UV Coatings and Short-wavelength Cutoff

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Enabling the LUVOIR mission's compelling ultraviolet (UV) science goals, while also maintaining broadband capabilities to support the exoplanet science mission and other general astrophysics observations, will require a high-performance broadband reflective coating. Of the common metallic mirror coatings (gold, silver, aluminum), only aluminum is capable of providing high reflectivity into the UV at wavelengths as short as 90 nm. However, almost immediately upon exposure to air (even at very low pressures), an oxidation layer forms on the surface of aluminum-coated mirrors that dramatically reduces its UV performance. Protective overcoats (usually a fluoride such as LiF, MgF_2, or AlF_3) are used to arrest the oxidation once it has begun, and protect the aluminum layer from further oxidation. These overcoat layers themselves can also impact the reflectivity of the mirror at the shortest wavelengths. Current technology development efforts are focused on improving deposition processes to maximize protected aluminum coatings at wavelengths between 90 – 150 nm, while maintaining high reflectivity at longer wavelengths through the visible and near-infrared. Figure 1 shows a number of reflectivity curves for demonstrated and theoretical protected aluminum coatings.

Typical protected aluminum coatings employ aluminum with a single, thin layer of MgF_2. This is the coating used on the Hubble Space Telescope, and provides excellent reflectivity (>85%) at wavelengths longer than ~120 nm. Short ward of 120 nm, the reflectivity sharply drops to about 20%. Current research efforts are developing Atomic Layer Deposition (ALD) processes for depositing a very thin (~few nanometers) layer of MgF_2 which may provide protection from oxidation while maintaining the high-reflectivity of bare aluminum.

Aluminum protected by LiF provides reflectivity greater than 80% at wavelengths as short as 110 nm, and depends critically on the coating process employed. Its cutoff wavelength is around 100 nm. It is important to also note that LiF is a hygroscopic material that deteriorates when exposed to water vapor. Mirrors coated with LiF would need to be held under a constant dry purge during the entire integration and test phase, as well as launch. This would prove extremely challenging for a system as large and complex as LUVOIR. Alternatively, protecting the LiF layer with a thin layer of AlF_3 can prevent the absorption of water vapor and stabilize the performance of the coating over long periods of time (see Figure 2).

Figure 1 also shows two theoretical curves for an aluminum mirror protected by AlF_3 only. The first curve is a theoretical best-case in which no oxide layer has formed on the Al undercoat. The second curve shows the theoretical performance assuming a 3 Angstrom layer of oxide has formed between the Al and the AlF_3 overcoat. Both coatings show improved performance below 100 nm compared to either MgF_2 or LiF, as well as better performance at higher wavelengths. Layer thicknesses and process conditions affect the resulting performance and may allow further optimization.

Several technology development efforts are currently underway to optimize these coatings and the deposition processes, including both physical vapor deposition (PVD) and atomic layer deposition (ALD). New techniques that allow the overcoat to be deposited immediately after the deposition of the base Al layer will reduce the thickness of the oxide layer that forms, or prevent it all together. Process improvements will also help increase the reflectivity, as well as its uniformity across the mirror surface.

