Investigating Coating Materials and Processes for FUV to NIR

Bala K. Balasubramanian
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91009

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Astrophysics

Excerpts from a report from Prof. Paul Scowen, ASU

- It has been recognized that at mid to far ultraviolet wavelengths ($90 < \lambda < 300$ nm), it is possible to detect and measure important astrophysical processes, which can shed light into the physical conditions of many environments of interest.

- For example, in the local interstellar medium (LISM) all but two (Ca II H and K lines) of the key diagnostic of resonance lines are in the ultraviolet (Redfield 2006).

- In addition to the fruitful science areas that ultraviolet spectroscopy has contributed since the early 1970s, France et al. (2013) have emphasized the role of ultraviolet photons in the photodissociation and photochemistry of H_2O and CO_2 in terrestrial planet atmospheres, which can influence their atmospheric chemistry, and subsequently the habitability of Earth-like planets.

- Similarly, new areas of scientific interest are the detection and characterization of the hot gas between galaxies and the role of the intergalactic medium (IGM) in galaxy evolution (Shull et al., 2012).

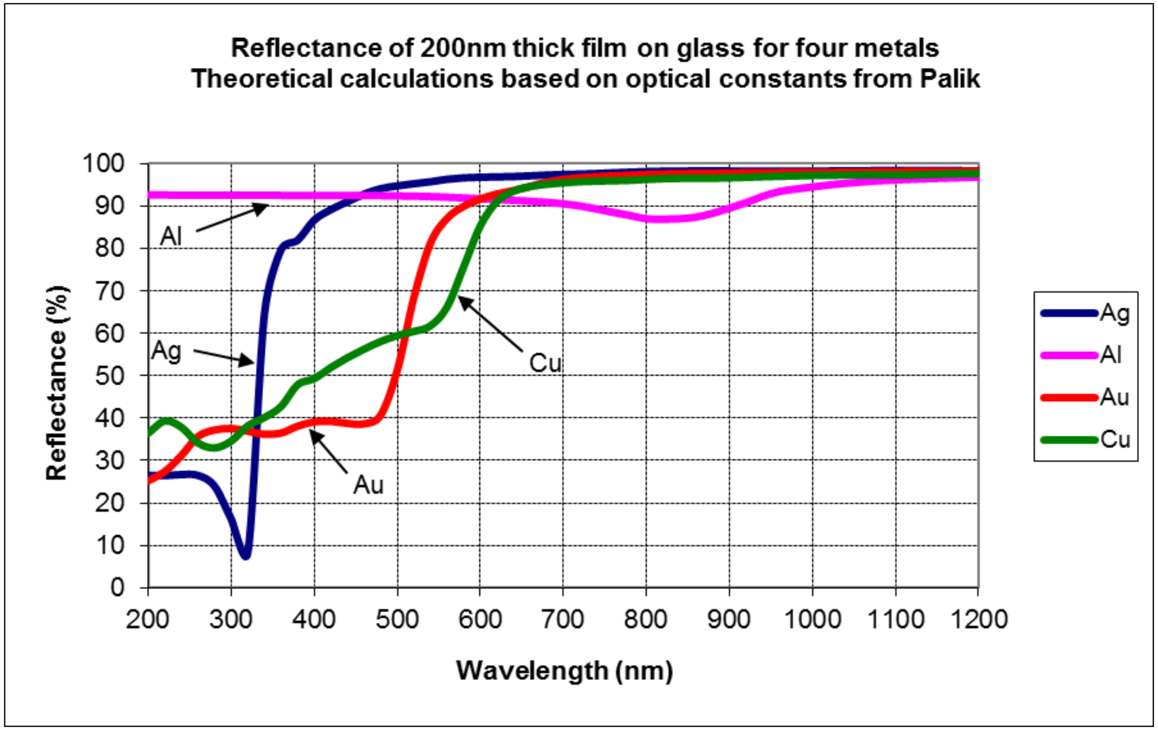
COR Program Goals

- 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 that we have adopted for this project: "Development of UV coatings with high reflectivity (>90-95%), high uniformity (<1-0.1%), and wide bandpasses (~100 nm to 300-1000 nm)".

- High reflectivity coatings covering the 100-120nm spectral region is considered important for studying intergalactic matter (IGM). The COPAG assessed the degree of difficulty to achieving this as very high.

- Void-free thin films of absorption-free materials are required to protect and maintain high reflectivity and durability of aluminum mirrors in laboratory and pre-launch environments. Precisely controllable and scalable deposition process is also required to produce such coatings on large telescope mirrors.

Background

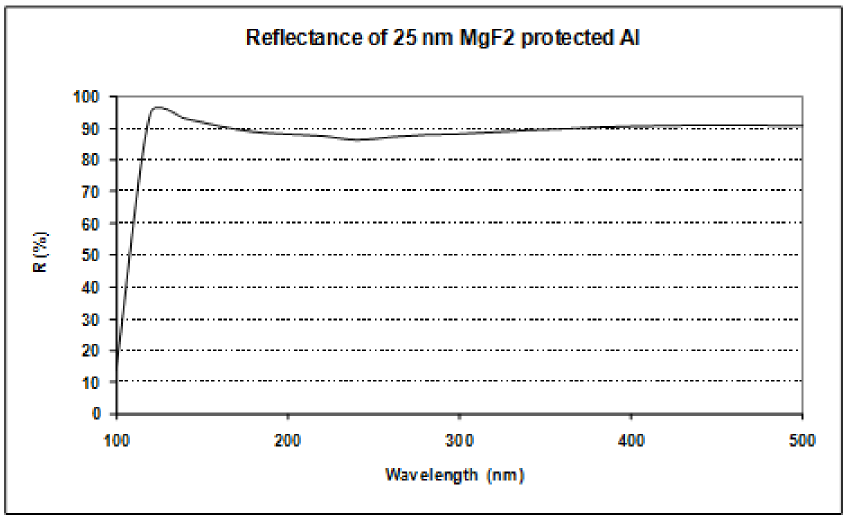


Reflectance of 200nm thick film on glass for four metals
Theoretical calculations based on optical constants from Palik
Reflectance (%)
Wavelength (nm)
100
90
80
70
60
50
40
30
20
10
0
200
300
400
500
600
700
800
900
1000
1100
1200
Al
Ag
Au
Cu
Ag
Al
Au
Cu

