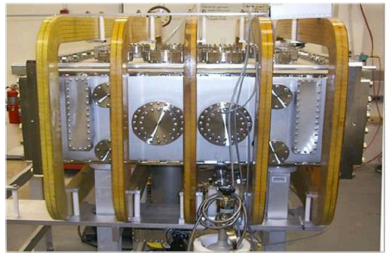
E_{etch} for AlF_3 > E_{etch} Al_2O_3

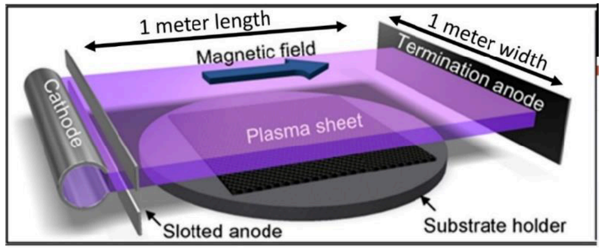
Approach: Using Ultra-Low T_e Plasmas to Remove Oxide and Passivate Al surface with Fluorine

LAPPS: Large Area Plasma Processing System

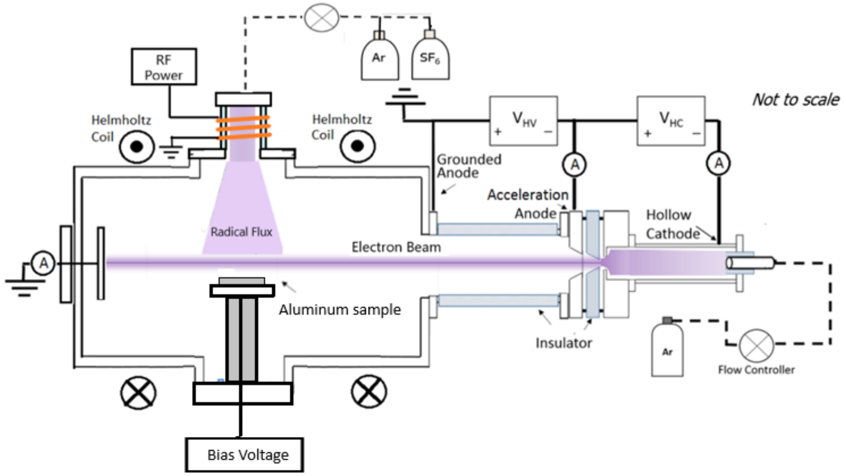
A processing system based on electron beam generated plasma







Radical Source: Inductively Coupled Plasma (ICP)



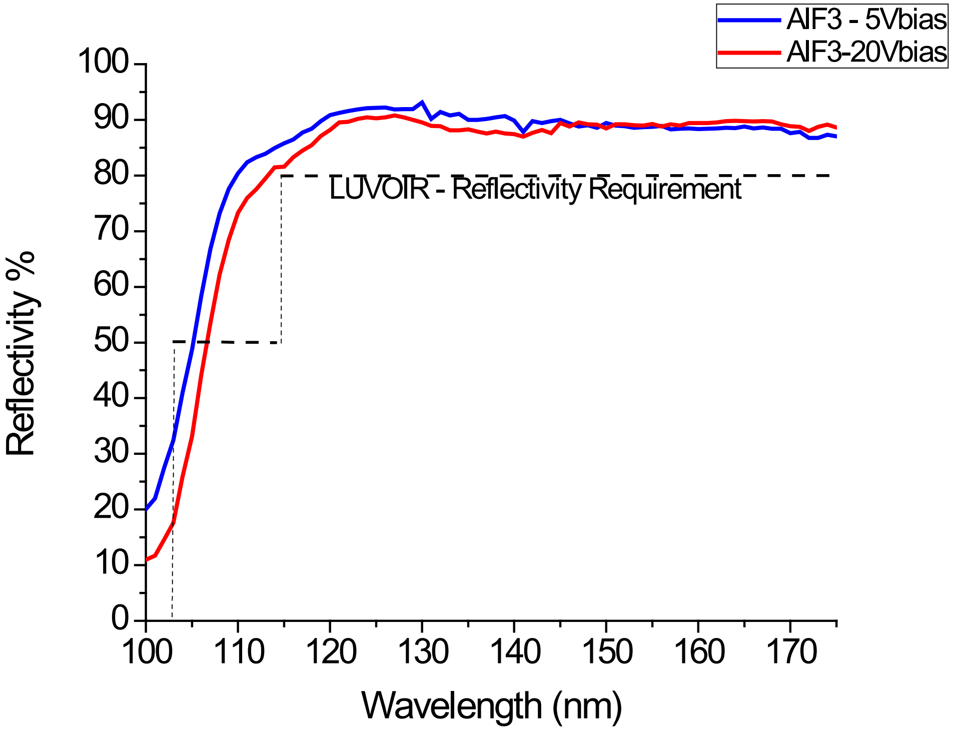
Basic Operation

- High-energy (~ keV) beam injected into background to drive plasma production
- ***Easily scaled to large area processing***
- Advantageous plasma properties
  - Easily controlled species production
  - Low electron temperature (T_e) plasma (<1 eV) → Low ion energy (<5 eV) → Low/No Damage

