FUV to NIR Mirror Coatings Development

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Outline

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4. Initial Results
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COR Program Directions

- The NASA Cosmic Origins Program Annual Technology Report (COR Technology Needs, Table 7, Item 8.1.3., page 43, Oct 2011) defined the primary goal:

  - ***“Development of UV coatings with high reflectivity (>90-95%), high uniformity (<1-0.1%), and wide bandpasses (~100 nm to 300-1000 nm)”.***

- ATLAST and Exoplanet programs emphasize this need, urgency and challenges.

Project Goals

Oxidation of Al mirror surface causes absorption of UV photons thus degrading mirror reflectivity in the UV.

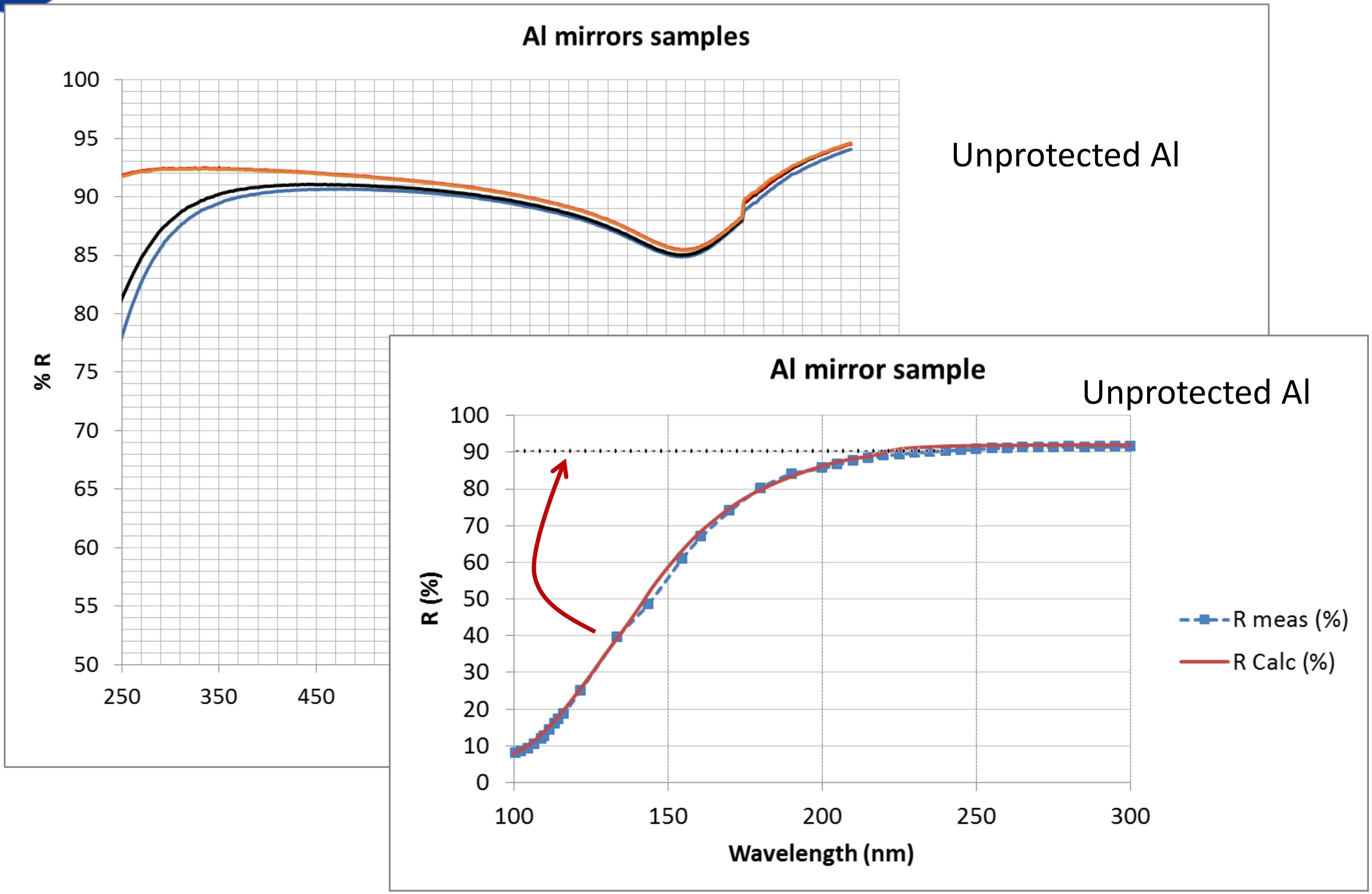
Therefore:

- Identify and develop ***void-free thin films of absorption-free materials*** to protect and maintain high reflectivity and durability of aluminum mirrors in laboratory and pre-launch environments.

- Develop precisely ***controllable and scalable deposition processes*** to produce such coatings on large telescope mirrors.

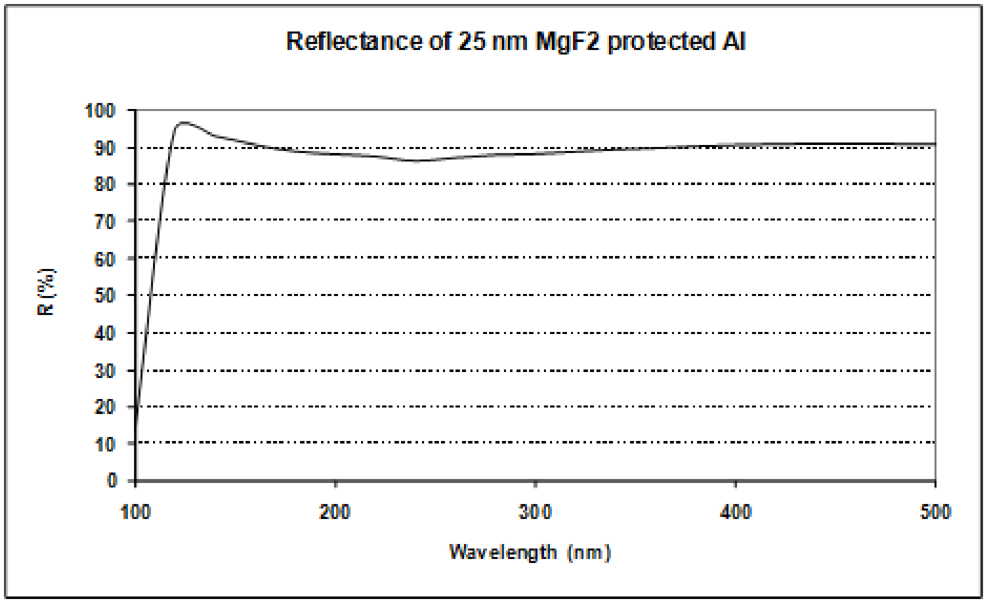
- Desired Performance goals: ***R > 90% over 100 to 1000nm***

Context


Al mirrors samples
100
95
90
85
80
75
70
65
60
55
50
% R
250
350
450
Unprotected Al
Al mirror sample
Unprotected Al
100
90
80
70
60
50
40
30
20
10
0
R (%)
100
150
200
250
300
Wavelength (nm)
R meas (%)
R Calc (%)