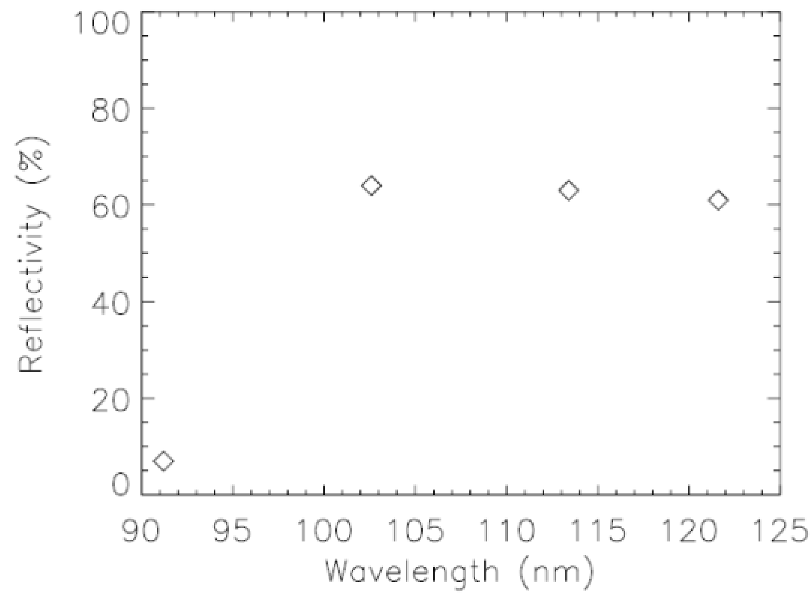
Background

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

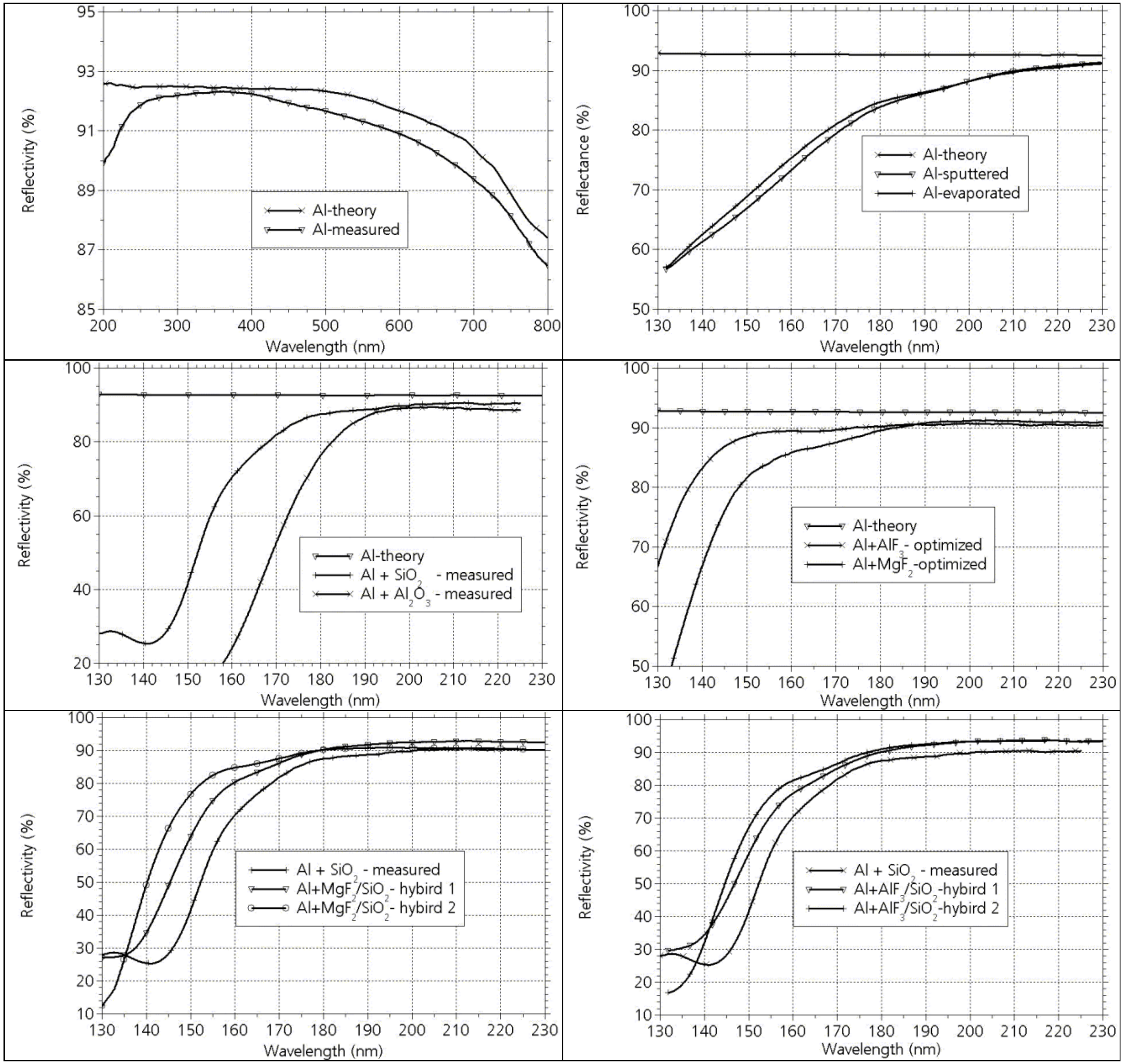
FUSE (Far Ultraviolet Spectroscopic Explorer)



