National Aeronautics and Space Administration

Specialized Ultraviolet Coatings for Smallsat/Cubesat Optics

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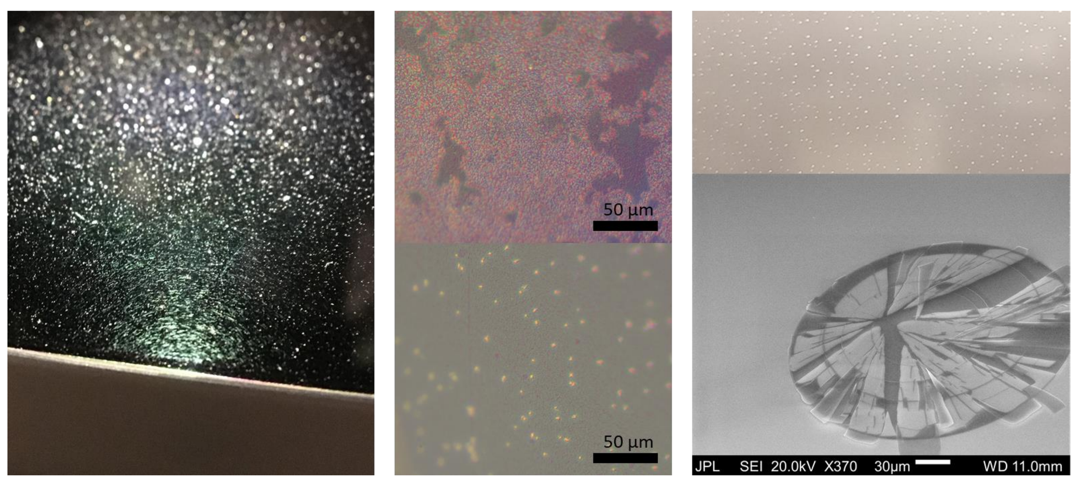
Program: Innovative Spontaneous Concepts

Background & Project Objective:

- Spectrally-selective optical components are a critical part of UV sensing systems, particularly where multi-channel or broadband measurements are made, since these require some amount of red rejection (e.g. filter wheels on HST or SWIFT).
- Deep-UV dielectric mirrors have also been considered for SMEX/MIDEX telescope concepts like DUET(JPL) and SYNERGY (GSFC) in order to provide additional long wavelength rejection at the focal plane.
- There is a substantial need for high-efficiency, UV-transmitting filtration where total instrument throughput is often low and robust commercial filter solutions are not available.
- With existing equipment at JPL's Microdevices Laboratory (MDL) we can coat optics ~200 mm in diameter, a useful platform for filter and mirror components for smallsats, cubesats, and instrument-scale optics.
- A successful development effort at JPL has produced many successful low-refractive-index metal fluoride materials that are useful for protected aluminum mirror coatings (e.g. sounding rocket SISTINE, and cubesat SPRITE, both with CU Boulder)
- This project attempts to extend the JPL approach for ALD metal fluorides using anhydrous hydrogen fluoride to enable more complex multilayer dielectric coatings.
- If successful, the ALD approach may allow for techniques (e.g. nanolaminates) to mitigate thermomechanical failure in fluoride thin films which continue to plague even the most modern examples of UV coatings deposited by conventional physical vapor deposition methods as shown in **Figure 1**.
- As a starting point we must demonstrate that we are able to deposit high-index (n > 1.5) deep UV fluoride thin films by ALD



(a) (b) (c)

Figure 1. (a) Photograph of crazing and texturing of a multilayer red-blocking filter applied to a glass substrate for a sub-orbital astrophysics instrument. **(b)** Nomarski micrographs of roughened and blistered surfaces of a multilayer, fluoride-based antireflection coating on fused silica for a flight instrument development program at JPL. **(c)** Photograph (top) of blistering on a multilayer metal-dielectric bandpass filter and a scanning electron micrograph (bottom) showing a closeup of the mechanical damage from a single blister.

FY19 Results:

- Identified several candidate materials based on the optical properties of thin films deposited by conventional methods and the predicted viability of possible ALD half reactions from thermochemical analysis.
- **Figure 2** shows model predictions of dielectric mirror coatings and beam-splitter dichroic coatings operating in the far ultraviolet (FUV).
- Procured lanthanum precursor (La-FMD, Strem Chemicals) which has previously been reported in ALD processes for La_2O_3.
- Successfully demonstrated a process utilizing hydrogen fluoride as a co-reactant to deposit LaF_3 films, see **Figure 3**. This is the first demonstration of this material using this ALD approach.
- HfF_4 thin films were also demonstrated using an existing source (TEMA-Hf) that we currently utilize for HfO_2 processes, see **Figure 4**.
- All films were characterized by ellipsometry, FUV/NUV reflectance, atomic force microscopy and SEM. Mutlilayer high/low stacks were attempted using HfF_4 and AlF_3 as the constituent layers.
- Quarterwave stacks up to 28 total layers were deposited targeting a narrowband mirror operating at center wavelength near 250 nm, see **Figure 5**.
- FUV reflectance analysis indicated the edge of strong absorption is ~ 130 nm for LaF_3, and ~150 nm for HfF_4