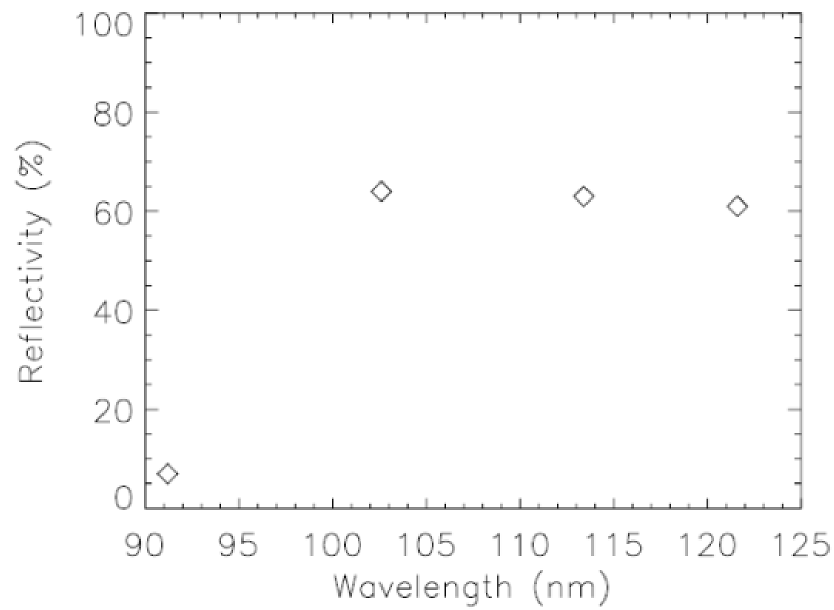
Historical Background

Hubble Telescope MgF_2 coated Al mirror >115nm through visible wavelengths



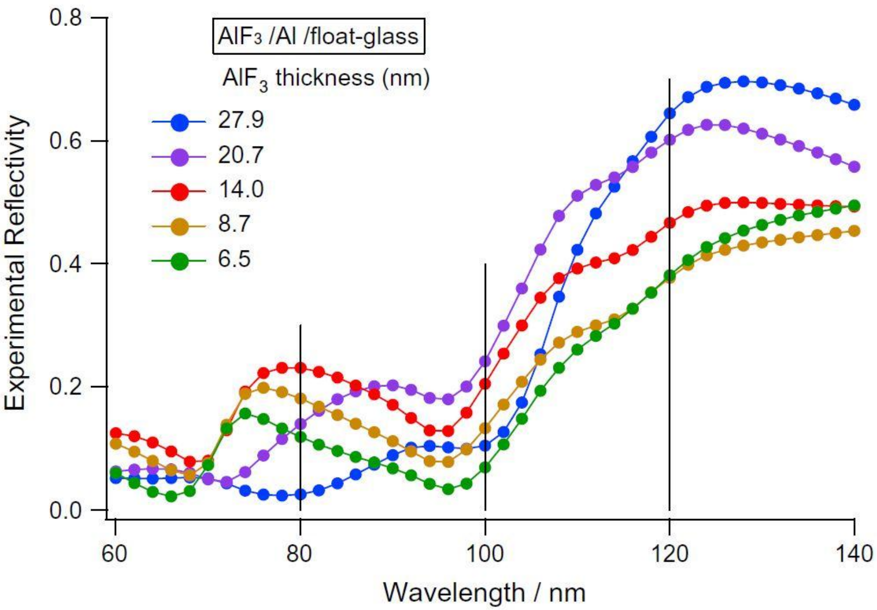
MgF_2 protected Al (calculated with optical constants from literature)

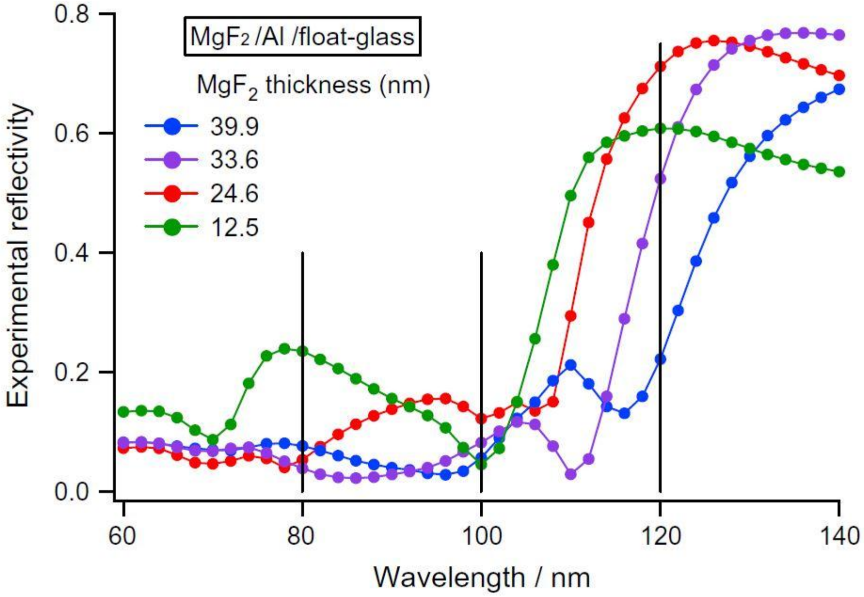
FUSE (Far Ultraviolet Spectroscopic Explorer)



LiF protected Al mirror reflectivity (adopted from Oliveira, et al., Proc SPIE, Vol.3765 (1999)).

MgF_2 and AlF_3 on Al





AlF_3/Al coating reflectivity in the DUV [Bridou, et al., (2010)]

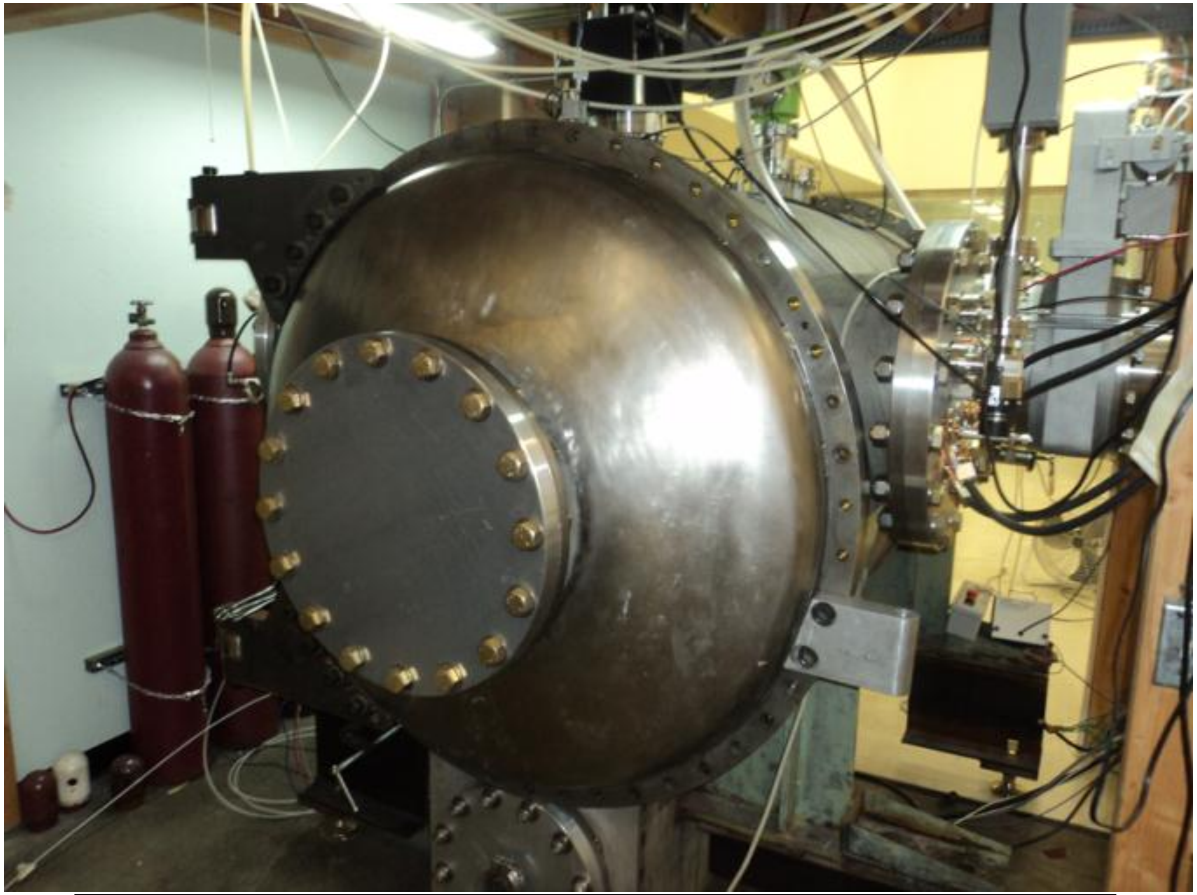
MgF_2/Al coating reflectivity in the DUV [Bridou, et al., (2010)]