MgF_2 protected Al (calculated with optical constants from literature)

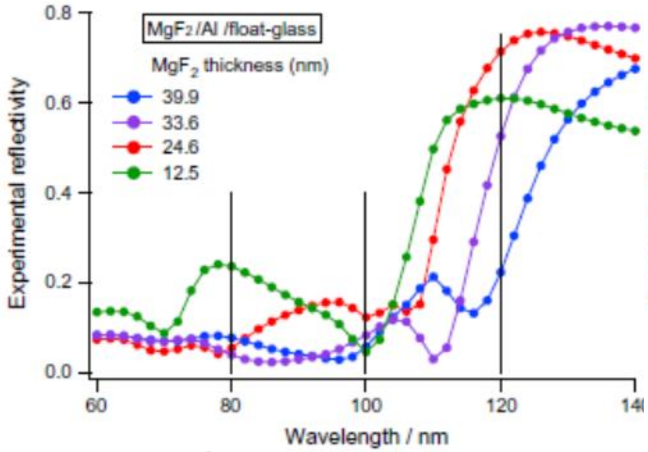


LiF protected Al mirror reflectivity (adopted from Oliveira, et al., Proc SPIE, Vol.3765 (1999)).

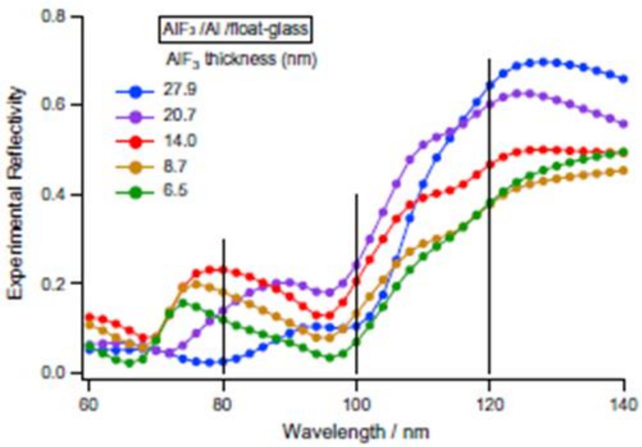


Measured reflectivity of Al mirrors with various protective layers
Figures adopted from Yang, Gatto and Kaiser, Proc SPIE vol.5693, (2005)

MgF_2 and AlF_3 on Al



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



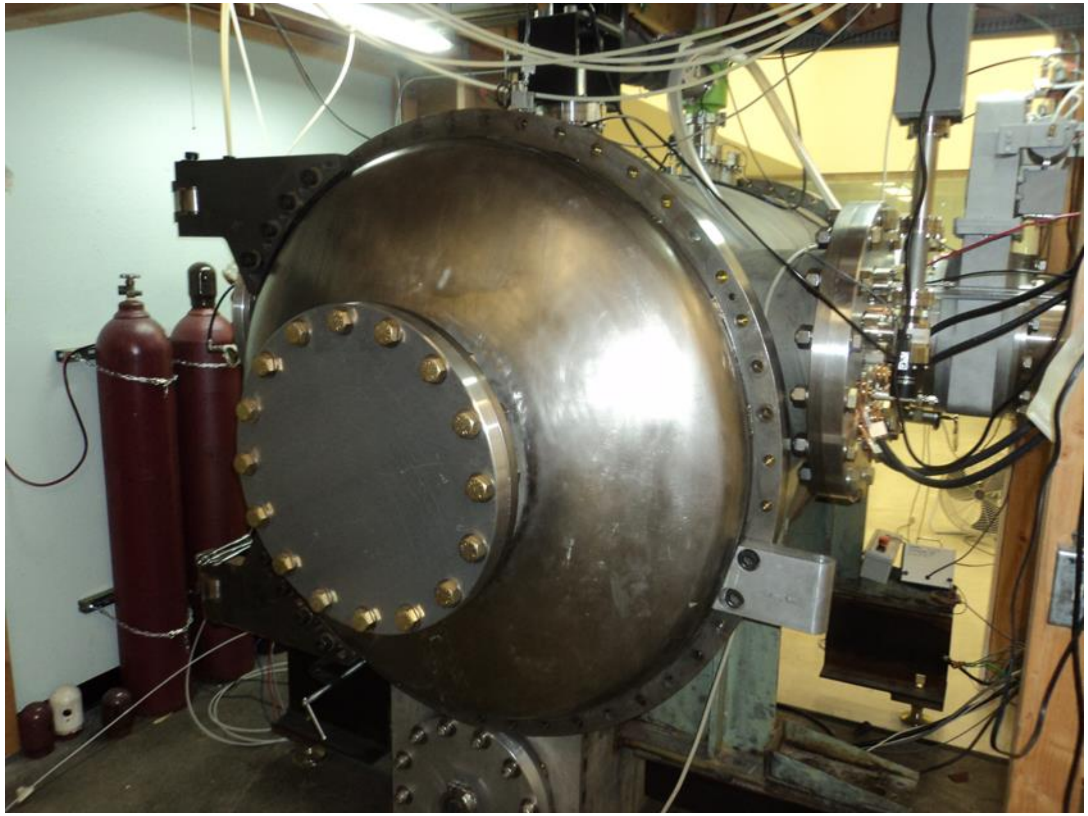
AlF_3/Al coating reflectivity in the DUV [Bridou, et al (2010)]

Candidate Materials

Several fluorides: CaF_2, LiF, MgF_2, LaF_3, AlF_3, 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.
- Coatings were prepared on fused silica and silicon substrates. UV grade fused silica substrates of 2 inch diameter were specially prepared with both sides polished and one side polished regions over which coatings could be prepared in the same run to enable multiple experiments / measurements with one sample.
- Detailed characterization of these coatings is in progress.