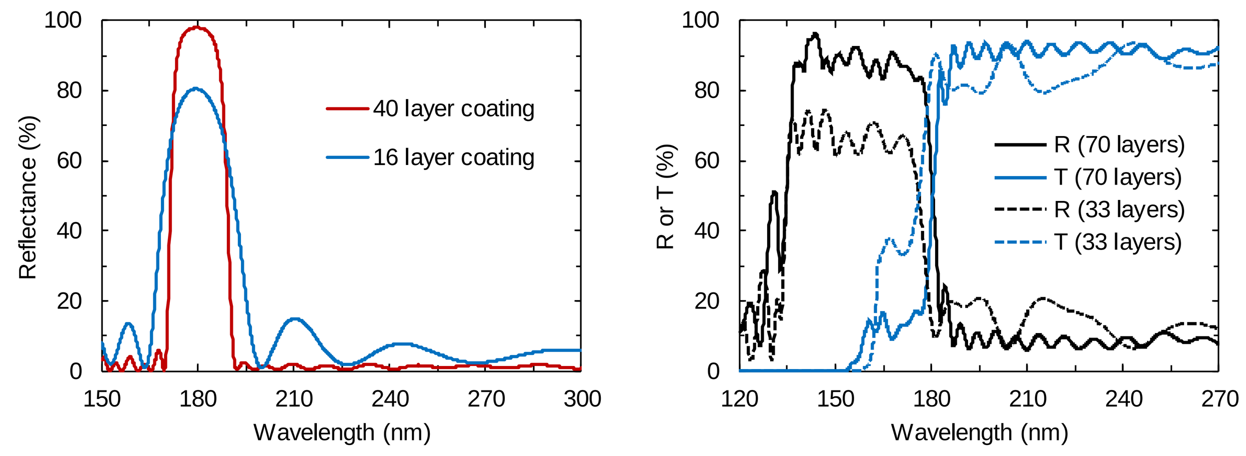


Figure 2. (left) Theoretical model of a dielectric narrowband reflector with 16 or 40 layers of alternating LaF_3 and AlF_3 at normal incidence and assuming front surface effects only on a fused silica substrate. **(right)** Theoretical model of a UV dichroic beamsplitter similar to the spectral bands implemented on the GALEX mission. Index models used in these calculations were derived from ALD AlF_3 and literature values for PVD LaF_3.

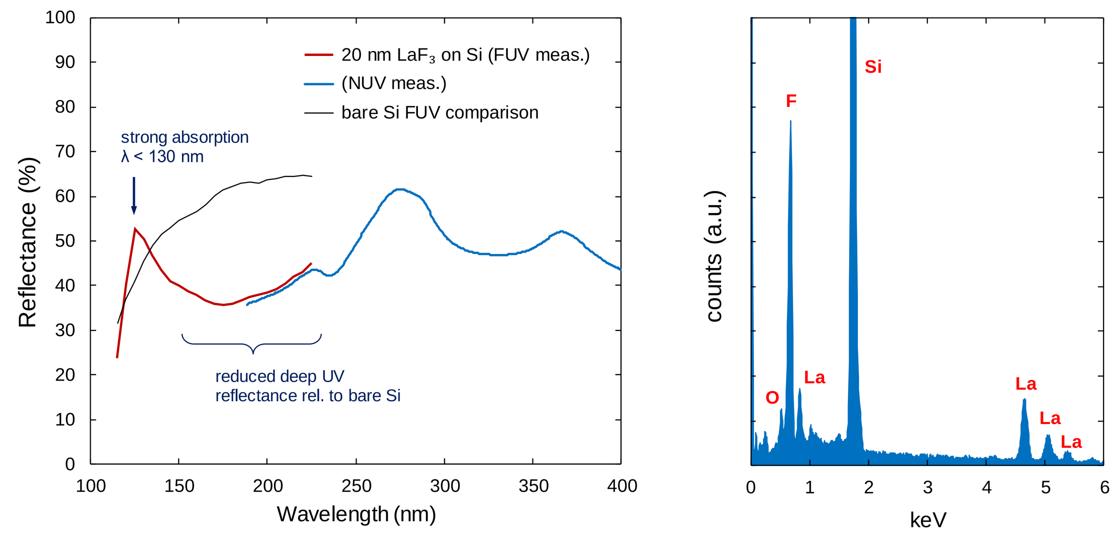


Figure 3. (left) Measured reflectance of 20 nm LaF3 thin film deposited on a silicon wafer. Minimal absorption loss is observed for λ > 130 nm. **(right)** SEM-EDS analysis is used to confirm film composition.