R.A. Meger et al., US patent no. 5,874,807 (Feb. 1999)
S.G. Walton et al., ECS Journal of Solid State Science and Technology, 4(6) N5033-N5040 (2015)

Low ion energy shows ability to grow high quality fluoride films

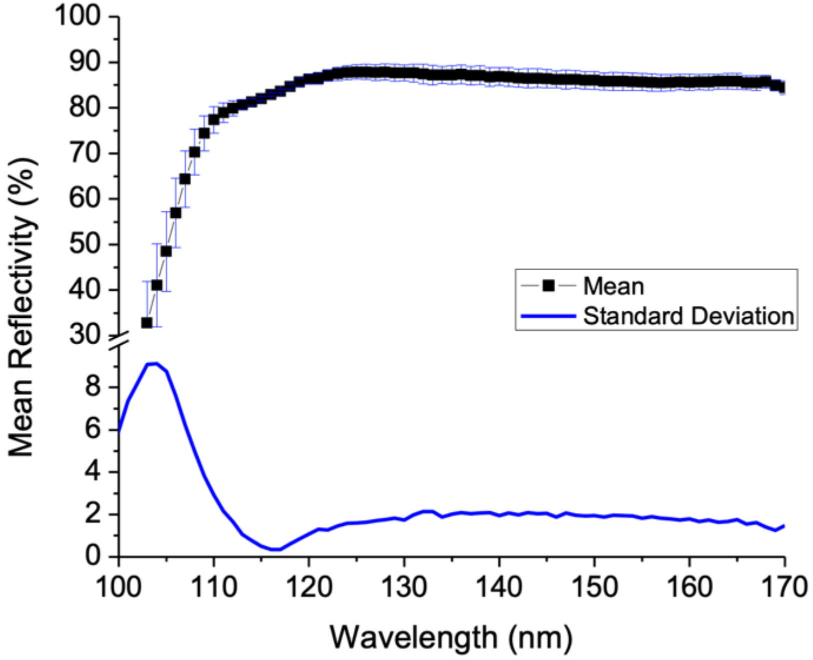
- Low ion energy processing capability → excellent reflectivity
- Demonstrates ability to grow fluoride coating without surface roughening or affecting underlying Al layer.



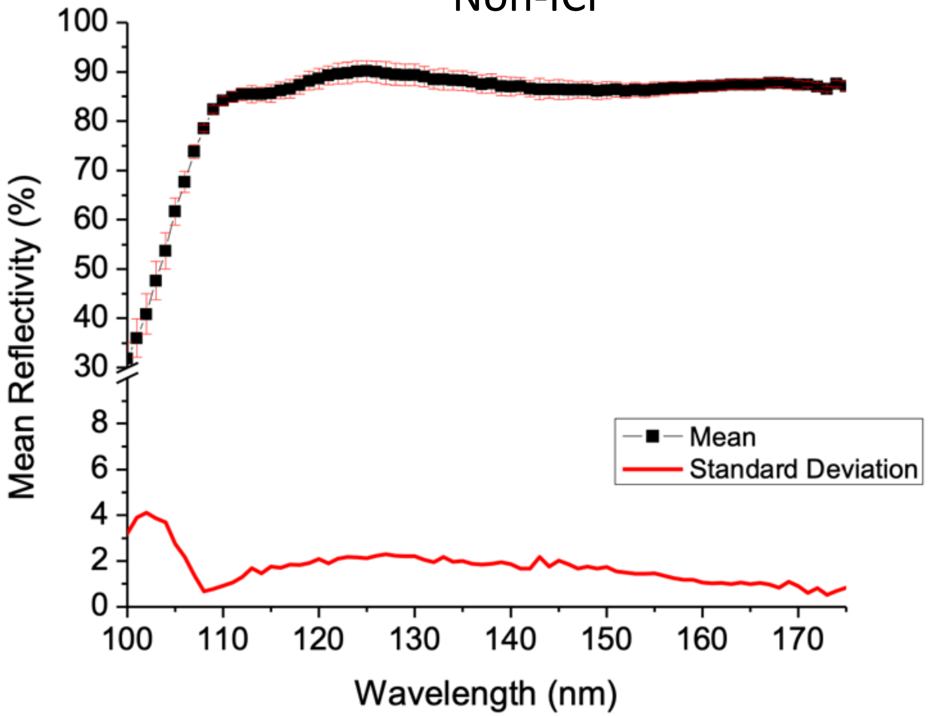
June 10, 2011

Uniformity Tests: ICP *vs.* Non-ICP (FUV)