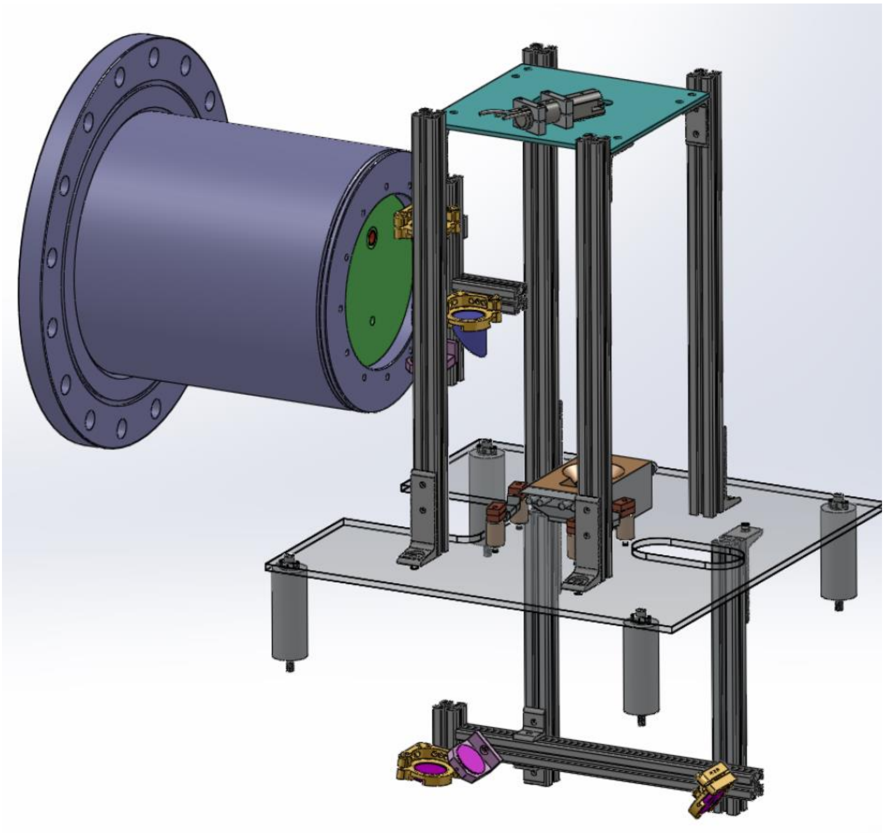
1.2 m Coating Chamber

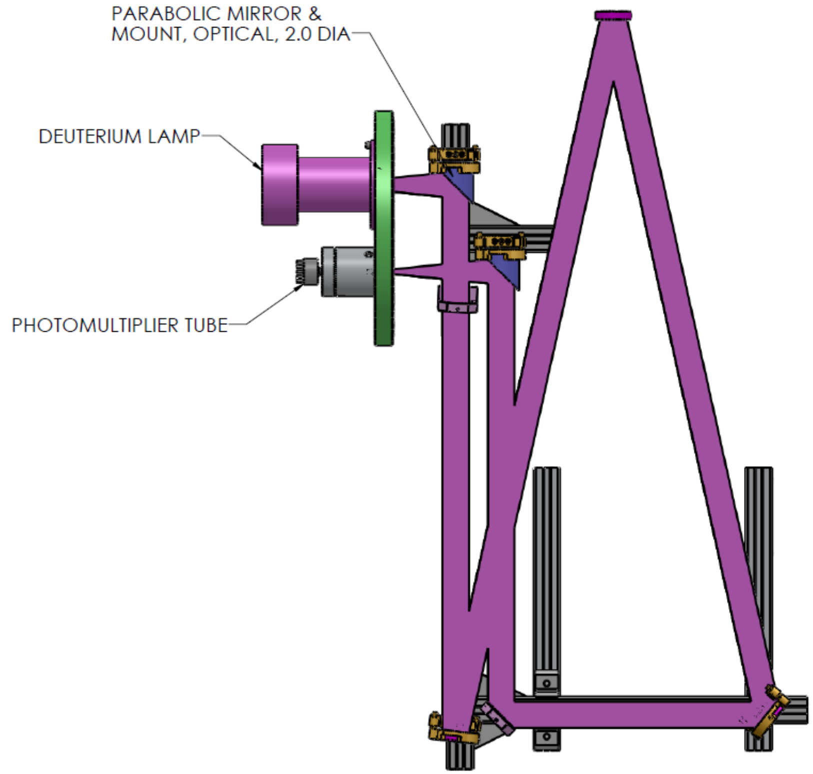


Coating chamber employed to produce various coatings for initial experiments with conventional coating techniques

Courtesy: Zecoat Corp.