Candidate Materials

Several fluorides: CaF_2, LiF, MgF_2, LaF_3, AlF_3, LuF_2, Na_3AlF_6, YbF_3 and GdF_3

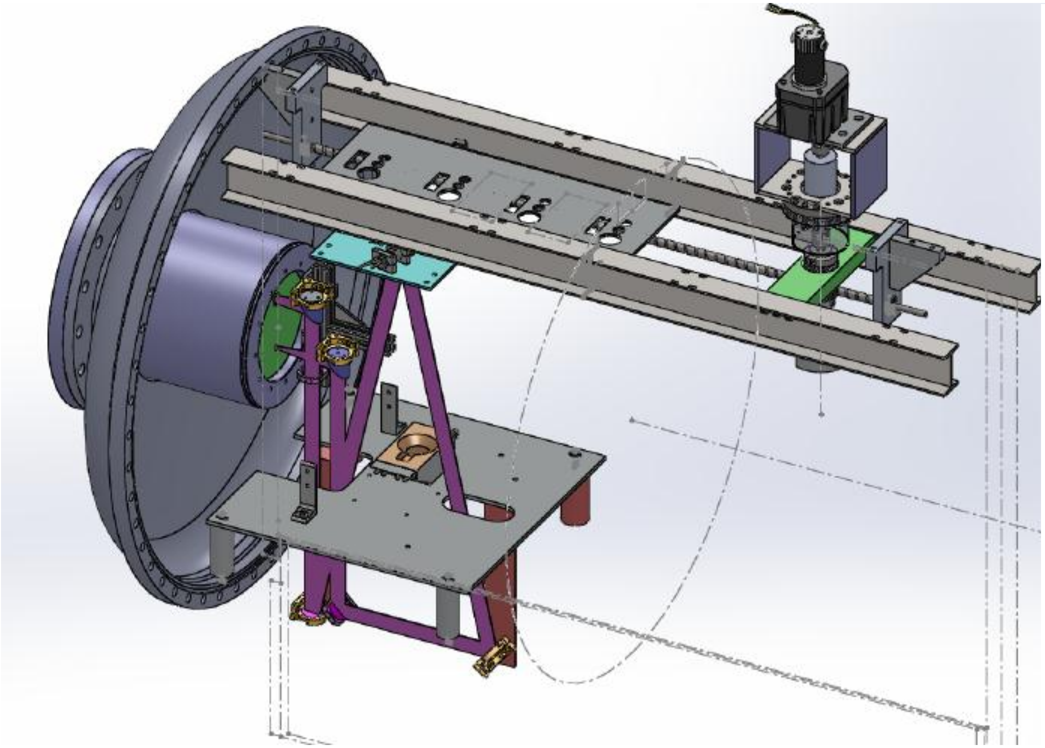
- Produced single layer coatings of MgF_2, LiF, AlF_3, LaF_3, Na_3AlF_6 and GdF_3 with conventional thermal evaporation at pressures in the range of $5x10^{-7}$ to $1x10^{-6}$ Torr and temperatures in the range of 180 to 200C.
- Preliminary double layer (LiF+AlF_3) and (LiF+MgF_2) protected Al mirror samples by conventional evaporation process
- Preliminary MgF_2 protected Al mirror samples by ALD process

Coating Chamber

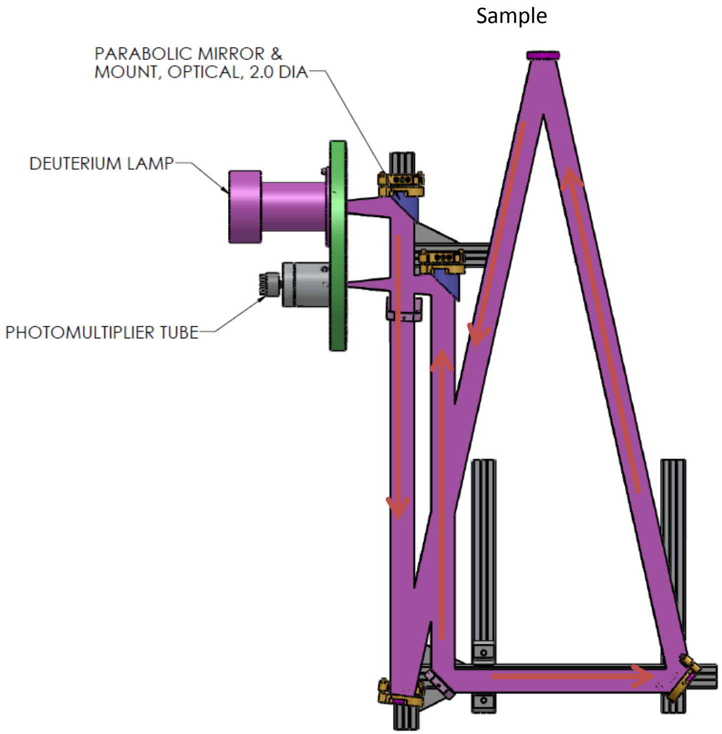


A 1.2 meter coating chamber fitted with process controllers, thickness monitor and gas analyzer. (courtesy: Zecoat Corp)

Chamber Enhancements

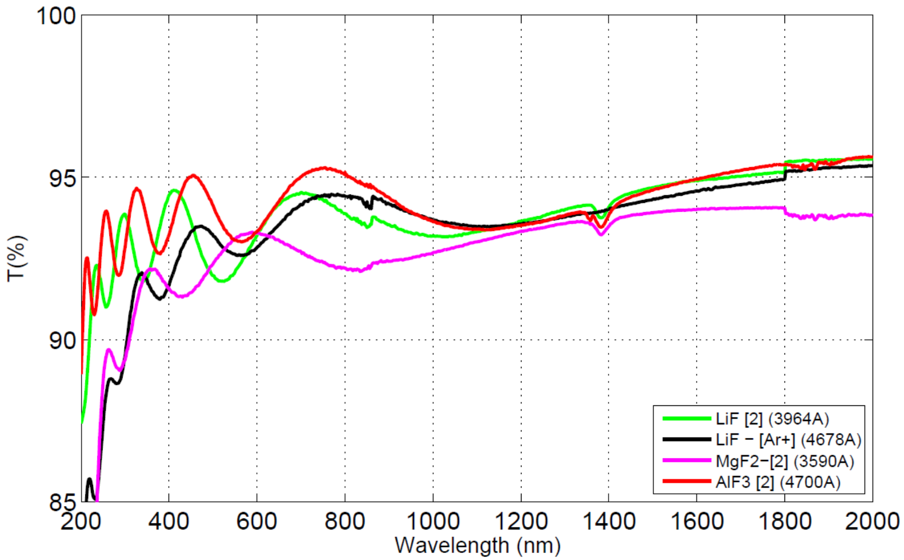


Upgrades to the coating chamber fitted with FUV optical monitoring system and sample transport cum masking mechanism to enable multiple coatings without breaking vacuum. (courtesy: Zecoat Corp.)

