Enhanced Fluoride over-coated Al Mirrors for FUV Astronomy

Manuel A. Quijada[1], Javier del Hoyo[1], Steve Rice[1], Felix Threat[1]

1. NASA-GSFC Code 551, Greenbelt, MD, United States.

ABSTRACT

Astronomical observations in the Far Ultraviolet (FUV) spectral region are some of the more challenging due to the very distant and faint objects that are typically searched for in cosmic origin studies such as origin of large scale structure, the formation, evolution, and age of galaxies and the origin of stellar and planetary systems. These challenges are driving the need to improve the performance of optical coatings over a wide spectral range that would increase reflectance in mirrors and reduced absorption in dielectric filters used in optical telescope for FUV observations. This paper will present recent advances in reflectance performance for Al+MgF2 mirrors optimized for Lyman-alpha wavelength by performing the deposition of the MgF2 overcoat at elevated substrate temperatures. We will also present optical characterization of little studied rare-earth fluorides such as GdF3 and LuF3 that exhibit low-absorption over a wide wavelength range and could therefore be used as high refractive index alternatives for dielectric coatings at FUV wavelengths.

Description and Objectives:

1. To develop on a large scale (up to 1 meter diameter) coating of mirrors using a Al+MgF_2 coating process to enhance performance in the Far-Ultraviolet (FUV) spectral range
2. Study other dielectric fluoride coatings and other deposition technologies such as Ion Beam Sputtering (IBS) that is known to produce the nearest to ideal morphology optical thin film coatings and thus low scatter
3. Optimize deposition process of lanthinide trifluorides as high-index materials that when paired with either MgF_2 or LiF will enhance reflectance of Al mirrors at Lyman-alpha

Approach for Objective 1:

Retrofit a 2 meter coating chamber with heaters/thermal shroud to perform coating iterations at a high deposition temperatures (200-300°C) to further improve performance of protected Al mirrors with either MgF_2 or LiF overcoats

Tasks Description:

- Design and fabrication of internal heat shields for GSFC 2-meter Chamber.
- These wall panels were made out of stainless steel and were designed to easily interface with the existing internal configuration of the chamber.
- Optimized coating parameter for high FUV reflectance of a distribution of slides in center and out to a ~0.5 meter radius.

Physical Vapor Deposition (PVD):

Material is heated until it reaches vapor form
Material is deposited on the substrate where it condenses
Typical deposition rates are 10-100 Å/Sec.

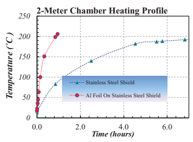
Top view inside chamber

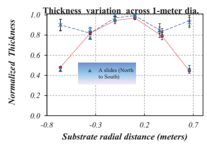
Bottom view (looking up) with chamber cover on

Power supply

Quartz Tungsten Halogen Lamp

- The Images above show the fully assembled internal heat shields , power supply and quartz halogen lamps
- Heater were first tested on 08/13/13 and found maximum temperature reached was only 100 °C after 5 hours
- Doubled lamp power output from 500 W to 1000 W each (4000 W total)
- Additional testing yielded a maximum temperature of 130 °C
- Further testing done after wrapping heat shield panels with aluminum foil provide for a much quicker raise in temperature, reaching 220 °C in less than 1 hour (see graph below on the right)
- Performed a coating run with small 2x2in substrates located at various radius inside chamber (see graph below on the left)

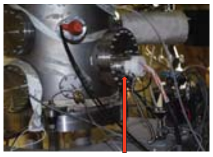




Approach for Objective 2:

Upgrade existing Ion Beam Sputtering (IBS) chamber with a two-gas flow controller system. Krypton gas is used during IBS deposition. In addition, Freon (CF4) is used as reactive gas to replenish the targets (MgF2) stoichiometry. Finally, we added heaters to the chamber to improve microcrystalline film properties.

Ion Beam Sputtering Coating Chamber

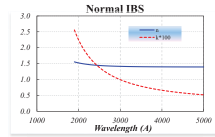


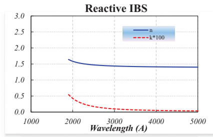
Reactive gas intake

Reactive Ion Beam Sputtering (RIBS)

- Non-thermal evaporation process
- Atoms from a target are ejected by momentum transfer from energetic atom-size particles
- Particles are energized by an ion gun
- Deposition rate are much lower than PVD 1-5 Å/Sec.

- Optimization and characterization of MgF2 films using the IBS process did not give satisfactory results (see graphs below)
- Problem is thought to be traced at degradation of cathode filament due to reactive fluoride containing gas (Freon) in chamber



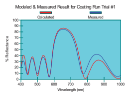


Approach for Objective 3:

Optimize deposition process of lanthinide trifluorides as high-index materials that when paired with either MgF_2 or LiF will enhance reflectance of Al mirrors at Lyman-alpha

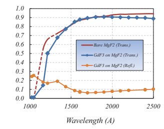
Tasks Description for FUV Dielectric Coatings:

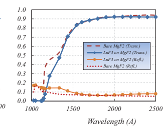
- Choose a high-index (H) and low-index (L) pair combination
- Form a pair of (H,L) layers with thicknesses equal to a Quarter-Wave Optical thickness at the design wavelength.
- Repeat the stack above until desired reflectance is achieved.