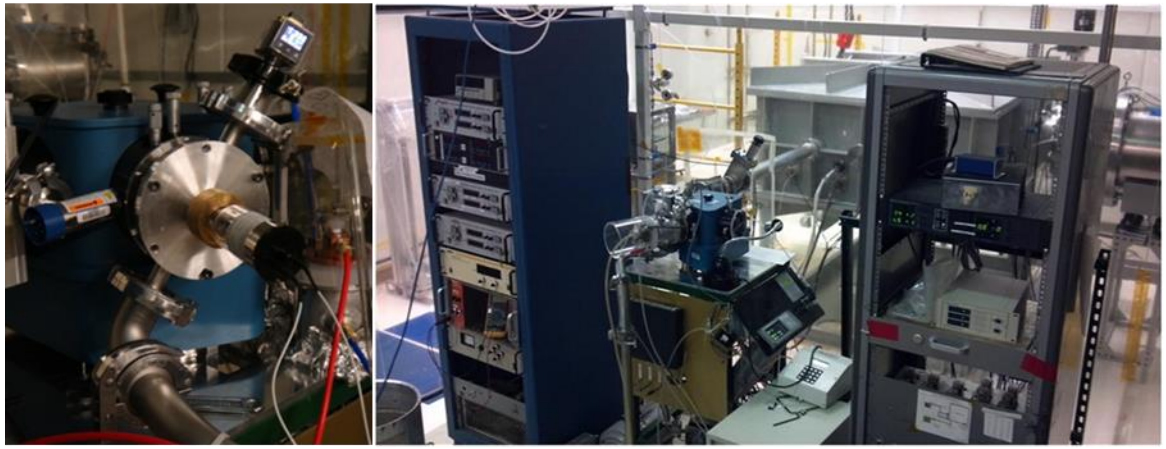
Reflectometer
(work in progress)





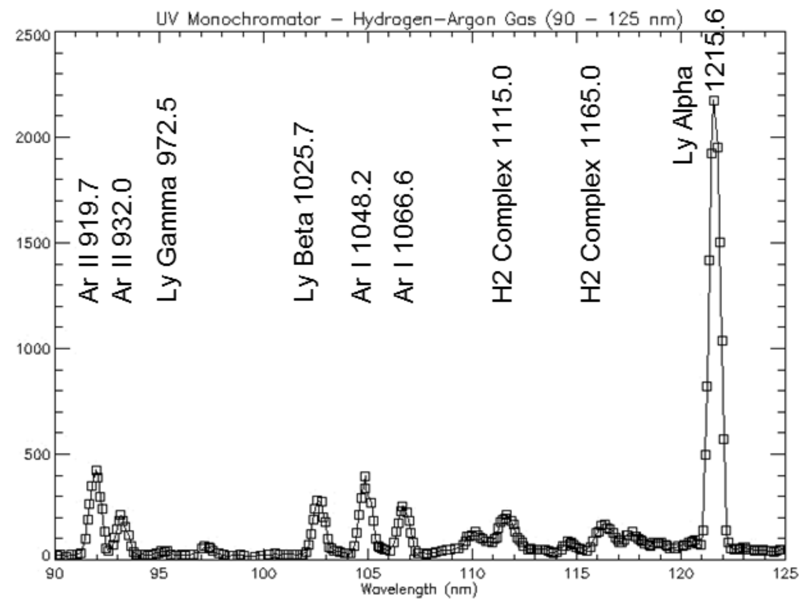
Courtesy: Zecoat Corp.

FUV measurements at Univ. of Colorado



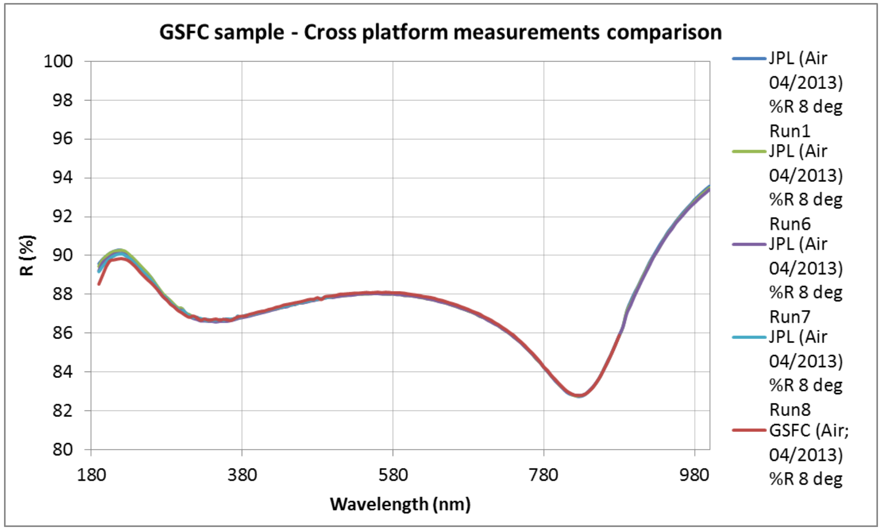
FUV measurement system at Univ. of Colo. (Courtesy: Prof. James Green). The light sources include sealed Pt-Ne and deuterium discharge lamps, and windowless gas discharge systems. These can provide a host of emission lines from 400 – 2000 Å, and continuum emission >1608 Å. The monochromator is a normal incidence McPherson - it's selectable bandwidth can be scanned over the full 400 – 2000 Å range. The vacuum tank is operated in a class 2000 clean tent.