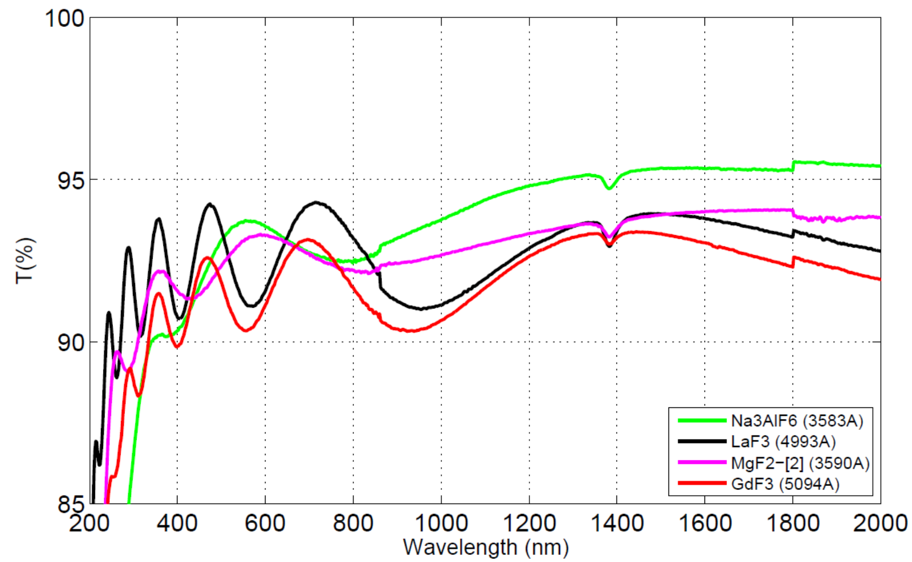


FUV reflectometer system inside the coating chamber for *in situ* diagnostics of the growing film. (courtesy: Zecoat Corp.)

Single layer coatings

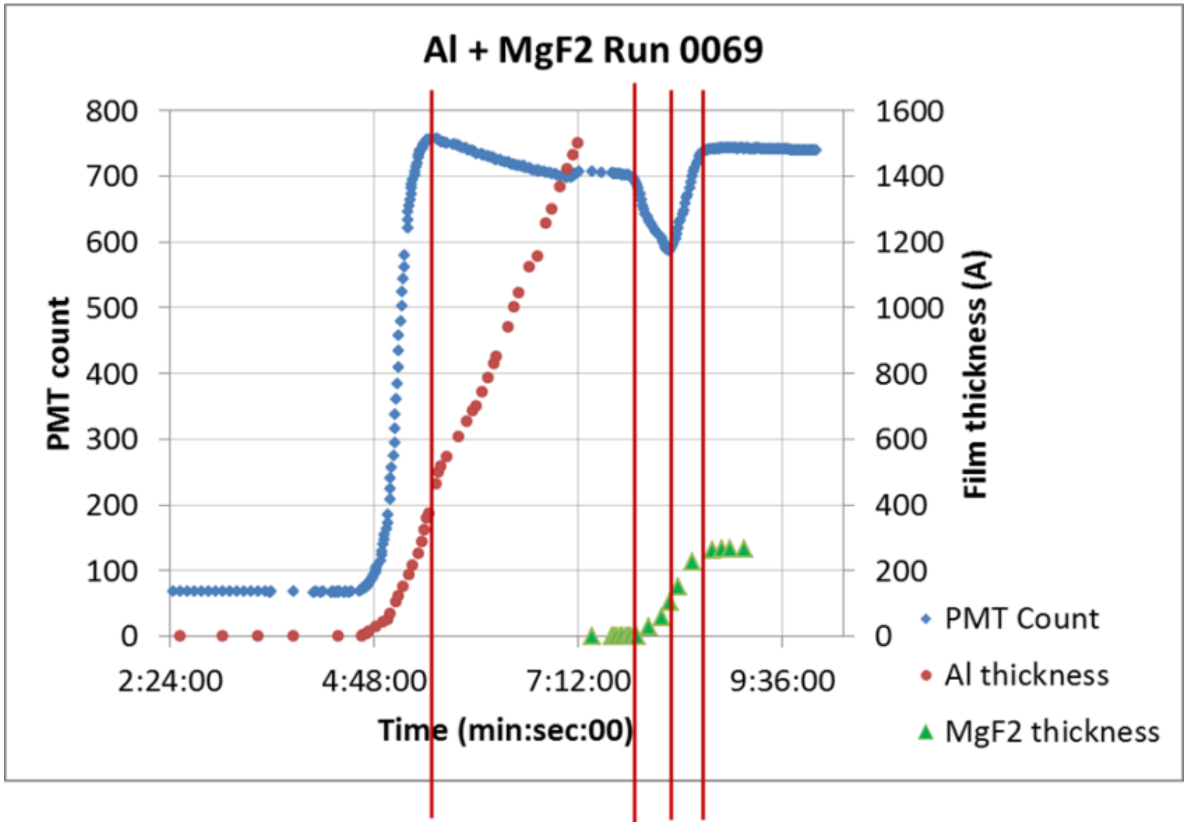


Transmittance spectra of single layer coatings of AlF_3, MgF_2, and LiF on uv grade fused silica substrate. The numbers in parenthesis indicate thickness in Angstroms. Angle of incidence: 0 deg.



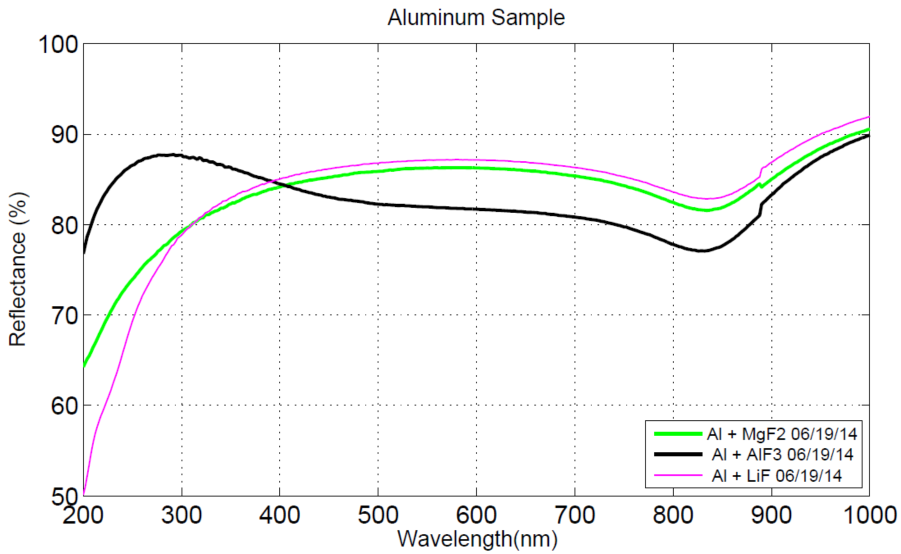
Transmittance spectra of single layer coatings of GdF_3, MgF_2, LaF_3, and Na_3AlF_6 on uv grade fused silica substrate. The numbers in parenthesis indicate thickness in Angstroms. Angle of incidence: 0 deg.