ICP



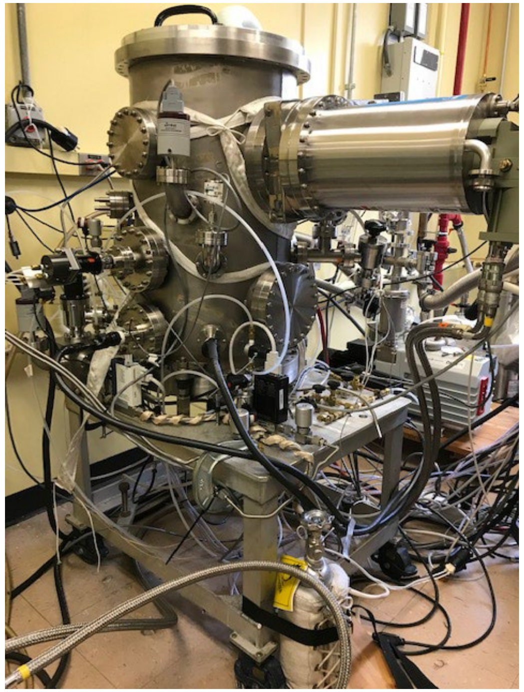
Non-ICP



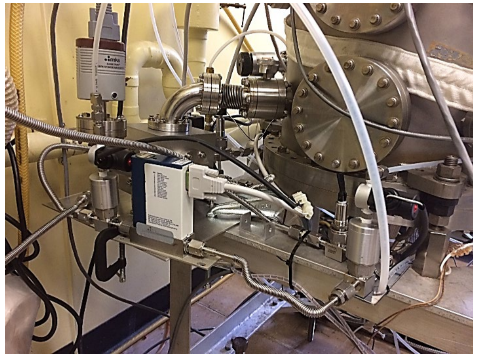
- The FUV reflectance displays a peak value close to 90% at Lyman-Alpha
- Excellent uniformity (standard deviation among 5 samples is < 0.20 %) over 115-180 nm
- 5 eV case had best reflectivity characteristics.

- Surface roughness does not seem to be significantly affected by ion energy.