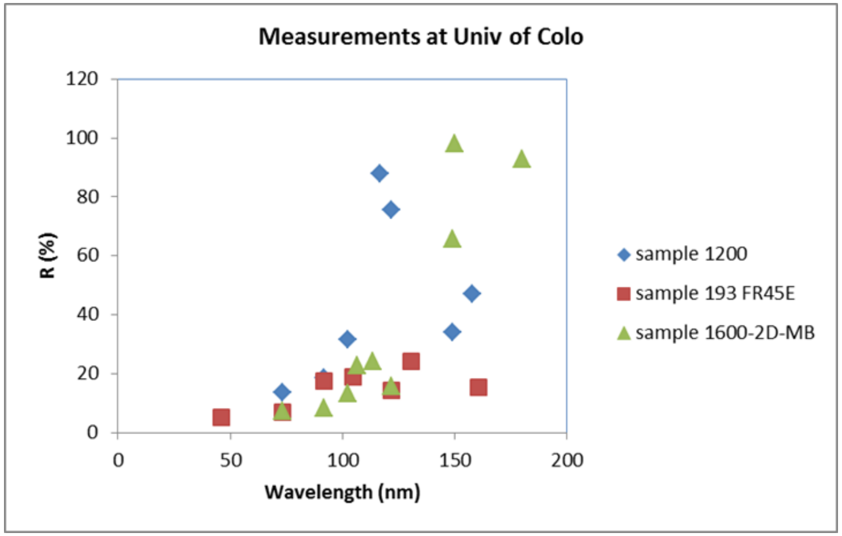
FUV measurements at Univ. of Colorado



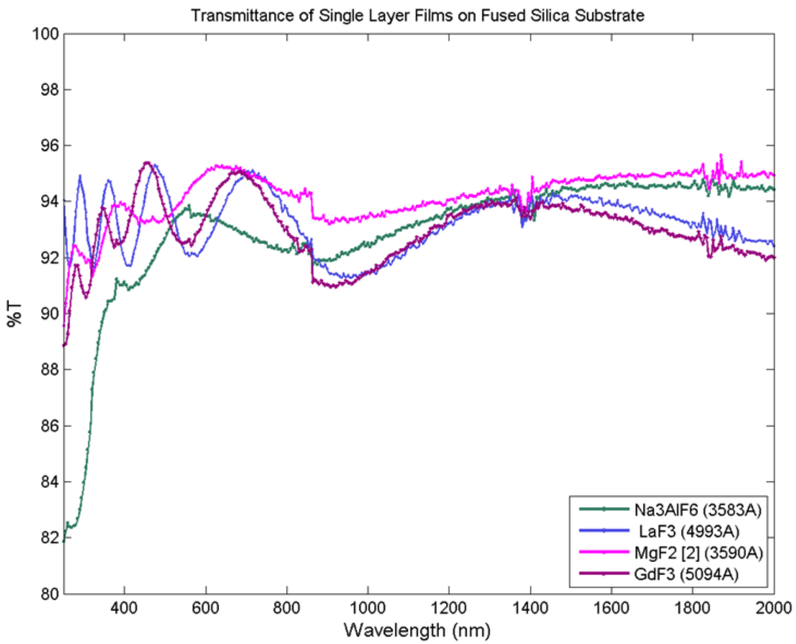
Representative measurement results from Univ. of Colorado FUV measurement system indicating its current functionality for further work.

Commercial samples measured

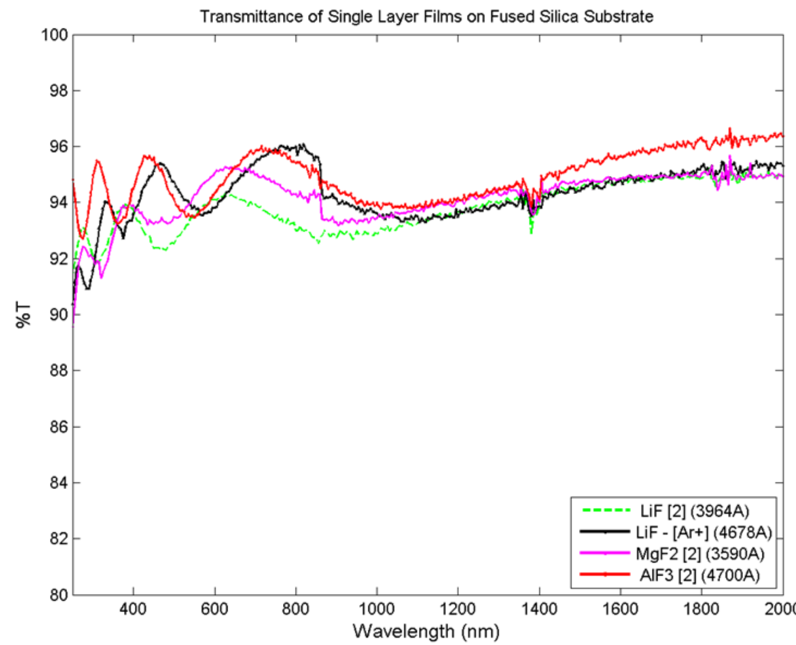




Single layer coating samples
Measured Transmittance



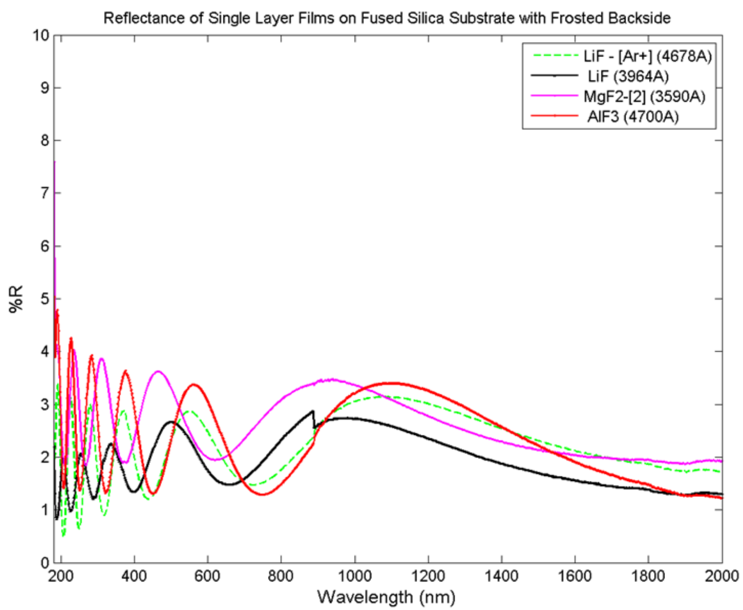
Transmittance spectra of single layer coatings of GdF_3, MgF_2, LaF_3, and Na_3AlF_6 on uv grade fused silica substrate. The numbers in parenthesis indicate thickness in Angstroms. Angle of incidence: 0 deg.