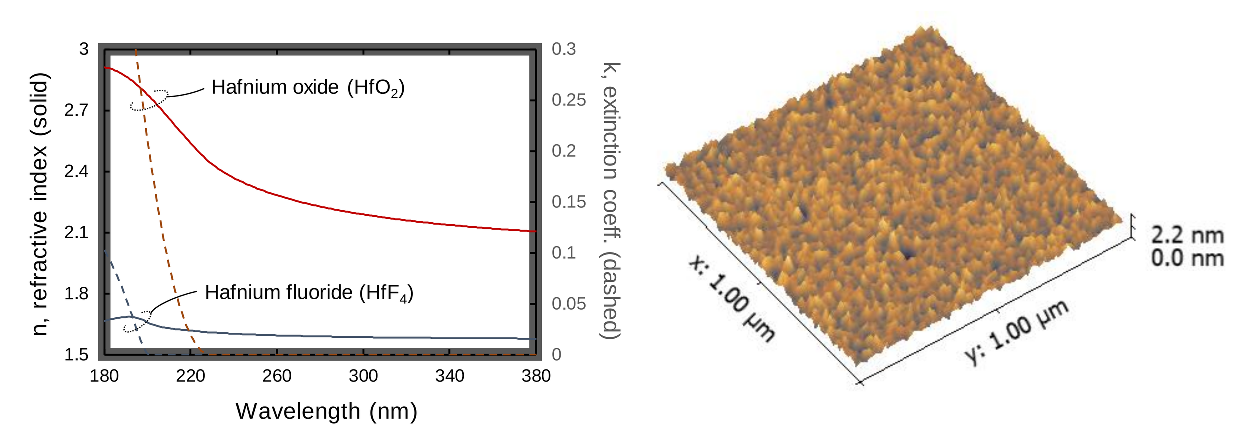


Figure 4. (left) Refractive index of HfF_4 thin films deposited by ALD compared to HfO_2. **(right)** Atomic force micrograph of 67 nm HfF_4 film deposited on a silicon wafer shows a low rms surface roughness of 2.4 ±0.2 Å.

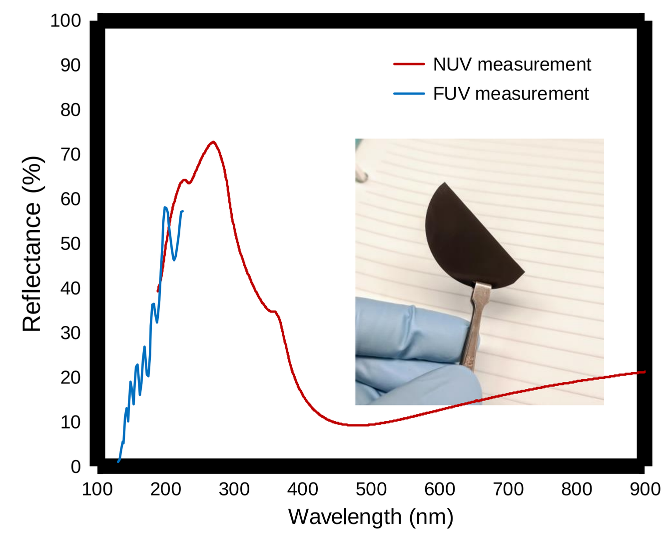


Figure 5. Measured reflectance of a 28 layer HfF_4/AlF_3 dielectric mirror. Inset shows sample deposited on silicon wafer with no signs of delamination or stress-related fractures. Secondary peaks indicate additional layer thickness calibration is required for maximum performance.

Benefits to NASA and JPL (or significance of results):

- The ALD approach can enable thin film deposition strategies that can engineer coating stability in a way that is not possible with conventional methods (e.g. nanolaminates or mixed composition films). This can be used to mitigate thermomechanical effects that cause failures in complex ultraviolet optical coatings.
- Additional work is needed to fully evaluate the optical properties of ALD high-index fluorides and their dependence on process parameters. Additional work is also required to optimize the modeling and deposited performance of many-layer quarterwave stacks of ALD films.
- A new JPL capability for high-index metal fluoride materials by ALD can also extend the short-wavelength performance of delta-doped detector-integrated anti-reflection coatings (baseline for CASTOR concept).
- Elements of this ISC-RTD work were incorporated into a NASA Astrophysics Research and Analysis proposal submitted in FY19 in collaboration with BYU, University of Arizona, and Columbia University (ranked E/VG but not selected).
- Continued development could allow for in-house solution to more complex UV optical coatings with improved durability over state-of-the-art.

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Poster No. RPC-234