FUV monitoring

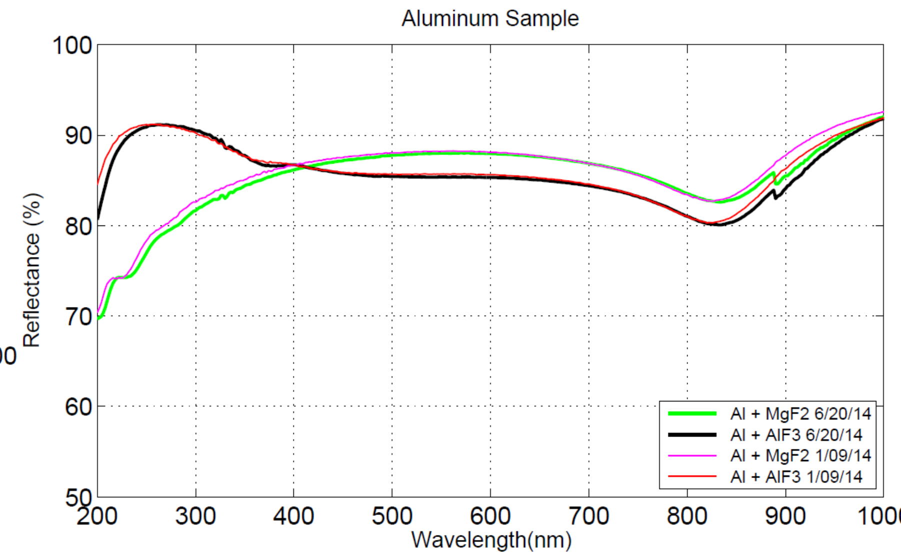


in situ FUV monitor diagnostic signal while growing Al film followed by MgF_2 film

Single layer protected Al mirror coatings

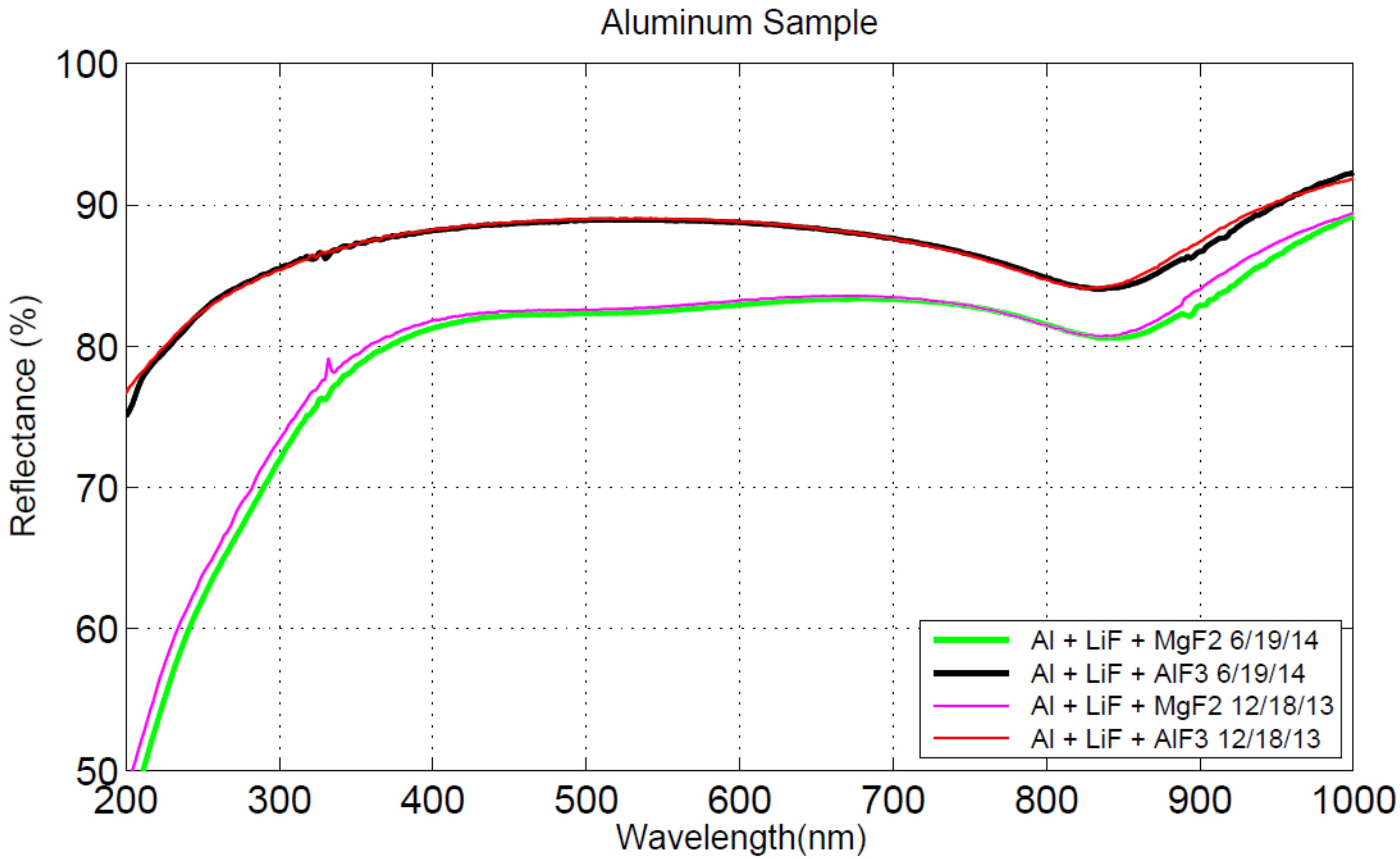


Reflectance of single layer protected Al mirror samples on fused silica substrates



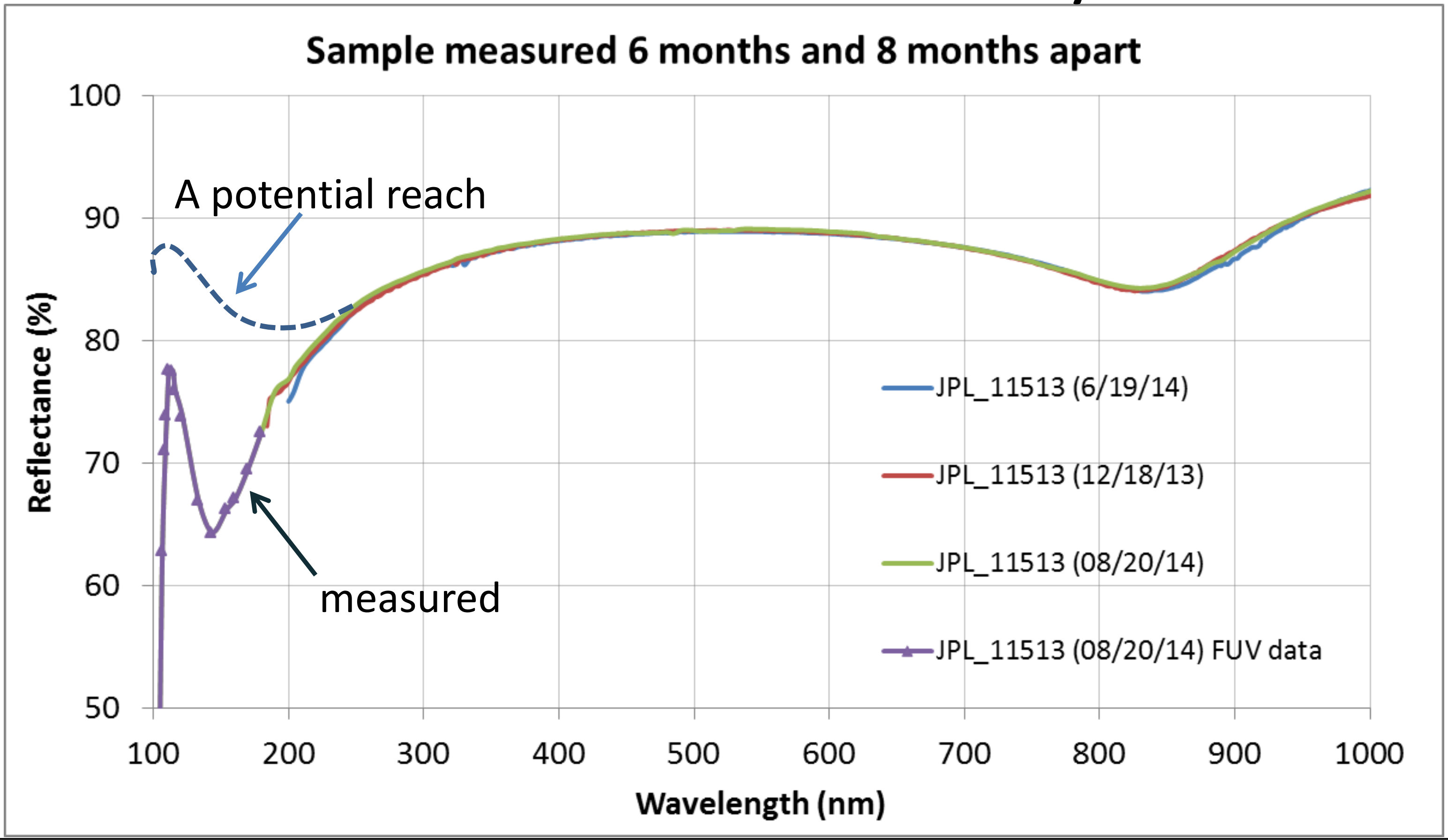
Reflectance of single layer protected Al mirror coatings in the 200 to 1000nm range, measured 6 months apart; the samples remained in the lab in a dry nitrogen flow box except during measurements involving a few days of exposure to normal lab environment with ~30 to 40% humidity.