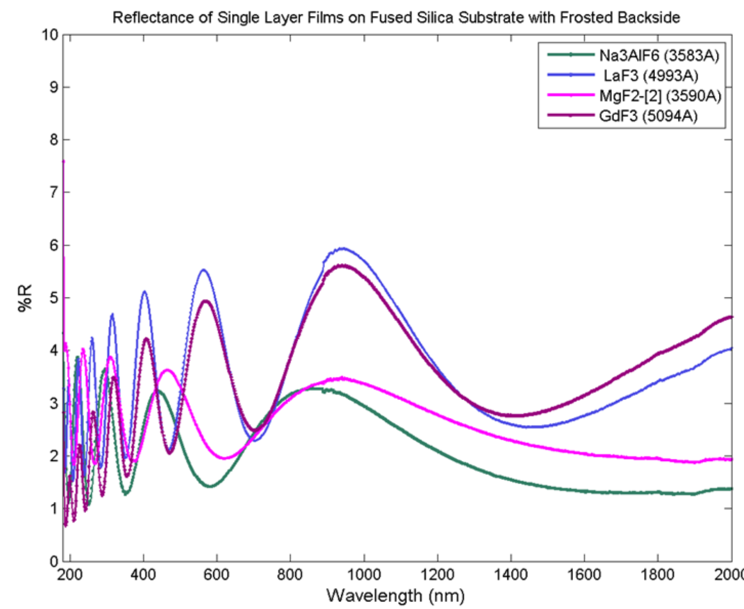


Transmittance spectra of single layer coatings of AlF_3, MgF_2, and LiF on uv grade fused silica substrate. The numbers in parenthesis indicate thickness in Angstroms. Angle of incidence: 0 deg.

Measurements done with a Perkin Elmer UV-VIS Spectrophotometer

Single layer coating samples
Measured Reflectance



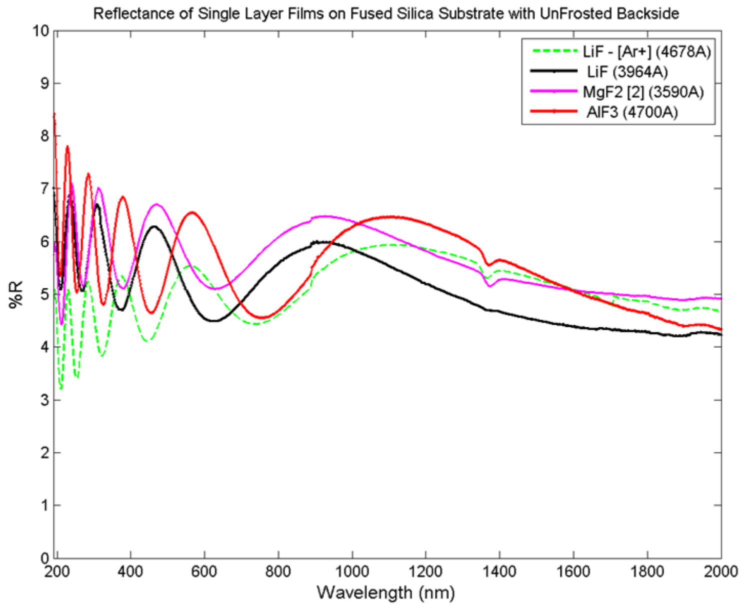


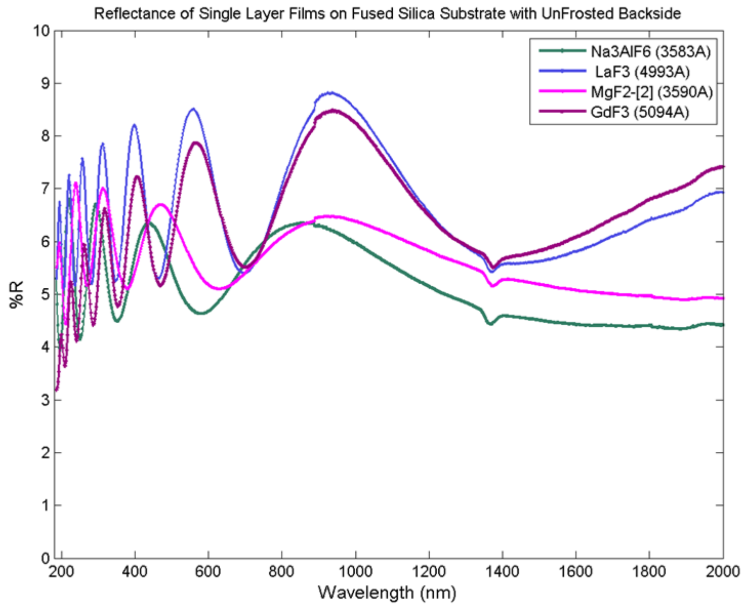
Reflectance spectra of single layer coatings of MgF_2, LiF, and AlF_3 on uv grade fused silica substrate with frosted backside. The numbers in parenthesis indicate thickness in Angstroms. Angle of incidence: 8 deg