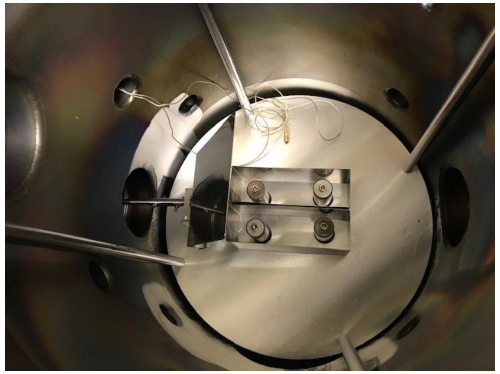
Research Coating Chamber Capabilities



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



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

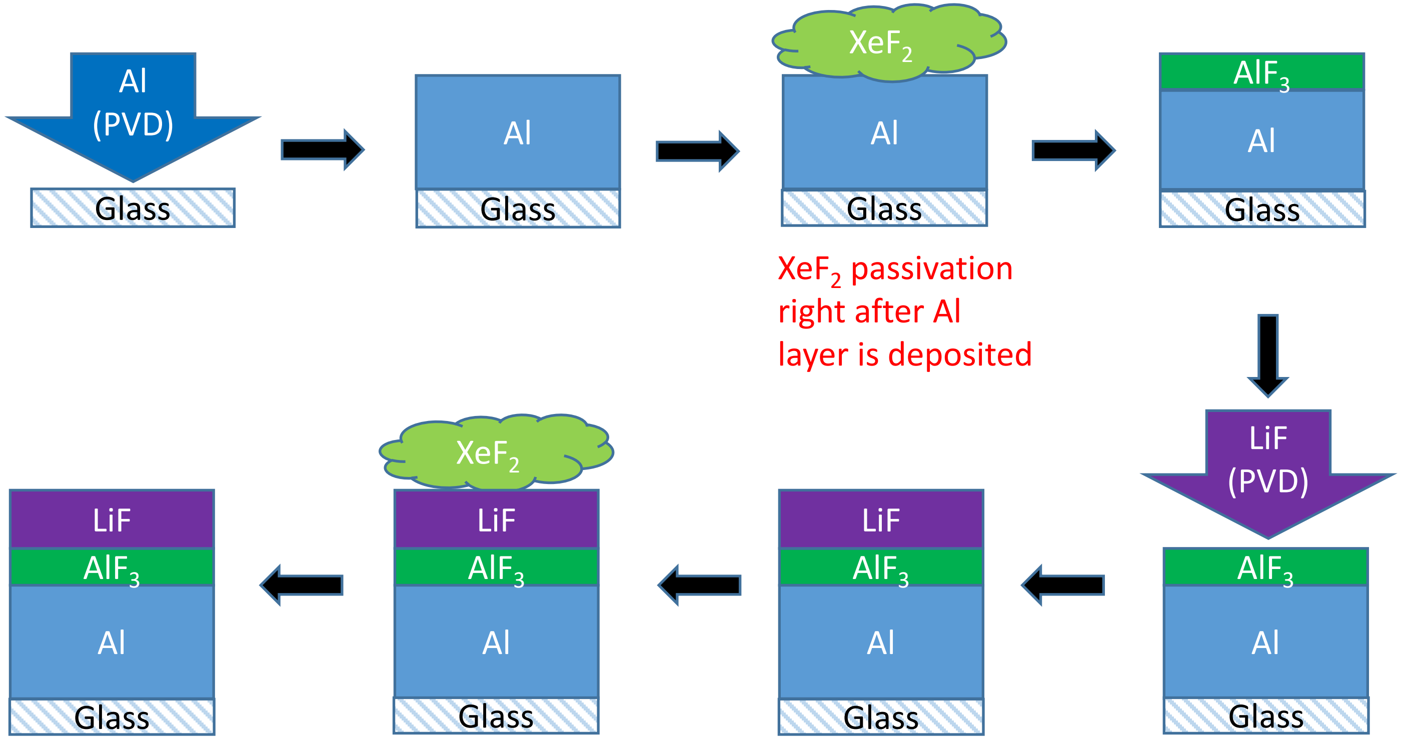


Inside view of RC with 2-material PVD deposition system.

R&D for combined PVD & fluorination of Al-based high performance FUV coatings.

Chamber is in operation and experimentations on producing various schemes of fluorination are on-going

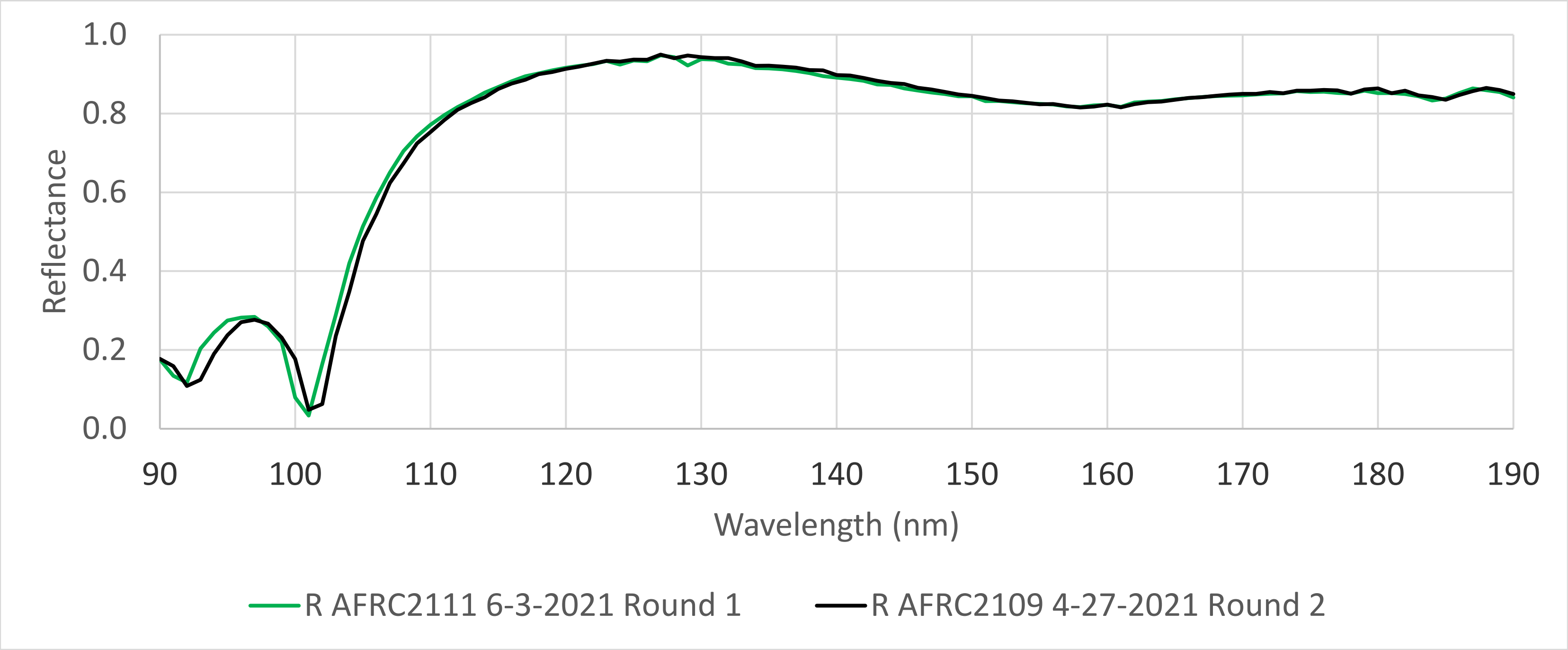
Reactive Physical Vapor Deposition (rPVD)