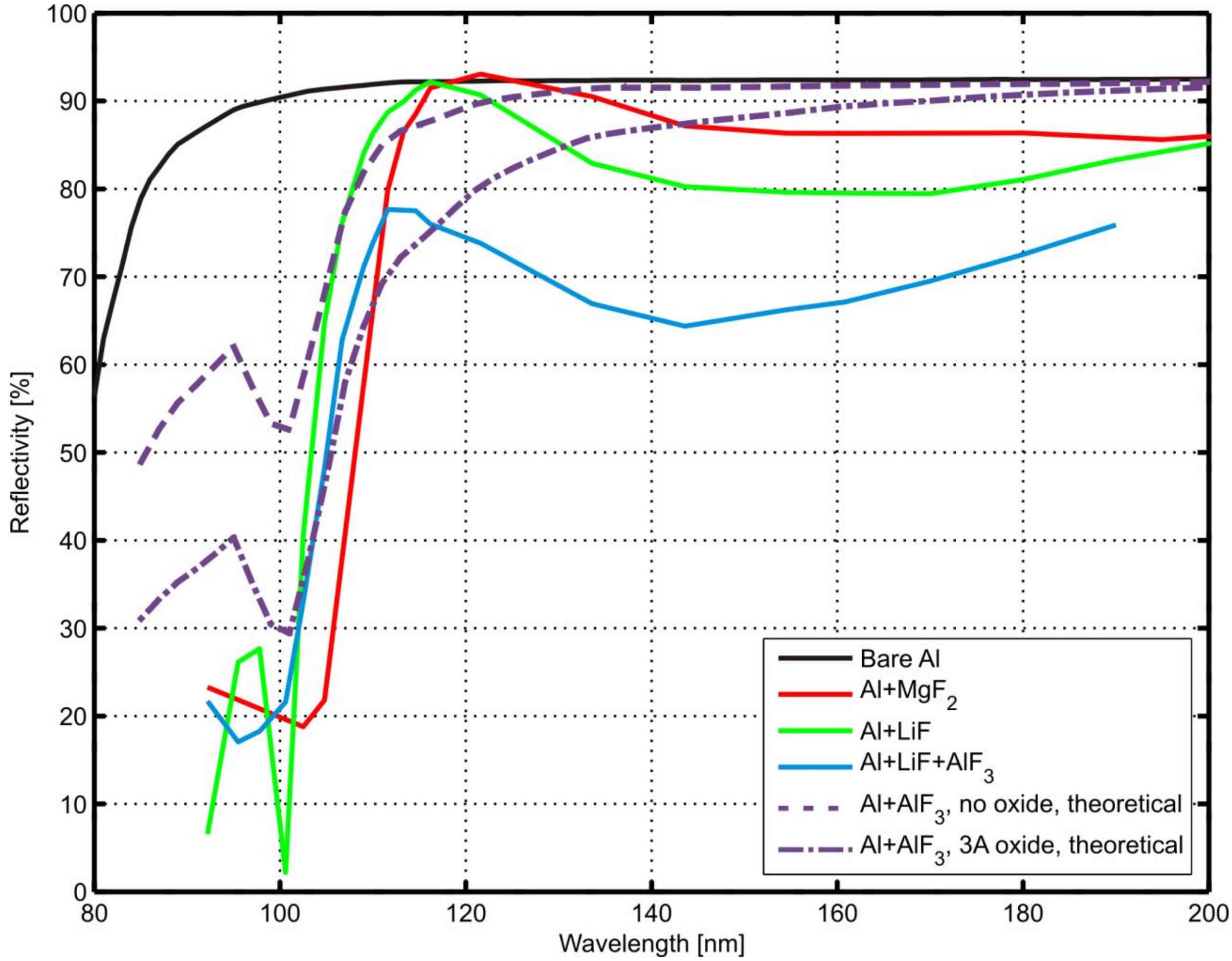

Figure 1 – Theoretical and demonstrated performance for various Aluminum coatings. The theoretical, un-oxidized bare Al performance is shown in black. Demonstrated performance for MgF_2 and LiF overcoats are shown in red and green, respectively. A LiF overcoat protected by a thin layer of AlF_3 is shown in blue. Finally, theoretical performance for an AlF_3 overcoat is shown in purple for two scenarios: without an interstitial oxide layer (*dashed*) and with a 3 Å interstitial oxide layer (*dot-dashed*). This figure was adapted with permission from J. Hennessy, *et al.*, "Performance and prospects of far ultraviolet aluminum mirrors protected by atomic layer deposition," *J. Astron. Telesc. Instrum. Syst.* 2(4), 041206 (2016), with contributions from M. Quijada at GSFC and K. Balasubramanian at JPL.

