Recent Progress on 2012 SAT for UVOIR Coatings

2014 Mirror Technology/SBIR/STTR Workshop

By

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Outline

- Motivation: The need for better performing coatings in the Far-Ultraviolet (FUV)
- Project Objectives
- Methods & Facilities
- Results
- Conclusions & Future Plans
- Acknowledgements
Enhanced FUV Coating Applications

- Distant and faint objects are typically searched for in cosmic origin studies:
  - Origin of large scale structure
  - The formation, evolution, and age of galaxies
  - The origin of stellar and planetary systems
- Astronomical observations in the Far Ultraviolet (FUV) spectral region are some of the more challenging
- Very limited option of reflecting coatings to use at FUV wavelengths:
  - Modest reflectivity offered by those coatings
  - Al+MgF₂ [typically 82% at Lyman-alpha, 1216 Å] that are used on reflecting surfaces of FUV instrumentation
- Improved reflective coatings for optics at FUV could yield dramatically more sensitive instruments.
- Permit more instrument design freedom
Project Objectives

- Develop coating deposition processes to improve performance in Far Ultraviolet (FUV)

- Three main objectives:
  - Use a reactive Ion Beam Sputtering process to make better MgF$_2$ films
  - Study low-absorption materials for dielectric coatings in FUV spectral region
  - Improved FUV reflectance performance of aluminum mirrors over-coated with MgF$_2$ and LiF

- 3-year performance period (Started in FY12)
Physical Vapor Deposition
GSFC Coating Facilities

- PVD, IBS, and RF Magnetron Sputtering deposition chambers
- Coatings produced: Al, MgF2, SiO\textsubscript{x}, LiF, Al\textsubscript{2}O\textsubscript{3}, Ag, Cr, Y\textsubscript{2}O\textsubscript{3}

PVD coating chamber (1-meter)  Reactive Ion Beam Sputtering
Missions supported:
- Astronomical Observatory (OAO) & Ultraviolet Explorer (IUE)
- FUSE, HST (COSTAR, GHRS & COS)
Coating Deposition Processes

**Vacuum evaporation**

- 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.

**Sputtering**

- 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 rates are much lower than PVD 1-5 Å/Sec.
Model of Film Growth vs. Temperature

- Zone model of film growth vs. substrate temperature (After Movchan & Denchishin (1969))
- Three zones as function of $T_s/T_m$
  - Zone 1 ($< 0.25$): Feathery “frost” with columnar growth separated by many voids
  - Zone 2 (0.25 to 0.45): Densely packed columns
  - Zone 3 (> 0.45): Polycrystalline structure

Computer simulation growth process (Karl Gunther)
2-meter Chamber Heat Panel Concept

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

8 PANELS

4X LIGHT MOUNTS

SINGLE VIEWPORT 10” X 10” SQUARE

ADJUSTABLE LIGHT MOUNT

November 21st, 2014

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Earlier test of heaters showed 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 provided for a much quicker raise in temperature, reaching 220 °C in less than 1 hour.
Optical Characterization: \( T(\lambda), R(\lambda) \)

ACTON VUV Spectrometer

- Spectral range: 30-300 nm
- Source: Windowless H2-purged source (H2 emission lines between 90 nm and 160 nm and a continuum at higher)
- Detector: PMT with fluorescence coating

Perkin Elmer Lambda 950

- Spectral range: 190-2500 nm
- Universal Reflectance Accessory
Ion Beam Sputtering Coating Chamber

- Upgrade chamber with a two-gas flow controller system.
- Krypton gas to be used in the ion-beam sputtering depositions.
- Freon (CF4) used as reactive gas to replenish the targets (MgF2) stoichiometry.
- Added heaters to the chamber: To improve microcrystalline film properties.
Characterization of MgF2 films produced with the IBS process were not as good as conventional PVD results. As a result, coating runs of LiF films using reactive IBS were attempted. The problem could be traced to degradation of cathode filament due to reactive fluoride containing gas (Freon) in the chamber. The solution would be to procure an ion gun source without a filament:

- Cost is over $100k
- Efforts were not pursued due to budget constraints
FUV Reflecting Dielectric

- 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 dielectric materials:

L: MgF₂ (n ~ 1.45)
H: GdF₃; LuF₃ (n ~ ?)

Note: The larger the difference between (n_H - n_L) the better contrast and fewer layers needed to achieve a given R.
GdF₃ and LuF₃ Films Characterization

- 430 A GdF₃ film on MgF₂ substrate

*Graph showing transmittance and reflectance spectra for a 430 A GdF₃ film on MgF₂ substrate.*

- 435 A LuF₃ film on MgF₂ substrate

*Graph showing transmittance and reflectance spectra for a 435 A LuF₃ film on MgF₂ substrate.*
GdF$_3$ and LuF$_3$ Films Optical Constants

![Graphs showing Extinction Coefficient and Refractive Index vs Wavelength for GdF$_3$, LuF$_3$, and MgF$_2$.](image)
A/R Coating Example

• 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
Design 1: 5 pairs MgF$_2$/GdF$_3$ on Al layer
Design 2: 10 pairs MgF$_2$/GdF$_3$ on MgF$_2$ substrate
Al+MgF₂ Mirror FUV Performance

- Predicted vs. measured reflectance of bare Al and Al+MgF₂ reflectance (Al: 50.0 nm; MgF₂: 25.0 nm)

- Enhanced performance is obtained by heating (~220 °C) substrate during MgF₂ deposition

- Reflectance is > 80% even at 115.0 nm
Micro-roughness Al+MgF2 Coatings

Standard Deposition

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<th>x20 mag/angstroms</th>
<th>PV (Å)</th>
<th>Sq (Å)</th>
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<td>128</td>
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<tr>
<td>average</td>
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Hot Deposition
Recipe: Al (43nm, ambient)+LiF(8nm, ambient)+LiF(16.4nm, 250 °C)

$R_{ave}(100-150nm): 59\% \text{ (FUSE)} \ 75\% \text{ (Hot)}$
Al+LiF Mirror FUV Performance Cont..

![Graph showing reflectance vs wavelength for different mirror configurations.]

- **Al (50nm) + LiF (24.4nm)**
- **Al (50nm) + LiF (15nm) + MgF (5nm)**
- **Al (50nm) + LiF (18nm)**
- **FUSE**

Wavelength (nm)

Dual bowl fixture
ICON (Ionospheric Connection Explorer): Study Earth’s low-orbit ionosphere

GOLD (Global-scale Observations of the Limb and Disk): Imager to map Earth’s thermosphere & ionosphere

Al+MgF₂ Coating Test Runs (265°C)

- Coating Run 7/14: 92% @ 133.6 nm
- Coating Run 8/5: 91% @ 154.5 nm
- Coating Run 8/18: 91% @ 133.6 nm
Conclusions and Future Plans

- 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.
- Successful demonstration of enhancement in FUV reflectance using a large 2-meter chamber.
- Characterization of lanthanide tri-fluoride material candidates to determine their FUV transparency for development of dielectric coatings.
- On-going task of depositing Al(50)+LiF(15nm)+MgF₂(5nm)
- Produce FUV reflector using dielectric (MgF₂/GdF₃) pairs
- GSFC Internal Research & Development to setup pilot program to study synthesis of MgF₂ films using ALD process
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