XeF_2 passivation
right after Al
layer is deposited

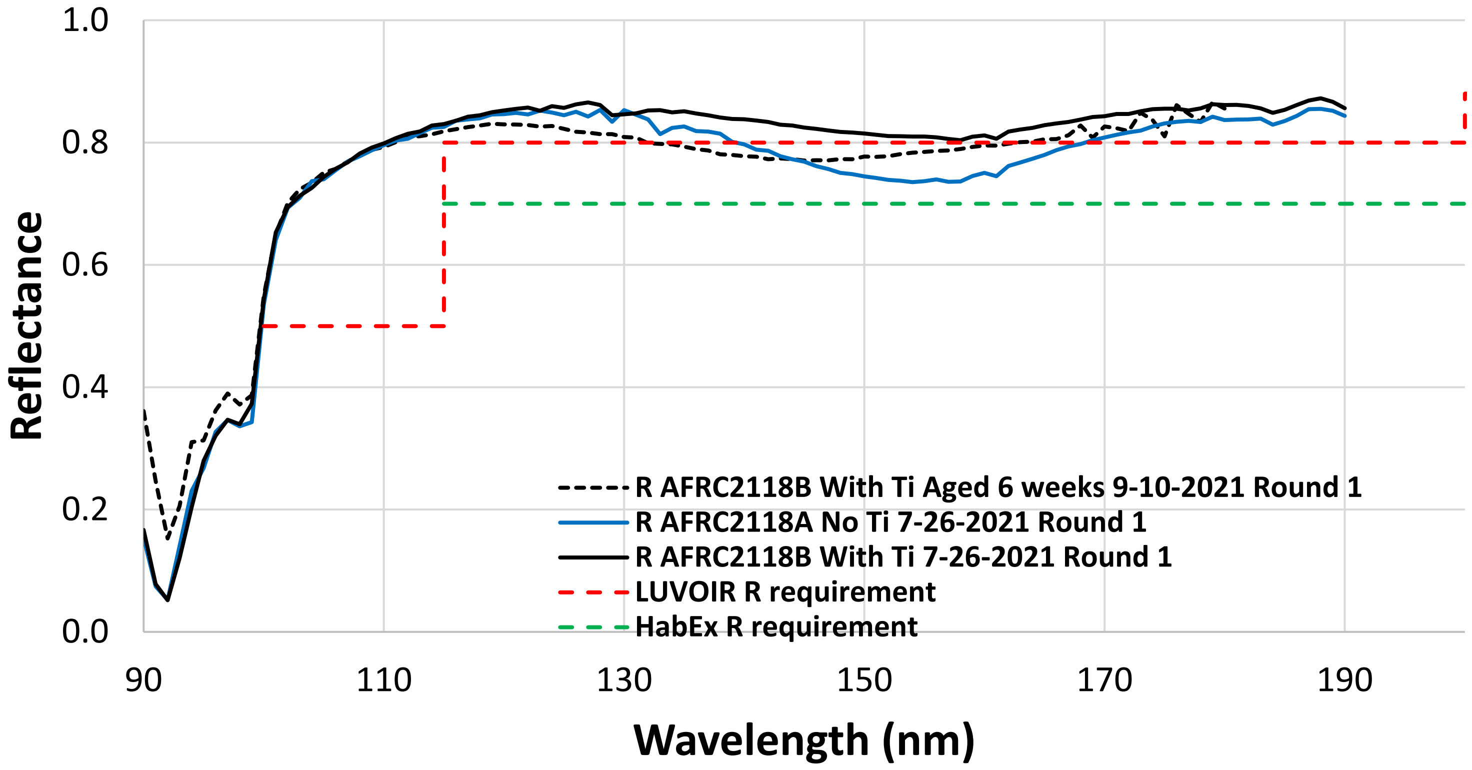
Reflectance Result rPVD: Al+LiF

Highest R at H Lyman-alpha **ever reported** ☺