Reflectance spectra of single layer coatings of GdF_3, MgF_2, LaF_3, and Na_3AlF_6 on uv grade fused silica substrate with frosted backside. The numbers in parenthesis indicate thickness in Angstroms. Angle of incidence: 8 deg

Measurements done with a Perkin Elmer UV-VIS Spectrophotometer with a Universal Reflectance Accessory

Single layer coating samples
Measured Reflectance



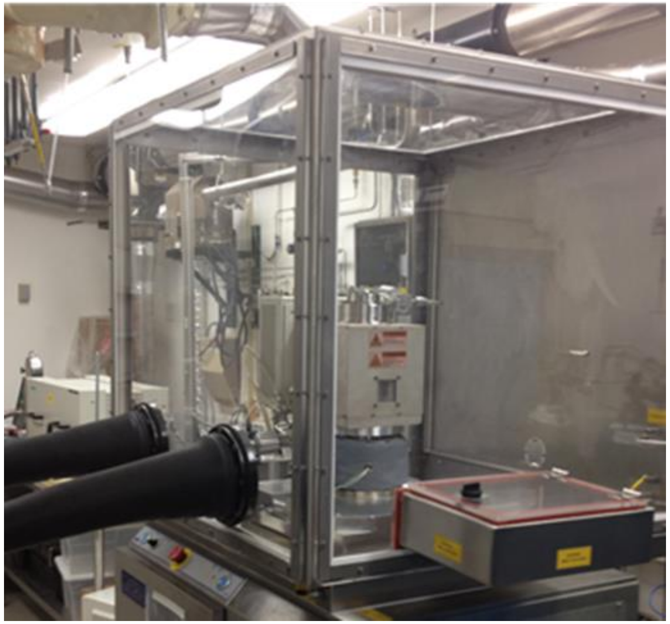


Reflectance spectra of single layer coatings of AlF_3, MgF_2, and LiF on uv grade fused silica substrate with unfrosted backside. The numbers in parenthesis indicate thickness in Angstroms. Angle of incidence: 8 deg

Reflectance spectra of single layer coatings of LaF_3, GdF_3, MgF_2 and Na_3AlF_6 on uv grade fused silica substrate with unfrosted backside. The numbers in parenthesis indicate thickness in Angstroms. Angle of incidence: 8 deg

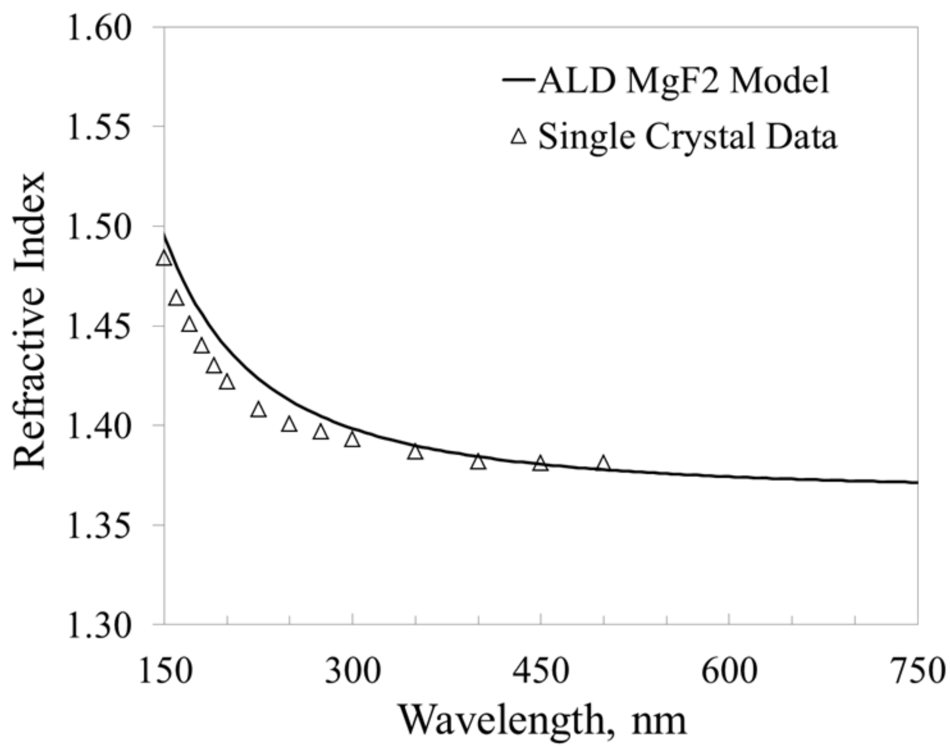
Measurements done with a Perkin Elmer UV-VIS Spectrophotometer with a Universal Reflectance Accessory

ALD system at JPL



ALD coating system at JPL

MgF_2 Film by ALD



Refractive index of MgF_2 film recently grown with ALD process at JPL. MgF_2 deposited with Mg(CpEt)2 and HF at 200 °C, ~100 nm; Model is ellipsometric best fit for measurement over the range 1.5 – 6.5 eV; Film appears transparent in this range, apparent k=0; Single crystal data from (Williams, Applied Optics 18, 1979)

Plans for the coming year (FY14)

- Produce protected Al mirror samples with chosen protective layers
- Develop and perform environmental tests (humidity and thermal cycling) to establish protection of Al and its reflectivity, particularly in the deep UV. Measure R, before and after environmental tests, and characterize the surface microscopically.
- Develop and optimize ALD process for absorption-free thin MgF_2 coatings, and MgF_2 protected Al mirrors.
- Compare the performance characteristics of protective coatings made by conventional techniques (e.g., IAD) and by ALD

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Team Members:
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Nasrat Raouf, JPL
Shouleh Nikzad, JPL
John Hennessy, JPL
Michael Ayala, JPL

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