Double layer protected Al mirror coatings



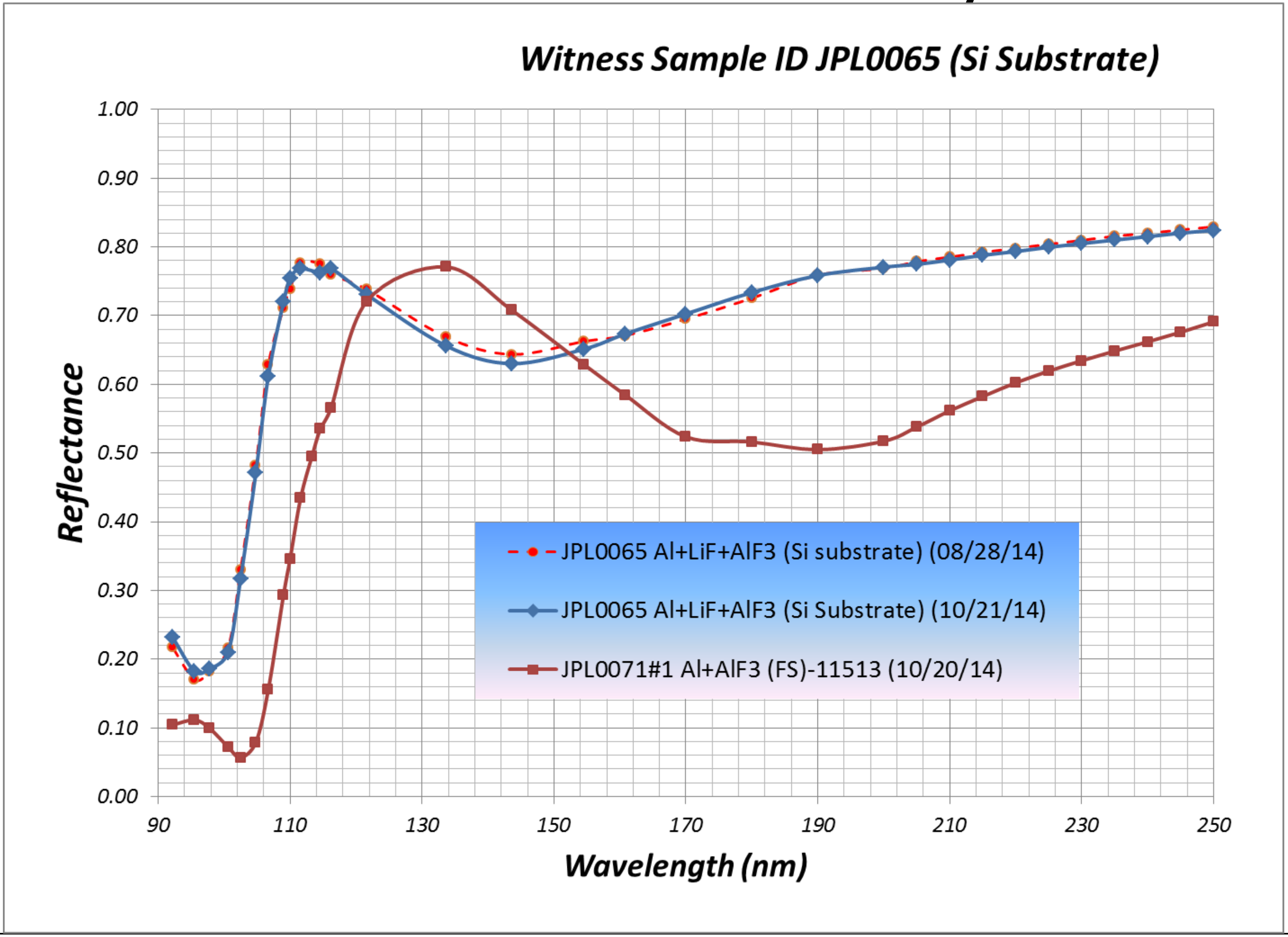
Reflectance of Al+LiF mirror samples with MgF_2 and AlF_3 protective layers. Measured after 6 months, these samples show little degradation. These were stored in dry nitrogen flow box except during measurements involving a few days of exposure to normal lab environment with ~30 to 40% humidity.

Double layer protected Al Performance Stability



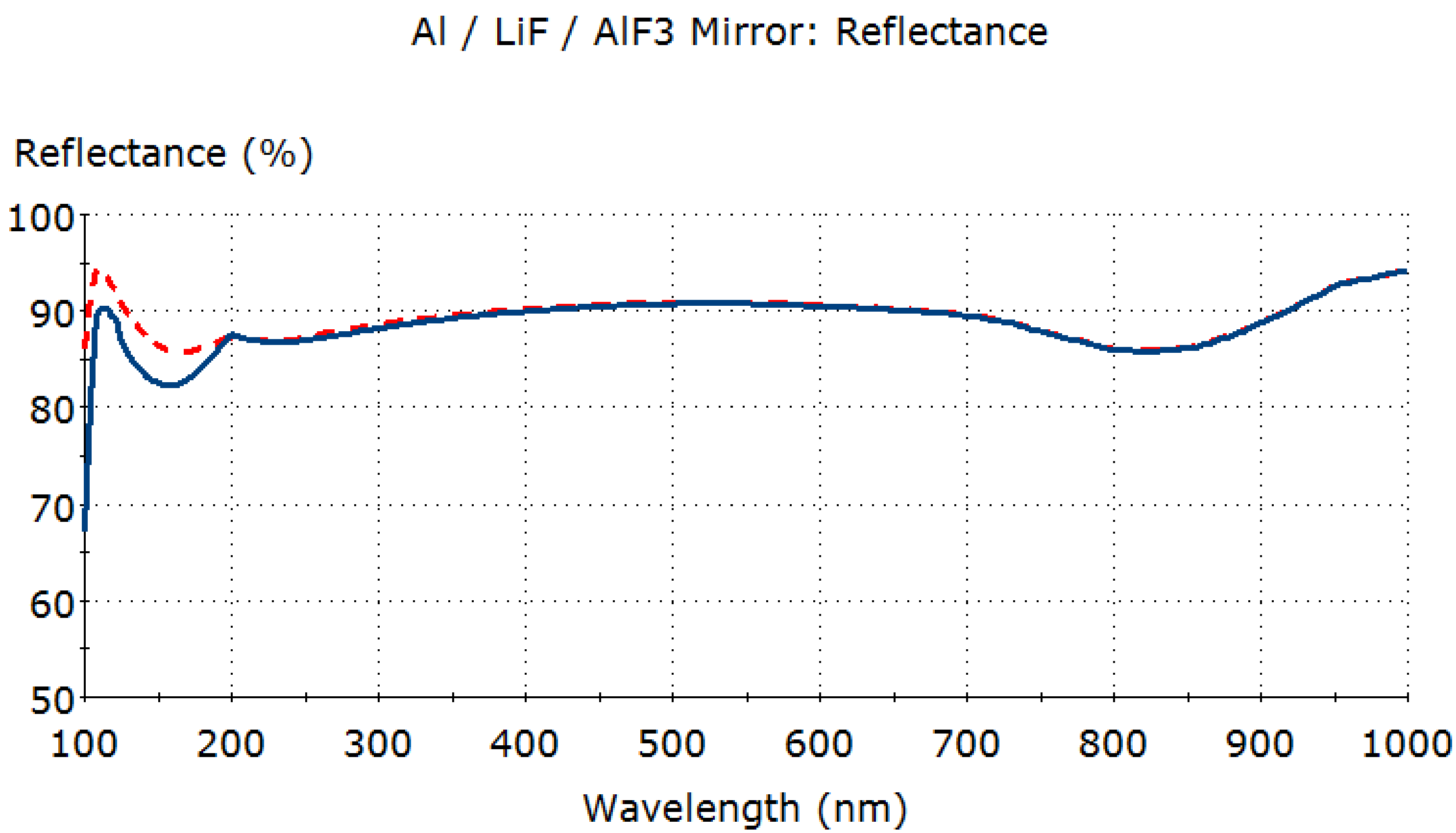
$Al+LiF+AlF_3$ mirror sample measured after 6 months and 8 months apart showing little or no degradation. Measurements were made at JPL and at GSFC with two different instruments showing excellent agreement. FUV measurement in addition to UV-VIS included in this chart (08/20/14 trace) was made at GSFC with an Acton spectrometer designed for such measurements in the FUV.