Options for FUV coating candidates: Low Index: MgF_2 (n~1.38)
High Index: LuF_3, GdF_3

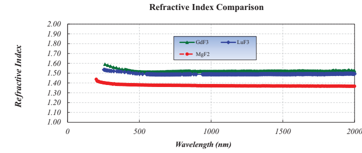
The two graphs below show transmission and reflectance of GdF_3 (right) and LuF_3 (left) films grown on MgF_2 substrates. These data are used to extract refractive index for both of these materials.





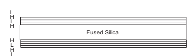
MgF_2 & LiF substrates

The data on the graphs shown above were used to obtain refractive index (n and k) for MgF_2 , GdF_3, and LuF_3 films. The results are shown in graph

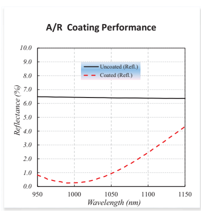


Example of A/R coating design and fabrication:

- A/R to suppress FS reflection losses near 1000 nm
- Design includes 2 layer pairs of GdF_3(H)/MgF_2(L) (181 and 200 nm respectively) on both sides



Performance is 0.25% near 1000 nm



Spectral Characterization:

Spectrometer used to collect spectral scan of transmission and/or reflectance from 90 nm to 2500 nm are two gratings instrument shown below

Perkin Elmer Lambda 950

ACTON Research Corporation (VM-521-SG

PE Specifications

- Double-beam ratio recording grating monochromator
- Wavelength range: 180-3300 nm; Resolution: .05-5 nm
- Quartz Tungsten Halogen and D2 lamps
- Lead-sulfite and PMT detectors
- Photometric Range: Up to ±8 Absorbance units (with attenuation)
- Universal Reflectance Accessory for normalized reflectance between 8° and 68° angle of incidence.

•ACTON Specifications

- One-meter high-vacuum monochromator (1200 grooves/mm)
- Wavelength range from 30 nm to 325 nm .
- Windowless hydrogen-purged light source (discrete H2 emission lines between 90 nm and 160 nm and a continuum at higher λ
- Photomultiplier Cathode Tube with light –pipe equipped with a fluorescence coating (sodium salicylate) for converting FUV to visible light
- Sample compartment allows absolute transmission and reflectance measurements at varying angles of incidence (12-68°) without the need of a reference

Al+MgF_2 Coating Performance:

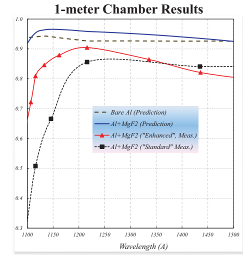
3-step coating process:

- Al is coated on the substrate at room temperature to the planned layer thickness
- As soon as possible after the Al deposition, overcoat the Al layer and substrate at room temperature with a thin 4-5 nm layer of MgF_2 in order to protect the Al from oxidation and contamination.
- Heat the substrate to 200-300 °C and finish the planned final MgF_2 thickness MgF2.

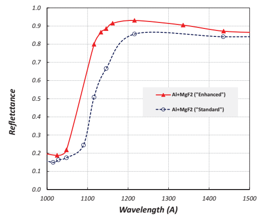
Results:

1-meter Chamber Results

- Predicted vs. measured reflectance of bare Al and Al+MgF_2 reflectance (Al: 50.0 nm; MgF2: 25.0nm)
- Enhanced performance is obtained by heating (~220 °C) substrate during MgF2 deposition
- Reflectance is > 80% even at 115.0 nm



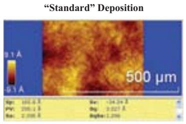
2-meter Chamber Results



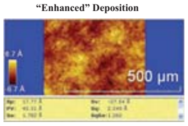
- Recently started test run in center of 2-meter chambers to optimize the 3-step process for depositing Al+MgF_2 coatings
- Graph on left display reflectance data taken of test coupons done in this chamber.
- "Standard" test sample was prepared under normal conditions on 08/22/2013
- "Enhanced" was produced with a "hot" (220°C MgF_2 deposition done on 11/27/2103.
- These data represent an important milestone

Micro-roughness Al+MgF2 Films

"Standard" Deposition



"Enhanced" Deposition



AM21301C	x20 mag/ angstroms	
	PV (Å)	Sq (Å)
top left	75.58	6.146
top right	101.2	5.196
center	128	4.021
bottom left	200.1	3.027
bottom right	100	3.282
average	120.97	**4.3344**

AMCT131A	x20 mag/ angstroms	
	PV (Å)	Sq (Å)
top left	45.31	2.249
top right	40.19	2.331
center	50.96	3.304
bottom left	44.39	2.923
bottom right	50.85	3.854
average	46.34	**2.9322**

The tables above show micro-roughness results on two classes of Al+MgF_2 coatings done with the MgF_2 layer deposited at ambient (left) and at elevated (right) temperatures. The table on the right shows the average roughness for the elevated MgF_2 depositions is 30% smaller.

Conclusions

- Reported gains in FUV reflectivity of Al+MgF2 and Al+LiF mirrors by employing a 3-step process during PVD coating deposition of these materials.
- Successfully demonstrated gains in FUV reflectance using a large 2-meter chamber that will allow coating up to 1 meter diameter optics.
- Characterization of lanthanide tri-fluoride material candidates to determine their FUV transparency for development of dielectric coatings.
- Will plan to refurbish a second 1-meter chamber to perform IBS film deposition of MgF2/LiF materials.