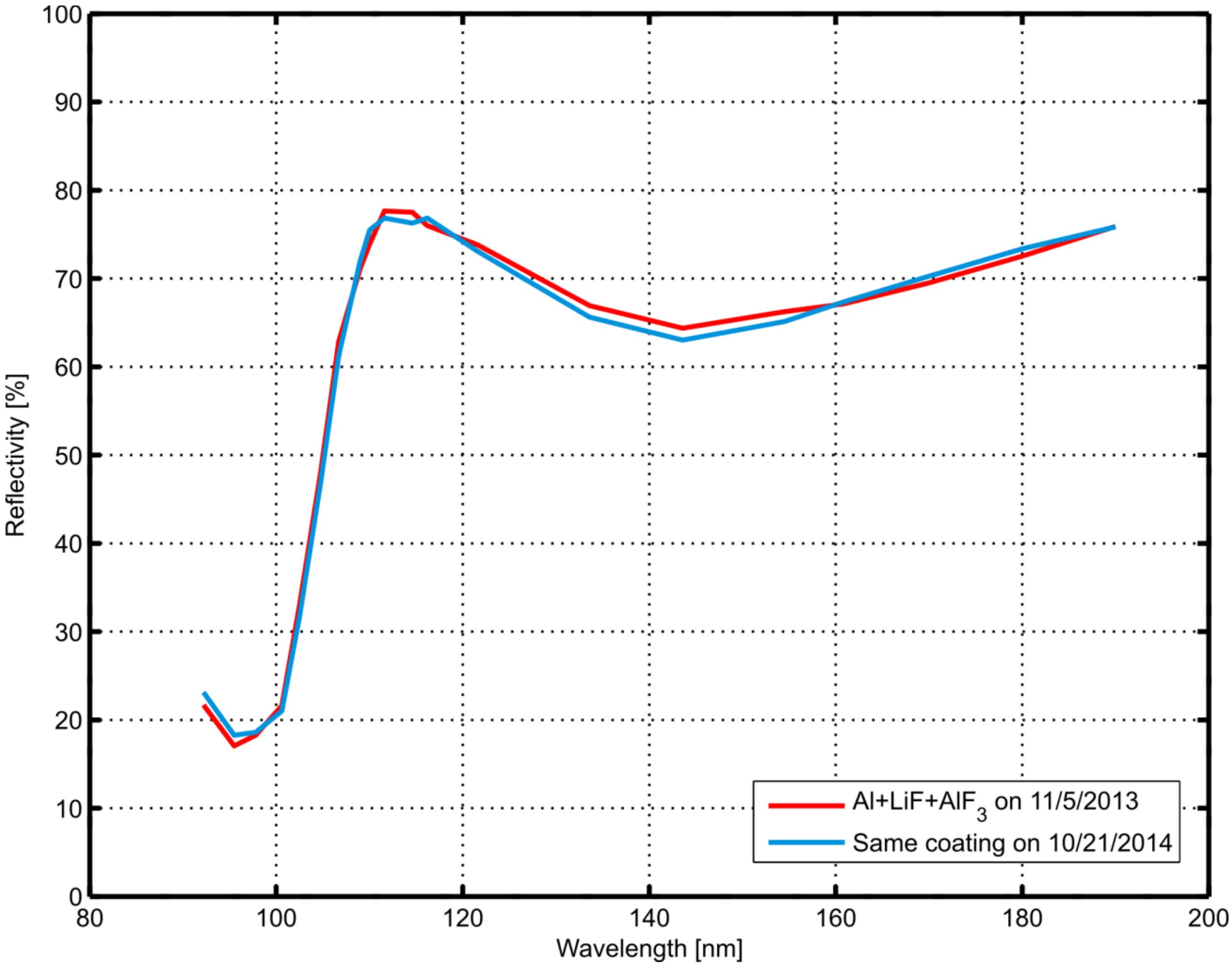

Figure 2 – Demonstrated stability for an Aluminum coating protected by LiF, and further overcoated with a thin layer of AlF_3. The AlF_3 helps prevent the LiF coating from absorbing water vapor from the ambient environment, thus preserving the as-deposited performance of the coating. Data provided courtesy K. Balasubramanian at JPL.