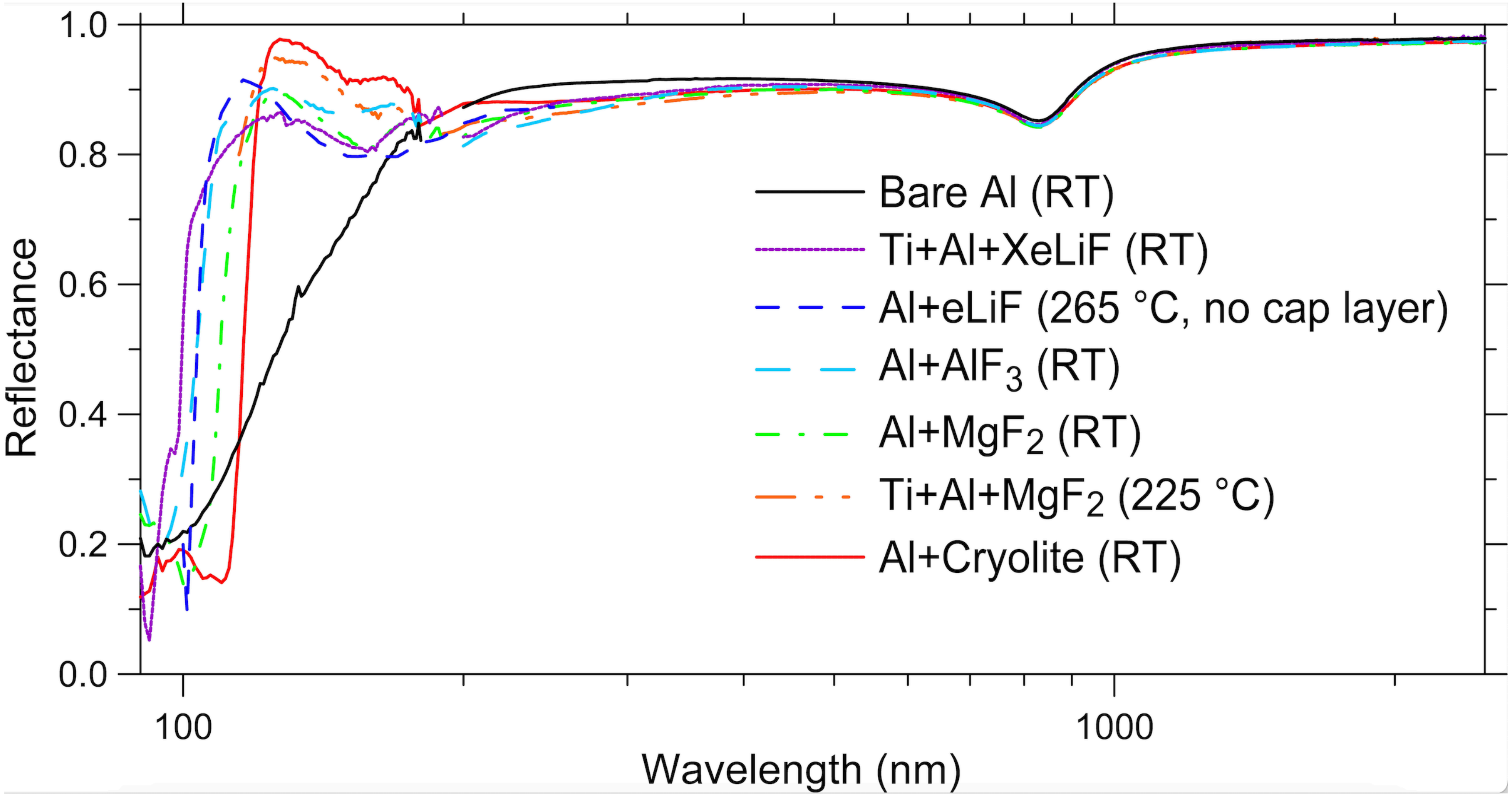


Technical Targets

- R data of mirrors with and without Ti seed layer meeting HabEx and LUVOIR R requirements