Performance Stability



Al+LiF+AlF_3 mirror sample and Al+AlF3 mirror sample measured after 6 months and 8 months apart showing little or no degradation. Measurements were made at GSFC with an Acton spectrometer

Theoretical models

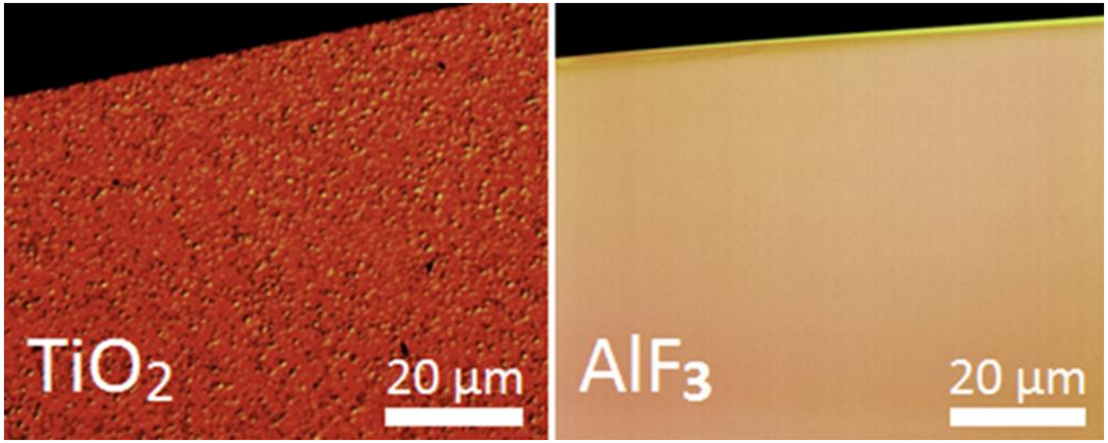


Al+LiF+AlF_3 Coating design calculations

Note: Optical constants from literature are extrapolated from 185 down to 100nm for these calculations

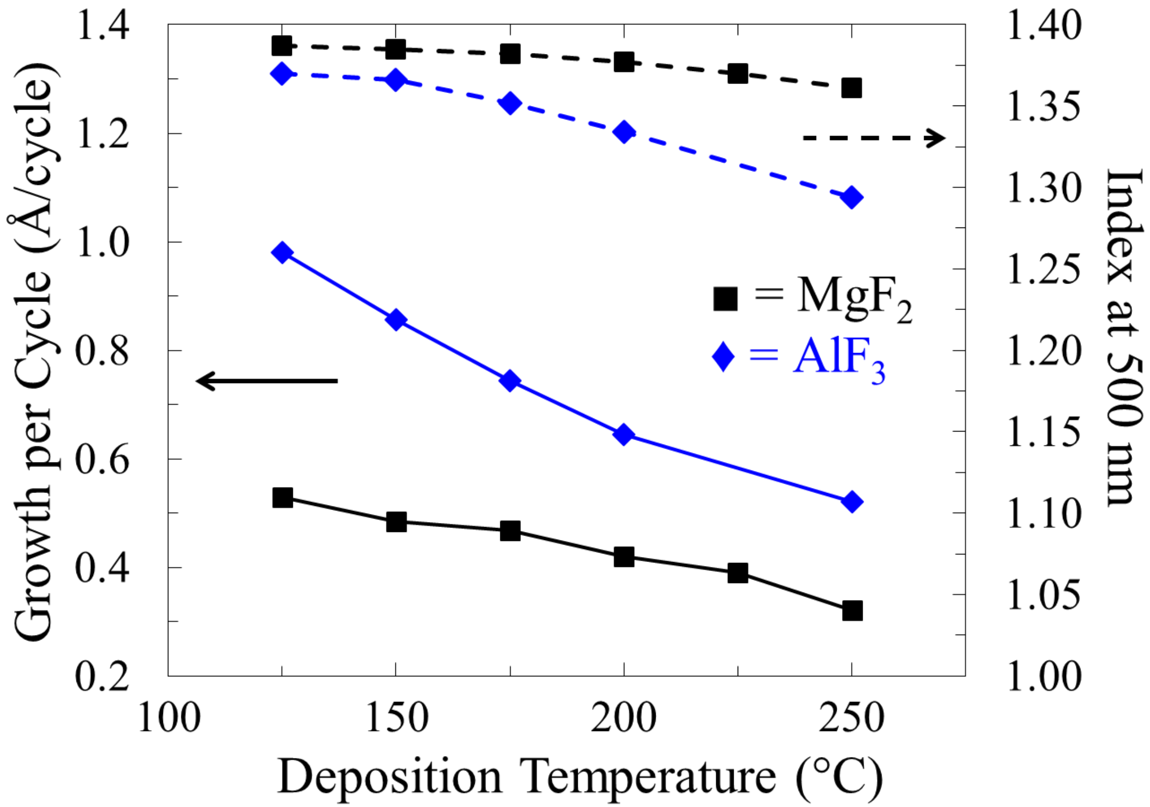
Atomic Layer Deposition (ALD)

ALD coating system at JPL; gas feedthroughs and process controls enable AlF_3 and MgF_2 coatings development



