**Enhanced Fluoride over-coated Al Mirrors for FUV Astronomy**

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**ABSTRACT**

Astronomical observations in the Far Ultraviolet (FUV) spectral region are some of the most 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. 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 some laboratory rare-earth fluorides such as GdF₃ and LuF₃ that exhibit low-absorption over a wide wavelength range and 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+MgF₂ 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 lanthanide trifluorides as high-index materials that when paired with either MgF₂ or LiF will enhance reflectance of Al mirrors at Lyman-alpha.

**Approach for Objective 1:**

Retrofit 2 meter coating chamber with heaters/thermal shroud to perform coating iterations at a high deposition temperature (200-300°C) to further improve performance of protected Al mirrors with either MgF₂ or LiF overcoats.

**Tasks Description:**

- Design and fabrication of internal heat shields for ISG chamber.
- Design and fabrication of internal configuration of the chamber.
- Optimal coating parameter for high FUV reflectance.
- Optimal coating parameter for high FUV absorption.
- Perform a coating run with small 2x2in substrates located at various radius inside chamber (see graph below).
- Heater were first tested on 08/13/13 and found maximum temperature reached was only 100 °C after 5 hours in temperature, reaching 220 °C in less than 1 hour (see graph below on the right).
- The above images show the fully assembled internal heat shields, power supply and quartz halogen lamps.

**Results:**

- Predicted vs. measured reflectance of bare Al and Al+MgF₂ reflectance.
- Enhanced performance was achieved by heating (220 °C) substrates during MgF₂ deposition.
- Reflections > 98% even at 150μm.

**Approach for Objective 2:**

Upgrade existing Ion Beam Sputtering (IBS) chamber with two gas-flow controller system. Krypton gas is used in 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.

**Tasks Description:**

- Design (through the use of computer-aided design (CAD) software) and build of a new, large-scale (≥1 meter diameter) coating chamber.
- Perform coating iterations in the new chamber.
- Optimize deposition process of lanthanide trifluorides as high-index materials that when paired with either MgF₂ or LiF will enhance reflectance of Al mirrors at Lyman-alpha.

**Al+MgF₂ Coating Performance:**

3-step coating process:

- Al+MgF₂ 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 with substrates at room temperature with a thin 0.5-1um layer of MgF₂ in order to protect the Al from oxidation and contamination.
- Heat the substrates to 200-300°C and finish the planned heat MgF₂ thickness MgF₂.

**Optimization and characterization of MgF₂ Films using the 3-step process during PVD coating deposition of these materials.**

**Spectral Characterization:**

Spectrometer used to collect spectral scan of transmission and/or reflectance from samples.

**Micro-roughness Al+MgF₂ Films**

The tables above show micro-roughness results on two classes of Al+MgF₂ coatings done with the MgF₂ layer deposited at ambient (left) and at elevated (right) temperatures. The table on the right shows the average roughness for the elevated MgF₂ deposition 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 trifluoride material candidates to determine their FUV transparency for development of dielectric coatings.

- Will plan to refurbish a second 2-meter chamber to perform IBS film deposition of MgF₂/Al materials.