Broadband Reflectance



Comparison Various Coating Technologies

Coating Technology	Coating Properties						
	λ Value @ R>60%	TRL	Largest Optics Coated	Elevated Substrate Temperatures Required?	Max. Relative Humidity for Coating Stability	Dielectric Layer Deposition Process	µ-roughness
Bare Al	>150 nm	6	> 1 meter	No	~70-100%	-	~0.78 nm
Al+MgF_2	>111 nm	6	> 1 meter	No	~70%	PVD	~1.84 nm
Al+LiF	>101 nm	6	~0.5 meter	No	< 30%	PVD	Fresh 1.5-2.5 nm Aged >3 nm
Al+eLiF+MgF_2	>102 nm	~5-6	~ 0.3 meter	Yes	~60 %	eLiF (PVD) MgF_2 (ALD)	1.5-2.5 nm
Al+AlF_3 (e-beam)	>105 nm	~4	5x5 cm^2	No	~60%	E-beam Plasma	~0.81 nm
Al+XeLiF	>103 nm	~3	5x5 cm^2	No	~60%	Reactive PVD	~1-1.5 nm

Conclusions

- The Large Area Plasma Processing System at NRL has demonstrated oxide removal and fluorine passivation of Al mirrors **over 6” diameter area**
  - 15 nm – 25 nm thick AlF_3 optical coatings
  - Reflectivity approaching specs for next generation space telescope mirrors
    - <R>(100-200nm) = 81%
    - <R>(120 – 3000nm) = 93%
  - Demonstrated control of FUV reflectance properties of Al with a metal fluoride overcoat (MgF_2, AlF_3) by varying ion energy, radical density, and plasma exposure time.
  - Verification of reflectance uniformity, environmental stability, microroughness and polarization characterization has been demonstrated to be at TRL 4.
- A second coating technology (XeLiF), which involves passivation with a fluorine containing precursor (XeF_2) gas is showing promising reflectance in the FUV.
- The surface XeF_2 passivated Al does not show (via AFM) significant changes in low to moderate humidity even after months in nominal lab conditions.

Acknowledgments

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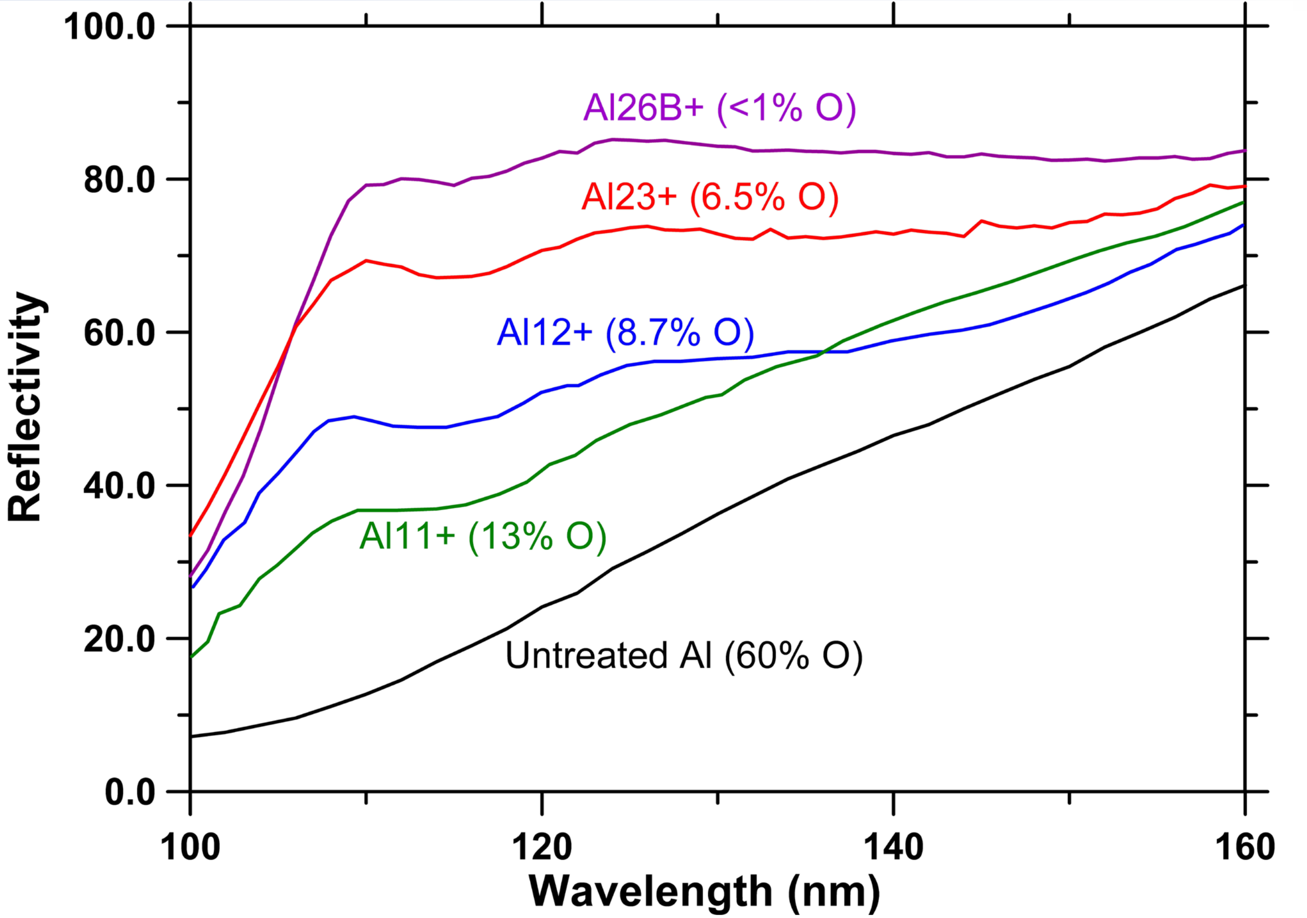
Backup Slides