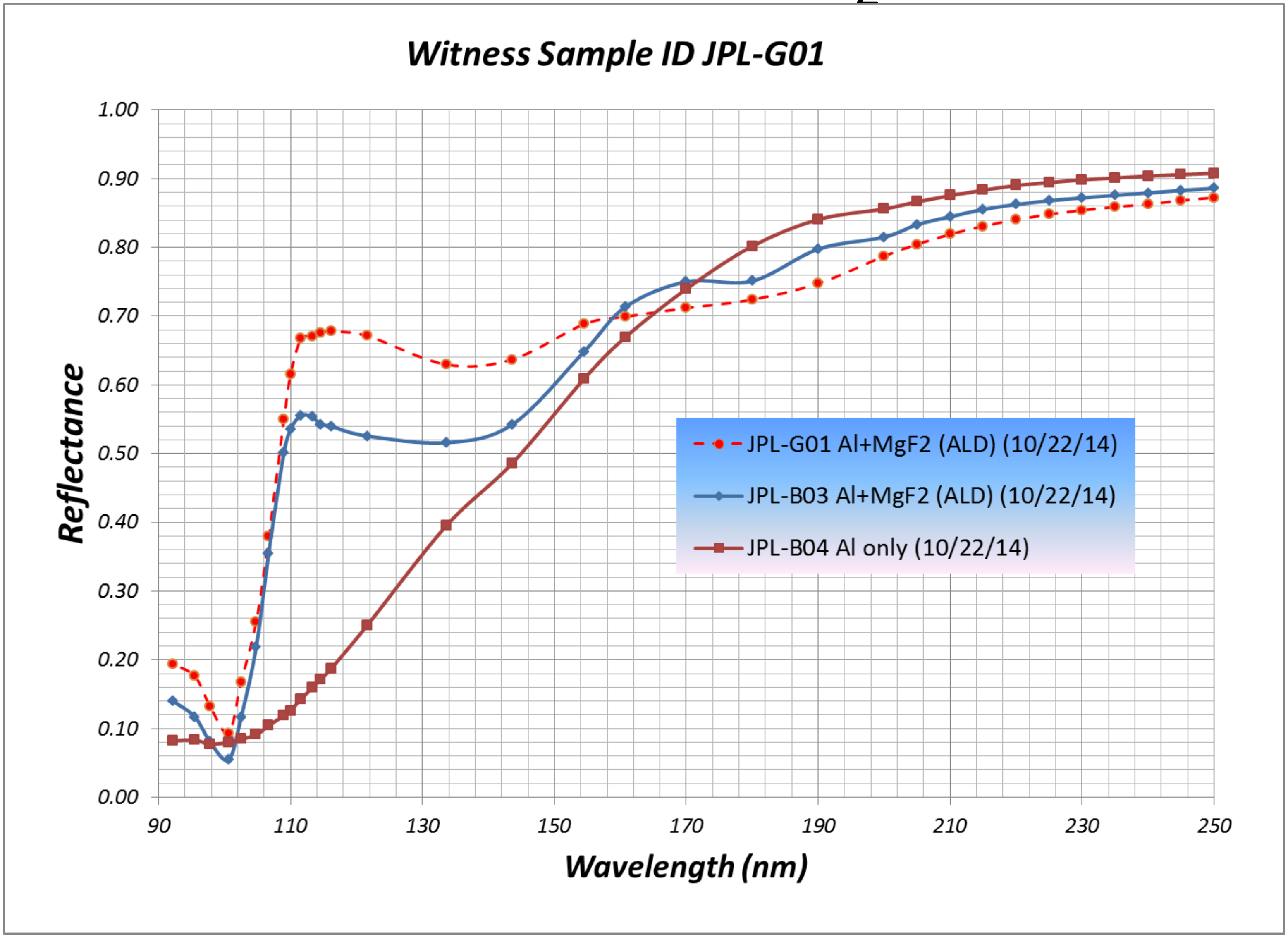
Optical interference micrographs of 100 nm TiO_2 deposited by ALD on silicon at 250 °C showing significant grain structure, compared to a 100 nm AlF_3 deposited by ALD at 200 °C imaged under similar conditions.

ALD thin films of MgF_2 and AlF_3



Refractive index and growth per cycle for ALD MgF_2 and AlF_3 films deposited on HF-cleaned silicon substrates as characterized by spectroscopic ellipsometry.

ALD coatings of MgF_2 on Al



Reflectivity of Al+MgF2 (ALD) films produced at JPL and measured at GSFC in Oct 2014

Summary & Further Work

- MgF_2, AlF_3 and LiF are promising protective coatings in bilayer combinations over Al
- Encouraging performance stability of preliminary protected mirrors as measured in two different labs across the country over 10 months
- Preliminary ALD coatings of MgF_2 and AlF_3 show very smooth surfaces and nearly absorption free (k~0) optical properties
- Further work in plan for both techniques to improve Al mirror reflectance in the 100 to 200nm wavelength range with optimum layer structures
- Detailed environmental tests to follow

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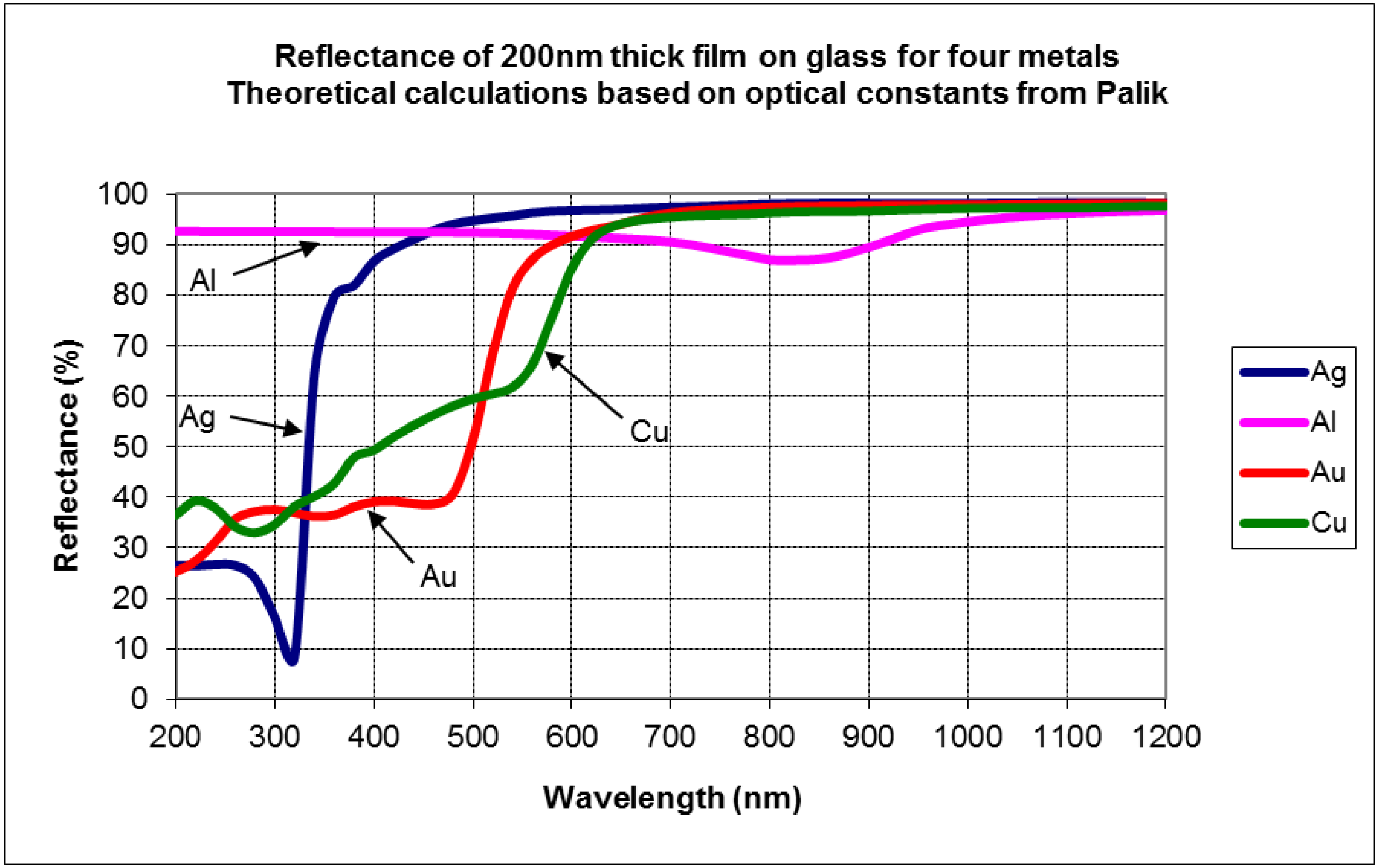
Background-2



Aluminum is the only material that covers the entire spectral range of interest
But Al oxidizes rapidly in normal environment degrading UV reflectivity