TRL 3 Validation: FUV Reflectance versus O_2 Content



FUV Reflectance for Ebeam + Radical Source Treatments with varying treatment time and varying ion energy
- **Correlating XPS results with process conditions seems hint at two possible trends**
- **First – increased ion energy led to slightly higher oxygen content**
- **Second – longer exposure time led to slightly higher oxygen content**
- **Overall – higher oxygen content was correlated with decreased FUV reflectivity**

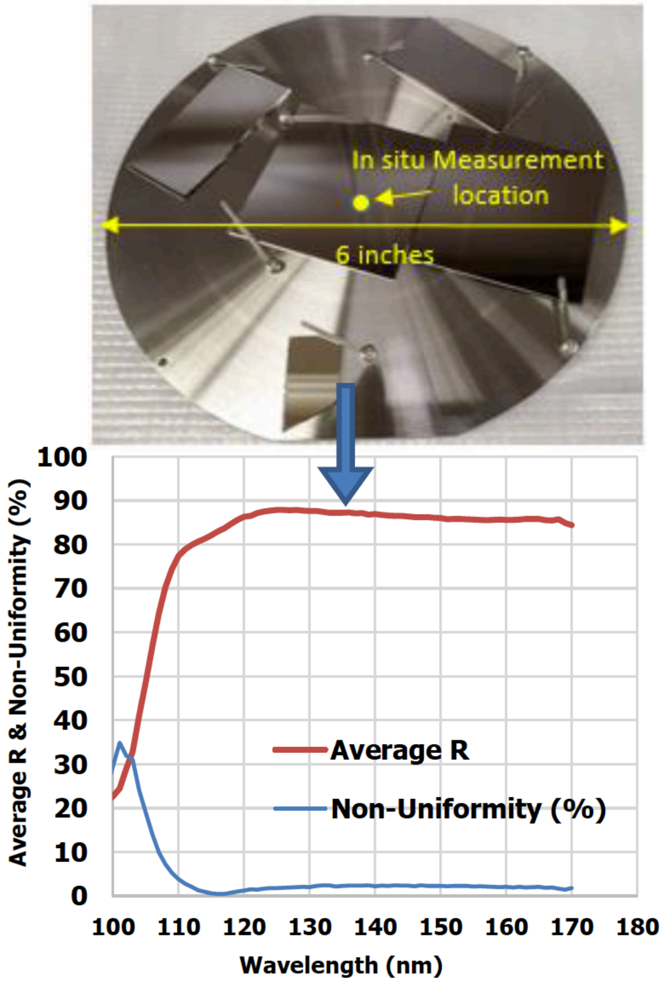
Uniformity Performance Large Area Growth in 6” LAPPS Reactor

Uniformity across 6” substrate holder:

- Target thickness 25 nm
- 5 samples treated simultaneously
- Real time monitoring of center sample
- Post treatment reflectivity analysis of all samples
- Post treatment ellipsometry mapping of fluoride thickness for all samples.

Ex situ ellipsometry mapping results

Sample	Chamber location	Average thickness
Al8A	top	24.6 ± 1.37 nm
Al5	middle	25.5 ± 1.74 nm
Al6	right	23.9 ± 2.54 nm
Al7	left	22.1 ± 0.59 nm
ECA1	bottom	24.9 ± 1.37 nm



Top: Sample configuration for the uniformity test. Bottom: Mean reflectance (red) and R non-uniformity (blue) from 6” sample array.

UV/Vis/NIR Polarized Reflectance